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Interactive comment on "Development and Assessment of a High Spatial Resolution (4.4 km) MISR Aerosol Product Using AERONET-DRAGON Data" *by* Michael J. Garay et al.

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Response to A. M. Sayer (Referee)

We thank Dr. Sayer for his careful review of the manuscript and his useful comments. Below we provide specific responses to the comments. The reviewer's comments are listed first in italics, and the responses are below.

1. As the authors note, the MODIS 3 km aerosol product was found to have poorer performance than the nominal 10 km product when compared to AERONET, which is the converse of the authors' experience with MISR, where the higher resolution improves things. My understanding is that with MODIS this is mostly an algorithmic issue

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whereby finer resolution means more potential for noise/bias in the assumed surface reflectance relationship. What is the reason that going to a higher resolution makes things better for MISR? Is it a consequence of the way the land surface reflectance is modelled in the MISR standard algorithm, or does it suggest that 17.6 km was perhaps too coarse a resolution to use initially? The conclusion (page 13 lines 8-13) suggests the latter is the case, but I did not see direct evidence; it is definitely plausible, but I don't see why scene variability should lead to a persistent low AOD bias (as opposed to random noise) unless it's nonlinearity in the radiative transfer, or something in the way the algorithm partitions surface vs. atmospheric contributions to the satellite signal.

The reasons for the improvement of the MISR AOD retrievals when the spatial resolution is increased from 17.6 km to 4.4 km are complex. As the reviewer correctly notes, there are important fundamental differences between the MISR aerosol retrieval approach and the MODIS Dark Target (DT) or Deep Blue (DB) algorithms. The MODIS algorithms rely on assumed relationships in the surface spectral reflectances to account for the lower boundary condition. Overall, these relationships work well on a global basis, but are apparently adversely affected by the presence of noise, which increases as the resolution increases due to the reduction in the spatial averaging. The MISR retrieval approach, on the other hand, attempts to separate the angular contribution from the (assumed variable) surface and the overlying aerosols, which are assumed to be spatially homogeneous. To first order, when the aerosols are not spatially homogeneous – as in Figures 1, 6, and 7 – then this approach is likely to incorrectly assign this variability to the surface. This results in the surface contribution to the top of atmosphere radiances being overestimated, leading the algorithm to retrieve a lower AOD to compensate. This issue is explicitly described in the "Summary of Recommendations" in the assessment of the MISR V22 AODs by Kahn et al. (2010).

Going to higher resolution requires that the aerosols are spatially homogeneous on a much smaller spatial scale, so it is less likely that true aerosol variability is assigned to the surface, resulting in higher AODs. That said, even though the algorithms are iden-

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tical, there are other consequences of changing the retrieval resolution that are more difficult to tease out. As the focus of this paper was on demonstrating the improvement in the MISR retrieved AODs relative to AERONET when the algorithm is run at a higher spatial resolution, rather than a complete description of the MISR retrieval algorithm, we felt it was out of scope to go into these details in the present work. It is our intention to further investigate these changes and report the results in a future publication.

Based on the suggestion of the both reviewers, we have added the following text to the manuscript to highlight the issue of aerosol variability and its effect on the retrieved AODs: "Kahn et al. (2010) also identified a number of issues in the performance of the V22 MISR aerosol retrieval algorithm, including: lack of extremely low AODs in the MISR data compared to AERONET that causes an apparent "gap" in the comparison plots; the appearance of quantization noise; lack of particle types in the aerosol look up table to adequately represent all observed aerosol types; and a frequent underestimate of AOD relative to AERONET over land when the AOD was greater than about 0.4. The authors speculated that this underestimate was due to insufficiently absorbing particles being selected in cases where absorbing aerosols were present, or AOD variability at the 17.6 km spatial scale of the retrieval being incorrectly treated as surface variability reducing the contribution of aerosols to the top of atmosphere reflectances, resulting in a systematic underestimation of the AOD in these situations."

