# Responds to Reviewers

## Reviewer 1

This paper derived two global monthly mean dust aerosol optical depth climatological datasets based on CALIOP and on MODIS observations. However, I still have some major comments on the methodology. I suggest this paper to be published after major revision.

Major comments: (1) For MODIS dataset, two different separation methods of DAOD are used over land and ocean. However, the separation method seems to overestimate the DAOD over ocean. For example, over the Northern Atlantic, the DAOD should decrease when dust transports away from the dust source region. However, the new dataset shows an artificial increase from land to ocean near the coastal region. The authors should check carefully that the different methods over land and ocean used in this paper can provide consistent results. Furthermore, the new MODIS dataset shows quite unrealistic large DAODs over land and ocean in high latitudes of Northern Hemisphere in some seasons. What's the reason for this?

**Reply:** Thanks for the questions and comments.
Indeed, because the two MODIS AOD products, i.e., Dark Target (DT) over ocean (and dark vegetation surface) and Deep Blue (DB) over land, are developed based on different methodologies and implemented by different groups, they have discontinuity problem in transition regions, e.g., along the coastline region. This issue has been reported in previous studies such as Yu et al. 2021. For MODIS dataset in this study, DAOD is derived from DT AOD retrieval over ocean and DB AOD retrieval over land. Therefore, the discontinuity in MODIS AOD would propagate to DAOD.

In addition to the DT vs. DB issue, we also used different methods to derive DAOD from AOD over land and ocean, which adds another level of uncertainty or maybe additional discontinuity. To identify the discontinuity problem in this study and understand the potential causes, we further investigate the variation of meridional mean AOD and DAOD over latitude range 5°N-30°N (Figure 1) and 20°S-5°N (Figure 2) along longitude from 30°E to 60°W.

Figure 1 represents the longitudinal variation of the meridional mean TAOD and DAOD over Northern Africa between 5°N and 30°N with the stars indicating land-ocean transition point. In this region, the MODIS and CALIOP AOD have a similar pattern and there is not an obvious discontinuity in TAOD and DAOD over the coastal region.

However, when checking the TAOD and DAOD in the Southern Africa between 20°S and 5°N, we noted an abrupt increase in MODIS-based TAOD and DAOD in coastal region (indicated by star makers) for all seasons. As shown in Figure 2, the meridional mean TAOD based on CALIOP (blue line in Figure2) in this region has a peak over land (i.e., east of the star). In contrast, the MODIS based TAOD peaks at the transition point, which seems to be a result of the abovementioned DB-to-DT discontinuity problem.

The problem is even more severe for the DAOD (lower panel of Figure2); summer (JJA) and fall (SON) seasons in particular. This is a sharp and unrealistic peak around the transition point (10°E). Note that CALIOP derived DAOD is drastically different and rather smooth.

Cloud contamination in MODIS aerosol retrievals is likely the cause of this issue. As discussed in the manuscript and pointed in many previous studies, MODIS aerosol retrieval is more susceptible to cloud contamination. Cloud contamination can lead to an overestimation of TAOD but underestimation of FMF, therefore, overestimation in DAOD (see line 605~611 in the manuscript for details). To support this point, we derived the frequency of dust and cloud coexisting within 5-km CALIOP aerosol and cloud profile products. To this end, we first identify the dusty profiles using the lidar depolarization-based method described in the manuscript (see Section 2.1). Then we search for the presence of any cloud in the same profile. The dust-cloud coexisting frequency is defined as ratio of the number of dusty profiles with cloud presence with respect to the total dusty profiles.

Figure 3 shows meridional mean dust-cloud co-existing frequency in the two regions, i.e., Northern (5°N ~ 30°N) and Southern (20°S~5°N) Africa. It is evident that clouds are more frequently coexisting with dust over Southern African coastal region than Northern Africa. As such, TAOD and DAOD retrieval based on MODIS are more susceptible to cloud contamination over coastal region in Southern Africa than in Northern Africa, which causes more obvious discontinuity in TAOD and DAOD in Southern Africa.

Regarding to unrealistic large DAOD in Northern Hemisphere (NH) high latitudes in some seasons: for over-ocean DAOD, cloud contamination and limited sampling are major issues. For example, in summertime and over North Pacific, we found that DAOD was too high. We know that the cloud fraction is high in summer, which limits the aerosol retrieval and introduces cloud contamination issue.

