Atmospheric Measurement Techniques

Manuscript Number: AMT-2011-62

Title: Where do we need additional in situ aerosol and sun photometer data?: a critical examination of spatial biases between MODIS and MISR aerosol products

Authors: Y. Shi, J. Zhang, J. S. Reid, E. J. Hyer, T. F Eck, B. N. Holben, and R. A. Kahn

General Comments:

This paper examines the performance of three satellite aerosol optical depth (AOD) retrieval algorithms over land: MODIS dark target (DT), MODIS Deep Blue (DB), and MISR. The authors begin with comparisons against ground-based AERONET sunphotometer measurements for eight selected sites. Next, the authors examine how each of the MODIS algorithms compares with MISR spatially by looking at ratios, differences, regressions, and gradients. In addition, the authors provide supplementary material that provides more detailed, seasonal breakdowns of their analyses in the form of a single KML file suitable for use with Google Earth.

I found this to be a very interesting paper, appropriate for the journal, and this type of analysis is extremely important for both developers of satellite aerosol retrieval algorithms as well as the aerosol community as a whole. That said, I believe the paper would benefit in a number of places from a more detailed discussion of the underlying ideas upon which the authors base their conclusions. A few additional references would help place this work into a larger context and direct readers to the more extensive literature on this subject. MISR and MODIS AOD retrievals have been compared in the past, but the authors present their analysis in a novel way and include MODIS DB, which has only recently become available for the Terra satellite platform. The paper is well organized and well written, for the most part, with a few minor linguistic lapses. Although the abstract suggests that the supplementary material contains GeoTIFF files, I only found a single KML file, as mentioned above. Finally, it's not clear to me that this work actually addresses the question raised in the title, as to where we need additional in situ aerosol and sun photometer data. The second part of the title may be a more appropriate for this paper.

I have provided specific comments and technical corrections below, and I'm happy to engage in further discussion with the authors, as appropriate. I believe this is important research and some relatively minor changes will result in a significantly stronger manuscript and a substantial contribution to the community.

Specific Comments

The comments below are presented in terms of page and line number in the manuscript as much as possible.

Page 4297, Line 5: It's not clear that the question raised here, "is the distribution of AERONET sites sufficient to cover the spatial and temporal variations of the aerosol state globally?" is actually answered in this paper. It seems to me like that might be an appropriate topic for another paper, but I don't think it's addressed here.

Page 4297, Line 13: It seems like you want a reference to go along with the comment "land features and particle properties have spatial coherence…" Perhaps Anderson et al. (2003) would be appropriate.

Page 4297, Line 14: I don't see how the conclusion, "we would expect satellite retrievals of aerosol products to share similar patterns in their biases" follows logically. This might be more correct if "in their biases" was removed. If I compare two "perfect" retrievals, then there would be no pattern to the biases, right?

Page 4297, Line 6: I think it's probably important to mention that this "reported uncertainty" is the 1-σ uncertainty because otherwise it's unclear what these ranges mean. See Kahn et al. (2011) for a detailed discussion of this point.

Page 4297, Line 23: Where are the collection 5.1 MODIS DB AOD uncertainties for Terra reported in the literature? I'm not aware of any extensive validation of this particular product.

Page 4300, Line 1: I don't understand the comment about retrievals over snow and ice. Kahn et al. (2010) doesn't evaluate the performance of the MISR product over snow and ice (there's only a generic comment in the paper). Does MODIS DB perform (accurate) retrievals over snow and ice, making it important to highlight this difference?

Page 4300, Line 2: Once again, it's probably important to mention that these are 1-σ uncertainties (i.e., approximately 68% of the retrievals are expected to fall within the reported error envelopes).

Page 4300, Line 14: Why is the qualification "near" needed? Although the MISR observations occur over a period of seven minutes centered on the nadir-look which is simultaneous with MODIS, the MISR retrieval assumes that the aerosol is unchanging over this ±3.5 minutes.

Page 4300, Line 18: I believe there's a slight overlap of the MODIS swaths near the poles, so gridding over six hours will potentially combine data from different orbits. This doesn't affect the analysis here because this will only occur at the swath edges (i.e., MISR does not overlap).

