Responses to Community' Comments

We are sincerely grateful to the editors and the community for their valuable time and constructive feedback on our manuscript. The comments are insightful and valuable, and have helped us to clarify and improve our study. We address each point raised in detail below, with our responses provided in bold.

Community #1

General Comments: The authors utilized a variety of observational data and reanalysis data to study the impact of dust aerosols on the three-dimensional structure of precipitation systems of different sizes. Nevertheless, certain methodological and interpretive aspects warrant further elaboration and refinement.

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

Q1: As a spectral instrument, MODIS cannot directly observe aerosols beneath clouds. Although the authors employed a spatiotemporal interpolation method for aerosol matching, it is worth clarifying whether a cloud fraction threshold was applied during the interpolation process, particularly for PS regions with high cloud coverage.

Reply: We appreciate this insightful question. In our study, no cloud fraction threshold was applied during the interpolation process. To assess the potential influence of cloud coverage on our spatiotemporal interpolation approach, we conducted sensitivity tests using Modern-Era Retrospective Analysis for Research and Applications for version 2 (MERRA-2) data. Specifically, we artificially removed varying proportions of valid data to simulate different cloud cover conditions. For each precipitation system (PS), the averaged MERRA-2 AOD in the PS region was taken as the "true" AOD. Then, these AOD data were removed (white blocks in Fig. 1), and additional values were randomly removed from surrounding areas (gray blocks) to represent different cloud fractions. Our interpolation algorithm was then applied to the AOD data under varying cloud cover conditions, and compared with the true values. Figures 2 and 3 summarize the results.

Across different missing data fractions, the interpolated AOD agrees well with the "true" AOD, with root mean square error (RMSE) remaining low and correlation coefficients exceeding 0.8. Although performance slightly decreases with increasing missing data (e.g., declining correlation and slightly higher RMSE), the overall impact remains minor. This result is likely because the frequent Saharan dust outbreaks in the study region, which persist for several days. Thus, even under high cloud cover condition, valid data from surrounding

grids and adjacent days still provide sufficient information to estimate dust aerosol conditions of PSs.

