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Atmospheric Chemistry and Physics Discussions

Interactive comment on "An observationally-constrained estimate of global dust aerosol optical depth" *by* David A. Ridley et al.

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Response to Reviewers

We would like to thank all reviewers for their helpful comments and criticism on this work. We believe we have addressed the comments and made changes to the methodology and manuscript where possible. We now include supplementary figures and several of the figures in the manuscript have been updated.

Key changes include: âĂć Analysis and statistics generated for log(AOD) rather than AOD

âĂć Instrument uncertainty included in the estimate

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âĂć Regional bias correction of satellite data by AERONET

âĂć Uncertainty in bias correction propagated through analysis

âĂć Marine Aerosol Network (MAN) data included

âĂć Supplementary figures of AERONET and satellite AOD histograms

âĂć Comparison of model AOD with daily AOD from MAN

âĂć Supplementary comparison with deposition flux

The key changes are that the global dust AOD is decreased from 0.033 to 0.030 and the uncertainty increased from 0.006 to 0.011 (2σ) as a result of considering instrument uncertainty and the uncertainty on the updated AERONET bias correction of the satellite retrievals. The observational estimate is hence closer to the AEROCOM model estimate. We believe that this better corrects for regional biases in the satellite retrievals while representing the inherent uncertainty in using limited in-situ measurements to apply correction factors over large regions. The regional estimates of seasonal dust AOD from the different satellite instruments are generally in closer agreement. The observational estimate is also brought closer to the MERRAero dust AOD; the previous discrepancy was of some concern because MERRAero assimilates MODIS AOD and may be expected to represent the dust AOD better than models without assimilation. The agreement between model and observational estimate improves over the mid-Atlantic, reducing (but not eliminating) the potential for systematically high dust removal in the models. While many of the quoted numbers change as a result of our reanalysis, all other conclusions remain essentially the same.

Please find the reviewer-specific comments and responses (blue italics) listed below.

Kind regards, David Ridley

Anonymous Referee #3 In this manuscript the authors present a global reconstruction of dust AOD based on satellite data and sun photometer retrievals, using sun photome-

ter data to correct satellite bias and various model simulations to separate the regional contribution of dust from other aerosols. This is a really nice manuscript with some good ideas and a dataset the has the potential to be a widely cited reference. Because of this potential it is necessary to be extra careful, though. The authors have followed previous methodology, including the weaknesses. I'd like to see these addressed before I support the publication of this manuscript.

We thank the reviewer for their comments and generally positive view of the research. We appreciate the points raised and believe that the major concerns have been addressed, detailed below.

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Major Comments: 1. One of my major concerns is the use of the different emission schemes in different models. This will have an impact on the calculation of the dust AOD (eq. 1). How much of the model-ensemble uncertainty is due to different emission schemes and how much due to inter-model variability? Without the ability to plug the same emission scheme into each of the models this is difficult to assess. Through the ensemble of satellite instrument and model combinations we can separate the impact of model diversity in non-dust AOD from the model regional-to-global scaling. This is presented in Table 2, where we assume that the bias is symmetrical around the estimate.

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2. I haven't found an explanation why the AOD reconstruction is limited to the 15 regions. Why do you not reconstruct AOD over the whole globe and show it on a map (e.g. using a yearly median)? You can still only calculate the correction factor using the dust-dominated regions.

Our rationale for using the 15 regions is to isolate the regions that are more influenced by dust than other aerosol species to minimize the effect of mis-categorizing errors in

non-dust AOD from the model as dust AOD. For example, the large AOD from pollution over East China is not always fully represented by the models and would result in a significant bias in the dust AOD inferred over this region. We therefore exclude regions such as this, Europe, and remote areas far from dust sources. Furthermore, through comparison between satellite retrievals and AERONET and the Marine Aerosol Network (MAN) we find that the retrievals are much less reliable in some locations, such as the Southern Ocean, and therefore unlikely to produce useful results. Lastly, the bootstrapping process requires many iterations of the dust AOD calculation at each location and is time-consuming. We have added this rationale to the manuscript as follows (pg 8):

"We focus on regions in which the dust AOD often dominates to reduce potential errors from biases in modeled non-dust AOD."

This is followed by examples of key uncertainties in the non-dust AOD (e.g. regions influenced by biomass burning).