Page 4300, Lines 10-11: You claim that the records "provide representative observations [of] the aerosol state…" How do you know these are "representative"? I can't speak to all of the sites, but Maricopa, AZ (in the Sonoran desert) is certainly not representative of Boulder, CO (in the Rocky Mountains), or Fresno, CA (in the San Joaquin Valley), but

all these sites are in the Western US. The differences among the sites in India (e.g., Kanpur and Vishakapatnam) are also dramatic.

Page 4301, Line 17: To calculate the AOD from the AERONET observations at the MISR and MODIS wavelengths, was a linear fit in linear (AOD, wavelength) space used, or a linear fit in log-log space? The Shi et al. (2011) paper referenced here mentions the O'Neill approach (i.e., log-log), but it should be made clear. Also, what was done for Banizoumbou, which doesn't appear to have a 500 nm band?

Page 4301, Line 19: Does a "30 min temporal window" mean ±30 minutes or ±15 minutes?

Page 4301, Line 20: Since the satellite data were aggregated into 0.5° grids, how can you guarantee that an AERONET site is going to be within 0.1° of what I assume is the center of a grid cell? I think what you're probably doing is finding the nearest 0.5° grid center to the AERONET location.

Page 4301, Line 22: It's hard to make sense of Table 1 without knowing how many points (N) were included in the statistics. It would also help to include N for the full range of AOD and the range less than 0.5. Also, there's clearly something amiss comparing Fig. 1 to the intercept values in Table 1. Take Shirahama, for example. The plot shows the black line intersecting the x-axis at a value greater than zero. This means that the y-intercept must be less than zero, but it's given as 0.05 in Table 1. I was initially struck by the fact that all the intercept values are positive, but this doesn't appear to actually be the case for MODIS DT at Alta Floresta, Shirahama, Banizoumbou, GSFC, or Maricopa. It's harder to tell what's happening for the other cases just from the plots.

Page 4301, Line 27: What does "reasonable correlations with the collocated AERONET data" mean? Since you've gone to the trouble to be quantitative in Table 1, why not be specific about this? For example, I don't think an R^2 value of 0.35 for MODIS DB at Solar Village is "reasonable" at all. Maybe I think an R^2 threshold of 0.5 is "reasonable," then I find that 75% of the comparisons between the MODIS, MISR, and AERONET AODs are "reasonable." 81% of the MISR, 79% of the MODIS DT, and 60% of the MODIS DB comparisons are below this (arbitrary) threshold. The breakdown of how the correlations behave for the full range of AOD and the range less than 0.5 is also interesting. In particular, MODIS DB shows less "reasonableness" when restricted to low AOD, but the sample size is very small.

Page 4302, Lines 1-2: It might help to be more explicit in this sentence. Which specific sites are dominated by which aerosol species? It's also not clear to me why slope differences indicate microphysical property issues. A thought might be to make the plots in Fig. 1 in log(AOD) space, rather than linear AOD space. In general, AOD values are low, and plotting things in linear space makes a blob at small AODs and draws your eye to the outliers at high AOD. (Linear) regression lines behave in the same way. They tend to emphasize the outliers at high AOD because these few retrievals act as strong "levers" on the overall quality of the fit.

Page 4302, Line 11: You mention that Maricopa doesn't have enough MODIS DT data points to plot the slope. What was the criterion for this cutoff? Also, even though you don't provide the slope in the Figure, the value still appears in Table 1. Is that consistent?

Page 4302, Line 13: I don't understand the comment about large intercept values at Kampur and Mongu for MODIS DB. Table 1 gives the intercepts as 0.04 and 0.17, respectively. The second one is large, but the first is not. See comment above about the intercept values reported in the table, which are clearly incorrect. I guess I follow the argument that when the AOD is low, then the "uncertainty" is driven by the surface. If the y-intercept is negative, then the surface albedo must be overestimated (like at Mongu for the MODIS DB algorithm). Conversely, if the y-intercept is positive, then the surface albedo must be underestimated (like at Banizoumbou and Solar Village for MODIS DB).

Page 4302, Line 16: The ability to retrieve AOD over bright surfaces with MISR is well known (e.g., Diner et al., 2001; Martonchik et al., 2004). Since MODIS DB was designed to retrieve aerosols over bright surfaces, it might be worthwhile citing Hsu et al. (2006) again.

