

Responses to Reviewers' Comments

We are sincerely grateful to the editor and reviewers for their valuable time spent on reviewing our manuscript. The comments are constructive and valuable, and we have tried our best to address the issues raised by the reviewers in revised manuscript. Please find our item-by-item response (in bold) to the comments (in black) raised by the reviewers, and the paragraphs added in the revised manuscript (in red).

Reviewer #1

General Comments: The aim of this manuscript is to statistically understand the effect of dust aerosols on the three-dimensional structure of precipitation systems of different sizes. This is an interesting and valuable attempt, as it is not common to study aerosol effects based on a large number of observational samples with the whole precipitation system as the research unit. Also, the authors have carefully considered the influence of meteorological conditions and employed multiple approaches (e.g., partial correlation analysis, and CAPE constraint) for investigation. So I think this work is well-constructed and scientifically meaningful, hence can be accepted for publication after the minor issues are addressed.

Reply: We thank the reviewer for the valuable time and constructive comments, which have helped us to improve our manuscript. All comments have been addressed item by item.

Major Comments:

Q1: L177-180: The authors categorized PSs into three types: small-sized ($< 2000 \text{ km}^2$), medium-sized (between 2000 km^2 and 10000 km^2), and large-sized ($> 10000 \text{ km}^2$). Please clarify the reason for selecting these specific thresholds.

Reply: Thank you for raising this point. The area thresholds used in this study were determined based on previous studies on the characteristics of PSs. For instance, Liu et al. (2019) classified PSs with areas $> 2000 \text{ km}^2$ as mesoscale convective systems (MCSs) in their analysis on the intensity, height, and size variations of PSs under El Niño–Southern Oscillation conditions in the tropics and subtropics. They also found that PSs exceeding $10,000 \text{ km}^2$ contribute significantly to the annual mean rainfall (Fig. 7e in their paper). Similar thresholds have also been widely adopted in other studies (Zipser et al., 2008; Liu et al., 2017). The relevant references for the thresholds have been added in the manuscript.

Liu, C., Chen, B., and Mapes, B. E.: Relationships between Large Precipitating Systems and Atmospheric Factors at a Grid Scale, *Journal of the Atmospheric Sciences*, 74, 531-552,

10.1175/jas-d-16-0049.1, 2017.

Liu, N., Liu, C., and Lavigne, T.: The Variation of the Intensity, Height, and Size of Precipitation Systems with El Niño–Southern Oscillation in the Tropics and Subtropics, *Journal of Climate*, 32, 4281–4297, 10.1175/jcli-d-18-0766.1, 2019.

Zipser, E. J., Liu, C., Cecil, D. J., Nesbitt, S. W., and Sherwood, S.: A Cloud and Precipitation Feature Database from Nine Years of TRMM Observations, *Journal of Applied Meteorology and Climatology*, 47, 2712–2728, 10.1175/2008jamc1890.1, 2008.

Q2: Figure 3: Why do other characteristics of PSs significantly increase under dusty conditions, while the differences in PS areas between clean and dusty conditions are not apparent?

Reply: It can be seen that the precipitation areas are larger at most heights under the dusty conditions (Fig. 5). However, for stratiform precipitation, the areas below the freezing level decrease under high dust loading due to the evaporation effect. It should be noted that the precipitation area in Fig. 3 is calculated based on the number of raining pixels with PR near-surface rain rate greater than 0 mm/h, which is closer to the changes in the lower layers (i.e., below the freezing level) shown in Fig. 5. We have added the following clarification in the manuscript:

"It should be noted that the near-surface precipitation area shown in Fig. 3 primarily reflects the changes occurring in the lower layers (i.e., below the freezing level), as depicted in Fig. 5. Therefore, the differences in precipitation areas between clean and dusty conditions are not pronounced, although other characteristics of PSs increase significantly under dusty conditions."

Q3: Section 4: In the analysis of physical mechanisms, this manuscript mentioned both the CCN effect and the IN effect of dust, but failed to clearly distinguish between these two effects. A more explicit elaboration would be necessary and beneficial.