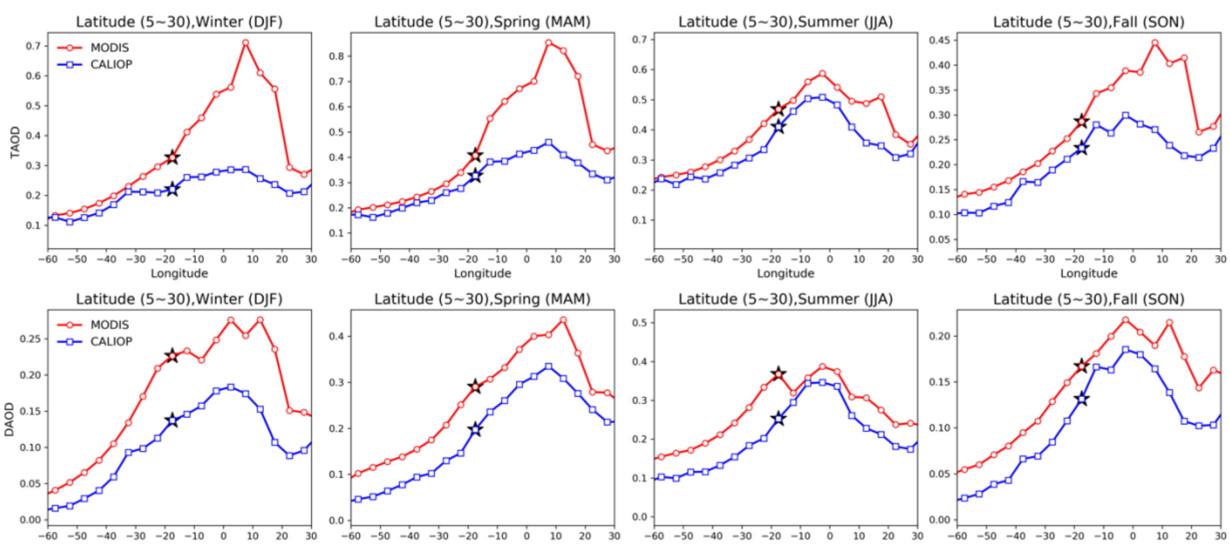


Figure 1. Meridional mean TAOD (upper panel) and DAOD (lower panel) over latitude range 5°-30°N. The star locates at the longitude that represents the most frequent coastal line longitude over the latitude interval. In other words, it is transition point between MODIS DB AOD over land and MODIS DT AOD over ocean.