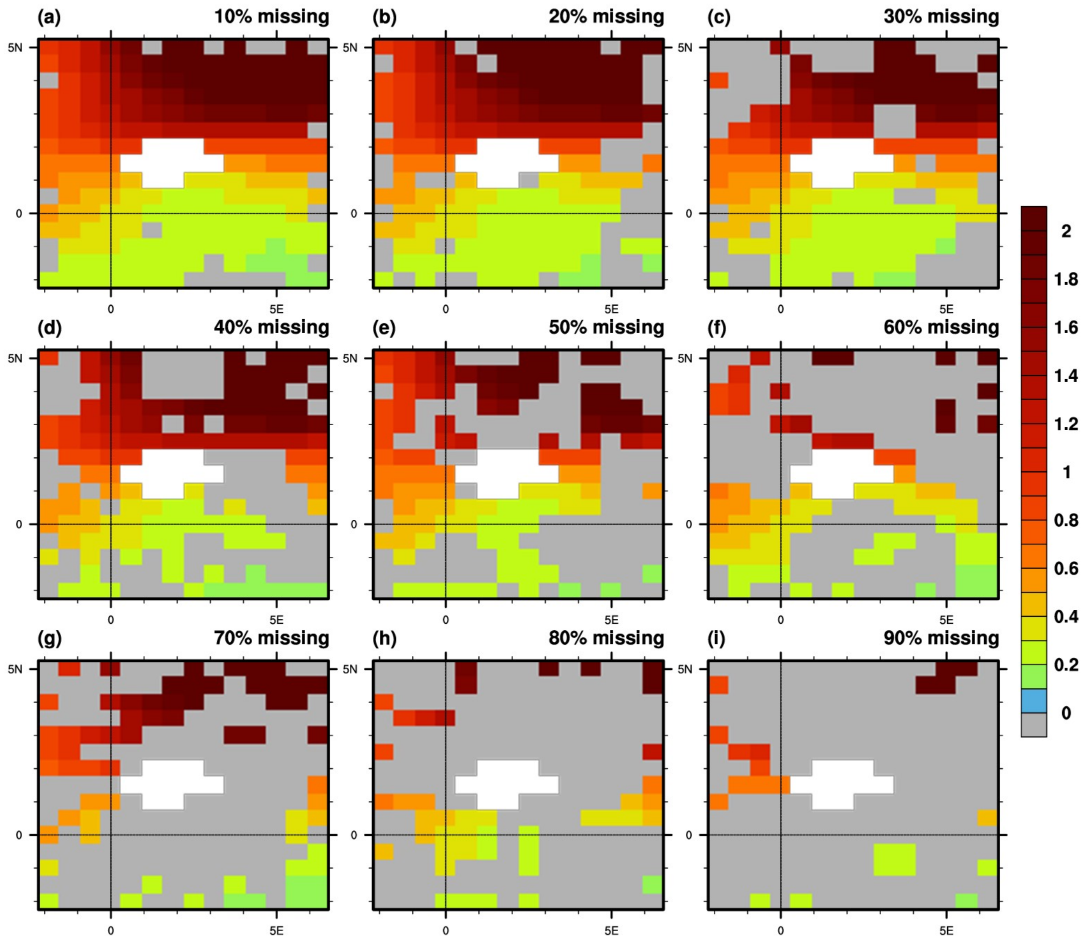

Figure 1. Spatial distribution of AOD for a PS case under varying proportions of artificially removed data. White blocks denote removed AOD data in PS region, and grey blocks denote additional removed data with different proportions from surrounding area.

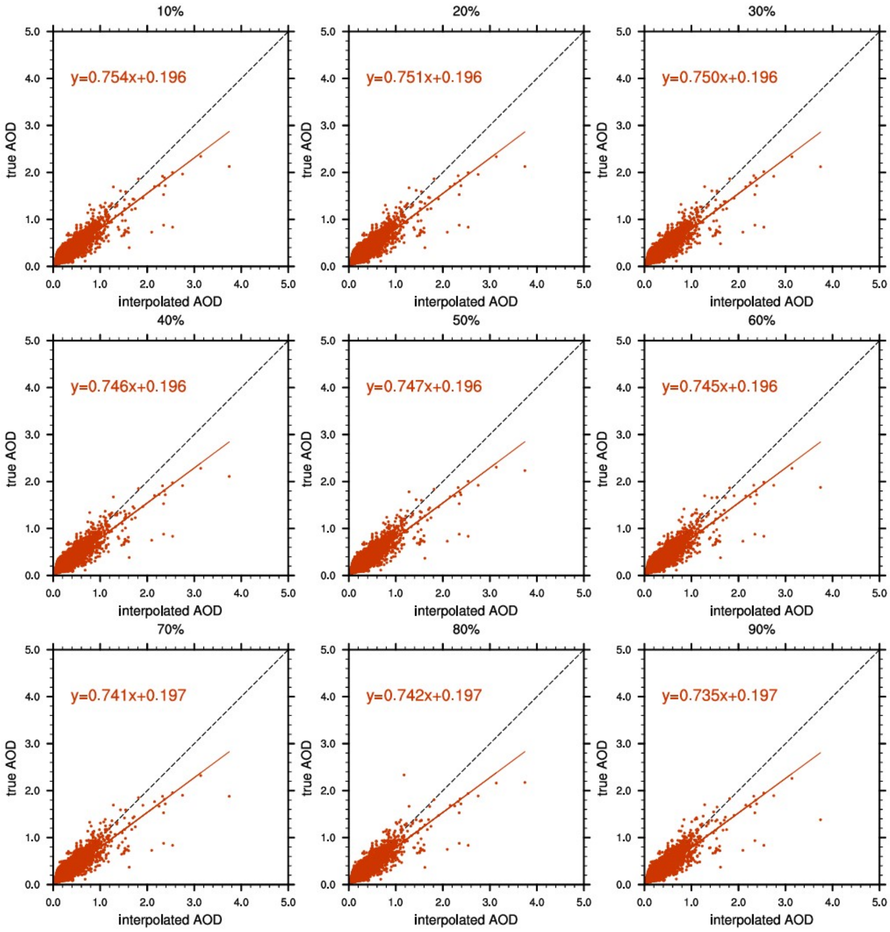

Figure 2. Scatter plots of interpolated AOD (y-axis) versus true AOD (x-axis) for different proportions of artificially removed data.

