Answers to anonymous referee #3

We would like to thank the reviewer for his/her time and effort reviewing our study. We have found the comments to be constructive and helpful.

In this reply, the comments from the reviewer are in black, and our answers are in red. The new text and lines of the revised document where the adjusted text can be found are also in red. In the revised document, all new text is marked in blue, and deleted text is crossed out in red.

Minor comments:

1. The authors analyzed the influence of dust aerosols on clouds and precipitation in 14 summers from 2000 to 2013. However, the probability of dust occurrence in southeast China is very low. What is the proportion of dust days in the total samples? If the proportion is too low, does the study have statistical or scientific significance?

   A: According to our strict definition, dusty days account for about 5% of the total precipitation days. Although the proportion of dusty days to total precipitation days is low, our sample size is still sufficient to support our study and all results were statistically significant (e.g. Figs. 9 and S9).

   Southeast China is relatively far from the original source of dust, so a relatively fixed atmospheric circulation conditions (northwest wind) is required to transport dust to this area, then under this circumstances, the observed cloud and precipitation characteristics are jointly determined by the combination of obviously different aerosol conditions and weather conditions, which creates an ideal test bed for us to isolate the combined effects from dust aerosol and meteorology conditions on precipitation. If the study area is chosen at the source of dust, its weather conditions are not uniform, it is not conducive for us to separate the two effects.

   In addition, the results from this study have significant scientific meanings. Because the purified dust aerosol effects on precipitation vertical structure should be also valid in other places, where the dynamic effects may not be isolated easily. And the method of isolating the influence of dynamical and aerosol conditions on cloud precipitation can be applied to other regions.

   We clarified this point in the Section 4 as:

   "Although the heavy dusty days in southeastern China is not frequent, the generally accompanied synoptical pattern provides us ideal testbed to isolate the dust aerosol effects from dynamic effects on precipitation. And the associated mechanism and effetcs should be also valid in other region, where the dynamic effects may not be isolated easily. And the method of isolating the influence of dynamical and aerosol conditions on cloud precipitation can be applied to other regions."

2. In Figure 2, the authors analyzed the backward trajectory on 12 June 2006. Please explain whether this is representative for the whole study period.

   A: We clarified this point in the revision:

   "We likewise examined the backward trajectories of other dusty days, such as 20 June 2010 (Fig. S1), 11 June 2012 (Fig. S2), 16 June 2012 (Fig. S3), etc., the dusty air mass was from the Gobi and/or Taklamakan Desert as well. This suggests that the backward trajectory of the dusty air mass on 12 June 2006 is representative for the whole study period. Liu et al. (2011) also found that dust in southeast China originated from the Gobi Desert and Taklamakan Desert in northwestern China."

Liu, J. J., Zheng, Y. F., Li, Z. Q., Flynn, C., Welton, E. J., and Cribb, M.: Transport, vertical structure and radiative properties of dust events in southeast China determined from ground and space sensors, Atmospheric Environment, 45, 6469-6480, 10.1016/j.atmosenv.2011.04.031, 2011.

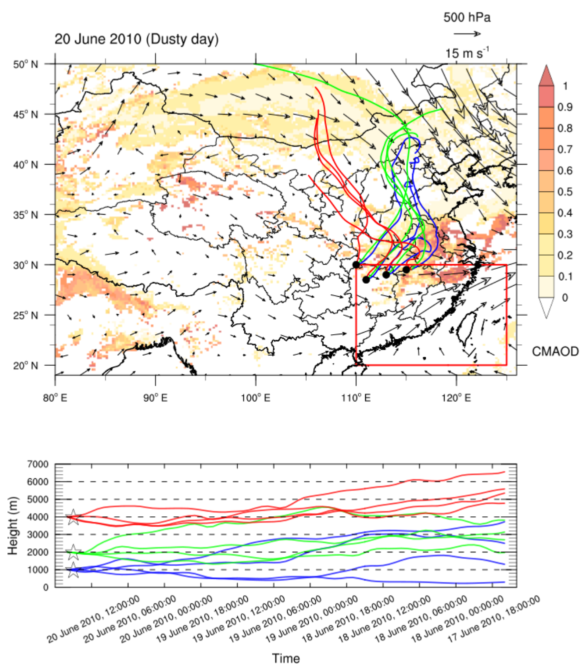

Figure S1: Horizontal distribution of coarse mode aerosol optical depth derived from Terra MODIS, wind fields at 500 hPa, and 72-hour back trajectories from the HYSPLIT model on 20 June 2010. Where the red box indicates the study area, the geolocation of four starting points are at 28.5° N, 111° E; 29° N, 113° E; 30° N, 110° E; and 29.5° N, 115° E, with altitudes of 1000 m (blue line), 2000 m (green line), and 4000 m (red line), extrapolated from 20 June 2010 at 13:00 UTC.

