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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

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

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Anonymous Referee #5 The manuscript describes a new potential tool for validation of mineral dust in global and regional models, based on a combination of remote sensing data and global climate models. The work is certainly of interest and could provide an additional useful tool to the modeling community. In general the methodology appears sound and the paper is well organized and written. A few minor revision are nevertheless needed in my opinion before the paper could be published.

Thank you for your assessment of the work. We have addressed your concerns below.

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Major comment The construction of the global AOD dataset is the central part of this work. It stems mainly from remote sensing observations, form both satellites and ground-based AERONET stations. I think that too little information is provided regarding data processing (e.g. temporal aggregation) and uncertainties in these types of observations and their relation to dust AOD.

In Section 3.1, we have added more information to the methodology on the process of developing the seasonal AOD from observations and the revised bias correction process using AERONET. We discuss the aerosol properties assumed in MODIS and MISR retrievals in Sections 2.1 and 2.2. In addition, we have incorporated the instrument AOD retrieval uncertainty into the bootstrapping process and acknowledge uncertainties related to these factors in Section 4.4 "Discussion of the remaining uncertainties". From that section:

"Some of the discrepancy between the dust AOD from models and observations is likely born out of simplifications in representing particle morphology and minerology and the resulting impact on the AOD. The models in this study assume a globally fixed refractive index for dust and either spherical or spheroid particle shapes. We do not quantify the uncertainty from mineralogy and morphology here; however, several studies have shown the influence of refractive index and shape upon the derived optical and radiative properties (e.g. Balkanski et al., 2007; Kalashnikova and Sokolik, 2004; Scanza et al., 2015). Scanza et al. (2015) estimate a reduction of approximately 6% on the global dust AOD when accounting for spatially varying mineralogy in the Community Atmosphere Model (CAM-5). Particle morphology and minerology may also present a general bias in AOD retrievals as well as the models. Simplified particle shape modeling during retrieval has been shown to cause underestimation of AOD from space-based retrievals and overestimation from ground-based observations (Kalashnikova and Sokolik, 2002). Similarly, strongly absorbing dust can result in underestimation of the AOD, although improvements in MODIS Collection 6 have been shown to alleviate this (Hsu et al., 2013). The impact on the observational estimate of dust AOD will be dependent upon the specific assumptions made by the MODIS and MISR retrievals, both of which take particle non-sphericity into account but using different methodologies (see Sections 2.1 and 2.2 and references therein). Finally, potential biases exist via erroneous filtering of thick dust plumes during the retrieval (Baddock et al., 2016)."

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Specific comments 2, 8-9: please add a reference here. Added

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2, 14-16: Why PM2.5 in particular? You do not discriminate the size in your product. Good point, thank you. We now just discuss in terms of PM

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2, 24: It would be useful to mention already here what is the general strategy of the work, and why you will use all of the following data from observations or model. Maybe add a table or a brief description in the text, so that the reader can already have a better idea of the role of each type of data in this paper. We have elaborated on the usage of the data products in the introduction to the data description:

"To derive an estimate of dust AOD we make use of AOD retrievals from three satellite instruments as well as surface-based sun photometers to provide a 'ground-truth' for correcting the satellite retrievals. We use in combination with four global aerosol models that provide information on a range of estimates for the non-dust aerosol AOD and the spatial distribution of dust aerosol (see Section 3 for a full description of the methodology)."

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3, 15: the usage of the angstrom exponent is not clear, please rephrase. Rephrased as follows: "The wavelength-dependence of the AOD, described by the angstrom exponent (Ångström, 1964) between the AOD at 440 and at 870 nm, is used to distinguish AOD dominated by coarse aerosol that is indicated by a lower angstrom exponent than for fine aerosol (e.g. O'Neill et al., 2001; Reid et al., 1999)."

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4, 24: this sentence is not clear; also the reference is missing from the list. Rephrased and reference added

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8,20-24: How is your central estimate derived? Is it the mean of the distribution derived from the set of all possible combinations of models and satellite data depicted in Figure 4? Also, please describe more in detail how all the combinations were constructed in the previous section.

We have clarified the methodology in the closing paragraph of the methodology description as follows:

"This process is repeated for all combinations of the 3 satellite instruments, 4 model estimates for non-dust, and 4 model regional-to-global scaling factors; this produces 48 realizations, 16 per satellite instrument, each with an uncertainty estimate. We use the kernel density estimation method (Silverman, 1986) with a Gaussian kernel and standard smoothing to determine a probability density function for the global dust AOD based on the 48 realizations."

And clarified the description of Figure 3 in Section 4.1:

Figure 3 summarizes our observationally-constrained global dust AOD estimate, averaged over the 2004 – 2008 period, for the combination of all data and for each of the satellite instruments individually.

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