Reply: Thank you for this valuable comment. We agree that the CCN and IN effects of dust were not clearly distinguished in the original manuscript. In our study, both effects are expected to influence PS properties, but it is indeed challenging to clearly separate them based solely on observational data. To address this concern, we have added the following paragraph in the section of "Conclusions" of the revised manuscript:

"In our study, both the CCN and IN effects of dust contribute to changes of PS properties. Given the complexity of the microphysical processes within PSs, it is challenging to clearly separate these effects based solely on observational data. For future work, we propose conducting model simulation studies and statistical analyses of PSs that develop in warm clouds and comparing the results with those of PSs exceeding 6 km as considered in this study. This comparison would

help to understand the distinct roles of CCN and IN effect on precipitation structure."

Minor Comments:

Q1: L14: The term 'dimensions' in 'varying horizontal dimensions' may be misleading, as it refers to size rather than dimension here.

Reply: We have replaced 'dimensions' with 'sizes' in revised manuscript.

Q2: L21: I would recommend rephrasing the sentence 'significant dust-related Ps changes persist' to 'significant dust-induced changes in PS properties persist' for greater clarity and precision.

Reply: Done!

Q3: Figure 1: PS2 and PS4 have noticeably smaller areas compared with the other PSs. As stated in L109-110, only PSs larger than 80 km² were selected. Therefore, these two PSs should be excluded from this part of the analysis to avoid potential misinterpretation.

Reply: We appreciate this helpful comment. To avoid potential misinterpretation, we have removed the identification of these two PSs in Fig. 1, and updated the table, and corresponding text accordingly.

"As an example, Figure 1 shows the spatial distributions of near-surface rain rate and AOD for the 4 PSs that occurred over Atlantic Ocean on 27 February 2008, and their general characteristics are given in Table 2. It can be seen that different PSs are highly variable in terms of the horizontal scale, as well as other properties and dust conditions. For example, PS2 and PS4 have similar horizontal sizes but exhibit noticeable differences in storm top heights and surface rain rates, implying differences in thermodynamic and dynamic conditions, or possibly aerosol effects. In particular, the higher maximum 30 dBZ echo top height and greater convective precipitation percentage in PS4 demonstrate stronger convective intensity, with a greater number of ice-phase particles. Moreover, it is interesting that PS1 and PS3 have different precipitation areas but similar other properties, such as maximum 30 dBZ echo top height, surface rain rate and convective precipitation percentage, which may be due to their locations in adjacent regions, resulting in relatively consistent background fields and dust aerosol concentrations."

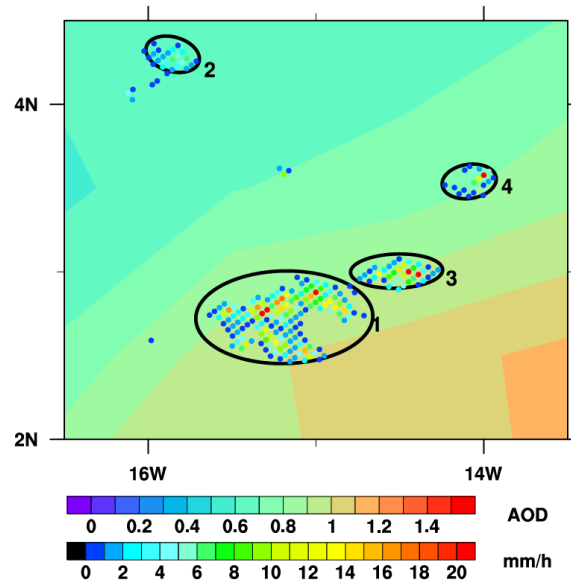


Figure 1. Near-surface rain rates of several PSs idealized as ellipses over the tropical Atlantic Ocean on 27 February 2008 measured by PR (orbit number: 58594). The shaded map is the spatial distribution of MODIS AOD. The four PSs are numbered and represented by black elliptical outlines.

Table 2. The general characteristics of the 4 PSs.

	PS1	PS2	PS3	PS4
Mean AOD	0.73	0.75	0.75	0.77
Near-surface Precipitation Area (km²)	2849.00	529.10	752.95	427.35
Mean Storm Top Height (km)	9.08	6.38	9.20	8.13
Mean Surface Rain Rate (mm/h)	4.74	1.88	4.57	2.86
Maximum 30 dBZ Echo Top Height (km)	11.25	4.50	11.25	7.75
Convective Precipitation Percentage (%)	58.57	38.46	54.05	42.86
Area Fraction of PCT85 ≤ 250 K (%)	65.00	0.00	43.24	19.05

Q4: Figure 6: Why are the significance levels of the differences between maximum radar reflectivity profiles of PSs under clean and dusty conditions not marked, as was done in the other profile figures?