Page 4302, Line 19-20: How do spatial comparisons between MISR and MODIS relate to point comparisons between MISR and AERONET and MODIS and AERONET? They seem like two entirely different things. To make the argument that larger scale comparisons are required, I think you'd probably want to regress MISR and MODIS against one another at the AERONET sites to see how large the differences are. See Kahn et al. (2011) for a discussion of how such a comparison should be done.

Page 4302, Line 27: Which regressions does "these" refer to? The regressions in Fig. 1 and Table 1? Do you actually have a mechanism for answering this question? I think to answer this, you want to compare satellite/AERONET regressions for AERONET sites in close geographical proximity, rather than making maps of the instrument to instrument regressions against one another.

Page 4303, Line 10: When referring to the climatology, I think it's fine to mention particle type (e.g., "heavy smoke aerosol plumes"). However, since this study deals only with AOD, be careful not to attribute particle type to the satellite retrievals. So, rather than writing "dust plumes are visible over North Africa…" you could either write "dust plumes are common over North Africa…" (referring to the climatology) or "regions of high AOD likely associated with dust plumes are visible over North Africa…" (referring to the retrievals.

Page 4303, Lines 21-22: You've been incredibly generous by referring to the observed differences as "uncertainties." Here, I think "differences in the retrieval processes" is appropriate, however.

Page 4303, Line 25: These results for the Western US agree with the results reported in van Donkelaar et al. (2006; 2010).

Page 4304, Line 8: The sentence should more appropriately read, "… underestimates the biomass burning AOD compared to AERONET."

Page 4304, Lines 9-10: The figure labels in Fig. 2 are confusing. Typically the top row is (a) and (b), then the bottom row is (c) and (d). Here the top row is (a) and (c). This also leads to some confusion in the body of the text. Also, why are there any retrievals plotted over the ocean? Neither MISR nor MODIS retrieves aerosols over the ocean using their respective land algorithms. This should be corrected in the figure.

Page 4304, Lines 18-19: What does "consistent to a reasonable degree" mean?

Page 4304, Line 20: In the previous plots the (small) wavelength difference between MODIS and MISR has been ignored (550.0 nm for MODIS and 557.5 nm for MISR). When taking the ratios of the AODs, as in Fig. 3, however, this adds an additional (small) factor that depends on the Angstrom exponent of the aerosol. Using the equation for the Angstrom exponent, it can be shown that the ratio of MODIS to MISR AOD is bounded by 1.04 (for an Angstrom exponent of 3) and 0.96 (for an Angstrom exponent of -3). The ratios discussed in the text as being significant lie well outside these bounds, though. Not accounting for the wavelength difference also leads to (small) differences in the AODs themselves, of course.

Page 4305, Lines 15-17: I believe the argument here only applies to locations where the AOD ratio is greater than one.

Page 4305, Line 20: Where do you think the multiple scattering regime is reached?

Page 4306, Line 3: I think the point could be expressed more clearly. Regions with large intercept values indicate locations where the MODIS DT assumed surface reflectance is too low, typically in arid and semi-arid regions with high surface reflectance. This was also pointed out and discussed in some detail in Kahn et al. (2010).

Page 4306, Lines 13-20: While I agree with the sentiment in this section, what's missing is a discussion of the temporal aspect of the problem. How long does it take to build up a statistically useful database once a new AERONET site comes online? Let's say, at best, you get two satellite observations per month of the new site (limited by the orbit, clouds, etc.). That means six observations per season per year. While this is certainly better than nothing, you probably need at least two years of continuous AERONET observations to get something useful. More important, however, is the particle information, which is less frequently available, requiring a longer time record.

Page 4307, Lines 15-16: I'm not sure that the Yellow Sea should be included in a comparison of land retrieval algorithms.

Page 4307, Line 22: What does “relatively large” mean with regard to the AOD differences?

Page 4309, Line 21: Why use a longer data record with different spatial gridding for the AERONET data?

Page 4311, Lines 11-12: I don’t know that you can conclude that “most of the issues with satellite retrievals… relate to surface reflectance characterization” based on this analysis. It could be that BOTH surface reflectance and particle properties are problematic. For example, it’s been shown that transported non-spherical aerosol causes problems with the MODIS AOD retrievals in the Western US (Liu et al., 2007).

Page 4311, Lines 18-20: This sentence might be overstating the case. I would agree that regional measurements may be useful, particularly when made over poorly observed regions. Whether and how these measurements are incorporated into global algorithm development determines whether they have “significant value.”

