

First of all, we would like appreciate the reviewer's comments and suggestions. Listed below are our answers to the questions and suggestions given by the reviewer. Each comment of the reviewer (black) is listed and followed by our responses (blue).

Anonymous Referee #2

By means of model simulations, the study demonstrated that clouds and precipitation response differently due to differences in the morphologies of convective and stratiform clouds to increasing aerosols. In convective clouds, aerosols suppress the autoconversion rate, increase cloud number concentration, and enhance evaporative cooling. The enhanced cooling leads to an increase in the intensity of downdrafts, gust fronts, and updrafts, which enhance condensation and precipitation. Such results are consistent with other studies. The authors also argue that this process is more important than the latent heat release from freezing in terms of rainfall enhancement following experiments with and without ice. In stratiform clouds, the acceleration of downdrafts is less significant due to smaller clouds depths, therefore, the suppression of precipitation by aerosols dominants. The underlying physical processes are clearly elaborated. I would recommend the paper for publication after addressing the following comments.

My main concerns are the conclusions drawn from the experiments with and without ice that the aerosol effect on gustiness plays a much more important role than that of freezing and freezing. While it is well known that evaporative cooling is an important factor to enhance precipitation based on both previous studies and the present study, the evidences presented here to support the argument concerning its relative importance are not sufficient.

There are two issues involved:

1) In the no-ice experiments, cloud top is over 10km and there is no ice, which means the liquid clouds are extremely thick. According to this study, cloud thickness plays a very important role in determining the aerosol effect on the acceleration of downdrafts. Thicker clouds provide longer paths for cloud particles to evaporate. Therefore, the aerosols effect on gustiness may be overestimated in such idealized thick liquid clouds.

We repeated the no-ice simulations in DEEP by preventing cloud-droplet evaporation above the freezing level. We still have larger cumulative precipitation in the high-aerosol run than in the low-aerosol run in these repeated simulations. Hence, the qualitative nature of results in DEEP is robust to cloud-droplet evaporation above the freezing level. This is because more than 90% of difference in cloud-liquid evaporation (driving differences in downdrafts and low-level convergence) between the high- and low-aerosol runs occurs below the freezing level whether ice physics is turned on or not. In MID, most of difference in cloud-liquid evaporation between the high- and low-aerosol runs also occurs below the freezing level. However, the regions of main evaporation and initial downdrafts are lowered in MID as compared to those in DEEP, leading to shorter path for downdrafts to follow to the surface in MID than in DEEP.

2) In the case DEEP, CAPE is increased by increasing the humidity forcing. This reduces the rain suppression effect by aerosols due to increases in available water vapor. Therefore, warm rain processes may not be suppressed effectively and may still be the dominant mechanism to generate precipitation (similar to the TOGO COARE case in [Tao, et al, 2007]). In such a scenario, freezing is certainly not as important as the evaporative cooling. In the Case MID, the humidity forcing is reduced and the aerosol effects on precipitation through freezing could show up. If this is the case, the relative importance of evaporative cooling and freezing is not really determined by cloud thickness but humidity. What if CAPE is increased by changing vertical temperature gradient instead of the humidity forcing? Will this lead to significant enhancement of precipitation by freezing while the cloud is still deep in CASE DEEP?

First of all, we want to note that DEEP is just an observed ARM case. We did use the observed humidity forcing for DEEP and did not increase humidity forcing for simulations in DEEP.

We repeated simulations in DEEP by putting a strong temperature forcing around 6 km. This forms an inversion layer around 6 km; this is similar to putting a strong temperature forcing for the formation of an inversion layer around 1 km in SHALLOW. For these repeated simulations, we did not change the observed humidity forcing. However, due to the formation of the inversion layer around 6 km, cloud-top height cannot exceed 6 km. Hence, we are able to generate a similar cloud-type to that in MID with no modifications on the humidity forcing but with those on vertical temperature gradient via the temperature forcing as suggested by the reviewer here. These repeated simulations show increasing precipitation with ice physics but decreasing precipitation with no ice physics with increasing aerosols. Hence, we can see the relative importance of evaporative cooling and freezing is determined by cloud thickness from these repeated simulations. In other words, just the change in temperature gradient (but not in humidity forcing) for the change in cloud type between deep convective clouds and cumulus clouds does not change the identified relative importance of evaporative cooling to that of freezing by simulations with changing humidity forcing between those two different cloud types (described in the manuscript).

Specific questions and comments:

1. Page 4318 line 19, “The reduction of heat within the system by the evaporation of cloud liquid due to the reduction in aerosol concentrations is ~ 40 times larger than that released by cloud liquid freezing as shown in Table 2.” It’s not clear which two numbers were compared. “due to the reduction in aerosol concentrations” should be “due to the increase in aerosol concentrations”?

Here, we compared the difference (high-aerosol run minus low-aerosol run) in the domain-averaged cumulative heat reduction from evaporation of cloud liquid at the last time step (10^8 J m^{-2}) (see the first column in Table 2) to the domain-averaged cumulative latent heat release from freezing at the last time step (10^8 J m^{-2}) (see the third column in Table 2).

As discussed in the introduction, one of main purposes of this study is to compare the parcel buoyancy effect associated with warming from particle freezing to the gustiness effect associated with evaporative cooling for the invigoration of convection and the precipitation enhancement due to increasing aerosols. Here, we compared evaporative cooling playing an important role in gustiness with heating from freezing playing an important role in buoyancy; increasing evaporative cooling intensifies the gustiness, while the increasing latent-heat release from freezing intensifies the parcel buoyancy, and the comparison shows that evaporative cooling is ~40 times larger than warming due to the latent-heat release from freezing.

We corrected “due to the reduction in aerosol concentrations” to “due to the increase in aerosol concentrations”

2. Table 3. The numbers in the third row shift to the left.

They will be moved to the center in the revised manuscript; the submission of new manuscript will be done after editor’s preliminary decision on these our responses.

3. Vertical profiles of latent heat absorption and release will be more useful to demonstrate the influences of evaporative cooling and freezing on cloud development.

These profiles will be added in the new manuscript;

4. Fig.5. Some lines are difficult to identify. It is better to use thicker lines or different symbols.

We modified figure 5 following the comment here and this modified figure will be added to new manuscript after editor’s decision.

5. Fig.8. Need to clarify whether the results are from the experiments with-ice or no-ice.

Just high-aerosol and low-aerosol (but not high-aerosol-no-ice and low-aerosol-no-ice) are in legends in Figure 8. This indicates Figure 8 is for the high- and low-aerosol runs (with ice as described in Table 1) for each of DEEP and MID and the high- and low-aerosol runs for SHALLOW (with ice but not activated). However, to make it clearer, caption for figure 8 is revised as follows:

“Figure 8. Vertical distribution of time-averaged updraft mass flux for the high- and low-aerosol runs. The high- and low-aerosol runs for DEEP, MID, and SHALLOW include ice physics, though ice physics is not activated in SHALLOW.”