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Atmospheric Measurement Techniques
Discussions

Interactive comment on "MODIS Collection 6 MAIAC Algorithm" *by* Alexei Lyapustin et al.

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- Dear Jeff,

Thank you the review of our paper. You practical perspective representing both wide range of applications and modeling and data assimilation communities is extremely valuable. To address your requests, we added a new section "Prognostic error modeling", and provided more material related to a) AOD discrepancy on the boundaries of geographic regions, and b) continued calibration degradation of MODIS Terra. Our specific response follows your review items.

Thank you,

Alexei.

Received and published: 22 July 2018 Overview: This is a very well written theoretical

basis document sort of paper on the MAIAC algorithm. Often papers are criticized for being too long or involved, but typically I disagree-wanting to know how to reproduce the work and try and get a feel of what the authors are really thinking. This current paper is an outstanding example of how such ATBD papers should be written and published in the peer reviewed literature. I have been familiar with the basic nature of MAIAC, and yet after reading the paper I have an even more thorough understanding and know how to apply the data. The authors discuss the algorithm thoroughly, what works, and what the limitations are. In the "pre review" gave Lyapustin et al., some small corrections that need not be repeated here. I did have a few major comments that I said did not to be address immediately for public review but did need attention before final publication. They are neither hard nor time consuming, but it does I think need to get done. Thus, I would like the following three things to be addressed in the final revised paper. 1) Prognostic error modeling: As is typical for satellite aerosol products, MAIAC is compared in bulk to all available AERONET in a regression (Figure 7). Bias and RMSE are calculated. I consider this a "diagnostic error model." Now I understand that this paper is more of an ATBD style, and expect that a thorough verification paper will be forthcoming. But one minor addition to Figure 7 (say a Figure 7 b) is a plot of RMSE and or RMSD (if there is a consistent bias) as a function of retrieved (e.g., MAIAC) AOD. That will give you the actual error bar for any retrieval. Consider- if we knew AERONET AOD, we would have no need of MAIAC. You need to know what the error is at any given place and time, and you only have the MAIAC algorithm, to go on. What the authors will undoubtedly find is that their error is parabolic, with a well-defined flat noise floor at low AODs, then growing nonlinearly. I would like to know based on the bulk analysis what that noise floor is, and how nonlinear the error is. The authors can devise more complicated error model, including the addition of other non-MAIAC data at hand, but that for certain is not necessary here.

- To accommodate this request, a new section (10.5 Accuracy Assessment of MAIAC AOD) was added with new Figure 8 and Table 5. The new text starts at the second half of this section.

10.5 Accuracy Assessment of MAIAC AOD Figure 7 presents results of the global MAIAC AOD validation against AERONET (Holben et al., 1998) showing correlation coefficient, average bias, and rmse for individual AERONET sites along with the global scatterplot during 2000-2016. The detailed validation analysis of MAIAC dataset, and its comparison with the standard products from MODIS or other sensors deserves a separate consideration, so this analysis merely serves to illustrate the overall quality of MAIAC aerosol retrievals. Figure 7 shows a) predominantly high correlation with AERONET except for the world regions where typically both AOD and its range of variation are low (e.g., south-western USA or south of South American continent); b) globally low bias and rmse except major biomass burning, industrial or mineral dust source regions such as Sahara, Sahel and sub-tropical Africa, Indo-Gangetic Plane, south Asia and China. The higher rmse in these source regions is typical of all aerosol retrieval products and is expected due to high variability of aerosol types and properties, often in combination with the bright land surface increasing uncertainties of satellite retrievals. The bias shows clustering of results, and gives a clear indication for the required tuning of MAIAC regional aerosol models, e.g. in South Asia and China. Some of these biases come from the seasonal variation in aerosol properties (e.g., Mhawish et al., 2018) which will be implemented in the next version of MAIAC. The global scatterplot of Fig. 7 shows that 66% of retrievals (grey area) agree with AERONET within $\pm$0.05$\pm$0.1AOD which improves over the standard accuracy assessment of 15% from the DT algorithm over land (e.g., Levy et al., 2013). While the global assessment may serve as a useful indicator of accuracy, the true performance of any algorithm is inherently regional and local, as shown by R/rmse/bias statistics for each AERONET site. To generalize these assessments into regional prognostic error models, we computed rmse and bias (or rmsd) binned to retrieved AOD for different world regions. These results are summarized in Figure 8 where the line shows the mean and shaded area represents $\pm$ one standard deviation. Our analysis and results of independent studies (e.g., Superczynski et al., 2017; Mhawish et al., 2018) show that MAIAC AOD has little dependency on view geometry. Although MAIAC accuracy somewhat decreases over

bright surfaces, here the regional analysis was done for all AERONET sites together. Figure 8 shows that the linear model for both mean and standard deviation can serve as a reasonable proxy for both rmse and bias (rmsd), for instance: rmse = a + b$\times$AOD $\pm$ (α + $\beta\times$AOD). (23) The regional linear regression model parameters are given in Table 5. This table also includes Australian continent not shown in Figure 8 for the lack of space. A more detailed MAIAC AOD error analysis, as in Sayer et al., (2013), will be given separately.