Reply: We have replaced Figure 6 with a new version below, which includes the significance test results.

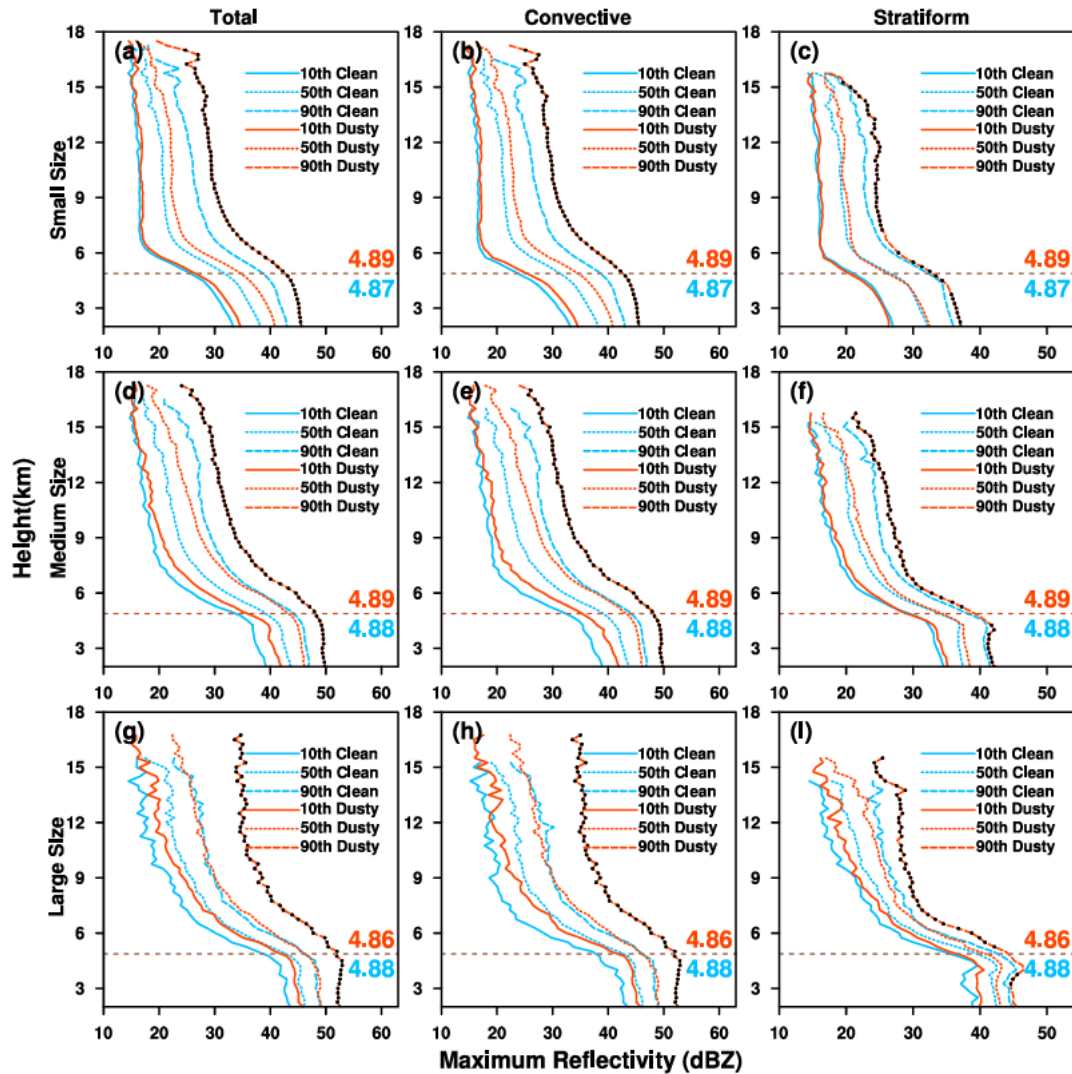


Figure 6. Vertical profiles of the 10th, 50th, and 90th percentiles of PS maximum radar reflectivity for total, convective and stratiform precipitation of small-sized (upper row), medium-sized (middle row), and large-sized (bottom row) PSs under clean and dusty conditions. The horizontal dashed lines show the freezing level with values labeled. The black dot on the red line of 90th percentile profile indicates that the difference between clean and dusty conditions is statistically significant at the 95% confidence level using a Student's t-test.

