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Atmospheric Measurement Techniques
Discussions

Interactive comment on "A 12-Year Long Global Record of Optical Depth of Absorbing Aerosols above the Clouds Derived from OMI/OMACA Algorithm" *by* Hiren Jethva et al.

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The authors are thanking the anonymous reviewer for offering constructive comments, which have helped us refine the content of our manuscript.

Following is the response to each comment and suggestion made by the reviewer.

RC: Referee Comment AC: Author's Response

RC: Both ACAOD and aerosol corrected COD are derived from their retrieval algorithm. However, no validation effort is provided for the derived aerosol corrected COD values. I understand that this is a paper that focuses on ACAOD, but the authors shall at least

discuss how the uncertainties in the derived aerosol corrected COD would affect the derived ACAOD and vise versa.

AR: The near-UV 'color ratio' technique employed in the OMACA algorithm retrieves both ACAOD and aerosol-corrected COD simultaneously. The two pieces of information, i.e., UVAI and reflectance at 388 nm from OMI, allows us retrieving two quantities as reflected in the 2D retrieval diagram shown in Figure 1. While the primary focus of the paper is to highlight the ACAOD product, its spatial-temporal distribution, and initial validation against ORACLES/HSRL-2 observations, we are working with the ORACLES team to perform a detailed validation of the OMACA product, both ACAOD and COD, using airborne in situ and remote sensing measurements. The results of the validation analysis will be covered in a dedicated follow-up publication.

Section 4 Preliminary Validation is now updated with our intention of a follow-up publication on a detailed validation of the OMACA product.

We don't expect to see an interdependency of ACAOD and aerosol-corrected COD retrievals as both quantities are derived simultaneously that explain the two-channel TOA measurements. The inversion philosophy is quite analogous to that adopted in the standard MODIS cloud retrievals where the TOA signal at 0.86 μm is largely responsible for COD magnitudes, and 2.1 μm is for the effective radius. In the present case, the reflectance at 388 nm with an aerosol correction determines the retrieved values of COD and magnitudes of the observed UVAI drives the ACAOD retrievals. So, the assumptions about aerosol and cloud models made in the inversions are the ones that determine the actual uncertainties in both retrievals.

RC: For this product to have a board user community, and especially for modelers, the uncertainties in retrieved properties (such as aerosol corrected COD and ACAOD) shall be provided at the individual retrieval level. Uncertainties are not included in the current data fields as shown in Appendix I. Given the uncertainty in SSA of +-0.03, an uncertainty in ACAOD could be introduced on the order of 20-50% (Table 3). I wonder how much the uncertainties in their regional and global time series of ACAOD are attributed to uncertainties in SSA, or are a direct reflection of temporal variations in SSA.

AR: Reviewer has correctly pointed out here that the uncertainties in the retrieved properties aren't provided at the individual retrieval level. This is a complex task due to the very nature of uncertainty in ACAOD/COD that depends on multiple assumptions made in the inversion. Errors in the ACAOD retrievals resulting from the uncertainty in each major assumption, i.e., SSA, ALH, and AAE, have already been tabulated in Table 3, 4, and 5. The uncertainty in these assumptions can vary on both sides, i.e., underestimation and overestimation, from the assumed state. Moreover, individual uncertainties can also be of opposite signs leading to the partial cancellation of errors in the retrievals. In this situation, it is hard to estimate actual errors in the ACA retrievals especially when the true state of the atmosphere is unknown to the algorithm.

Looking at the potential use of the OMACA product in the numerical models, we will consider including the pixel-level retrieval uncertainties in the next upgrade on the basis of the sensitivity of ACAOD/COD to these assumptions individually, such as presented in Table 3, 4, and 5.

We assume here that uncertainty in the SSA is random, i.e., distributed on both sides, positive and negative. An OMI-AERONET comparison figure shown to address one of the following comments show that OMI SSAs are spread over both sides of collocated AERONET inversion. Given this assumption, it is expected that the resulting errors in ACAOD/COD retrievals are subjected to the partial cancellation on a monthly regional scale. Moreover, the daily regional time-series of SSA displayed in Figure 2 do not show any apparent long-term trend; rather it demonstrates the known seasonal variations in aerosol absorption properties for both smoke and dust.

