Dear Editor:

We have gone through two reviewers' general and specific comments carefully and revised the paper accordingly. We appreciate their comments that have improved the quality of our paper. Below is our point-to-point response to the reviewers' comments and suggestions *(reviewers' comments are in italic)*.

We look forward to further comments and suggestion from you and the reviewers on the revised manuscript.

Thank you very much!

Hongbin Yu on behalf of all the co-authors

Response to Review #1

We thank the reviewer for the comments and have revised the paper accordingly. Below is our point-to-point response to the comments and suggestion.

Trans-Atlantic African Dust transports are of great scientific interests to satellite observations and model simulations over the past 50 years. The remarkable June 2020 African dust outbreak was historical in many ways, and thus a better understanding of the event from different viewpoints is particularly valuable to improving not only our satellite observations and retrievals, but also our model skills in simulating extreme events like this. This paper therefore makes significant contributions in at least the following three perspectives: 1) evaluated how well different observations (satellite and in-situ) are consistent to each other in observing extreme dust events; 2) proposed the plausible synoptic scale weather conditions that facilitated the dust transport, and 3) evaluated how well model simulations are consistent to observations that are crucial for improving our model capabilities in future.

The paper is well constructed with very organized structure. The discussions in the paper are very thoughtful with very solid scientific evidence based on observations and comparisons. The profound experience of the coauthors in both observations and model simulations is highly reflected in the writing of the paper and very impressive. Their understanding on the African dust origination, transportation, and modulation, as evidenced in the paper, shed valuable light on future African dust related scientific investigations.

It is highly recommended that the paper is accepted as is in its current format.

Thanks for the comments.

I have the following two general comments that are for discussions and future work, not for any changes to the current paper. And I don't really anticipate any responses from the

authors to answer these questions for the publication of the current paper. I hope the discussions between the authors and the audience can foster any future research interests, collaborations, and scientific explorations:

1) *How geostationary satellites (ie. GOES-R) may observe the event with much higher temporal resolution?*

   Yes, geostationary satellites can be used to track the evolution of dust at high temporal resolution. In this study, we have used SEVIRI images to identify important contribution of rapidly evolving mesoscale convective systems (MCS) in producing dust emissions in West Africa. This provides important insight into dust emission processes of this historic event. Similarly, a use of GOES-R observations can provide more accurate information on when the dust plume reaches Caribbean islands and southern U.S. at much higher temporal resolution. This can be pursued to interpret high-frequency surface aerosol observations in the Caribbean Basin during the event.

2) *How well the data synergy of the Aqua/Terra MODIS + S-NPP/N20 VIIRS may help improve African dust event observations with increased temporal sampling?*

   The synergy of MODIS Terra and MODIS Aqua in this study has allowed for characterizing the day-to-day variation of dust plume without significant spatial gap. Given that the S-NPP/N20 VIIRS measurements are taken at different times than Aqua/Terra MODIS measurements, an integration of S-NPP/N20 VIIRS with Terra/Aqua MODIS could increase the temporal sampling of dust plume. However, such a synergy needs to first reconcile possible differences between VIIRS and MODIS retrievals, which is beyond the scope of this paper.

3) *The paper has very valuable and thoughtful discussions on how model should improve to better capture the characteristics of such synoptic scale events. How about satellite observations or event future satellite designs? What are the additional information we want to know about these events that are currently lacking in the observations from space?*

   In this study, we have been focusing on satellite observations of AOD and vertical distributions. Our study shows that vertical distribution of dust is essential to understanding the dust transport and deposition and linking satellite measurements with surface observations. It is thus important to have a spaceborne lidar mission that can continue CALIPSO data record (probably at finer temporal resolution, e.g., hourly sampling) once the CALIPSO is decommissioned.

   This work has focused on characterizing the evolution of atmospheric loading or optical depth of the trans-Atlantic dust plume. Such intense dust events also provide a great opportunity of following the full life cycle of dust plumes and investigating changes of dust particle properties along the trans-Atlantic transit. A follow-on study is made available by routine and largescale satellite measurements of particle size and shape properties, such as the depolarization ratio and color ratio from CALIOP, Angstrom exponent and fine-mode

fraction from MODIS, as well as non-spherical fraction from MISR. For intense events, tracking the dust plume is more feasible and satellite observations of dust properties tend to have higher accuracy. The altitude-resolved observations from lidar are particularly useful because the data allow for following dust plumes in the free atmosphere where the interference of marine aerosol is minimized. Such studies should also benefit from the adoption of more advanced technology and hence improved particle property retrievals in future satellite missions.

We have briefly discussed these points in section 4.