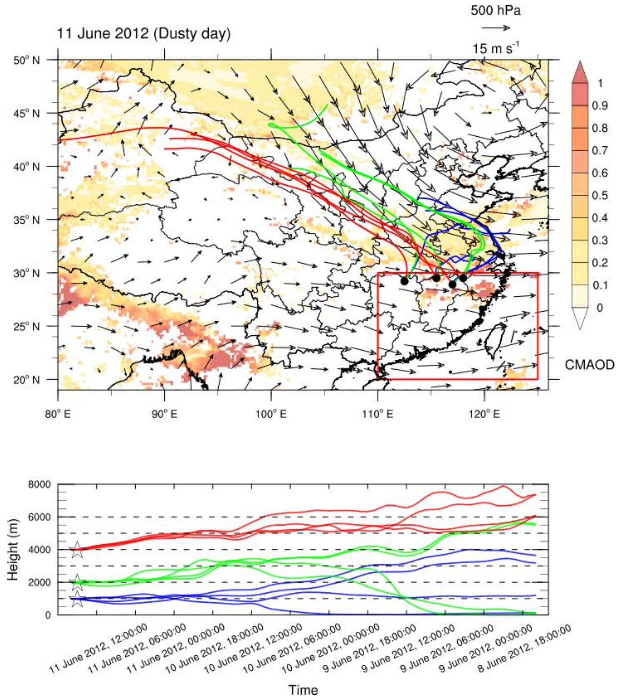

Figure S2: Horizontal distribution of coarse mode aerosol optical depth derived from Terra MODIS, wind fields at 500 hPa, and 72-hour back trajectories from the HYSPLIT model on 11 June 2012. Where the red box indicates the study area, the geolocation of four starting points are at 29.5° N, 115.5° E; 28.9° N, 117° E; 29.2° N, 112.5° E; and 29.5° N, 118° E, with altitudes of 1000 m (blue line), 2000 m (green line), and 4000 m (red line), extrapolated from 11 June 2012 at 18:00 UTC.

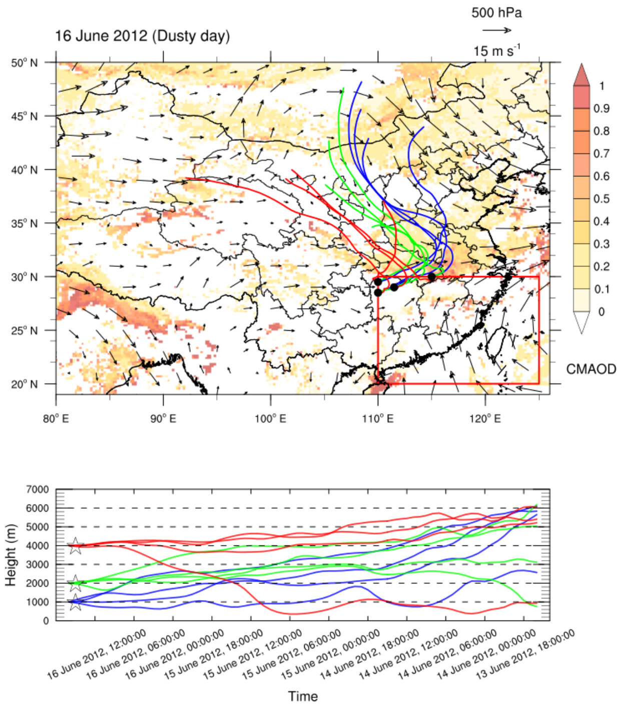

Figure S3: Horizontal distribution of coarse mode aerosol optical depth derived from Terra MODIS, wind fields at 500 hPa, and 72-hour back trajectories from the HYSPLIT model on 16 June 2012. Where the red box indicates the study area, the geolocation of four starting points are at 29.5° N, 110° E; 29° N, 111.5° E; 30° N, 115° E; and 28.5° N, 110° E, with altitudes of 1000 m (blue line), 2000 m (green line), and 4000 m (red line), extrapolated from 16 June 2012 at 13:00 UTC.

3. How do the authors define warm rain?

A: We clarified this point in the revision:

"Warm rain is defined as those with PTT warmer than 0 °C."

4. In Figure 4e, why is the difference between cleaning and dust conditions minimum when the ppt is -20 to -15 (green lines)?

A: When the PTT is -20°C to -15°C (green curves), the difference between cleaning and dust conditions is relatively small but still evident (as shown in Fig. 4 after excluding other curves).

