Response to Dr. Colarco - Reviewer's comments are *italicized*; response are not.

The paper is an evaluation and correction of the MODIS Deep Blue (DB) aerosol optical depth (AOD) product. The objective is to develop empirical corrections to the DB product in order to facilitate its use in operational data assimilation models. They ad- dress numerous sources of bias in the distributed DB product and provide a prognostic error model that can serve as the basis of corrections.
Mostly the paper is thorough and well written. This group has previously provided similar analyses of the MODIS over ocean AOD product and the MODIS over land Dark Target AOD product, so they are on familiar ground. This is a logical extension of that previous work, although in places the text seems too presumptive of deep familiarity with that work, and I try to point out in the detailed comments where I think some clarity could be introduced that wouldn't have me scrambling for additional reference material. Most of my comments are also for clarification. I think the paper is otherwise suitable for publication.

Thank you very much for your general comments and detailed suggestions.

Question/Comment: 1. The introduction seems quite well written.

Answer: We thank Dr. Colarco again for his warm encouragement.

Question/Comment: 2. In Section 2 I think there should be a little more information provided about the DB product. The product is available at 10 km nadir resolution. How many pixels of what resolution does that comprise? What are the cloud screening criteria? Can you get a 10 km DB retrieval from a single pixel? Later there is some discussion of the number of 1 km pixels used, but some explanation here would be helpful.

Answer: Agreed. We have added more discussion as suggested in section 2. "The DB algorithm is applied to the 1 km cloud free MODIS pixels, and then these 1-km retrievals are aggregated into the 10 km resolution data (Hsu et al., 2004). To identify cloud free pixels, in addition to applying the cloud screening method following the MODIS Cloud mask algorithm (Hsu et al., 2004) on the original 1km pixels, DB also uses AOD spatial variance computed every 3x3 pixels to remove potential cloud contaminated pixels. The DB aerosol index AI is also used to retain pixels with heavy aerosol loading which are misidentified as cloudy pixels using the MODIS cloud masking algorithm."

Question/Comment: 3. In Section 2, page 7819, line 12 you state the Aqua DB extends 2002 - 2010, but in section 5 you evaluate 2010 and 2011. So change 2010 to 2011. Also, why does Terra stop in 2007? I think it has to do with radiance calibrations, but please clarify.

Answer: Thanks for pointing this out. We have modified the Aqua data availability from 2010 to 2011. Terra stops in 2007 due to the known calibration issues (personal communication with Dr. Hsu). We have added the following phrase in the text “due to the known calibration issues”.

Question/Comment: 4. Section 3, Table 1: I didn't find this table very useful as laid out. Instead, I found the multiple columns in Step 2 and 4 confusing. In any case, the table is never referred to again. As a tool to help interpret the flow of the paper it fails. Maybe a graphical flow chart would be better. Also, under step 5 you say the data is aggregated to 1 degree grid, while in the text you talk about 0.25 degree grid. Please clarify.

Answer: Thanks for the suggestion. We have changed Table 1 to a flow chart and added explanation in section 3 regarding the flow chart. " Details of the evaluation procedures are illustrated in Fig. 1. Four main steps include (1) evaluating the performance of the DB products with respect to QA flags included in the datasets, (2) studying the uncertainties of the DB products as functions of observation conditions, (3) assessing the uncertainties of the DB products in relation to the spatial variations of AOD and surface albedo, and (4) developing empirical correction procedures. In the second step, the performance of the DB AOD data was analyzed as functions of various parameters including low boundary conditions, viewing geometry, cloud contamination, aerosol microphysical properties, and other observing conditions. After applying the empirical correction steps, both ¼ degree and 1 degree (Lat/Lon) DA-quality DB AOD products were generated, and the ¼ degree products were generated for evaluation purposes only. "

Question/Comment: 5. Caption to Figure 1 indicates shading is percentage data density. Judging by the numbers I guess it is fractional data density (fraction of 0.06 as opposed to 0.06%). Clarify.

Answer: Thanks for the comments. We have made the change (now Fig. 2) as suggested. "The fractional data density is shown in Fig. 2 for every 0.5 increments of AOD for both AERONET and DB."