RC: Page 5, lines 32-33, I am not really sure what the authors mean by this sentence "These two components the OMACA algorithm is identical to the ones adopted in the

operational cloud-free OMI/OMAERUV two-channel algorithm."

AR: This sentence refers to the Aerosol Layer Height and Surface Albedo datasetsâĂŤboth are directly adopted from the OMAERUV cloud-free algorithm. Not only that, the aerosol type identification scheme and aerosol models (microphysical and optical properties) are also identical to the ones designed for the OMAERUV.

RC: Page 5, line 24, The ALH dataset, which was derived using 30 months of collocated CALIOP and OMI data, is used for aerosol vertical profiles. Was this ALH dataset derived using aerosol above cloud scenes only? If the ALH dataset was derived using cloud-free scenes, how representative is the ALH dataset for aerosol above cloud cases?

AR: The OMI-CALIOP climatology of ALH was derived using mostly clear-sky observations in both datasets with maximum LER in OMI dataset restricted to 0.25. The threshold in LER (0.25) largely avoided ACA scenes that are assigned with the best quality OMACA retrievals (Table 1).

The time-series of fractional AOD shown in Figure 9 (right-hand axis in blue ink) of the original manuscript demonstrated that a large fraction of the total column AOD, about 80%-100%, was retrieved as aerosols above the clouds during the seasonal biomass burning and dust episodes. Moreover, the transport of aerosols over the ACA hotspot regions is known to occur above the boundary layer and between the altitudes 3-6 km, as observed from CALIOP lidar. Note that the minimum (maximum) ALH assumed in the OMACA was fixed to 3.0 km (6.0 km) even if the gridded ALH climatology dataset is assigned with lower (higher) layer height. For these reasons, we expect that the OMI-CALIOP ALH database derived from cloud-free observations over the ACA regions is also a representative for scenes with aerosols above the cloud. The remaining uncertainty in ALH would translate into the corresponding error in ACAOD already presented in Table 3.

This description has been added in the revision (section 3 Uncertainty Estimates)

RC: Page 6, lines 29-30, “Observations of aerosols above cloud found outside the boundaries of these 14 pre-selected regions are assigned a fixed SSA of 0.89 and 0.9 for the smoke and dust aerosol types, respectively.” Justifications or references are needed for values mentioned here.

AR: The SSA values of 0.89 (smoke) and 0.9 (dust) prescribed for regions outside the 14 pre-selected regions are merely our assumptions. These values correspond to the aerosol model having a moderate level of absorption for both aerosol types (see Appendix I, aerosol models). We emphasize here that though the OMACA is a global product, it was primarily designed to capture ACA events over major and some minor regions of the world. The selection of regional boundaries was made according to the monthly and seasonal ACA frequency of occurrence maps shown in Figure 5. The pre-selected regions adequately encompass the areas of frequent aerosol-cloud overlaps.

This description has been further clarified in the revised paper (section 2.2.2.3)

RC: Page 8, lines 23-25, “Notice that the current OMACA product does not use the OMMYDCLD product while making above-cloud aerosol retrieval. Instead, we use the information on the geometric cloud fraction derived from OMMYCLD in the post-retrieval analysis.” I wonder why the OMMYDCLD product is not used in the retrieval process. The authors seem to use LER > 0.2 to distinguish clear from cloudy scenes. But wouldn’t the use of OMMYCLD result in a more accurate estimation of cloud coverage over a given scene? How do the authors deal with partially cloudy scenes?

AR: As the reviewer has correctly mentioned here, the OMMYDCLD product hasn’t been used while deriving the OMACA product. However, we positively consider integrating the OMMYDCLD product into the OMACA algorithm in the near-future upgrade. This will help us to better understand OMI sub-pixel cloud variability and its impact on the retrievals.

However, we have used the OMMYDCLD product in the post-retrieval analysis to derive all results presented in this paper. Using the information on the geometric cloud fraction

calculated from OMMYDCLD, we adopted a threshold of 0.50 and 0.75 to carry out the frequency of ACA and ACAOD/COD analyses, respectively (section 2.2.3).