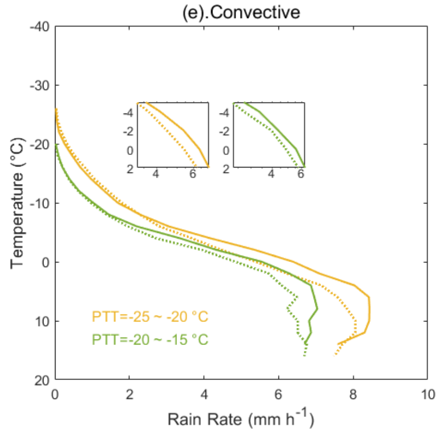

Figure 4: Differences in vertical profiles of convective precipitation for pristine (dashed line) and dusty (solid line) conditions for given PTT. Different color stands for different PTT. Each subpanel focuses on the rain rate in the mixed layer (temperatures between -5 °C to 2 °C).

5. In Figure 5, why do the negative values of the difference all appear at 5km? Does it mean that the vertical LH of the convective clouds and stratus clouds have similar feedback to dust aerosol? In addition, the color bar values displayed on the right of the figure are incomplete, please adjust them.

A: Thanks for pointing this out. It is near the altitude of 5km that the heterogeneous freezing process dominates. The presence of dust intensifies the heterogeneous freezing process, making it easier for ice to form, resulting in an increase in positive heating and a decrease in cooling. This process is basically the same for convective and stratiform precipitation. Therefore, the negative values of the difference (it means an increase in positive heating and a decrease in cooling) generally centered at 5km. In addition, the color bar values in Figure 5 have been adjusted, as shown below.

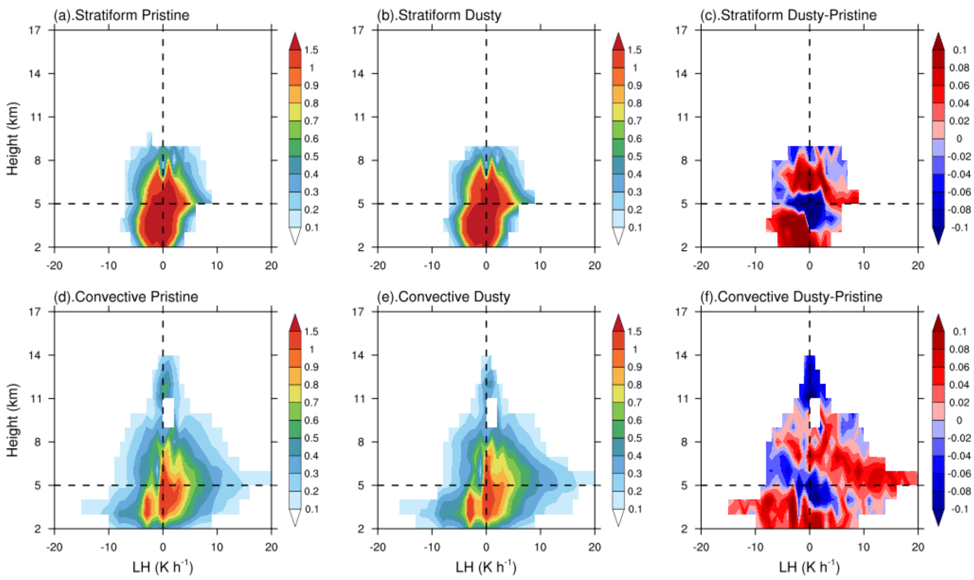

Figure 5: Contoured frequency by altitude diagrams (CFADs) of LH (retrieval from VPH) in pristine (the first column) conditions, dusty (the second column) conditions and the differences between them (the third column) for stratiform (the first row) and convective (the second row) rains.

We clarified this point in the revision as:

"Under dusty conditions, stratiform and convective rains exhibits an increased positive heating near 5 km altitude and a decrease of negative heating (cooling) at higher layer. From the difference of CFAD of LH (Fig. 5c and 5f), the negative values of the difference all appear around 5km where the heterogeneous freezing process dominates. The presence of dust intensifies the heterogeneous freezing process, making it easier for ice to form, resulting in an increase in positive heating and a decrease in cooling. The LH vertical structure of stratiform and convective rains have similar feedback to dust aerosol. Meanwhile, the cooling (i.e. negative LH) in layer lower than 5 km is also enhanced based on Fig. 5c and 5f."

