Response to comment by Anonymous Referee #2

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Review of "Potential indirect effects of aerosol on tropical cyclone intensity: convective fluxes and cold pool activity" by Krall and Cotton

Major comments:

This manuscript describes simulations of a Western Pacific typhoon conducted with RAMSv4.3. A series of sensitivity studies with increasing concentrations of cloud condensation nuclei (CCN) are analyzed, and conclusions are made about how the CCN influenced the evolution of the typhoon. The paper is well-written and easy to follow, and the quality of the graphics is fine. However, I do not feel that the conclusions made are justified through the analysis presented.

It is well known and there have been multiple studies published showing that tropical cyclones with different intensities will result when CCN concentrations are varied. The authors attempt to expand upon these previous studies by showing how quantities such as the total amount of supercooled liquid water, downward flux, size of the cold pool, and hydrometeor mixing ratios vary for simulations with different CCN. The authors claim that the differences in these fields, and the difference in evolution that they see between their simulations are caused by the variations in CCN number. However, a closer look at their analysis shows that this conclusion is worrisome for a number of reasons:

1) For the most part, the variation between simulations is not a monotonic function of CCN number. For example, in Fig. 5 the largest spike in the supercooled water is associated with the C3000 simulation (not C5000). The two simulations with the lowest supercooled water seem to be either C100 or C5000. The C1000 and C3000 simulations typically have more cold-pool grid cells than the C400 or C5000 simulations. The C1000 and C3000 simulations also typically have larger wind speeds than the C400 or C5000 simulations. The lack of a monotonic relation with CCN number lends one to suspect that a lot of the differences between simulations are not directly caused by variations in CCN number, but rather simply exhibiting the response of a non-linear system due to noisy initial conditions. In order for the authors to demonstrate that their results are due to variations in CCN, their results must be interpreted in the context of how variations in other fields affect the TC intensity.

2) A lot of the results in the paper are shown at specific times (e.g., 86, 84 or 68 hours after the simulations were initialized). Given the spikiness of the signals shown in Fig. 5, 6, 9 and 13, comparing plotted fields at specific times may result in misleading conclusions about whether the differences exhibited in supercooled water or downward flux at specific times are due to the differences in CCN between simulations, or whether they are just due to slight differences in the evolution of the fields between the simulations. Why were these specific times chosen? If alternate times were chosen would the same systematic differences exist? Can you average over longer time periods and apply some statistical tests to determine the degree of difference between the simulations?

We thank the reviewer for taking the time to critique this important work. The reviewer is concerned that the differences among the simulations is not due to just variations in CCN concentrations. But as these are a set of experiments with identical initial conditions, other than variations in CCN concentrations, we find it difficult to understand how other factors may be playing an important role. These differences are large enough that they certainly cannot be explained by computer round-off error or truncation.

1) The reviewer is concerned about the fact that the response is not a monotonic function of CCN concentration. But we have seen this non-monotonic response in a number of simulations. The most recent papers are Carrió et al,(2010), Carrió and Cotton(2010) and Carrió and Cotton(2011). These are simulations of the response of urban convection, and an idealized simulation of the response of a hurricane, to variations in CCN concentration. In each case a non-monotonic response is seen in which once the CCN concentrations exceed a “tipping point” cloud droplet sizes are so reduced that not only is warm cloud collision and coalescence reduced but so also are the efficiencies for ice particle riming. This results in larger amounts of water substance being thrust into anvil levels, which reduces the precipitation efficiency of the convective clouds, and total rainfall, and thereby the strength of low-level cold-pools. Based on other work in our group we think that the non-monotonic response to CCN concentrations makes very good physical sense.
2) Certainly a more comprehensive net-effect analysis is warranted for further study. Particular pains were taken to include a holistic view of the model simulations by supplying multiple time dependent response analysis (i.e. Fig 4, 5, 6, 8, 9, 13). The intention of this study was to provide a physical basis for potential responses to additional CCN. Now that the basis is established here and in other papers, the authors agree that a more quantitative net-effect analysis is a natural follow-up.
3) We agree that such a budget analysis would be desirable. But that has been done in the more idealized simulations referenced above. This was a huge simulation and thus such a budget analysis would have been exceedingly computationally expensive. Moreover this work was done by a MS student and thus time to perform extensive budget analysis was not available.
4) Tests were performed at coarser grid spacings where the dynamic response to aerosols was not represented correctly but nothing finer than 3km was used. Remember this is a large domain, very expensive simulation.
5) We agree that simulations at more intermediate values of CCN would be desirable but given these results are consistent with the results Carrió and Cotton(2010) for an idealized hurricane and the Houston urban heat island simulations of Carrió et al,(2010) and Carrió and Cotton(2011) we think that the case for the a “tipping point” is quite conclusive.