Q5: Figure 10: Numerous shape markers are used to represent different hydrometeors in the cloud, but these markers are not clearly labeled. A legend explaining this should be added.

Reply: The legend have been added.

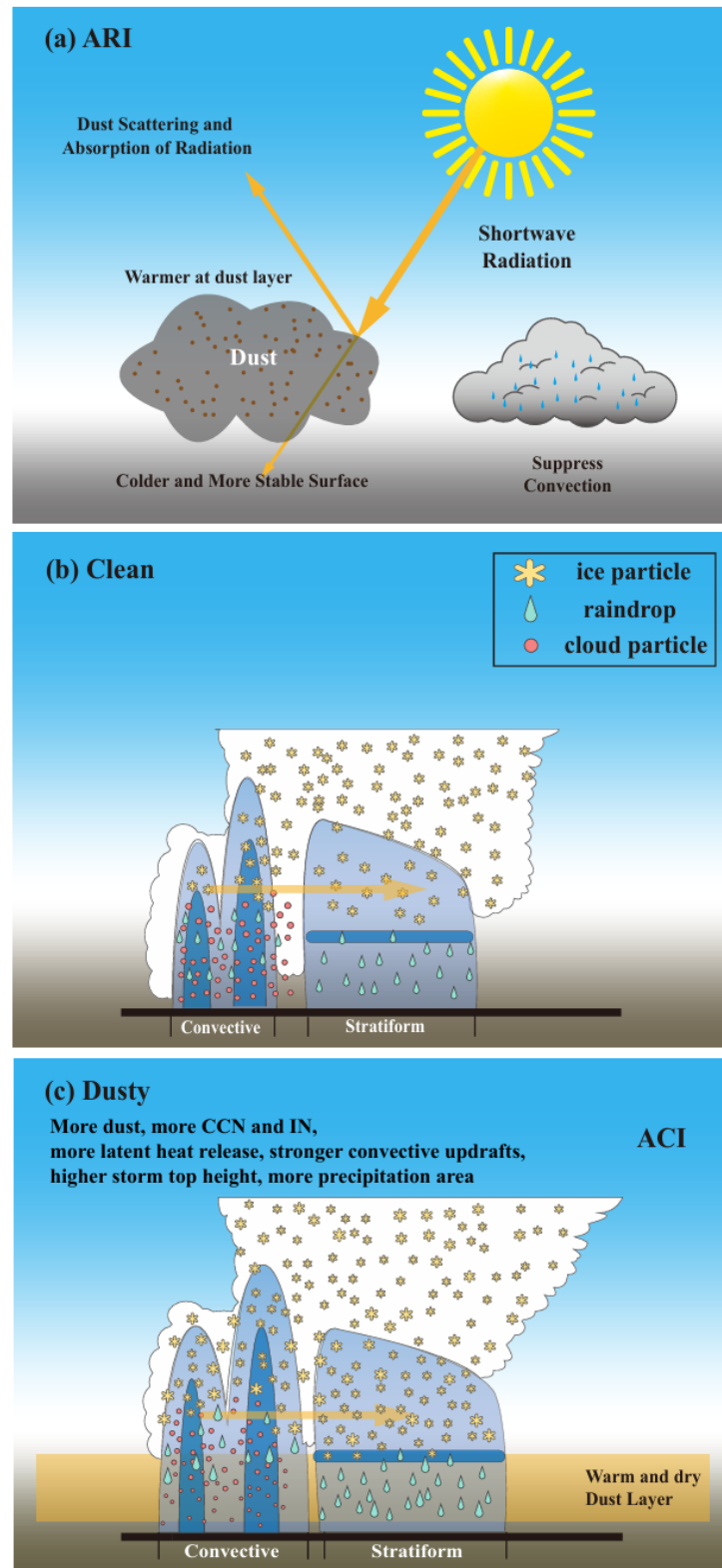


Figure 10. Schematic plot of dust aerosol effects over the tropical Atlantic Ocean.