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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Theoretical basis for convective invigoration due to increased aerosol concentration" *by* Z. J. Lebo and J. H. Seinfeld

Anonymous Referee #1

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This simulation study investigates the fundamental causes for CCN and IN aerosols on the invigoration and rainfall amounts from deep convective clouds. The simulation is performed with two microphysical schemes: a two moment bulk microphysics and bin microphysics. The analysis of the simulation results is done in depth and the conclusions are consistent with the simulation results. However, this paper has several major problems that need to be corrected before it can be accepted for ACP.

Major comments:

1. The most advanced bin microphysical schemes are represented by direct interactions between the bins via interactions kernels (e.g., Khain et al., 2004, as referenced in the paper). However, the collision-coalescence processes in the version used in this study are represented by the moment-conserving numerical solution to the stochastic

collection equation of Tzivion et al. (1987) for the first two moments of each distribution. This limits the realism of the calculated particle size distributions with respect to the state of the art. These differences are important, because of the sensitivity of the results to the balance between evaporation and sedimentation processes, which are quite sensitive to the tails of the distributions.

2. It is stated that "The choice of 32 bins allows hydrometeors to attain appreciable sizes for precipitation to occur while minimizing the risk of creating numerical instability due to very large particles falling through grid boxes within a single time step". With the lowest bin diameter at 3.125 micrometer, the largest bin size would be 3.125*2**(32/3)=1,625.5 micrometer. This means that the largest hydrometeor cannot exceed a melted diameter of 1.6255 mm. The authors correctly highlight the balance between the evaporation and sedimentation rates as a major cause for the sign and intensity of the effects on invigoration and precipitation amounts. Therefore, this major underestimate in the sedimentation rate is a very serious limitation that defeats the purpose of this study. Furthermore, the hydrometeor type of hail is missing, at least from the description given at Section 3.1.1. Even worse, in polluted situation the hail grows preferably to large sizes (Khain et al., 2011, Andreae et al., 2004). The hail in these situations well exceeds the diameter of 1.6255 mm. This incurs a gross underestimate of the sedimentation rate from the convective cores, especially in the polluted situation. Respectively, the whole basis of this paper is undermined. Specifically, the nice logical inferences are based on simulations that are inherently incapable of simulating properly the impacts of aerosols on the balance between sedimentation and evaporation. Without overcoming this major problem the study is not publishable.

3. The conclusions include the following text: "Our results conclusively demonstrate that any and all changes in the precipitation at the surface are dominated by changes in the mass of condensed water and the competition that exists between evaporation/sublimation and sedimentation...". I agree with this statement, but the results do not "demonstrate conclusively" anything beyond that. Actually, the problems with

at least the sedimentation rate render the simulations not representing faithfully the aerosol effects. Respectively, the verb "demonstrate" that is very frequently used should be replaced. Demonstrate means "to make evident, or to prove".

Minor comments:

Page 2776 line 3: "Cold rain" should be replaced with "mixed phase"

Page 2776 line 4: Collision and coalescence are important in mixed phase precipitation, because the resultant super-cooled rain can freeze readily into hail embryos. This is often observed to be the case in polluted tropical clouds.

Page 2776 line 6: Koren et al., 2005, is not a modeling study.

Page 2776 lines 13-14: The paper of Rosenfeld et al. 2008a argued a non-monotonic dependence. It showed based on conceptual considerations that aerosols can increase or decrease precipitation in different circumstances.

Page 2776 line 16: Please state which kind of model Van den Heever et al. (2006) used. Please spell her name correctly throughout the manuscript.

Page 2776 line 25: Please add that these two schemes were simulated on the same dynamic framework.

Page 2776 lines 27-28: This is a major point that was discussed in Rosenfeld et al. (2008a) on a conceptual level. It is appropriate to quote it here, before going to the specific simulations.

Page 2777 Line 7: Microphysical changes do occur, but the dynamic response to them is decreased due to the wind shear.

Page 2777 Line 17-19: This is not the full story. Reference here the combined effect of solar and thermal radiation on the net forcing.

Page 2780 lines 7-8: The CAPE was not changed. The amount of released gravita-

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tional energy is changed, which is equivalent to changing the effective CAPE.

Page 2780 line 10: At least for completeness, please add that Rosenfeld et al. 2008a also discussed the greater low level cooling and hence greater upward heat transport that consumes more static instability and hence must incur invigoration. Following is the relevant text from that paper: "The enhanced evaporative cooling of the added cloud water, mainly in the downdrafts, provides part of the invigoration by the mechanism of enhanced cold pools near the surface that push upward the ambient air. The greater cooling below and heating above lead to enhanced upward heat transport, both in absolute terms".

Page 2790 line 7: The aerosols do affect cloud microstructure regardless of the wind shear. Please change the text to read: ... on the invigoration of deep convective clouds. Page 2790 line 28: This is not "a small change", because the microphysical sensitivity is scaled to the logarithm of the CCN.

Page 2791 line 11: This does not seem right. The fluxes should be corrected for the size of the time steps.

Page 2792 line 9: Please address here the concerns raised in the comment of Dr. Fan with respect to the reference of the resolutions of other studies.

Page 2793 line 15: Please address here the concerns raised in the comment of Dr. Fan with respect to the reference of the resolutions of other studies.

Page 2793 lines 24-25: Change km to m.

Page 2796 lines 7-9: This is a qualitative agreement, because precipitation amount should decrease beyond a certain optimum according to Rosenfeld et al., 2008a. The threshold of CCN for inverting the effect will probably increase considerably and the effect will be larger in a model that simulates more correctly the sedimentation. Page 2797 line 9: Not so. The deposing releases latent heat that is more than offsetting the added qt.

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Page 2800 line 19: In addition, supercooled water extends to greater heights (Fig. 6). Therefore, latent heat of freezing is delayed to greater height and more concentrated there. This is in line with the conceptual model of Rosenfeld et al., 2008a that this study is testing. The smaller particles that freeze aloft evaporate more readily, as already discussed.

Page 2802 line 26: Comparison of Figures 5 and 11 shows that there is less rain forming and hence more cloud water that is lofted to the supercooled levels and eventually freezes. This should invigorate the convective cores. Because no large hydrometeors are allowed to form and fall through the convective cores in this model, the small ice evaporates to a greater extent outside the cores and the net result is less precipitation. Here the lack of possibility to produce large hail is limiting the speed of conversion of supercooled water to large ice hydrometeors and their efficient precipitation with minimal evaporative loss, and severely limiting the decreasing of qt by sedimentation and the respective increasing of the updraft and invigoration.

Page 2803 line 28: Sedimentation of ice is grossly underestimated due to size limit of the largest bin and due to lack of hail.

Page 2805 line 18: This effect is over-rated due to the underestimate of the sedimentation from the convective core.

Page 2807 line 21: How adding more cloud droplets freezing at warmer temperatures is limiting the supersaturation aloft and enhancing the supercooled liquid water content?

References:

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