6. In Figure 9, what is the criterion or basis for the selection of CAPE thresholds?

A: There are two criterions for the selection of CAPE thresholds. First, the differences between defined strong and weak CAPE groups should be great enough. Second, it is required that both groups have enough sample size. After the experiment, it was found that the threshold of weak (strong) CAPE was taken as 25% (55%) of the cumulative probability of CAPE for pristine raining samples as more appropriate.

We clarified this point in the revision as:

"All pristine stratiform and convective raining samples are divided into two groups with strong CAPE (i.e. over 700 J kg^{-1} for stratiform rains and over 1100 J kg^{-1} for convective rains) and weak CAPE (i.e. weaker than 350 J kg^{-1} for stratiform rains and 700 J kg^{-1} for convective rains) to check the impacts of dynamic conditions on the PTT-NSRR relationship. There are two criterions for the selection of CAPE thresholds. First, the differences between defined strong and weak CAPE groups should be great enough. Second, it is required that both groups have enough sample size. After the experiment, it was found that the threshold of weak (strong) CAPE was taken as 25% (55%) of the cumulative probability of CAPE for pristine raining samples as more appropriate. "

Answers to anonymous referee #4

We would like to thank the reviewer for his/her time and effort reviewing our study. We have found the comments to be constructive and helpful.

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This study investigated the impact of dust aerosol and atmospheric convective available potential energy (CAPE) on the formation of precipitating clouds in southeastern China. Overall, while the paper presents some interesting findings on the relationship between dust and CAPE and precipitation, there is one limitation that should be addressed before the potential publications.

A: We thank for the reviewer's positive comments on our work and are happy to address his/her concern as follows.

Major comments:

My main concern is the causality claimed in the paper. While the study provides the relationship between dust, CAPE, and the vertical structure, it is not clear to what extent these relationships are causal. For example, the impacts of dust may not be fully revealed by comparing the dust conditions and pristine conditions. As dust conditions are usually associated with certain synoptic backgrounds (i.e., strong north wind), the synoptic pattern itself will lead to the difference in CAPE. It would be helpful to see a more thorough examination of potentially confounding variables that can better isolate the effects of dust aerosols.

A: Yes, we agree that the difference in CAPE should be mainly determined by synoptic conditions instead of aerosol. CAPE, as an indicator of convection strength, makes impacts on precipitation vertical structure independently from dust aerosols. The data analysis on satellite observations confirmed that PTT_0 decreases 0.41-0.65°C per 100J kg^{-1} CAPE. In section 3.4, we isolated the dust aerosol effects on PTT_0 from CAPE effects using partial differential analysis of composite function.

Indeed, there are multiple potential confounding variables that nay lead to changes of PTT_0. According to the reviewer's suggestion, we conducted additional sensitivity tests of PTT_0 to updraft velocity (W), water vapor (RH) and wind shear in this revision using the same method for CAPE.

As shown here and in the supplementary material of Figure S12, S13 and S14, although PTT_0 showed some correlations to those variables (it is not surprising), the relationship of PTT_0 to them at 750 and 500 hPa are NOT as stable and significant as that to CAPE. For example, PTT_0 of stratiform (convective) precipitation shows positive (negative) correlation to updraft velocity at 750hpa but very weak correlation with it at 500hPa. Similar results were found for wind shear and water vapor. This is because the precipitation top height varied from case to case thus has different sensitivity to cloud dynamic and thermodynamic conditions at different altitudes.

Based on this analysis, CAPE as a measure of the convective instability energy has the best representativeness of dynamic effects on precipitation vertical structure.

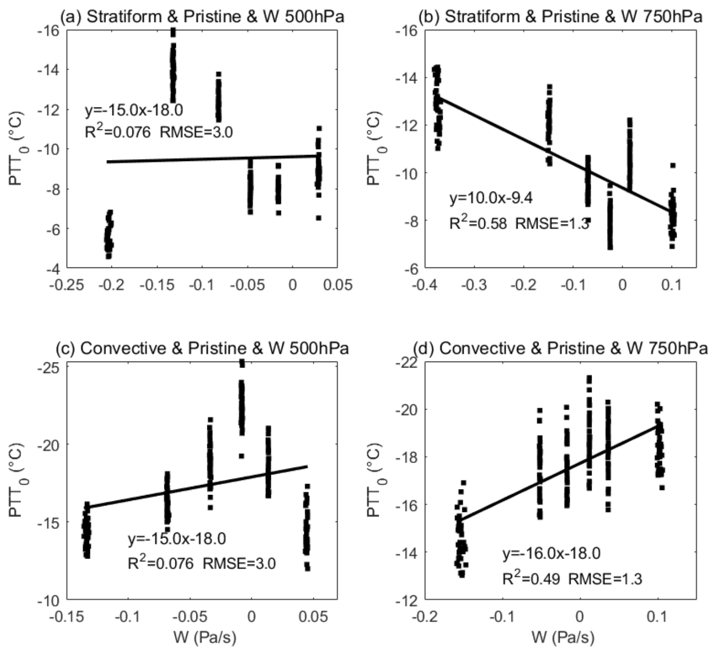

Figure S12: The variation of PTT_0 with updraft velocity (W, Pa/s) at 500 hPa (a,c) and 750 hPa (b,d) for deep stratiform precipitation (the first row) and deep convective precipitation (the second row) under pristine conditions. The results are derived from randomly selected 70% precipitation samples from total.