Question/Comment: 6. Page 7821, line 12 you indicate r^2 values shown in Figure 1. They are not shown in Figure 1.

Answer: Thanks for the comments. We have added r^2 values in Fig. 2 (Fig. 1 from the previous version).

Question/Comment: 7. Page 7821, line 20, you could make a mention of this information appearing in Table 2.

Answer: Thanks for the comments. We have made the change as suggested.

Question/Comment: 8. Page 7821, line 28, other regions have insufficient numbers of collocated MODIS and AERONET points. What is the criteria for sufficiency?

Answer: Thanks for the comments. We modified the paragraph to "As indicated from Fig. 3, only four regions, namely North Africa, Europe, East Asia, and West Asia, have more than 400 collocated data points that are sufficient for an evaluation study with respect to various observing conditions."

Question/Comment: 9. Page 7822, line 7, you say "regions other than North Africa," but I think you mean regions other than the four (North Africa, Europe, East Asia and West Asia).

Answer: Thanks for the suggestion. We have deleted the following sentence to avoid confusion. "Regions other than North Africa either have ... and AERONET AOD values."

Question/Comment: 10. Figure 4, could you please explain the binning? Why aren't the different colored dots vertically aligned? I mean: shouldn't the green, blue, and black dots appear at the same point on the x axis? Also, the legends in Figure 4a and 4b really should be the same, with all four colored dots. Breaking up like this is confusing.

Answer: Thanks for the suggestions. Within each plot, the binning method is the same for all of the components. The corresponding mean AERONET AOD for all the data points in each bin was plotted as the bin's X-axis value. For a given AOD bin, the total numbers of retrievals in that bin are different for different regions or aerosol types. Thus the bin averages for each AOD bin are different for different regions/types (represented by different color dots), which means that although exactly the same binning method was used, the dots are not vertically aligned. Also, we have modified the legends in Figure 4a and 4b based on the suggestion from the reviewer. Discussion was added to section 3.1: "The RMSE models were created using the same binning method for all of the components within each panel. The corresponding mean AERONET AOD for all the data points in each bin was plotted as the bin's X-axis value."

Question/Comment: 11. This is a general comment about the figures. Beginning about with Figure 4 the captions for the multiple sub- panels get to be torturous. This is maybe the worst in Figure 19, which also contains an error in the last bit ("(a), (b), and (e) but for Aqua" should read "(a), (c), and (e) but for Aqua"). Clarity could be improved by titling the individual panels. Alternatively, where they are clearly some tabular form (columns = Aqua and Terra, for example) you could label the columns and rows. Just a thought.

Answer: Thank you for the suggestions. We have modified the captions as suggested.

Question/Comment: 12. Page 7823, line 5, it is not obvious to me why the large scattering angles somehow fail the "very good" retrieval QA. Could you explain?

Answer: It is because the surface reflectance databases that c5.1 DB uses do not use the high scattering angle data for angular curve fitting. Thus, the c5.1 DB algorithm does not allow

retrieved AOD with scattering angles greater than168° to be passed into the "Very Good" category.

Question/Comment: 13. Page 7824, text describing figure 7a seems not correct. I see an increasing trend in delta with increasing view angle, and values do not appear to be around -0.09 for 0 degree view angle.

Answer: Thanks for pointing out the confusing descriptions. We reworded the sentence that is on page 7824 line 8 to "As θ values increase the $\Delta\tau_{A\text{-}M}$ changes from -0.07 to about zero, indicating a smaller bias for a larger θ values."

*Question/Comment: 14. Page 7824, line 23: this is pedantic, but doesn't fine mode fraction *have* to be smaller than 1 (or, at least, never exceed 1)?*

Answer: Thanks for the suggestion. We deleted "all of which are smaller than 1.0. Also," on page 7824, line 23

Question/Comment: 15. Last paragraph of Section 3.2.2, I found this confusing on the first read. Then I realized you did the fine mode fraction analysis based on your own construction of that, not from DB product. So, to clarify, fine mode fraction is from AERONET data and you assign to the collocated DB retrieval. Is that right? So your final sentence here could be emphasized that you want to tie the microphysical aspects to something reported in DB product, not to something externally constructed.

