Review of "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

This article reports an analysis of both CALIOP and MODIS retrievals spanning over a decade in order to compile climatological records of the spatial variability of dust aerosol optical depth and its interannual (and inter-decadal) variability. For the CALIOP record, the authors also obtained vertical profiles of extinction efficiency using the methodology previously developed in Yu et al. (2015). Overall, this is insightful work that could be an important contribution to the field and the paper was a pleasure to read. I do have a few major comments relating to the methodology and the interpretation of the results. The article thus requires major revisions.

Main comments:

- There is a very large difference in the DAOD obtained from the CALIOP (0.029 on a global basis) and the MODIS record (0.063 on a global basis). The MODIS result of a global DAOD of 0.063 is about one-and-a-half to two times other estimates in recent papers (Ridley et al., 2016; Voss and Evan, 2020; Gkikas et al., 2021), and much larger than simulated by any global aerosol model (see Figure 3 in Gliss et al., 2021). Therefore, I think the authors should include more discussion of what is causing their MODIS climatology to yield a much larger DAOD than other literature estimates. That should include a more detailed error analysis, and particularly an analysis of errors affecting the MODIS estimate such as errors in the DAOD/AOD ratio (see further comments below).
- A key part of the methodology that is novel is obtaining the ratio of DAOD to AOD from MODIS data, which allows the authors to obtain a climatology of DAOD from well-established MODIS Aqua retrievals of AOD. However, more details should be provided of the procedure for obtaining DAOD/AOD, especially as errors in this procedure seem to be a likely culprit of the large differences between the CALIOP-based and the MODIS-based climatology (e.g., lines 427-9).
    - It seems that the DAOD/AOD ratio over land was calculated using the previous analysis in Pu and Ginoux (2018). Considering how important this is for the final results, this method should be summarized and explained here, and its strengths and limitations discussed.
    - It's briefly mentioned that the methodology of Yu et al. (2020) was used to obtain the DAOD/AOD ratio over ocean (line 280). Please similarly explain this method in sufficient detail for the reader to understand this.
- Related to the previous comments is that the authors should expand the discussion in Section 4 to propagate their uncertainties into their final results, obtaining error bars on the DAOD climatologies from both MODIS and CALIPSO. For CALIPSO, paragraph 1 includes an error estimate due to assumptions about the dust depolarization ratio; it seems straightforward to propagate the error of the lidar ratio into this estimate and perhaps from CALIPSO's low sensitivity (an error estimate for that is also discussed earlier in the paragraph). For MODIS, there is some quantitative analysis of errors mentioned near the end of section 4 but more

detail should be added. This would be a combination of the well-characterized errors in the AOD retrieval and errors in the DAOD/AOD ratio.

- Line 352-4: Here and in the rest of this section, the suggestion is made that CALIPSO's lower sampling frequency could be a cause for the systematically lower DAOD from CALIPSO than from MODIS. I think this is incorrect. A lower sampling frequency is just as likely to produce an overestimate of DAOD as an underestimate, so producing a systematic underestimation of a factor of two for many different regions is in my view implausible. Please correct this.
    - Line 370-1: I think this statement is similarly statistically incorrect. Why would episodic sampling of dust events produce a systematically lower DAOD, especially when you have 12 years of data and so many total retrievals?

Other comments:

- The abstract notes a climatological record over the last two decades, but the period spanned is really 2007-2019. Please correct.
- Lines 242-4: Yu et al. (2021) recently did a detailed analysis of the diurnal variability of dust AOD that should be mentioned here. And can you roughly estimate the error you expect from the difference in daytime and nighttime distributions based on Yu et al. and Kittaka '11? I think this should be small (~10%?) relative to your other errors.
- Line 247-9: This statement seems a bit vague. Could you be specific as to how large you expect the solar noise to be? If that's larger than 10% then the statement would sound less subjective to the reader.
- Line 270-2: This sentence is unclear. Could you include a supplementary graph on how sensitive your results are to this criteria of 10 retrievals per month?
- Section 3.1 is very long and a bit difficult to read. I recommend adding sub-sections to improve readability.
- Line 317-8: could you explain why the coarse size of dust contributes to the positive depolarization ratio?
- Line 319-20: If DAOD over ocean is derived from TAOD and FMF, then how do you remove the AOD due to sea salt? See my comment above regarding a need for more detail on how the DAOD/AOD ratio is calculated for MODIS.
- Is the global DAOD you report weighted by the area of each grid point? It'd be helpful to note this somewhere.
- Line 384-6: A recent paper by Huang et al. (2020) showed that Asian dust indeed gets more spherical during transport so might be good to include here.
- Line 438-9: Please elaborate on how specifically the seasonal cycles of dust emission and transport are consistent with previous results.
- Line 480-4: Here and elsewhere, the authors include some insightful explanations on how errors in cloud screening affect both CALIOP and MODIS retrievals. Are you able to quantify the difference in the AOD between CALIOP and MODIS that is due to these errors from simultaneous retrievals from both?
- Line 592: should be "desert" not "dessert" :)
- Line 610: what do you mean by appropriate, exactly?

- Line 614: here and elsewhere, could you define what you mean by “coarse mode”, exactly? What particle size range does that refer to? Definitions differ for that differ in the literature.
- Line 615: although fine dust accounts for a small fraction of the mass, it accounts for a larger fraction of the DAOD, so this statement should be corrected.
- Line 616-8: this is helpful information. Could you be clear here what the bias is of the Aqua MODIS DAOD relative to AERONET, and what the error is? And since coarse mode includes sea salt, is this a one-to-one comparison?
- Line 649: could you be quantitative here about the correlation? I think whether MODIS and CALIOP-based DAOD “correlate well” is subjective and I personally was surprised the correlation was not higher.
- Line 653: I think here k is the correlation and R^2 is the variance explained.

References

Gkikas, A., et al., 2021. ModIs Dust AeroSol (MIDAS): a global fine-resolution dust optical depth data set
Gliss, J., et al., 2021. AeroCom phase III multi-model evaluation of the aerosol life cycle and optical properties using ground- and space-based remote sensing as well as surface in situ observations. Atmospheric Chemistry and Physics 21, 87-128.
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Ridley, D.A., Heald, C.L., Kok, J.F., Zhao, C., 2016. An observationally-constrained estimate of global dust aerosol optical depth. Atmos. Chem. Phys. 16, 15097-15117.
Voss, K.K., Evan, A., 2020. A New Satellite-Based Global Climatology of Dust Aerosol Optical Depth. Journal of Applied Meteorology and Climatology 59, 83-102.
Yu, Y., et al., 2021. A global analysis of diurnal variability in dust and dust mixture using CATS observations. Atmospheric Chemistry and Physics 21, 1427-1447.