Response at AMTD stage

November 4, 2016

We are very grateful to referee #1 for the careful reading of our manuscript and for providing constructive comments which helped to improve the manuscript. This document includes all the referee's comments as well as our replies to every one of them (revised text are given as red color).

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General comments

This paper seeks to improve the MODIS Dark Target (DT) aerosol optical depth (AOD) land retrieval by replacing the empirical surface reflectance estimation method with another empirical surface reflectance estimation method. Based on histogram and analysis and comparison against AERONET, the AOD retrieval seems to be improved (more often within the uncertainty envelope, fewer unphysical negative AOD retrievals).

This builds on a previous version of an algorithm developed by the authors, Wu et al (2016), which is listed in the bibliography as submitted to IEEE, 2016. Without seeing that paper it is impossible to judge some aspects of what is done and how this study builds on that, or what the extent of overlap between the two studies is. It seems strange to me to submit this paper as a follow up to one in a different journal which appears to still be in peer review. Why are they not one paper if they are both refinements to the same algorithm on the same theme (surface reflectance model), simultaneously under peer review? Since this analysis appears to work better than the Wu et al (2016, submitted) results indicated, why should that paper be published? In fact this paper (line 29 of page 4) explicitly notes that it is a reconsidered and updated version of a paper still in peer review!

My recommendation at this time is to wait until the outcome of the paper Wu et al (submitted to IEEE, 2016) is known. Maybe these two papers need to be combined into one. Without the context provided by that, I do not feel it is possible to give a full assessment of this paper at this time.

Reply: We admit that there are some confusing descriptions in the current manuscript that make readers misunderstand the relation between the current and previous study (Wu et al, IEEE 2016). The previous study focuses on improving the AOD retrieval by considering surface BRDF effects. It shows that the retrievals were improved for areas with heavy aerosol loading while they are less improved for areas with light aerosol loading. The current study is independent from Wu et al (IEEE 2016) but builds on the same algorithm, firstly developed for the previous study. This study aims at achieving better retrievals for cases of areas with light aerosol loading. Regarding that the surface bidirectional reflectance has a strong impact on the retrieval and need to be estimated more precisely for these cases, the spectral relationship of surface BRF was refined using ASRVN BRF dataset in the current study. Like in our reply to reviewer #2, we have added the necessary information about the algorithm in the new manuscript. By the way, we already resubmitted the previous study (Wu et al., 2016) to AMT on Nov 4, 2016. We hope that readers can get a fully understanding of our work.

Specific comments

I have a few other general comments at this point:

1. The paper involves a modification to the NASA MODIS DT aerosol product. Was the retrieval code (aside from the surface model improvement) also drawn directly from the MODIS operational code? I may have missed it but did not see this mentioned. From my understanding, this would be important to guarantee that the only difference in the results is from the surface treatment. The DT team do not appear to be listed as co-authors to this paper. However some of the plots look similar to those published by e.g. Levy et al so I assume some code was provided for parts of the analysis/plotting.

Reply: We have specified the accuracy of our code with a complete comparison to the MODIS algorithm, and we are confident that it gives exactly the same result. However, it was completely recoded, in another programming language, so we can use it to add the changes to it and do experiments. In this way, it will also be clear that co-authorship of the MODIS DT team is not necessary but we still acknowledge the help. It is true that some of the plots look similar to those published by Levy et al. But we use our own codes for the analysis/plotting.

2. Related to this, is there any plan to implement this in the next version of the MODIS DT code? If so, this should be stated; if not, why was this analysis done? It does not represent a theoretical advance and the results will not be transferable to other data sets, so I am not sure what the benefit of publication would be unless this will feed directly into a data set.

Reply: We initiated this study and identified the main weaknesses of the MODIS AOT algorithm. The MODIS team was made aware of this study and its results, but it is up to them to implement the results.

3. More information should be given about ASRVN, specifically items like uncertainties in its atmospheric correction. Errors in the ASRVN data will propagate into the empirical fit and in turn the AOD retrievals. The same is true about MCD43A1: although it is stated that Rdd is retrieved, the algorithm appears to be making assumptions about the other reflectance terms coming from this product, which has its own (independent) atmospheric correction.