2. Throughout, the MISR/AERONET comparisons show AOD at 558 nm. AERONET provides spectral AOD and related quantities such as Ångström exponent, and in some cases retrievals of e.g. aerosol fine and coarse mode AOD. MISR retrieves AOD at 558 nm and a set of aerosol mixtures which fit the observations. These MISR aerosol mixtures have defined aerosol optical properties and so can be used to compute Ångström exponent or spectral AOD (and are often used to provide a categorical indication of aerosol 'type', which is one of MISR's selling points). The main focus of the aerosol data user community has been on midvisible AOD since this has been the main quantity observed/retrieved by different techniques but it would be good to show similar *types of plot for Ångström exponent and/or AOD at MISR's other wavelengths. If these also improve then it provides an indication that, for example, the set of aerosol mixtures chosen by the retrieval is also improving, which is important for those interested in the 'aerosol type' applications of MISR data. This could be accomplished by adding analogues of Figure 4 for other wavelengths/ Ångström exponent.*

As Dr. Sayer is no doubt aware, and as described in more detail in Kahn and Gaitley (2015), particle property validation using AERONET requires specific aerosol loading and viewing conditions that are infrequently realized, particularly for a small sample size such as the AERONET-DRAGON cases discussed in this work. Ångström exponent comparisons, by their nature, are fundamentally qualitative because they relate spectral slopes that can vary significantly with even small changes in retrieved spectral AOD. The assessments presented in this work are specifically for midvisible AOD so, to avoid confusion, we have changed the title of the paper to "Development and Assessment of a Higher Spatial Resolution (4.4 km) MISR Aerosol Optical Depth Product Using AERONET-DRAGON Data." We have also made changes throughout the manuscript to highlight that this work is a comparison of AOD only. As part of the algorithm development for the new (V23) MISR aerosol product, we plan to assess the particle property information and present these results in a future publication.

3. The examples in this paper are drawn from AERONET DRAGON deployments. As the authors note, these are limited in geographical and temporal extent. There are a number of other areas where I think that the increase in spatial resolution might make a difference due to spatial heterogeneity on scales of a few km. For example, broken cloud fields (such as found in the Amazon) and near-source smoke or dust plumes (in many places of the world). It would be interesting to see a few examples of heterogeneous scenes like this (which don't necessarily have to be matched with AERONET sites) to see what the retrieval decides to do, both in terms of statistics of retrieved AOD, as well as whether a valid retrieval is obtained or not. This could have implications for aggregated statistics in level 3 products in some regions. If the authors

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would like some suggestions, I can provide some example MODIS Terra granules with interesting features (since MISR observes down the middle of MODIS Terra's swath).

Dr. Sayer makes some excellent suggestions for examining the performance of the MISR aerosol retrieval in heterogeneous scenes. Broken cloud fields and near-source plumes are of particular scientific interest. The work presented here was done to be included as part of an ACP/AMT special issue on "Meso-scale aerosol processes, comparison and validation studies from DRAGON networks." This is the reason for the specific focus on the AERONET-DRAGON results. That said, we would be very interest to get a set of cases from Dr. Sayer that could be examined as part of a more comprehensive retrieval validation effort.

4. A generalised danger in going to higher resolution is that artefacts can start appearing in a data set, due to contextual biases (e.g. related to surface cover) in the assumptions in the retrieval algorithm, leading to artificial structure in retrieved data fields which is taken to be real. This has been an issue for several other algorithms which operate at a higher resolution than the âĹij10 km scale common to most operational/heritage data products. In this case the DRAGON data suggest that, over these scenes at least, the bulk of the new finer-detail structure appearing in the MISR data is plausible. I would suggest adding a cautionary note to this effect to remind the reader of this possibility, perhaps around the end of the first paragraph in the conclusions where the 10 km/3km MODIS products are discussed, since this effect is not limited to the MODIS DT product.

This is an important point. The resolution of satellite retrievals is often dictated by the need to mitigate the effects of noise in the instrument observations. Retrievals are then built that contain assumptions about the behavior of the atmosphere and/or surface that seem to be appropriate for these spatial scales. When the scale of the retrieval is changed, these assumptions may no longer be appropriate, leading to unexpected retrieval results. To address this, the following has been add to the text immediately following the first paragraph in the "Discussion and conclusions" section: "Simply providing results at a higher spatial resolution does not guarantee an improvement in the performance of a satellite retrieval algorithm. From a remote sensing standpoint, observations are typically averaged over some spatial scale in an attempt to reduce the impact of random noise in the observations themselves. Changes to the resolution can introduce unexpected biases due to changes in the assumptions (e.g., spatial homogeneity, spectral relationships) developed and implemented for coarser resolution retrievals."

It is a little tangential to the main point of the article, but the MODIS aerosol products' horizontal pixel sizes for the nominal 3 km and 10 km products are only valid near the centre of the MODIS swath. The broad swath and scan geometry mean that pixels get distorted in shape and size as the view zenith angle increases (often called the 'bow tie effect'), which makes them a lot larger than these nominal sizes and causes them to overlap, and in turn affects the characteristics of the level 2 data. See e.g. Wolfe et al (1998) and Sayer et al (2015b) for details. In contrast the MISR pixel size is, to my understanding, much less variable across-track.