4) *I found the discussions on AOD and PM10 of the same event very intriguing. I know it is out of the scope of this paper, but for future work, it would be very interesting to see how the optical measurements or observations can track (or match) the density measurements or observations, for such extreme events.*

We agree that future work can examine relationships between AOD and surface PM concentrations quantitatively. Our collaborators at the University of Puerto Rico are looking into this issue by combining satellite remote sensing observations and PM measurements from the surface aerosol network in the Caribbean Basin.

5) *With AI/ML experts in the authorships of this paper, it is worthwhile to explore how AI/ML may help the community to forecast extreme events, or at least pick up the trajectory or other SAL patterns and properties in a much better way to establish a new African dust outbreak database that are valuable for both observations and model simulations.*

Great point. Indeed, some of our co-authors are actively exploring this direction. Thank you for your suggestion.

I also have a few very minor editorial suggestions that are only for the authors' consideration in the attachment.

We have gone through those editorial suggestions and incorporated them in this revision when appropriate. Thanks.

I strongly believe this paper will make significant contributions to advancing our understanding on the Trans-Atlantic African Dust Events from both sides of observations and model simulations. I sincerely look forward to the full publication of this important paper at ACP.

Thanks for the comment.

Response to reviewer #2:

We thank the reviewer for the comments and have revised the paper accordingly. Below is our point-to-point response to the comments and suggestion.

This study uses multiple satellite retrievals, ground-based observations, and GEOS global aerosol transport model to characterize a historic African dust event in June 2020. Compared with climatological geopotential height in June, the anomalous strength and northern shift of NASH together with Azores low contributes to the four-day accumulation of the dust near the African coast. Although the GEOS model can reproduce the historic dust event to some extent, it substantially underestimates AOD and aerosol extinction profiles compared with MODIS and CALIOP. The manuscript is well written, and results are clearly presented and well discussed. This study is a valuable contribution to understanding the synoptic factors favoring extreme dust events and improving model performance in simulating dust emission and transport. I only have minor comments and recommend publication after they have been answered.

Thanks for the comments.

General Comments:

What could cause the anomalous synoptic condition favoring extreme dust events like this one? Is it just due to natural variability, looking at the time series of the geopotential height in Fig. 12d? Or we might expect stronger and/or more frequent dust events in the future due to global warming? I also wonder if the reduction of anthropogenic emissions (i.e., greenhouse gases and aerosols) during COVID could play a role here. It is probably out of the scope for this study, but I would love to hear the authors' opinions on this. Such discussions could benefit future studies.

These are all great and important questions. The time series of the geopotential height in Figure 12d show substantial year to year variations but no significant trend. To attribute the observed changes to natural or anthropogenic factors, one would need to run a reliable earth system model to assess how changes in anthropogenic emissions have affected atmospheric circulations and dust transport, which is beyond the scope of this paper.

The reviewer raised an intriguing question about possible impact of anthropogenic emission reduction due to the lockdown during COVID-19 pandemic. Considering that Godzilla-like dust events have not occurred so far in 2021, we would like to believe the 2020 Godzilla dust event was not likely a direct result of the anthropogenic emission reductions due to the COVID-19 lockdown. The two events might be just coincident.

It is very rare for African dust to make it into the tropical eastern Pacific. I wonder which factors could play a major role here, the anomalous NASH or stronger AEJ? In Fig. 12, the

high-pressure system over the western Africa in June, 2020 greatly extends to the Gulf of Mexico compared with 1980-2019 climatology.

Great question. Yes, previous observations have suggested that African dust is rarely transported to the tropical eastern Atlantic Ocean, because of the existence of apparent barrier in central America (e.g., Nowottnick et al., 2011). Pu and Jin (2021) showed that AOD over eastern Pacific Ocean was negatively correlated with AEJ index, suggesting that the stronger AEJ would not be a reason for the elevated AOD over the Pacific Ocean. Both Pu and Jin (2021) and our analysis show that the high-pressure system in the tropical Atlantic Ocean in 2020 extended greatly to the Gulf of Mexico, in comparison to the climatology. This anomalous westward extension of the high-pressure system would be responsible for the record-breaking transport of African dust into the tropical eastern Pacific Ocean (shown in Figure 9g).

Specific comments:

Line 87, evolved to evolve?

Fixed. Thanks.

Figure 3 and 16, it might be better not to use black color for the background?

We replot the figures by using white background.

Figure 4, please add labels for the panels (e.g., a-h). It would be better to add a brief description for what is shown in color map (Fig. 4a).

Labels added. Thanks.

Figure 5, it would be better to change the latitude/longitude marks for CALIOP aerosol extinction curtains to be consistent with Fig. 13, 14, and 17.

We have changed the latitude/longitude marks in Figure 5 and Figure 7 to be consistent with other CALIOP curtain plots. Thanks.

Figure 17, please add labels for the panels.

Thanks. The panels have been labeled.