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Interactive Comment

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

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We thank the anonymous reviewer for his/her thoughtful comment and criticism. Our responses to the major points are below. The major points are enumerated and correspond directly to the major points, in order, from the reviewer's comments.

1. Within a deep convective cloud, the assumption that the cloud is at liquid saturation is unrealistic. However, the bulk model includes a saturation adjustment scheme that prevents a supersaturation from existing at the end of a time step by condensing the excess water vapor into droplets. However, *Chuang et al.* (1997) show that the condensational growth time scale for droplets may be larger than the time step of the detailed CRM used in the present study. This would lead to a

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supersaturation persisting through more than one time step. For this reason, we feel as though the results of the bin model ought to be more realistic in nature.

2. In order to address the large difference in precipitation and help remove the differences in activation of cloud droplets and nucleation of ice particles, we have modified the bulk scheme such that new droplets and ice crystals are formed following the same procedure as that of the bin model. The details of this change are noted in the methods section of the revised manuscript.

3. The difference in precipitation between the low and high RH cases was small due to model bias. The model has been updated as stated above and the simulations are constrained to 6 h to ensure minimal impact of the boundaries on the results.

4. The large difference in precipitation presented in the original manuscript was a result of limiting the number of bins. We thank the first anonymous reviewer for bring this to our attention. The number of bins has been increased to 36 for each hydrometeor category. Moreover, the assumption that the CCN number concentration is fixed with time, allowed for erroneously large droplet number concentrations, and thus limiting the rain water mixing ratio and precipitation. The predicted cumulative precipitation using the new bin scheme, with aerosol activation, advection, and regeneration as well as more bins, is much closer to that predicted with the bulk scheme. However, the domain-averaged cumulative precipitation predicted by each model do not agree. We have included a discussion in the revised manuscript regarding one of the main underlying assumptions of the bulk scheme: Saturation adjustment. The bulk model forces the saturation ratio to 1 at the end of a time step while the bin model allows a supersaturation to exist after the microphysics calculations are performed. This difference likely contributes to the inter-model difference in precipitation.

5. We have removed the *Barahona and Nenes* (2008) and *Barahona and Nenes* (2009) ice activation scheme from the current model so as not to bias the re-

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sults by including a scheme that is designed specifically for cirrus clouds. We realize that the dynamical core of the convective scheme creates an environment that lies outside of the range of values used to test/define the parameterization. Therefore, we have modified the ice nucleation scheme in the bulk model to match that of the bin scheme.

6. We have reorganized some of the figures but feel that it is best to separate the lowRH figures from the highRH figures since a major goal of this work is to analyze any potential RH impacts on the aerosol-induced effect on deep convective clouds. Also, the subscripts and captions have been corrected to properly reflect the figures.

7. We have included a more detailed description of the treatment of the CCN population in the revised manuscript. Briefly, the revisions include a detailed bin-resolved CCN population and activation of the CCN is predicted based up the ambient supersaturation and the critical supersaturation needed to activate CCN in each bin. The CCN are depleted due to activation, advected, and regenerated due to evaporation.

8. We have include figures showing the radar reflectivity factor (Z) in the revised manuscript. These figures, for both the lowRH and highRH scenario demonstrate that the models are internally consistent.

With the above modifications, we have rerun the suite of simulations described in the original manuscript and modified the analysis/conclusions to reflect the results of the more accurate microphysics scheme.

Below, we list our responses/modifications/etc. regarding the specific comments. The comments here are preceeded by the line number given in the anonymous review:

- Page 2784, lines 15-16: It is in fact true that N_{act} will be overestimated if the number concentration of CCN is not reduced due to activation. The aerosol activation scheme has been modified to include a binned aerosol size distribution and explicit aerosol tracking in that advection and regeneration are included.

- Page 2786, line 6: We have changed the statement “We distribute evenly the number of droplets that freeze due to deposition and contact freezing.” to “The freezing of cloud droplets in each bin by immersion freezing is computed by weighting the number of active IN by the ratio of the number of droplets within the given bin by the total droplet number concentration. The frozen droplets are transferred to the corresponding bin in the ice crystal distribution.”
- Page 2794, line 23: The statement has been removed.
- Page 2796, line 13: The spelling of “discrepancy” has been corrected.
- The statement “a small change would result in a negligible change in w assuming that q_t and if q_t were to have increased, the possibility for a decrease in w exists.” has been changed to “a small change in net latent heating would result in a negligible change in w assuming that q_t is relatively unchanged. On the other hand, if q_t were to have increased, the possibility for a decrease in w exists.”
- Page 2810, lines 17-18: The change in the sedimentation time scale and the autoconversion time scale are likely not one to one. It is argued in the revised manuscript that an increase in the riming process within the convective core may lead to more intense rainfall at the storm’s center, but a decrease in the collection processes due to much smaller particles leads to a decrease in sedimentation and ultimately a decrease in precipitation in the surrounding areas, ultimately acting to reduce the domain-averaged cumulative precipitation.

References

Barahona, D., and A. Nenes (2008), Parameterization of cirrus cloud formation in large-scale models: Homogeneous nucleation, *J. Geophys. Res.*, *113*(D11211), doi:10.1029/2007JD009355.

Barahona, D., and A. Nenes (2009), Parameterizing the competition between homogeneous and heterogeneous freezing in cirrus cloud formation - monodisperse ice nuclei, *Atmos. Chem. Phys.*, *9*, 1–13.

Chuang, P. Y., R. J. Charlson, and J. H. Seinfeld (1997), Kinetic limitations on droplet formation in clouds, *Nature*, *390*, 94–96.

Interactive comment on Atmos. Chem. Phys. Discuss., 11, 2773, 2011.