The difference in the MODIS swath (2,330 km) compared to the MISR swath (380 km for the nadir camera) shows that the change in the pixel size in the cross-track direction is a much larger issue for MODIS than it is for MISR. MISR is also a pushbroom sensor, compared to the whiskbroom MODIS sensor, so, again, the effects of the cross-track viewing geometry are smaller for MISR than they are for MODIS.

Figures 2, 4: It would be good to add in plot titles or captions which data are being plotted here (i.e. California case for figure 2, all DRAGONs in Table 2 for figure 4.)

The suggested changes were made.

Figure 4: There are about a dozen points with AERONET AOD of 0.8 or higher, which are quite low-biased in the 17.6 km data set, but much closer to 1:1 in the 4.4 km data set. Are these from the same location or date, or more randomly distributed throughout the data set? This is relevant since, if they're from the same place or time, it could

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indicate that the higher resolution is particularly helpful for that specific circumstance, and it is interesting to know where you see a benefit vs. where it doesn't make much difference. From Table 2 I infer they may be from the Seoul deployment but it isn't clear whether they're the same date or from sites around Seoul itself (urban) or elsewhere in Korea. Same question for the outliers in more moderate-AOD cases (AERONET about 0.35, 0.4, 0.7; MISR about 0.15-0.2) which also jump more in-family when the retrieval is done at 4.4 km. This comment relates to my general comment 1 about figuring out why the higher resolution is helping.

In spite of the range of AERONET-DRAGON deployments, the number of mostly cloud-free coincidences with MISR is fairly low. Table 2 illustrates the problem. This is the complete set of MISR/AERONET-DRAGON matchups that were identified. The AODs tended to be stratified, with the highest AOD cases being from Asia-Seoul. Figure 6 shows that the highest AODs were observed around Seoul on 9 May 2012. High AODs were also observed elsewhere in Korea on both 9 May and 25 May 2012. Page 11, lines 23-27 in the manuscript describe these cases.

What is particularly striking in Figure 4 is the overall elimination of low outliers. This seems to support the assertion that increasing the spatial resolution has the effect of reducing the low AOD bias apparent in the V22 algorithm results.

Page 9, line 10: Can you expand a bit more on what 'complex terrain' means here? I guess it means variable-altitude scenes or similar, but a brief mention of what is tested for/how it is done (e.g. spectral/spatial tests, ancillary data base, etc) would be useful.

The text was modified as follows: "No retrievals are performed over complex terrain (i.e., where the standard deviation of the regional surface elevation exceeds 500 m based on the MISR digital elevation model)."

Figures 5, 6, 7: these are all on the same AOD colour scale, from 0-1.4. Figure 5 however is a much lower-AOD scene than the others, so it's hard to make out the patterns and values. Perhaps this could be redrawn on the same scale as Figure 1, i.e.

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0-0.3? Also, for all these maps, it would be good if a different colour could be used for 'zero AOD' and 'no retrieval'; at the moment both are white. The colour bar font would benefit from being a little larger on all the maps (not legible on the pdf unless zoomed in).

The color scale was deliberately kept the same for all three figures to facilitate intercomparison of the cases. The spatial variability of the AOD in Figure 5 is really quite limited, so changing the scale does not reveal very much additional detail. For MISR (unlike MODIS) a zero AOD is actually a missing retrieval (i.e., if the algorithm retrieves an AOD of 0.0, then this is considered a "failed" retrieval). Only pixels in color indicate successful retrievals. The overall size of the color bar has been increased in the revised manuscript, hopefully improving legibility.

Figure 6, 7 captions: delete 'the' in 'the Korea', or change to 'the Korean peninsula'.

This was a typo, thank you for catching it.

Page 13, lines 14-19: I know that us data providers hate to hear the question, but if the authors are able to comment on whether there's a tentative schedule for the release of the new data set version, incorporating the higher resolution as well as the other updates mentioned in the referenced paragraph, that would be helpful. If it is up in the air then no need to include this.

The current plan is to deliver the updated algorithm to NASA Langley for processing in Spring 2017. The text has been modified as follows: 11The MISR aerosol algorithm team is working toward the release of an updated version of the aerosol retrieval in Spring 2017 that will have results reported globally at 4.4 km resolution."

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