

Anonymous Referee #1

Comment: The paper studies issues when estimating surface particulate matter concentrations from satellite observations by converting AOD to PM_{2.5} over continental US. Data from MODIS, MISR and CALIOP are explored together with ground-based PM_{2.5} measurements. This topic is of clear relevance to ACP, since spatial PM_{2.5} distributions are definitely of high interest to environmental monitoring and on the other hand AOD-to-PM_{2.5} conversion is a challenging task. The issues investigated concern AOD data quality and representativeness of column AOD or distinct layers for surface PM values.

However, the paper does not make clear, how the different aspects studied relate to earlier published work (what is confirmed, what is different, what is new) and how the combined use of the three satellite instruments can be beneficial. Here the integration of the different aspects into a comprehensive conclusion and recommendations for a way forward is missed.

Response: We thank the reviewer for these comments. We have revised the introduction and added the following text to more clearly state how the paper differs from other studies:

“This paper differs from past research efforts in several aspects. For one, the impact of passive satellite AOD data quality on the PM_{2.5}/satellite AOD relationship has yet to be investigated. Secondly, while other studies have considered the aerosol vertical distribution during estimation of PM_{2.5} from satellite AOD retrievals, this has not been examined over large spatial and temporal domains. Lastly, to the best of our knowledge, near-surface aerosol extinction from CALIOP has never been evaluated as a potential proxy for surface PM_{2.5} concentrations.”

See the response to the next comment about our edits to the conclusion section.

Comment: The conclusions presented seem to say that direct attempts to convert MISR or MODIS AOD or CALIOP layer AOD into PM_{2.5} will always exhibit too large uncertainties and a better way forward will be to assimilate AOD from MODIS, MISR and extinction profiles from CALIOP into a chemistry transport model, which is then used to calculate PM_{2.5}.

I suggest that the authors consider using common point filters, where possible, when different datasets are compared – this could strengthen their conclusions by avoiding to draw weak or misleading conclusions based on different samples (e.g. between operational and DA-quality datasets, between daily and hourly datasets).

Overall, the discussion and conclusions need to be firmed up and extended and the relation to other studies clearly be identified and discussed.

Response: We thank the reviewer for the thoughtful comments and suggestions. A

common point filter analysis has been completed and the results have been added into the paper. Please see the response to a later comment regarding this analysis for more detailed information about these changes.

We have added the following text to the conclusion section to reinforce the main points of the paper:

“Also, some of the past studies have shown that passive satellite AOD may be used to accurately estimate $PM_{2.5}$ for particular sites. However, this study shows that, even with the use of higher-quality DA AOD observations, column-integrated AOD derived from passive satellite sensors may not be used directly as accurate proxies for surface-based $PM_{2.5}$ over broad spatial domains. As discussed earlier, this is partly attributed to differences in the aerosol surface-to-column representativeness across the CONUS. Therefore, we caution the direct use of passive satellite AOD observations for $PM_{2.5}$ estimation over large areas, especially in regions where elevated aerosol plumes exist.”

Also, we have revised the introduction to include the relation of this paper to other studies. See the response to the previous question.

Comment: Detailed comments

p. 31638, l. 12: add that satellite measures “ambient”

Response: We thank the reviewer for the suggestion, however it is unclear what he/she means by adding that satellite measures “ambient”. We made the addition such that the sentence contains the phrase “total *ambient* particle extinction”. Please let us know if that is not the most appropriate location to make the revision.

Comment: p. 31640, l. 7: does this unavailability not apply to TERRA?

Response: We thank the reviewer for bringing this to our attention. Yes, the unavailability does apply to TERRA and a revision has been made to the text to account for this change.

Comment: p. 31641, l. 12-15: the sentence “For comparison purposes with the $PM_{2.5}$ data available (described further below), we have constructed daily-averaged “Level 3” AOD data using operational MODIS and MISR aerosol products after applying first-order QA as described in Sect. 2.1.” belongs into section 2.1 headlines section 3-5: I would reformulate without question (e.g. “impact of...”)

Response: We thank the reviewer for both of these suggestions. Firstly, we believe the sentence on p. 31641, l. 12-15 is properly placed in Section 2.2, as this is the section in which the quality-assured AOD datasets (i.e. DA datasets) are described, and thus its movement to Section 2.1 (focused on the operational AOD datasets) is unnecessary. Secondly, we would like to keep the section headlines as questions, as they are directly tied to the research questions stated near the end of the introduction, thus providing a

clear flow to the paper. We think this suggestion is more related to writing style, so we left the two places unchanged.