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3. The assumption on which the correction factor are based seem weak to me. It is true that most of the global dust AOD is dominated by the North African and East Asian region. But this doesn't mean that you only need to concentrate on a few region, but that the spatial distribution is no Gaussian. In fact, if you look at a histogram of a snapshot in time you will probably find that dust is spatially log-normally distributed. My suggestion to the authors is to look at the spatial distribution of the satellite and sun photometer data and if it's lognormal, try to take the logarithm of all initial AOD data such that it is spatially normally distributed and rethink their calculations (especially equations 1-3 and Figure 2) and discussion from that perspective.

We agree that the AOD is usually log-normal, thank you for this observation. We have repeated the analysis assuming the AOD is log-normally distributed when aggregating daily AOD retrievals into a seasonal mean with a standard deviation. Interestingly, we

find that this has a relatively small impact on the results, reducing the global dust AOD only slightly. However, this is certainly a better way to represent the statistics and have updated the manuscript accordingly.

We did use AERONET data from all stations when calculating the correction factor, not just those within the 15 regions (see pg6 line 29). However, based on comments from reviewers we have revisited the bias correction methodology and altered this to provide bias corrections for each region, based on the AERONET sites in that region (and using the Marine Aerosol Network where relevant). Histograms of the distribution of AOD for the satellite retrievals and for AERONET within each region are shown in Figure S1 to S3.

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4. Global means make sense for GHG but not for aerosols. Talking about a global mean AOD is meaningless. It gives you absolutely no information about what the AOD could be on any point on Earth. I know everybody's doing it and there's a weak argument that can be made for inter-paper comparison's sake. But this manuscript has the potential to be a widely cited reference and it has the means to provide data for more regionally-based comparisons in the future. Figure 4 looks very fancy but gives very little useful information. Maybe in addition to Figure 4 that compares with previous papers you could prepare a synthesis figure or table with which people writing papers in the future can easily compare their results (something like figure 9 but less messy – no offense to figure 9).

We understand the concern with using the global average AOD and its limitations. However, it is necessary to compare with the modeled estimates of Huneeus et al. (2011) and we find that the global dust AOD metric is useful for discussion of the factors leading to uncertainty in the observational estimate. We highlight the importance of regional assessment in Section 4.3:

"...tuning the models globally will not necessarily produce the right spatial and sea-

sonal distribution. Here we use the observational constraints developed in this study to highlight regional and seasonal discrepancies between models and observations in an effort to isolate potential errors that affect multiple models."

Regarding comparisons with future work: we intend for the regional data to be available for future studies to compare against; however, we now provide a summary (Table 3) that gives our observational estimate of average seasonal dust AOD in the regions considered to facilitate quick comparison.

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Minor comments: The references to air quality and health seem out of place in this manuscript. There is no need to mention these aspect if they are not discussed anywhere.

We respectfully disagree. We believe it is important to highlight the influence of dust on air quality when AOD retrievals are used in assessing surface PM2.5 in poorly monitored regions, such as Africa, as part of studies informing World Health Organization assessments (e.g. van Donkelaar et al., 2006; Evans et al., 2013).

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Page 2, lines 7-9: I don't know if that's a mistake in the original Huneeus paper, but if you give the median because the distribution is not Gaussian, then you shouldn't give the standard deviation, which is a parameter in the Gaussian distribution. The "AEROCOM median" was a combination of the models in the AEROCOM analysis and treated as a separate model. This has been clarified by referring to it as the AEROCOM "model median".

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Chapters 2.1, 2.2, 2.3: I would appreciate it if the description of errors was consistent between the three instruments. We have homogenized the error format

Page 6&7, lines 32-7: Looking at the data in Figure 2 I would guess that the data is not normally distributed. The choice of a linear regression to calculate the bias between AERONET and satellites is therefore doubtful. See my major comment 3. Hopefully the response to comment 3 addresses this point.

Page 8, Eq.1: In my experience, aerosol concentrations, loads, and therefore AOD are not normally distributed in space. The mean AODs calculated here may not be representative of the central tendency in each region. See major comment 3. Hopefully this was addressed in response to the major comment. The manuscript has been updated to reflect the use of log-normal distributions.

Page 10 line 3: AE<0.4 Figure 2: In the MISR panel, there are values only for one of the two regressions. Also I can see only one regression line This figure has been removed, following suggestions to improve the bias correction of satellite data to AERONET observations, and no longer applies a split regression for MISR. Information on the bias correction of the satellite retrievals is now presented in Table 1 and Figures S1 – S3.

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