The minimum LER threshold for detecting cloudy pixels is chosen to be 0.2. The retrieval associated with LER range 0.20-0.25 are flagged as of lower quality due to the chances of encountering partly cloudy-pixels for these retrievals (see Table 1). However, retrievals with LER>0.25 are considered to be more reliable (QFlag=0, best quality) owing to the increased probability of detecting fully overcast pixels. Currently, the OMACA algorithm treats each identified cloudy pixel as a fully overcast scene, even if it is partly cloudy as per the OMMYDCLD product.

RC: Page 10, lines 20-21, “53% (AOD>0.7, UVAI>1.0) of the total OMAERUV-AERONET SSA (440 nm) retrievals are found to agree within their estimated uncertainties of $\pm$0.03.” This means 47% (AOD>0.7, UVAI>1.0) of SSA retrievals are outside of the uncertainty range of +-0.03. I am not sure how the authors could come up with this statement “Therefore, we expect that the above-cloud SSA values assigned in the OMACA algorithm over different regions should be accurate within $\pm$0.03.”

AR: The statements referring to the statistics of OMI versus AERONET SSA comparison were derived from Jethva et al. [2014] paper based on the earlier OMAERUV dataset (version 1.4.2 released in 2012). Since then, the OMAERUV algorithm has been upgraded with several major changes, including better treatment of dust particles assuming realistic spheroidal shape distribution, accounting for angular scattering effects of clouds in the calculation of UV Aerosol Index, use of new minimum surface LER dataset using synergy of multi-year OMI and MODIS observations, and updated cloud screening and retrieval flagging scheme.

The regional, daily SSA dataset used in the OMACA product has been derived from this latest version of the OMAERUV (version 1.8.9.1) product released in 2017. As already described in the manuscript (section 2.2.2.3), we use UVAI-weighted averages of SSA for smoke and dust aerosol types using retrievals with measured UVAI>0.8 assuring that only high-quality retrievals are used in these calculations. The figure shown here compares the SSA derived from the latest OMAERUV product and the AERONET Level 2 dataset over global AERONET sites (unpublished). The comparative analysis demonstrates that the agreement between the two independent sets of SSA improves significantly at higher values of UVAI. Quantitatively, about 59% (83%), 65% (88%), and 72% (91%) of the matchups are found to be within the expected limits of ±0.03 (±0.05) difference given the observed range of UVAI>0.8, >1.5, and >2.0, respectively.

The reason for adopting an UVAI-weighted scheme precisely reflects the fact that the agreement between OMI and AERONET SSA improves at higher aerosol loading/absorption providing increased confidence in the satellite retrievals.

In the revision, we have modified the description of the OMI-AERONET SSA statistics according to the new comparison results discussed above, since it is consistent with the SSA dataset used in the OMACA algorithm.

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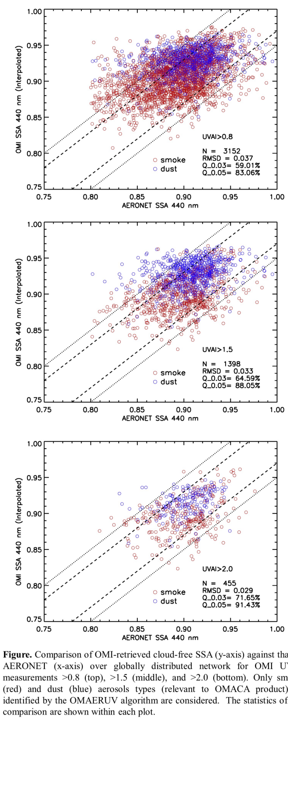

Figure. Comparison of OMI-retrieved cloud-free SSA (y-axis) against that of AERONET (x-axis) over globally distributed network for OMI UVAI measurements >0.8 (top), >1.5 (middle), and >2.0 (bottom). Only smoke (red) and dust (blue) aerosols types (relevant to OMACA product) as identified by the OMAERUV algorithm are considered. The statistics of the comparison are shown within each plot.

Fig. 1.