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Atmospheric Chemistry and Physics Discussions

Interactive comment on "The effects of cloud-aerosol-interaction complexity on simulations of presummer rainfall over southern China" *by* Kalli Furtado et al.

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Author replies for anonymous Referee #1

Specific comments:

1. Isolating the effects of giant CCN was not among the aims of this paper. We've clarified this in the Introduction, and explained more clearly the reasons underpinning our choice of model set-up (p3):

"Two-way coupling represents the minimum level of complexity in model physics required to represent depletion of aerosol during activation. We note that there exists an

lower complexity, double-moment system, in which aerosol are depleted by activation but are not recycled through clouds. It is not our intention to investigate such models here because they suffer from similar physical inconsistencies to single-moment schemes, and hence do not give a physically meaningful representation cloud-aerosol coupling. In this paper we will compare the commonly used fixed-aerosol assumption to the minimum-complexity, two-way coupling ((2), above); with the aim of understanding what new phenomena –if any– arise from consistently coupling clouds to aerosols, and whether these provide any benefits for model performance. By considering fixed-aerosol experiments with a range of aerosol concentrations, we identifying candidate mechanism for the differences between the one- and two-way coupled simulations."

We've also changed the abstract slightly to avoid giving the impression that we are seeking to isolate the effects of re-cycling from those of activation/depletion (we agree that this wasn't clearly worded before): "We focus on the effects of complexity in cloud-aerosol interactions, especially depletion and transport of aerosol material by clouds. In particular, simulations with aerosol concentrations held constant are compared with a fully cloud-aerosol-interacting system to investigate the effects of two-way coupling between aerosols and clouds on a line of organised-deep convection."

What we aim to do is compare a commonly used assumption (fixed aerosol) to the minimum complexity set-up that accounts for depletion during activation. If the aerosols are activated, then they must be recycled somehow. If activated aerosols are simply 'removed'/ 'lost', the system is not physically self-consistent, and the results would have little (if any) useful meaning. In our opinion, the only meaningful way to separate the effects of depletion during activation from re-population of interstitial aerosols is to introduce additional prognostic variables for in-cloud aerosol number concentrations. Because of the large increase in model complexity that this would involve, it is much more suitable for a separate publication. We therefore wish to argue strongly against including an investigation of these effects in this paper.

2. Fig. 2 caption has been revised.

3. corrected.

4. p9.L7–8. I've edited the text to be clearer: "The cloud-water content (Figs 4(e-h)) also peaks in 4–5-km layer indicating that condensation of liquid cloud is most active at these heights". The labels on Fig. 4 have been corrected.

5. p9.L8–10. We agree: the mass of melting snow influences the rain mass. New lines added on p10 clarify this point: "Note that this does not imply that snow is unimportant for the amount of rain. In fact, precipitating snow provides the mass flux into the melting layer from above. This is evident in the vertical profiles in Figs 4(e-h), which show that the rain-water content below the melting layer is limited by mass of snow immediately above. As the number of rain drops increases, the ratio of rain to snow increases because a larger mass of rain is needed to balance the snow-fall flux from above. In other words: in the cleaner simulations, the mass-flux from melting snow is transported by a larger number of (smaller) rain drops and a larger mass of rain resides in the column. Therefore warm-rain processes modulate the rain-drop number, and the rain-water content responds to this by increasing or decreasing so that the mass-flux of frozen precipitation from above is conserved. This process is discussed in more detail in Section 3.1.3."

6. p9.L11–12. With hindsight, this sentence was unnecessary and a bit confusing – we've removed it. (Incidentally, we meant that because auto-conversion is non-linear in the number of droplets, the production of rain is fastest at the height where droplet concentrations are lowest.)

7. The fixed aerosol number concentrations in these experiments mean that the droplet-number concentration does not vary much with height below the homogeneous freezing level. Now clarified on p9: "The cloud-droplet number profiles in the 5e7F and 5e6F are relatively uniform below the homogeneous freezing because aerosol number concentration is constant in these simulations."

8. p10. "in mixed-phase clouds .. needs a detailed analysis." We've significantly rewrit-

ten and expanded Section 3 to provide a more methodical discussion warm and mixed-phase processes. The new structure is based on discussion of 3 possible 'scenarios' of cloud aerosols interaction (explained in detail on p9): (1) warm-rain-processes dominate (2) cloud-droplet freezing dominated (3) mixed-phased-feedback dominated

We discuss the relative merits of each scenario in turn. (2) can be ruled out because it is not consistent with the simulated changes in ice- and rain numbers (see text). To some extent (2) and (3) cannot be disambiguated, because both affect rain-number in the same direction. However, we note that (2) is not consistent with the orders-of-magnitude of the changes in rain and graupel: the graupel-number changes are much too small to explain the changes in rain-drop number. Further, we've add to Fig. 4 a new experiments ("5e6_ACC") in which Na=5e6 but auto-conversion and rain-cloud accretion are both turned off (for T>-4C). In this experiment, the only possible aerosol-indirect effects are via changes in mixed-phase or ice process. The results show that 5e6F_ACC is similar to 5e7, not to 5e6. This strongly suggest the cloud-aerosol effects seen are very similar to the effects of suppressing warm-rain processes. This supports the conclusion that warm-rain processes are essential for simulating the cloud-responses seen in the full-microphysics simulations. It does not, of course, completely rule out the additional importance of mixed-phase processes, and this is noted in the revised text.

9. p10. Fig 5. Black symbols on Fig. 5. Thess symbols are for rain rates greater that 16 mm/h. The colored text-labels indicated the location of rain-rate-bin edges, i.e., the lie between the rows of colored symbols. We've clarified this in the Fig. 5 caption.

10. p12. Fig 6. Number of grid-points. An axis label has been added.

11. p15.L9–10. Agreed, the expanded Sec. 3 provides a more detailed analysis of this claim. Also the conclusions text (p16) has been modified to reflect the new analysis: "The simulations performed do not place an unambiguous constraint on aerosol effects mediated by mixed-phase processes (for example, the affects of aerosols on riming),

but experiments with direct cloud-to-rain conversions turned off suggest that warm-rain processes are at least essential to the simulated cloud responses."

I've also added a brief summary of the main model assessment results (p15): "The comparisons to observations show that forecasts with lower aerosol concentration give better predictions of histograms of hourly instantaneous rainfall rates. However, the same configurations underestimate the observed fluxes of short-wave radiation radiation in regions where cloud- and rain-water paths are large, but underestimate reflected SW fluxes from lightly precipitating cloud with low liquid-water paths."

Technical corrections :

all corrected; except for units of mm/h for rainfall amount (we believe this to be correct)

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