Comment: frequent repetition of using quality flags, unavailability of hourly DA-quality data, etc. can be removed

Response: We thank the reviewer for this suggestion. Again, this relates to writing style. We believe the repetition of our quality control procedures and unavailability of hourly DA-quality datasets helps to reinforce our methodology such that the reader does not become confused. We did not make changes for this suggestion.

Comment: p. 31643, l. 15-21: why are the numbers of the other studies higher than your numbers (also up to a factor of 2)?

Response: For this section, we explain that PM_{2.5}/AOD correlations are roughly a factor of 2 higher for the Eastern US as compared to the Western US. The reasons for this are mentioned at the end of the paragraph, as well as later sections of the paper (i.e. differences in aerosol surface-to-column representativeness between the Eastern/Western US). The higher PM_{2.5}/AOD correlations found in other studies are possibly due to differences in the temporal domains between the studies. For example, the Hu (2009) paper focused on the April through September months of 2003-2004, while our study includes all months from 2008-2009. Also, some of these studies focus on particular sites/cities, and as such do not have to worry as much about the changing aerosol vertical distribution across large areas.

Comment: p. 31644, l. 4: why are December 2007 data absent? – mention this in 2.1

Response: December 2007 data are absent because no hourly PM_{2.5} data (EPA Parameter Code 88101) were available before 2008. To be consistent, we did not analyze daily PM_{2.5} data (88101) before 2008 either. The following text was added at the end of the sentence on p. 31644, l. 4:

“(this month was not included in the analysis due to the lack of PM_{2.5} Local Conditions data, EPA Parameter Code 88101, before 2008).”

Comment: sec. 3.1: no discussion at all of hourly vs. daily analysis, what can we learn from it?

Response: To address this question, a common point filter analysis was completed in order to make the firmest conclusions about the hourly vs. daily analyses. We have added a paragraph explaining the common point analysis in Section 3.2. See the response to the next question.

Comment: sec. 3.1 and 3.2: to draw firmer conclusions and make a closer link between hourly/ daily as well as operational / DA-quality datasets, you should apply common point

filters – otherwise you risk that data points falling out contain specifically difficult or easy cases / outliers, which spoil the analysis – then you can make a clearer statement on p. 31644, l. 26 as currently done (“We believe that . . .”).

Response: We agree that the use of common point filters strengthens our conclusions, and we have included the results of such an analysis in Table 3. A corresponding discussion has been added to the text in Section 3.2, and is found below:

“In order to strengthen the results obtained in the hourly and daily analyses, we apply a common point filter to the data. Our common point filter refers to the requirement of valid points from all four data sources (i.e., hourly/daily PM_{2.5} and operational/DA AOD). As such, for common PM_{2.5} sites, correlations between hourly PM_{2.5} and 40 km average operational AOD, and daily PM_{2.5} and 1° x 1° average DA AOD, were computed (Table 3). Regional variations in the PM_{2.5}/AOD relationship found here are similar to those in earlier analyses presented in this paper, with higher correlations for the east than for the west. Also, the correlations from the hourly analysis are generally higher than those from the daily analysis, but with some dependency on region and satellite sensor. While this common point study implies that operational AOD may be a better estimate of PM_{2.5} than DA AOD, we note here that when only daily data are used (Table 2), there exists a distinct improvement in PM_{2.5} estimation from the operational to DA AOD datasets. Thus, it is reasonable to expect further improvement in the PM_{2.5}/passive satellite AOD relationship through the use of hourly DA-quality AOD datasets. These data are currently not readily available, however, so this topic is left for a future study.”

Comment: p. 31646, l. 19-23: this finding confirms one reason for the differences in AOD/PM2.5 correlations between eastern and western US – it is important to state so in the conclusions

Response: We revised the conclusion section and added the following bullet point:

“(3) Aerosol particle distributions tend to be more concentrated near the surface in the Eastern U.S and more diffuse vertically in the Western U.S. This regional variability in aerosol vertical distribution across the CONUS confirms one reason for the higher PM_{2.5}/satellite AOD correlations observed in the east compared to the west.”

Comment: p. 31647, l. 20-24: this agrees well with Hoff and Christopher 2009 – state so

Response: The following sentence was added to the text:

“This agrees well with the findings reported in Hoff and Christopher (2009).”

Comment: p. 31648, l. 7-10: this sentence is incomplete (of what?) and can thus not be understood

Response: We have revised the sentence as follows to avoid confusion:

“The average frequency of occurrence of aerosol particle presence (as measured by CALIOP total column AOD) above 2 km a.g.l for the U.S. is ~ 40% (Fig. 9b). Also, about 20% of data records (not shown) have at least 50% of aerosol particle presence above 2 km a.g.l.”