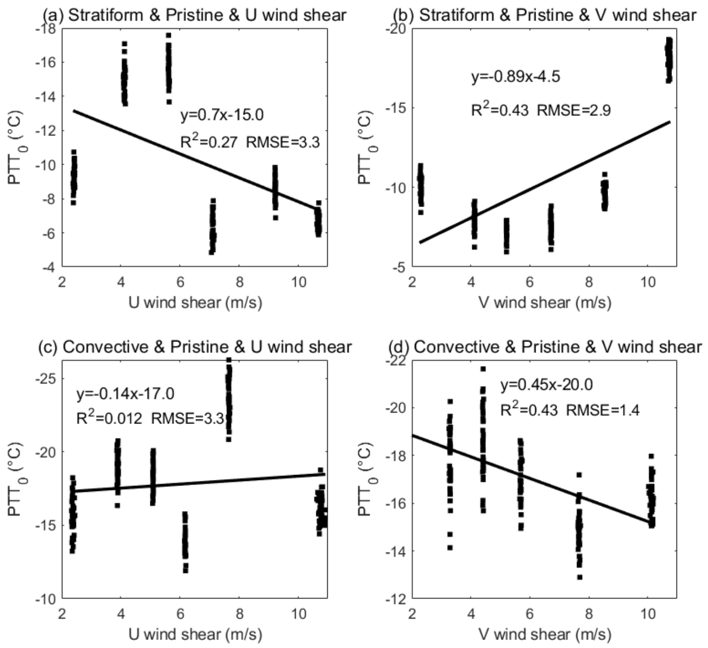

Figure S13: As same as Figure S12, but for U and V wind shear (m/s).

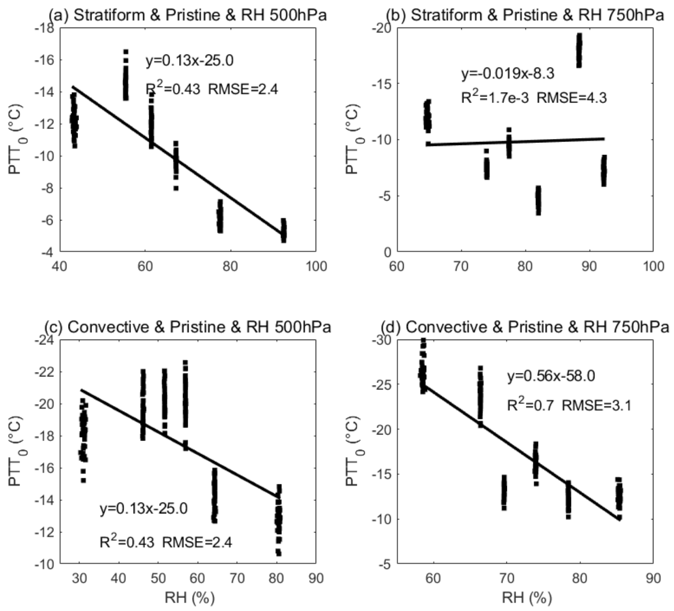

Figure S14: As same as Figure S12, but for relative humidity (RH, %) .

In the last paragraph of Section 3.1, we emphasized that:

"It should be emphasized that the difference in CAPE should be mainly determined by synoptic conditions instead of aerosol."

In the end of Section 4 "Discussion and Conclusion", we clarified that:

“It should be noticed there are several uncertainties in this study. ……In addition, the relationship between NSRR and PTT is influenced by multiple dynamic factors. Sensitivity tests of PTT_0 to updraft velocity (W), water vapor (RH) and wind shear were conducted using the same method for CAPE (Figs. S12, S13 and S14). The relationship of PTT_0 to them at 750 and 500 hPa are not as stable and significant as that to CAPE. This is because the PTH varied from case to case and is sensitive to multiple factors at varied altitudes. CAPE as a measure of the convective instability energy has the best representativeness of dynamic effects on precipitation vertical structure. Therefore, in this study, we mainly focused on CAPE.”