Page 4311, Lines 22-24: I only found a single KML file in the supplement, and no GeoTIFFs. In addition, it might be helpful to point out some examples of these “hotspots” to look at in Google Earth.

Technical Corrections

The technical corrections are presented in terms of page and line number in the manuscript as much as possible.

Page 4295, Affiliation 1: I think it’s “Grand Forks, ND”

Page 4295, Affiliation 3: “Greenbelt” is a single word.

Page 4296, Line 17: Missing a comma between “India” and “Asia” (I think). A more general comment about commas is that I noticed in lists there was inconsistent use of commas before the last item in the list. Although I personally prefer a comma before the final “and” (i.e., “one, two, three, and four”), I’m just looking for consistent usage throughout the paper.

Page 4296, Line 20: Should the supplement contain GeoTIFF files, in addition to the single KML file currently there?

Page 4297, Lines 10-11: The word “typically” is used twice, in a redundant sense.

Page 4297, Line 20: The “s” in “conditions” shouldn’t be capitalized.

Page 4299, Line 5: I think just “…fine mode AOD fraction over water…” correctly describes the MODIS product.

Page 4299, Line 9: I think the Zhang et al. 2006 reference should probably be Zhang and Reid 2006.

Page 4299, Line 9: The Kahn et al. 2007 paper is not in the reference list. I've included it in the reference list below.

Page 4299, Line 11: Should be "lower boundary conditions"

Page 4299, Line 27: The MISR swath is ~380 km, not ~360 km (Diner et al., 2002).

Page 4301, Line 4: "aerosol optical depth" can just be "AOD"

Page 4301, Line 5: Consider eliminating "of different products" from this sentence.

Page 4301, Line 8: The last word in this sentence should probably be "comparisons" rather than "results."

Page 4301, Line 15: Just "… with uncertainties…"

Page 4301, Lines 26-27: Why is "MODIS DB" in parentheses? The sentence is clearer if it is just "retrievals from the operational MODIS DT, MODIS DB, and MISR products show…"

Page 4302, Line 11: "... not provided for the Maricopa…"

Page 4302, Lines 25-26: I'm guessing the reference should be Hyer et al. (2011).

Page 4302, Line 26: It might be clearer to say, "… for different sites in the same geographical region."

Page 4303, Line 12: Should probably read "dust, smoke, and pollutants…"

Page 4303, Line 13: "… transports are also shown."

Page 4303, Line 14: "… the West Coast of the US"

Page 4303, Line 22: "… retrieval processes, as sampling biases…"

Page 4303, Line 23: "… not found in the spatially…"

Page 4304, Line 1: Might be more clear as "0.5 that appear over sparely vegetated land (e.g., the Andes Mountains…)

Page 4304, Line 3: "… characteristics, which deviate from the surface…"

Page 4304, Line 16: "Conversely, MODIS DB has much lower…"

Page 4304, Lines 20-21: This sentence would be clearer as, "… Figs. 3a and 3b show spatial plots of the MODIS DT and MODIS DB AOD divided by the MISR AOD, respectively." Taking the ratio already implies division.

Page 4304, Line 22: There's an extra space before the comma after "MISR".

Page 4304, Line 25: I think this should be "MODIS DT" not "MODIS DB" in this sentence.

Page 4305, Line 9: There are some extra words in this sentence. I think it should read, "Therefore, the AOD differences (MODIS DT – MISR) and (MODIS DB – MISR) for the green band are shown in Figs. 3c and 3d, respectively."

Page 4305, Line 20: "… aerosol loadings reach the multiple scattering regime."

Page 4305, Line 23: "… slope + intercept). Figures 4a, 4c, and 4e show…"

Page 4306, Line 2: "in the intercept plot of Fig. 4e…"

Page 4306, Line 17: "…property assumptions cause large uncertainties…"

Page 4307, Line 20: "… surface reflectivity in the visible…"

Page 4308, Lines 2-3: "For example, regions such as …"

Page 4308, Line 5: Do you mean to say, "data from many AERONET sites are available"?