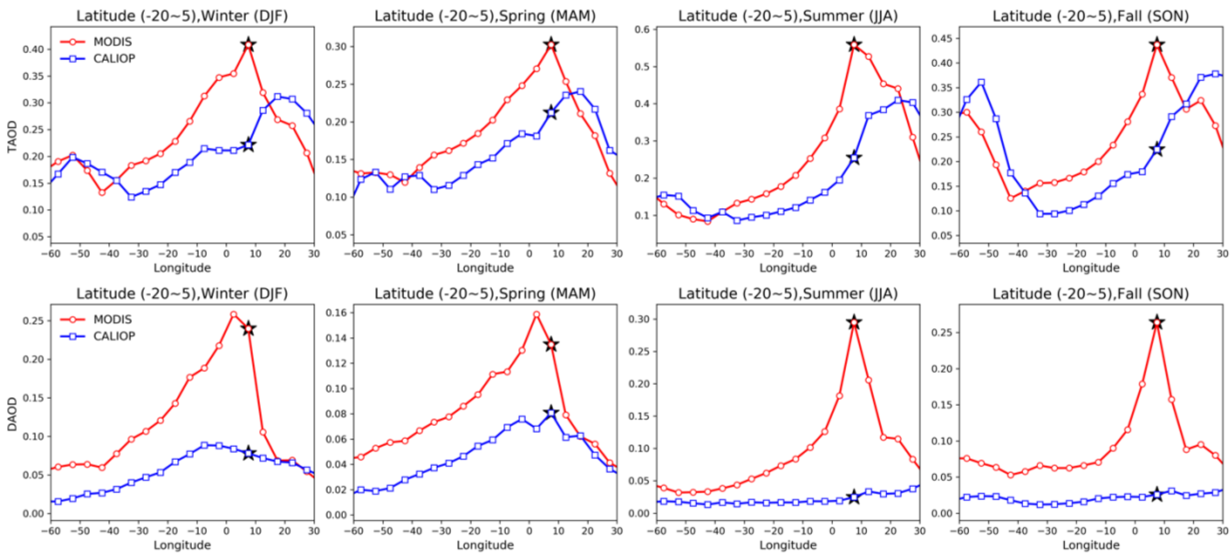

Figure 2. The same as Figure 1, except for latitude range 20°S-5°N.

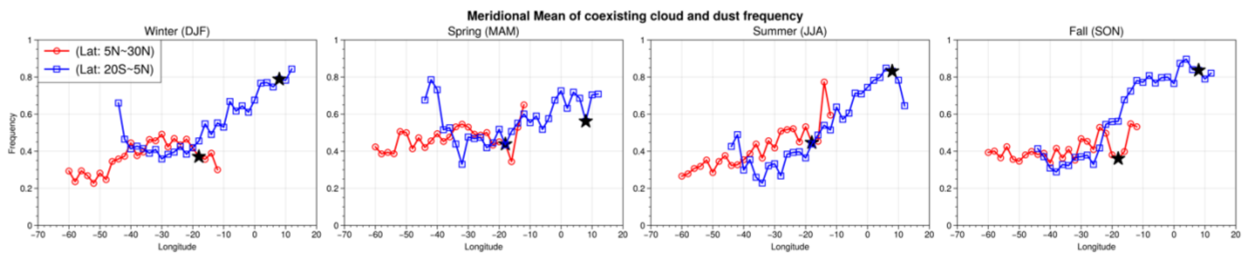

Figure 3. Meridional mean frequency of coexisting cloud and dust cases of latitude interval 20°S-5°N and 5°N-30°N based on CALIPSO retrievals. The star locates at the longitude that represents the most frequent coastal line longitude over the latitude interval. More specifically, the star on the right represents coastal line over latitude 20°S-5°N, the one on the left represents coastal line over latitude 5°N-30°N.

Clearly, both the cloud contamination problem and DB-DT discontinuity problem can cause significant errors and uncertainties in the TAOD and DAOD. We pointed this out explicitly as major limitation of MODIS-based results, in the discussion of Figure 5 (Section 4.1) of the revised manuscript. However, fixing these issues is far beyond the scope of this study and frankly out of our capability. We will leave them to the operational MODIS AOD retrieval teams.

(2) For CALIOP dataset, some mean dust extinction coefficient profiles in Figure 11 show quite sharp decreasing trend in the low levels over some regions, for example the profiles below ~0.5km in Figure 11(b). Could the authors provide mean dust extinction coefficient profile results from other literatures for comparison? And, as those profiles are all shown as low as 0km, how did the authors handle with bins below surface in the averaging process?

Reply: Thanks for the comment.
We compare dust extinction vertical profile from this study with the results reported in Yu et al. 2015. By comparing the top panel (bottom panel) of Figure 4 in this document with the blue curves in Figure 5 (Figure 6) bottom panel in Yu et al. 2015, we could see that dust extinction

from two studies agree very well. The minor difference could be due to the different data version used in the two studies.

We checked dust extinction for altitude lower than 0km, it is always zero. Therefore, we show dust extinction vertical profile starting from 0km in the manuscript, which is also consistent with that in Yu et al. 2015.