Reply: We have added descriptions of the accuracy of MODIS BRDF/albedo and the ASRVN data in section 2 in revised manuscript. We note that besides their own atmospheric correction, these datasets are also suffering the uncertainty/errors from the BRDF model itself such as large errors at a large scattering angle (e.g., sun behind the sensor) and large zenith angle. In addition, the rapid change of the land surface may be not well captured by the MODIS BRDF and ASRVN algorithm and cause some errors in their datasets.

4. In Figure 3, the blue points are partially hidden by the red points. It looks like there are two branches of blue data. This, and the curvature in the blue points, suggests that there is more going on here and these linear parameterizations may not be the best approach. This is also reflected in the large variability seen in the binned data in Figure 4. It is unclear how much more can be squeezed out of these empirical relationships to improve these retrievals. I suspect we are at the point of diminishing returns and a new approach developed based on theoretical considerations is necessary to achieve any- thing more than modest refinement. For example perhaps it would be more physically meaningful to parameterize the relation between BRDF kernels vs. NDVI, rather than the BRF vs. NDVI, since the color and kernels are close to the real-world intermediate step between surface cover and BRF.

Reply: Thanks for the reviewer's comments and suggestions.

- It's true that there is a large variability in the binned data. To reduce the nonlinearity in the BRF ratio, we have recalculated the ratio using a second-order polynomial fit method. The effects of the ratios with a large standard deviation is discussed and given in section 4.4 in revised manuscript, shown as bellow:

We also note that the BRF ratios still have a large uncertainty even by accounting for the scattering angle, which may cause errors of the AOD retrieval. The standard deviation for 0.644/2.12 ratio are about ± 0.1 and even larger for 0.466/2.12 ratio (about ± 0.12). To check the effects of BRF ratios uncertainty on the AOD retrieval, we performed a sensitivity test by given typical vegetation area where $R_{dd,2.12}$ is around 0.15 calculated by BRDF kernel code *brdf_forward* (the code website given in acknowledgments). In this test, we added one standard deviation on the BRF ratios (e.g., $R_{0.466/2.12} \pm 0.12$,$R_{0.644/2.12} \pm 0.1$). We found that the ratios uncertainty can cause > 0.054 ($> 22\%$) errors in the AOD retrieval under $\tau \leq 0.25$. Nevertheless, the errors become small as increasing aerosol loading. For example, when $\tau = 0.5$, the error of the retrieval is 0.025 (5%).

- We cannot directly give how much more can be improved in the AOD retrieval by further refining the parameterization. Nevertheless, according to the results of sensitivity study (in section 4.4 in revised manuscript), the retrieval can be potentially improved by 22% with a correct parameterization.
- As for the relation between BRDF kernels vs. NDVI, it may be much less meaningful than BRF vs. NDVI since the kernels and NDVI are not related with each other. BRDF kernel itself is a function of illumination and viewing angle, which does not refer to the surface type in a real world. Each kernel has its own assumption for the background surface. Specifically, the volume scattering kernel K_{vol} (so called RossThick kernel) is with the assumption of "a dense leaf canopy", whereas the geometrical scattering kernel K_{geo} (so called LiSparse kernel) is with the assumption of " a sparse ensemble of surface objects casting shadows on the background" (Lucht et al., 2000). Given the corresponding weights (f_{iso},f_{vol} and f_{geo}, see equation 1 in Schaaf et al. (2002)) for the three kernels, a linear combination of these kernels can be used to represent real reflectance of the land surface.

5. Four months of global data were processed. It would be good to see before/after maps of these four months, to judge how much difference these changes make to the global picture.

Reply: We have added global maps of the mean AOD (January and July 2008) (see Figure 7 and 8) and the corresponding description in revised manuscript. The other two months (January and July 2010) of data are not shown since they are similar to the data from 2008.

We look forward to hearing from you regarding our new submission. We would be glad to respond to any further questions and comments that you may have. Thank you all very much.

References

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