Table 5. Regional linear regression model parameters for the expected error (rmse) and bias (rmsd).

Figure 8. Absolute error (rmse, top row) and bias (rmsd, bottom row) of MAIAC AOD for different world regions as a function of retrieved AOD. NA and SA stand for the North and South America, respectively.

2) Use for data assimilation: Currently there are nine centers doing operational or near real time global aerosol modeling, four of which with operational data assimilation. Without a doubt, the field is moving towards data assimilation as one of if not the biggest “power users” of retrievals such as MAIAC. In DA, we are often in the situation of violating the fundamental assumption that errors between adjacent retrievals are uncorrelated. I think it should be emphasized in the paper that the way the retrieval has regional optical models outlined in blocks leads to very sharp inconsistencies in AOD across arbitrary lines. Similarly, you can see very strong deviations at the coastlines from time to time. This can be a problem for data assimilation or anyone trying to invert sources and sinks out of the data. This issue is noted in the paper (and I commend the authors for stating what does not work so well), but I think an example figure as to how big a deviation there can actually be.

- Section “Known Issues and Limitations, Item 4, was expanded as follows, with new Figure 9 illustrating mentioned geographic boundaries:

4. “Geographic AOD boundaries may sometimes be observed on borders of the re-

gional aerosol models when they have a significant difference in absorption. While this is not an issue over most of the globe, three transition zones may stand out during the biomass burning seasons (see Figure 4): the north-west boundary between India (model 8) and central Asia (model 2), and two transitions from central Africa to Sahel-Sahara (models 7-6) and to the southern Africa (models 7-2). Figure 9 shows one the worst case examples for each transition zone when at high AOD the contrast across the model boundary can be as high as 40-50% of the mean value, while it is not noticeable for most of the year when AOD is moderate-low.

Figure 9. Illustration of MAIAC AOD contrast on the boundary of aerosol models (see Fig. 4) caused mainly by the difference in aerosol absorption between the models: (a) transition 8-2 (day 82, 2010); (b) transition 7-6 (day 113, 2010); (c) transition 7-2 (day 237, 2010).

3) Overlap uncertainty: One thing we noticed when looking at the MAIAC data online, which I discussed in person with Alexei Lyapustin a few weeks ago was that it appears that under some circumstances the overlap regions between successive orbits can have led to significantly different values in AOD in the overlap. This behavior was inconsistent, being difficult to notice in retrievals of the environment 5 year ago, but being very prominent in data being collected right now. I think this issue should be listed in the paper, and the potential users should be explained what the current best idea of what this is, and any advice as to how we can control for it. Also note the timeline for correction. For example regarding 2& 3, today as I write this review you can see the sharp change along the meridian in western Africa https://landweb.modaps.eosdis.nasa.gov/browse/images/006/Both/MCD19A2-AOT/2018/A2018191/MCD19A2-AOT.A2018191.006.full.png. You can also see optical model change from land to water and scan lines as well. These spatially correlated errors might need a paragraph of discussion or two. But they are pretty common-just pick any day in the past few years and you will see them popping up. https://landweb.modaps.eosdis.nasa.gov/cgi-bin/browse/browseMODIS.cgi

- There are two different issues related to the question you raise. The first one is the global browse images of AOD in the MODAPS which are designed to show a qualitative global view of aerosol, but were never optimized for the science use. Currently, the browse algorithm sim-ply takes one of the sensors (Terra or Aqua) as the baseline, and fills-in the gaps (e.g. caused by clouds or glint over water) with the data from MODIS on the other platform (or other orbits disregarding the time difference). Due to the time difference between the orbits, in case of significant aerosol events (like dust storms over Sahara), such a straightforward approach will inevitably create boundaries clearly seen on the shown image. Since the nature of such “boundaries” is generic, one can easily find them for the earlier years before 2014, e.g. DOY 233, 242, 258 of 2010 for the Saharan coast of West Africa (the same tile). At the same time, the data from individual sensors are smooth. For instance, below we show the same image you provided as an example, followed by MAIAC retrievals for 2 tiles h16v06 and h17v06 for MODIS Terra and Aqua separately (indicated by letter A or T at the end of the time stamp provided on the images). The AOD scale for all images is the same, 0-2. For the tile h16v06 we have one orbit from Terra and 2 orbits from Aqua, the last two separated by 1h25m. AOD from Terra at 11:50 and from earlier Aqua 13:30 are consistent, although AOD from the second Aqua overpass is significantly lower over land.