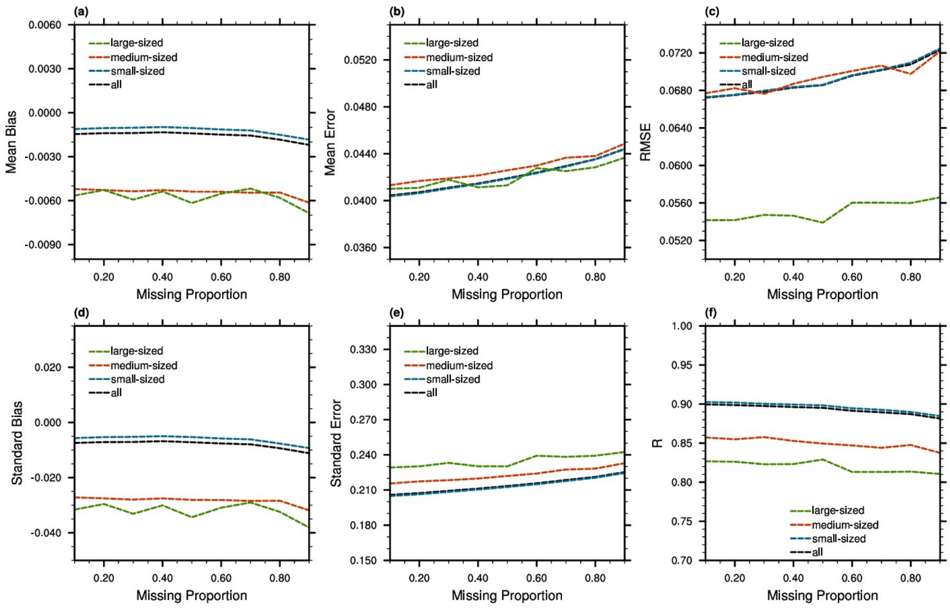

Figure 3. Variations in (a) mean bias, (b) mean error, (c) RMSE, (d) standard bias, (e) standard error, and (f) correlation coefficient of the interpolated AOD relative to the true values for PSs of different sizes, as a function of the proportion of missing data.

Q2: The study categorizes PSs into small (<2000 km²), medium (2000-10000 km²), and large (>10000 km²) classes based on their horizontal area. Could the authors please specify if these area thresholds were defined with reference to the climatological characteristics of PSs commonly found in the tropical Atlantic ITCZ region?

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 km² as mesoscale convective systems (MCSs) in their analysis of 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 km² contributed 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).

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.

Q3: The paper primarily focuses on the aerosol-cloud interaction process involving dust acting as ice nuclei. Could the authors elaborate on whether a more quantitative investigation was conducted regarding the associated water-phase processes? Furthermore, while the dust's radiative effect is not discussed in detail within the text, it is depicted in the Fig. 10. Could this aspect be explained more thoroughly?

Reply: Thank you for this valuable comment. In our study, we primarily focused on PSs with vertical development exceeding 6 km, and did not conduct a quantitative investigation of the associated water-phase processes. The microphysical processes within PSs are complex, and changes in the ice-phase processes due to the ice nuclei (IN) effect can also influence the liquid-phase processes below the freezing level. However, conducting a quantitative analysis of these processes is challenging when relying solely on observational data. In future work, we can perform statistical analysis on PSs that develop in warm clouds, which will allow for a more in-depth investigation of the liquid-phase processes and their interactions with aerosols.

For the second question, it is generally recognized that dust radiative effects stabilize the atmosphere and suppress convection. Therefore, the observed

enhancement of PS development in our study is more likely driven by microphysical processes, including the IN effect and the CCN effect. However, a few modeling studies (e.g., Cheng et al., 2019) have shown that dust radiative effects can delay convection initiation, allowing for energy accumulation, which may ultimately lead to more intense convective development once triggered. This highlights the complexity of dust radiative effects, thus it is difficult to quantify their impact using observational data. Future modeling studies will be needed to conduct sensitivity experiments to disentangle the contributions of dust radiative and microphysical effects.

Cheng, C.-T., Chen, J.-P., Tsai, I. C., Lee, H.-H., Matsui, T., Earl, K., Lin, Y.-C., Chen, S.-H., and Huang, C.-C.: Impacts of Dust–Radiation versus Dust–Cloud Interactions on the Development of a Modeled Mesoscale Convective System over North Africa, Monthly Weather Review, 147, 3301-3326, 10.1175/mwr-d-18-0459.1, 2019.

Q4: Figure 5 shows a reduction in the 20 dBZ area below the freezing level for stratiform precipitation in small- and medium-sized PSs under dusty conditions, which the authors attribute to the evaporation effect associated with the Saharan Air Layer. Is there more direct evidence supporting this proposed mechanism? For instance, was a significant variety in low-level humidity co-observed?

Reply: Table 4 of the manuscript presents statistical characteristics of meteorological variables for PSs under clean and dusty conditions. RHlow, defined as the mean relative humidity between 1000 and 850 hPa, is consistently lower under dusty conditions across all PS size categories. The difference of small-sized PSs is statistically significant at the 95% confidence level.

Q5: In Table 5, the sample sizes across different CAPE bins are notably imbalanced (e.g., for large PSs in the CAPE5 bin: clean n=5, dusty n=14). The statistical reliability of results derived from such small sample sizes is a concern.

Reply: Thanks for pointing this out. Large-sized PSs are much less frequent than smaller ones, and sampling is further constrained by the precipitation radar (PR) swath, as only PSs untruncated by the edge of orbit were selected in this study. Although significance tests were applied, the limited sample sizes may reduce result robustness. We will explicitly note this limitation in the revised manuscript when presenting Table 5.