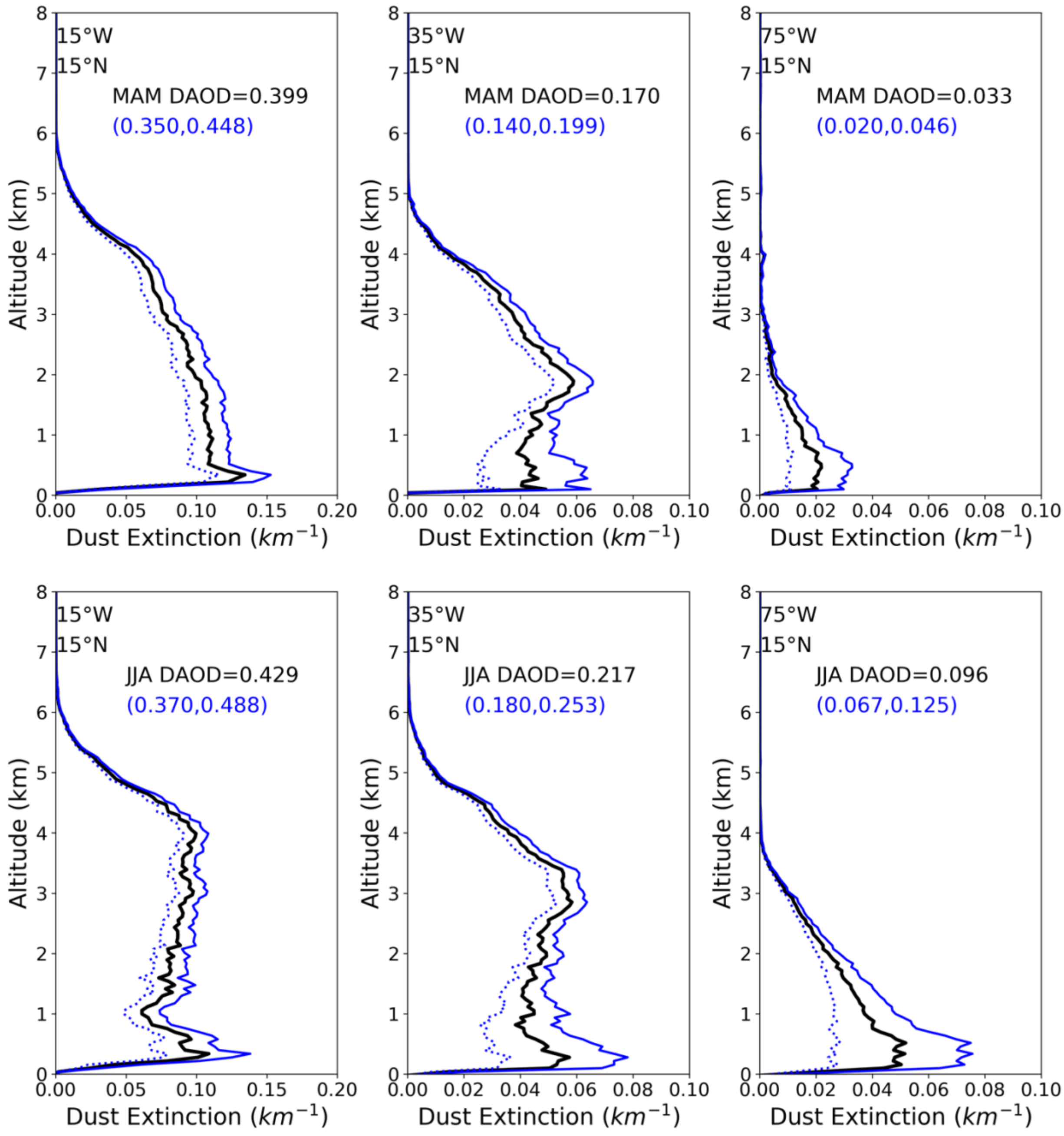


Figure 4. Vertical profile of 10°N-20°N averaged dust extinction coefficient ($km^{-1}$) at 15°W, 35°W and 75°W in MAM (top panel) and JJA (bottom panel) 2012. Dotted blue cure, solid blue curve and black thick curve are for low, high, and mean dust scenarios. Dust optical depth in mean dust scenarios and in (low, high) scenarios are noted in the plots.

## Reviewer 2

Review of the revised paper "Global dust optical depth climatology derived from CALIOP and MODIS aerosol retrievals on decadal time scales: regional and interannual variability" by Song et al. for ACPD. The authors have gone through great lengths to address the (voluminous) comments from myself, the other reviewer, and the community comment by Vassilis Amiridis. In particular, the paper is much improved by a more detailed discussion of the differences between the CALIPSO- and MODIS-based DOD estimates, differences of their estimates with literature studies over the past few years, and a comparison against AERONET data. In addition, there is a more detailed discussion of sources of uncertainty. As such, the authors addressed my main concerns well, and I recommend publication after considering two small remaining comments. Remaining concerns:

- This paper presents two new products, namely a DOD product based on CALIPSO and a DOD product based on MODIS. It looks like only the CALIPSO product is freely available to the community. Could you also make the MODIS-based DOD product freely available?