Figure

The second issue, which is indeed important, is related to the calibration updates of MODIS sensors. The current MODIS calibration approach (Lyapustin et al., 2014b) consists of time-dependent 1) response-vs-scan angle (RVS) correction by the MODIS Calibration Support Team (MCST); 2) polarization sensitivity correction of MODIS Terra by the NASA GSFC Ocean Biology Processing group (OBPG), and 3) residual de-trending and Terra to Aqua cross-calibration by my group. Last time, all three were consistently updated in 2013. Since that time, only RVS was updated; as a result, continued MODIS Terra degradation increases in latest years seen as striping and growing bias on the left-hand side of the scan in AOD images. The latter (bias) shows now consistently at low amplitude mostly over bright surfaces in the combined AOD browse images, which you are mentioning.

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Some hints of striping are now apparent in MAIAC AOD from MODIS Aqua as well. MCST, OBPG and our group have updated MODIS Terra and Aqua calibration in late 2017-early 2018, and it is now in testing at MODAPS. It will be implemented in MODIS Collection 6.1 Land Discipline re-processing (which includes MAIAC) scheduled for the second half of 2018. We expect a significant reduction of the discussed artifacts in MAIAC C6.1.

The above discussion was summarized and added to the "Known Issues and Limitations" section: Since 2014, when MODIS Terra/Aqua calibration was consistently updated (Lyapustin et al., 2014b), the continued calibration degradation of MODIS Terra increasingly shows in MAIAC AOD as striping artefacts and positive bias at left-hand side of the MODIS scan mostly over bright surfaces. The MODIS calibration was recently updated. It will be implemented in MODIS Collection 6.1 Land Discipline re-processing (which includes MAIAC) scheduled for the second half of 2018. We expect a significant reduction of mentioned errors in MAIAC C6.1 AOD.

Please also note the supplement to this comment:
https://www.atmos-meas-tech-discuss.net/amt-2018-141/amt-2018-141-AC2-supplement.pdf

Interactive comment on Atmos. Meas. Tech. Discuss., doi:10.5194/amt-2018-141, 2018.

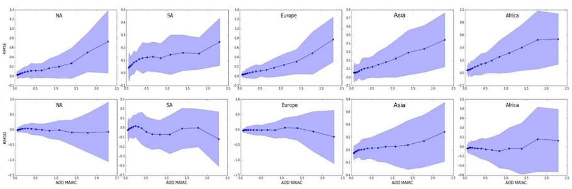

Figure 8. Absolute error (*rmse*, top row) and bias (*rmsd*, bottom row) of MAIAC AOD for different world regions as a function of retrieved AOD. NA and SA stand for the North and South America, respectively.

Fig. 1.

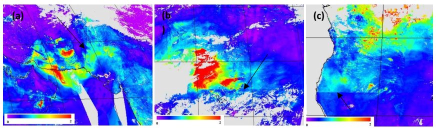

Figure 9. Illustration of MAIAC AOD contrast on the boundary of aerosol models (see Fig. 4) caused mainly by the difference in aerosol absorption between the models: (a) transition 8-2 (day 82, 2010); (b) transition 7-6 (day 113, 2010); (c) transition 7-2 (day 237, 2010).

Fig. 2.

Regions	*rmse*		σ_{rmse}	
	a	*b*	α	β
NA	0.034	0.13	0.049	0.20
SA	0.049	0.063	0.083	0.041
Asia	0.057	0.13	0.083	0.12
Europe	0.035	0.15	0.055	0.18
Africa	0.049	0.21	0.087	0.17
Australia	0.05	0.088	0.094	0.08
Regions	*rmsd*		σ_{rmsd}	
	a	*b*	α	β
NA	-0.0081	-0.0034	0.031	0.31
SA	-0.017	0.0065	0.11	0.07
Asia	-0.040	0.067	0.092	0.18
Europe	-0.019	-0.021	0.031	0.33
Africa	-0.0056	-0.028	0.088	0.30
Australia	-0.0076	0.085	0.15	0.11

Table 5. Regional linear regression model parameters for the expected error (*rmse*) and bias (*rmsd*).

Fig. 3.

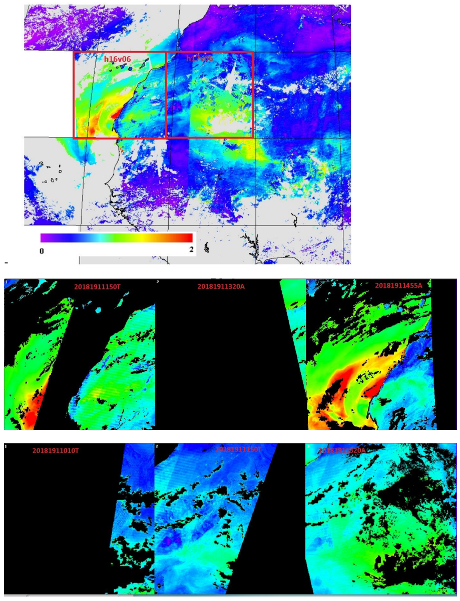
h16v06
0
2
1
20181911150T
2
20181911320A
3
20181911455A
1
20181911010T
2
20181911150T
3
20181911320A

Fig. 4.