Answer: Thanks for the suggestion. Your understanding is correct. To avoid the confusion, we have changed the sentence, "At last, the aerosol type flag, a parameter that is included in the DB products, was used to represent the aerosol microphysics in the empirical correction step (see Sect. 4).", on page 7825, line 11 to "At last, instead of using external calculated η from AERONET, the aerosol type flag, a parameter that is included in the DB products, was used to represent the aerosol microphysics in the empirical correction step (see Sect. 4). "

Question/Comment: 16. First paragraph Section 3.2.3 seems unnecessary.

Answer: Thanks for the comments. We think the first paragraph sets the tone for decoupling surface reflectance and microphysics. So we have left the paragraph unchanged.

Question/Comment: 17. Figure 11 seems to suggest biases in the DB product are essentially gone for retrievals that make use of more than 20 pixels. This point is introduced and discussed only briefly, but it leaves me scratching my head. It doesn't apply to Terra, but at least for Aqua does it explain most of the other biases you're seeing? Did you explore your other possible sources sorting on the number of pixels?

Answer: We thank the reviewer for his suggestion. Indeed, in our previous plot we didn't include the case when the retrievals make use of all 100 pixels. We have updated the figure with

the new bin (the number of pixels used equals 100). In fact the largest bias is found for this new AOD bin. Discussion regarding the new plot was added in section 3.2.4. "The quality of the DB retrievals was checked with respect to this parameter, and a noticeable high bias in $\Delta\tau_{A\text{-}M}$ of 0.11 was found when all of the 1-km pixels are used in the retrieval process, as shown in Fig. 12. The DB data has a low bias over most of the scenarios except when the number of pixels used is around 60-80. The pattern of $\Delta\tau_{A\text{-}M}$ increasing when 100 pixels were used is also found in Terra. However, for the rest of the scenarios, there is no systematic low bias found (See supplemental material Fig. 6)." We thank the reviewer for pointing out issues in the plot.

Question/Comment: 18. Plots are presented in Figure 12 for sensitivity of STE_sfc with respect to surface reflectance, AOD, and aerosol type. Figure 13 shows plots of STD_aod, but not in any way comparable to Figure 12. Figure 13 gets a parenthetical mention (page 7829, line 12) but no discussion as to what it is actually showing. I think I'm confused here as to how these are being used in the subsequent analysis. Some thresholds are given in Table 2 and in the text, but I can't figure out how those are arrived at. I feel like there's a missing figure like Figure 12 but for the STD_aod and associated discussion, as Figure 13 seems to imply only cloud contamination issues (or so the text says, it doesn't make any sense to me what I'm looking at). So I think some further explanation is warranted here for what is going on.

Answer: We thank the reviewer for his suggestion. We had done the study of STD_{AOD} following Fig. 13 (Fig. 12 from the previous version) as suggested by the reviewer. However, no significant trend is found between STD_{AOD} and surface reflectance or aerosol type. We have modified the text to include discussion on this issue (section 3.3) "Similar analyses were conducted for STD_{AOD} as functions of surface reflectance and aerosol type. However, no significant trend was found."

Figure 14 was introduced to show the STD_{AOD} as a function of AOD. Although globally an increasing trend is found between STD_{AOD} and AOD (Fig. 14a), over the study region the STD_{AOD} is nearly invariant with respect to AOD other than when AOD is smaller than 0.1 (Fig. 14b). STD_{AOD} cutoff has been used as a method to exclude cloud contaminated pixels (e.g., Shi et al., 2010). Figure 14b suggests a flat STD_{AOD} cutoff can be applied to the study region, which is applied in section 4.0. We have added this discussion to the text:

"Figure 14 was introduced to show the STD_{AOD} as a function of AOD. Although globally an increasing trend is found between STD_{AOD} and AOD (Fig. 14a), over the study region the STD_{AOD} is nearly invariant with respect to AOD other than when AOD is smaller than 0.1 (Fig. 14b). STD_{AOD} cutoff has been used as a method to exclude cloud contaminated pixels (e.g., Shi et al., 2010). Figure 14b suggests a flat STD_{AOD} cutoff can be applied to the study region, which is applied in the next section."