**Reply:** Thanks for the comments. We've uploaded MODIS-based DAOD products ($1^{\circ} \times 1^{\circ}$ *and* $5^{\circ} \times 2^{\circ}$ resolution) to the google drive. Now both CALIPSO and MODIS DAOD products are publicly available at 'https://drive.google.com/drive/folders/1aQVupe7govPwR6qmsqUbR4fJQsp1DBCX?usp=sharing'. The link is provided in Data availability part.

Line 403: please cite these previous studies.
**Reply:** In this part, we added a reference (Kar et al. 2018) regarding CALPSO Version 4 nighttime calibration at 532nm. In addition, we corrected the citation 'Chamara et al. 2017' to 'Rajapakshe et al. 2017'.

## Reviewer 3

Suggestions for revision or reasons for rejection (will be published if the paper is accepted for final publication)

1. The authors have used "interannual trends" in several places within the manuscript. I suggest not using this term as it is not commonly used.

**Reply:** Thanks. We choose to use more commonly used terms such as 'interannual variability' and 'trend' in the revised manuscript.

2. Lines 765-766: Please provide some information on EVI, MERRA-2 wind speed and precipitation to show their reliability for your analysis. In particular, a reanalysis of MERRA-2 is not a real observation. Please explain why they are not biased. Probably cite some references if you can find some.

**Reply:** Thanks for the comment. We add a reference Carvalho et al. 2019 for the assessment of MERRA-2 surface wind speeds and Reichle et al. 2017 for MERRA-2 land surface precipitation assessment.

3. Table 5: I think "inter-seasonal trend" is not a commonly-used word. Please check.

**Reply:** Thanks. In the revised manuscript, we use 'DAOD trend' in Table 5.

## References

Carvalho, D. (2019). An Assessment of NASA's GMAO MERRA-2 Reanalysis Surface Winds, *Journal of Climate*, *32*(23), 8261-8281. Retrieved Aug 5, 2021, from https://journals.ametsoc.org/view/journals/clim/32/23/jcli-d-19-0199.1.xml

Kar, J., Vaughan, M. A., Lee, K.-P., Tackett, J. L., Avery, M. A., Garnier, A., Getzewich, B. J., Hunt, W. H., Josset, D., Liu, Z., Lucker, P. L., Magill, B., Omar, A. H., Pelon, J., Rogers, R. R., Toth, T. D., Trepte, C. R., Vernier, J.-P., Winker, D. M., and Young, S. A.: CALIPSO lidar calibration at 532 nm: version 4 nighttime algorithm, Atmos. Meas. Tech., 11, 1459–1479, https://doi.org/10.5194/amt-11-1459-2018, 2018.

Reichle, R. H., Liu, Q., Koster, R. D., Draper, C. S., Mahanama, S. P. P., & Partyka, G. S. (2017). Land Surface Precipitation in MERRA-2, *Journal of Climate*, *30*(5), 1643-1664. Retrieved Aug 5, 2021, from https://journals.ametsoc.org/view/journals/clim/30/5/jcli-d-16-0570.1.xml

Yu, H., Tan, Q., Zhou, L., Zhou, Y., Bian, H., Chin, M., Ryder, C. L., Levy, R. C., Pradhan, Y., Shi, Y., Song, Q., Zhang, Z., Colarco, P. R., Kim, D., Remer, L. A., Yuan, T., Mayol-Bracero, O., and Holben, B. N.: Observation and modeling of a historic African dust intrusion into the Caribbean Basin and the southern U.S. in June 2020, Atmos. Chem. Phys. Discuss. [preprint], https://doi.org/10.5194/acp-2021-73, in review, 2021.

Yu, H. B., M. Chin, H. S. Bian, T. L. Yuan, J. M. Prospero, A. H. Omar, L. A. Remer, D. M. 1405 Winker, Y. K. Yang, Y. Zhang, and Z. B. Zhang. 2015a. "Quantification of Trans-Atlantic Dust Transport from Seven-Year (2007-2013) Record of CALIPSO Lidar Measurements." *Remote Sensing of Environment* 159:232–49.