References:

Carrió, Cotton, W. R., Cheng, 2010: Effects of the Urban growth of Houston on convection and precipitation. Part I: the August 2000 case. Atmos. Res., 96, 560-574.

Carrió, G. G., and W. R. Cotton, 2010: Investigations of aerosol impacts on hurricanes: Virtual seeding flights. Atmospheric Chemistry and Physics, Atmos. Chem. Phys., 11, 2557–2567.

Carrio´, G.G. and W.R. Cotton, 2011: Urban growth and aerosol effects on convection over Houston. Part II: Dependence of aerosol effects on instability, *Atmospheric Research*, doi: 10.1016/j.atmosres.2011.06.022

Saleeby, S.M., and W.R. Cotton, 2008: A binned approach to cloud droplet riming implemented in a bulk microphysics model. *J. Appl. Met. Climatol.*, **47**, 694-703..

Response to specific comments:

P.352—*The reviewer asks for statistical tests to show that the perturbation of windspeed, convective fluxes and hydrometeor species depend on the elevated CCN.*

Response: Each of these simulations are identical except for the variations in CCN concentrations. How then can the simulated results be attributed to anything but variations in CCN?

P.352 lines 20-28. *A lot of the statements in this section have not been demonstrated through analysis in the paper, and need to be removed or shown iI the paper(.eg.enhanced rainfall, move vigorous convective-produced downdrafts(seem to depend on which examine); do a budget analysis of amount of condensate thrust into storm anvil, etc.*

RESPONSE: Figure 9 shows a time analysis of cold-pool activity which is linked directly elsewhere in the paper (i.e. Figures 6 and 7) with elevated levels of SCLW (see also Figure 5). Figures 11 and 12 show elevated hydrometeor mass concentration and number concentration, respectively and are representative of the overall trend of elevated condensate in the upper atmosphere near the storm center.

P.357, line 25-26:*Can you supply a figure or identify the criteria that shows what part of the domain was affected by MODIS retrievals of elevated aerosol concentrations(ie., how high do the concentrations have to be to be considered elevated?)*

RESPONSE: The term "elevated" in this paper is used to describe any concentration of CCN above the control/background concentration of C100. A representative contour of the horizontal domain of elevated CCN is presented in Figure 14. A vertical profile of CCN that was uniformly applied to the horizontal domain of elevated CCN is provided in Figure 3. Text has been modified to clarify the term "elevated" as well as better describe the purpose of Figure 14.

P.358, lines12-13: *Explicitly show how much riming growth and collection are suppressed because they depend on many variables, and will also very depending on* *what the liquid water content is(lots of non-linear dependence can affect how large the riming and collection terms are)*

RESPONSE: While the details of particle growth and accumulation were not explored in this study, the various types of hydrometeors are shown in Figure 12. The detailed budget analysis of the microphysical behavior of riming and collection for different CCN concentrations is beyond the scope of this paper, but we agree that it deserves additional research treatment.

P.358, line 17:*Can you show the CCN? It is hard to interpret the results without seeing the evolution of the CCN field?*

RESPONSE: Figure 14 shows a representative example of a contour of elevated CCN being entrained in the storm. As the only change in the sensitivity tests was number concentration of the elevated CCN field, the other tests showed similar CCN field behavior.

P.359, line1: *If the delays are being attributed to CCN, why is the C3000 spike before the C1000 spike?*

Here again, only CCN amplitude is varied from one simulation to the next. Thus attribution can only be related to variations in CCN amounts. But as the reviewer already noted the response to these varying amounts of CCN is highly nonlinear. Initially when CCN is elevated and drawn into the storm, convection is altered(note we do not say enhanced as that depends on the intensity of convection and its location in the storm) and its alteration depends on the amplitude of the CCN concentrations. But once such an alteration in convection occurs the winds in the storm are perturbed thus the transport of the CCN varies, cold-pools change, etc and the entire behavior of the storm is quite different. It is beyond the scope of this paper to explain every perturbation in the sequence of responses to varying CCN amounts.