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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Impact of cloud-borne aerosol representation on aerosol direct and indirect effects" *by* S. J. Ghan and R. C. Easter

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This study considers how simplifying a state-of-the art GCM indirect effect parameterization affects aerosol amount, direct and indirect forcings. It finds that the simplifications considered here have relatively small effect on radiative forcing, an interesting result. I recommend the following improvements prior to publication. Most importantly, the manuscript lacks physical explanation for the experiments and their effects on results, making evaluation and application difficult.

1. The experiments need better definition and physical explanation. Do all experiments include both 1st and 2nd indirect effects?

AC: We have added statements indicating that 1st and 2nd indirect effects are treated in all experiments. We've also expanded the description of the DIAG treatment.

2. How much are clouds (cloud cover, distribution, cloud height) affected by the experiments?

AC: We have added a statement indicating that the longwave cloud forcing is insensitive to the aerosol treatment, and therefore that all the radiatively important aspects of simulated clouds are insensitive (with the caveat that aerosol effects on ice crystals are neglected).

3. The explanations for the biases of DIAG and RESUSP are not clear. Why is RESUSP removal larger than FULL? Why are the aerosols that have been resuspended scavenged more readily than those that remain within a cloud over successive timesteps? Is this because the clouds and/or precipitation are affected: RESUSP encourages increased cloud and precipitation? And I am really lacking a physical sense of what DIAG does.

AC: We have improved the descriptions of the RESUSP and DIAG treatments, and we have added a statement indicating that in-cloud scavenging is more efficient for DIAG and RESUSP because the activated aerosol is replenished each time step. Note that in the P-RESUSP treatment, the cloud droplets are evaporated and re-nucleated, and AP are resuspended then re-activated, in a computational sense. (Also, the evaporation and resuspension is done after the model history statistics are incremented.) From a physical standpoint, the stratiform clouds never really disappear. Instead, the droplet number and the cloud-borne/interstitial AP partitioning are fully recalculated each time step.

4. Nothing is said about effects on aqueous chemistry. Firstly, is gaseous oxidant uptake into cloud limited to new cloud growth, as AP uptake is? Secondly, one might expect in the RESUSP case that more oxidant would be consumed, are such effects present?

AC: None of the treatments change aqueous-phase production of sulfate because in MIRAGE, it depends only on the cloud fraction, the cloud liquid water content, and the

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concentrations of SO2, H2O2, and O3 . These concentrations are predicted for the entire grid cell, so there is no memory from one time step to another about reductions of the in-cloud SO2 and H2O2 by aqueous reaction and wet removal. We've added a sentence stating the insensitivity of aqueous-phase sulfate production.

5. Some of the plots tell the same story. Instead of showing some of the similar plots: a) A zonal mean similar to Figure 3 could be shown. B) It would be very interesting to bring in some observations. One possibility would be to compare the various model versions with observed sulfate as a function of month at some sites (e.g. IMPROVE or EMEP). Differences at higher latitude sites may be significant. Does the FULL result look best?

AC: We have removed figures 5 and 8, and added a figure comparing the zonal mean accumulation mode aerosol for each treatment. We have compared the simulated sulfate with observations in the arctic, and find that the sulfate simulated for the FULL case is too low. Thus, the aerosol reduction by the RESUSP and DIAG treatments makes the problem worse. We've added text discussing this finding.

6. Section 4. In contrast with the statement in the text, the indirect effect in DIAG differs significantly from FULL, why?

AC: We have explored this issue, and have found a significantly larger anthropogenic increase in droplet number for DIAG. But we cannot explain the larger increase in droplet number in terms of aerosol burden. We've added a figure illustrating the anthropogenic increase in droplet number.

7. Note that since other models have a larger indirect effect than this model, the absolute value of indirect effect variation of such experiments in other models would also be larger.

AC: We've expressed the biases in relative terms, which can be used to scale estimates by other models.

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8. The changes (for RESUSP, DIAG) to indirect forcing are opposite sign to direct forcing. Is this because of cloud changes such as in item 3 above?

AC: We cannot explain the different sensitivity of direct and indirect effects of anthropogenic sulfur for the RESUSP and DIAG treatments. The weaker direct effects for DIAG is consistent with the smaller increase in aerosol optical depth, but is inconsistent with a larger increase in accumulation mode aerosol number. The stronger indirect effects for DIAG is consistent with the larger increase in droplet number and with the larger increase in accumulation mode aerosol number, but is inconsistent with the slightly smaller increase in CCN concentration. We've added text discussing this.

9. Conclusion: This study demonstrates relatively small impacts on indirect forcing of some simplifications to the indirect effect treatment. Yet models have a very large range in indirect effect estimates. Can we conclude from this study that the cause of the large diversity among models is primarily because of differences in model clouds and other model climate components, rather than due to treatment of aerosols and aerosol indirect effect parameterization differences? If so then this seems an important conclusion that should be highlighted.

AC: We've added several sentences in the conclusions and in the abstract.

10. Abstract: State the direction of the biases, within which regions and for which variables?

AC: Done.

11. Summary, 2nd sentence. This study spans the range of models used to look at indirect effects, but not direct effects. Many models consider direct effects only and I don't think this study applies to them.

AC: We feel that results of this study are generally applicable, because this study shows that the simplest treatment of cloud-borne aerosol (DIAG) produces an over-prediction of aerosol in-cloud wet removal and under-prediction of aerosol mass loading and op-

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tical depth, which will affect estimates of direct forcing. On the other hand, there are undoubtedly some models/studies to which our results will be less applicable, such as those focusing on mineral dust or sea salt where coarse particles are more important. We have reworded the sentence in the summary.

Interactive comment on Atmos. Chem. Phys. Discuss., 6, 4341, 2006.