Page 4308, Lines 17-18: Perhaps this would be more clear as: "The use of 'global' statistics from AERONET to measure…"

Page 4308, Line 26: "… in Fig. 1 in the Amazon region…"

Page 4309, Line 19: "… for example: Northern India…"

Page 4310, Line 2: "seventeen" shouldn't be capitalized

Page 4310, Lines 18-19: You don't need "(type C region)" in this sentence.

Page 4311, Line 1: The second sentence should begin "AERONET has data from…"

Page 4311, Line 16: "… measurement can be made…"

Page 4312, Lines 11-12: "1. The ratio of MODIS to MISR…" The first clause was stated previously, and need not be repeated.

Page 4312, Line 15: "… South America, the Arabian Peninsula, and Western…"

Page 4312, Line 19: "2. A closer look at the comparisons…"

Page 4312, Line 20: "… high AOD 'features,' which…"

Page 4312, Line 27: There's no Levy et al. (201) in the reference list.

References: Some of the references need to be checked for consistent format and capitalization. Zhang et al. (2008a) and (2008b) need to be indicated in the reference list.

Table 1: "Solar Village" has an extra "l" in the first word.

Fig. 1: "Solar Village" is also misspelled in the figure.

Fig. 2: The labeling of the panels is inconsistent with the other plots. There shouldn't be any land retrievals over the oceans. "(a) MISR AOD that corresponds to operational…" "(c) MISR AOD that corresponds to MODIS DB"

Fig. 3: You should note the change in color scale from the top to the bottom. "(b) Similar to (a)"

Fig. 4: I notice that panels (a) and (b) have slightly different color scales. In the label "interception" should just be "intercept."

References

Anderson, T. L., Charlson, R. J., Winker, D. M., Ogren, J. A., and Holmén, K.: Mesoscale variations of tropospheric aerosols, J. Atmos. Sci., 60, 119–136, 2003.

Diner, D. J., Abdou, W. A., Bruegge, C. J., Conel, J. E., Crean, K. A., Baitley, B. J., Helmlinger, M. C., Kahn, R. A., Martonchik, J. V., Pilorz, S. H., and Holben, B. N.: MISR aerosol optical depth retrievals over southern Africa during the SAFARI-2000 dry season campaign, Geophys. Res. Lett., 28, 3127–3130, 2001.

Diner, D. J., Beckert, J. C., Bothwell, G. W., and Rodriguez, J. I.: Performance of the MISR instrument during its first 20 months in earth orbit, IEEE Trans. Geosci. Remote Sens., 40, 1449–1466, 2002.

Kahn, R. A., Garay, M. J., Nelson, D. L., Yau, K. K., Bull, M. A., Gaitley, B. J., Martonchik, J. V., and Levy, R. C.: Satellite-derived aerosol optical depth over dark water from MISR and MODIS: Comparisons with AERONET and implications for climatological studies, J. Geophys. Res., 112, D18205, doi:10.1029/2006JD008175, 2007.

Kahn, R. A., Garay, M. J., Nelson, D. L., Levy, R. C., Bull, M. A., Diner, D. J., Martonchik, J. V., Hansen, E. G., Remer, L. A., Tanré, D.: Response to "Toward unified satellite climatology of aerosol properties. 3. MODIS versus MISR versus AERONET", J. Quant. Spectrosc. Ra., 112, 901–909, 2011.

Liu, Y., Koutrakis, P., Kahn, R., Turquety, S., Yantosca, R. M.: Estimating fine particulate matter component concentrations and size distributions using satellite-retrieved fractional aerosol optical depth: Part 2–A case study, J. Air Waste Manage. Assoc., 57, 1360–1369, 2007.

Martonchik, J. V., Diner, D. J., Kahn, R., Gaitley, B., and Holben, B. N.: Comparison of MISR and AERONET aerosol optical depths over desert sites, Geophys. Res. Lett., 31, L16102, doi:10.1029/2004GL019807, 2004.

van Donkelaar, A., Martin, R. V., Brauer, M., Kahn, R., Levy, R., Verduzco, C., and Villeneuve, P. J.: Global estimates of ambient fine particulate matter concentrations from satellite-based aerosol optical depth: Development and application, Environ. Health Perspect., 118, 847–855, 2010.

van Donkelaar, A., Martin, R. V., and Park R. J.: Estimating ground-level $PM_{2.5}$ using aerosol optical depth determined from satellite remote sensing, J. Geophys. Res., 111, D21201, doi:10.1029/2005JD006996, 2006.