Comment: p. 31649, l. 24-29: why now such high correlations of 0.8? explain!

Response: We believe the higher correlations found here might be due to a lower number of data points, as this analysis required the collocation of PM_{2.5}, CALIOP, and Aqua MODIS observations. Thus, we consider such a finding to be tenuous (this is discussed in the conclusions section). We have added the following sentence at the end of the paragraph on p. 31649, l. 29:

“However, the correlations between PM_{2.5} and CALIOP/Aqua MODIS observations computed in this analysis should be considered with caution, as the low data count (fewer than 100 data points) make these findings tenuous.”

Comment: p. 31651, l. 13 (bullet point 1.): but this reduces coverage significantly by a factor of . . .

Response: We have edited the sentence on p. 31651, l. 13 as follows:

“(1) Application of aggressive QA procedures to passive satellite AOD retrievals increases their correlation with PM_{2.5} for all of the CONUS, but significantly decreases data counts by a factor of about 2.”

Anonymous Referee #2

Comment: The manuscript provides an extensive evaluation of the impact of quality assurance of MODIS Dark Target (DT), MISR, and CALIPSO aerosol products on surface-to-column representativeness on the PM_{2.5}/satellite AOD relationship for the Continental United States. Authors demonstrate that, as expected, improving the quality of satellite retrievals results in a better regression statistics with PM 2.5 data. The paper indicates that CALIOP near-surface extinction data may provide better PM_{2.5} estimates. The paper brings up the important topic of the potential use of satellite aerosol data for PM 2.5 monitoring. The paper is well written, the motivations are clear, and it is relevant for publication in ACP. The authors demonstrate good understanding of satellite data and potential retrieval artifacts. The study results are useful for environmental monitoring community.

Response: We thank the reviewer for his/her comments and warm encouragement.

Comment: General comments:

1. I think that the better way is to address the issue of data quality is to regress PM_{2.5}

data against nearly collocated AERONET AOD data to obtain benchmarking regressions for the East and West US coast for both hourly and daily datasets, and then evaluate how well satellite datasets with different quality flags reproduce these regressions. The AOD-PM_{2.5} regressions are not necessarily had to be linear.

Response: We thank the reviewer for these comments. We have completed an AERONET AOD/hourly PM_{2.5} analysis for the continental US and each time zone, the results of which are found in the new Table 4. The following discussion was added at the end of Section 3:

“As a final step for Section 3, we examine the hourly PM_{2.5}/AERONET AOD relationship for the CONUS. AERONET AOD (0.670 μm) measurements found within 0.3° latitude/longitude and the hour of an hourly PM_{2.5} observation were first averaged, and hourly PM_{2.5}/AERONET AOD correlations and data counts were then computed (Table 4). Similar to the results from the PM_{2.5}/satellite AOD analyses, a higher correlation is found for the Eastern Time zone (0.57) compared to the Pacific Time zone (0.47). Also, the hourly PM_{2.5}/AERONET AOD correlations are generally higher than those between hourly PM_{2.5}/satellite AOD (Table 1). These findings are not surprising, as AERONET is considered the benchmark for validation of satellite AOD retrievals.”

The following text was added in the datasets section:

“2.4 AERONET AOD

AERONET is a worldwide ground-based network of sun photometers that provides measurements of aerosol optical properties, and is currently used as the benchmark for validation of satellite AOD retrievals. AERONET AOD is reported at eight channels (0.34 to 1.64 μm), and has an uncertainty of 0.01 to 0.015 [Holben et al. 1998]. For the purposes of this study, AOD derived at 0.67 μm is used.”

Also, the following paper was added to the reference list:

“Holben, B.N., Eck, T.F., Slutsker, I., Tanré, D., Buis, J.P., Setzer, A., Vermote, E., Reagan, J. A., Kaufman, Y., Nakajima, T., Lavenu, F., Jankowiak, I., and Smirnov, A.: AERONET - A federated instrument network and data archive for aerosol characterization, *Rem. Sens. Environ.*, 66, 1-16, 1998.”

As for the comments related to a comparison between PM_{2.5} and satellite AOD datasets of varying quality, currently there are no hourly DA quality data for us to perform this analysis. Thus, we leave this topic for a future study.

Comment: 2. I agree with the previous reviewer that the recommendation part is missing; however it might be beyond the scope of this study. The take home message seems to be the need of synergistic use of satellite data combined with chemical transport model. The authors need to reinforce this message.

Response: We thank the reviewer for these comments. We have mentioned the need for the synergistic use of satellite data combined with a chemical transport model in the conclusion section. However, modeling is not the focus of this study, and thus we did not add new sentences to highlight its importance.

Comment: I recommend this paper for the publication.