Question/Comment: 19. Page 7829, line 16: please explain what the "buddy check" is and how it is used here.

Answer: Thanks for the suggestion. We have added further discussion in the text to clarify the concern:" buddy check was performed, which is a test that searches for adjacent retrievals, where retrievals without any adjacent retrieved AOD are rejected. It is designed to detect isolated retrievals and is aimed at removing retrievals that occur in between clouds and are subject to cloud contamination."

Question/Comment: 20. Page 7830: At this point I'm confused about the prognostic model. Is the prognostic model the same as the DA-quality DB? The choice of the slope correction limit to 1.3 (line 25) is stated to be arbitrary and pragmatic. So why 1.3? What is the sensitivity to 1.2 or 1.4?

Answer: Yes, the prognostic model is an important composition of DA-quality DB.

The correction limit of 1.3 for the slope correction is arbitrary. The number was chosen to limit the possible amount of correction that is applied to the data. A table was added to the paper to show the sensitivity study concerning the influence of the slope correction limit at the end of section 4.0. " Table 4 shows the sensitivity study concerning the arbitrary limitation of the slope corrections. For the selected slope limits of 1.1, 1.2, and 1.3, the smallest RMSE occurs when the slope correction limit is restrained at 1.3. Again, the main concern for restraining the slope correction is to avoid potential discontinuities in the data that are created by the application of large corrections."

Question/Comment: 21. Page 7831, line 11: The slope for Terra (Figure 17d) appears to be 0.95 and not 1.03.

Answer: Thanks for pointing out this error. We have changed "1.03" to "0.95"

Question/Comment: 22. Page 7831 and 7832: the concept of the "noise floor" is not defined, nor is it explained how the stated numbers are arrived at. Please expand.

Answer: Thanks for the suggestion. We added the definition of noise floor to the text: "Figure 19a shows two lines of noise floors. The noise floor is defined as the RMSE value when RMSE is invariant to AOD variations. The noise floor represents the basic RMSE introduced by the system."

Question/Comment: 23. Figure 20a: there is a typo in the title.

Answer: Thanks for the comment. The caption for Fig. 21 has been changed to "Figure 21. Scatter plot of Aqua DB versus AERONET level 2.0 AOD at 0.55 μm from 2010 to 2011 for an independent study. The blue line is the polynomial / linear regression line for all of the data. (a). for the original Aqua DB aerosol products, (b). for the DA-quality Aqua DB aerosol products"

Question/Comment: 24. Page 7834, line 9: I think I see what you're trying to say, but please clarify what you mean "data developing procedures."

Answer: Thanks for the suggestion. We modified pg. 7834, line 9 "The analysis results will be beneficial to the MODIS DB team and hopefully will be used in the DB c6 data developing procedures." to "The analysis results provide useful information to the MODIS DB team and hopefully will be considered in the DB c6 product."

Question/Comment: 25. I'm trying to come up with a summative question. Much of what's been done here is ad hoc, and maybe that's the nature of the beast, although it is suggested that this can filter back to the algorithm developers. Another group may approach the same problem with a different tool set (e.g., neural networks) and arrive at a different prognostic model. Is one approach more "right" than another? What are the limitations of your approach? Would more or less data lead to different conclusions? Can you speculate on this somehow?

Answer: We agree that different approaches may introduce different products for different applications. However our research target is clear: we are aimed at producing a quality assured level 3 product for satellite aerosol data assimilation. We addressed this issue by evaluating the uncertainty of the satellite aerosol product with respect to the physical basis behind the retrieving/observing algorithm. We believe this approach, in comparison with the neural networks approach, reveals existing issues in the current DB aerosol retrieval algorithm and insight that can be used for improving the next version of the DB aerosol products. This is a statistical based study, and therefore, the study would be more robust with a few more additional years included in the analysis.