

ANSWERES TO THE REVIEWERS:

“Comparison of aerosol optical depth from satellite (MODIS), Sun photometer and pyrhelimeter ground-based measurements in Cuba” by

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Anonymous Referee #2

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This manuscript focuses on the comparison of aerosol optical depth (AOD) retrieved using satellite (MODIS) and ground-based instruments (sun photometer and pyrhelimeter) in Cuba. This study draws conclusions about the different MODIS aerosol algorithms (Dark target and Deep Blue) for deriving aerosols on oceans and land, as well as, the distinct retrievals between the different sensors onboard Terra and Aqua platforms.

An interesting aspect of this paper is the potential to use pyrhelimeter measurements as a reliable source for aerosol characterization in the absence of sun photometer data, allowing for the reconstruction of AOD time series under such circumstances. It is a notable contribution to extend the existing AOD series in the Caribbean region, a key zone for studying dust transport.

However, the paper needs major modifications before being published.

GENERAL COMMENTS:

- The use of English is poor. I would strongly encourage the authors to have the paper checked by a native English speaker. There quite a lot of grammar problems, mistakes with figure numbers and general imprecisions which make the paper quite difficult to read and understand.

Answer: The manuscript has been revised extensively by a Professional Translator of English native language. Apart, as recommended the paper has been modified considerably in order to be improved scientifically, mainly in the section of results. Also the objective of the paper is clearly exposed.

- From the information given in the introduction, I understand there are no previous studies in scientific journals about the AOD series extracted from the Camagüey sun photometer, and in Cuba in general. If so, the AOD series presented in Figure 4 (a) is the first AOD series derived from sun photometry published in Cuba, and not enough discussion has been carried out on this important result. On the contrary, notable efforts have been devoted to the superficial and less interesting discussion on the AOD extracted from MODIS. Under this circumstance, a non-existing AOD time series can hardly be extended backwards in time, as is stated in both the Abstract and in the Introduction alike. I strongly recommend the authors reconsider the objective of this publication, placing emphasis on the AOD retrieval by the sun photometer and the Broadband AOD (BAOD) from the pyrhelimeter (both at Camagüey). MODIS comparison should be used once the complete AOD series in Cuba has been published and evaluated.

Answer: AOD data series by sunphotometer will be reported in future publication and here we report the climatology given by MODIS and its comparison with the others two series of BAOD and Photometer. The article is already long enough and it is focus on MODIS data, not on the characteristics of the other time series of data, but they serve for an interesting and necessary comparison. **See also the answers below.**

The systematic lack of high-impact references in the manuscript is very concerning. Despite the fact there are published few papers in the literature aimed at the aerosol characterization in Cuba, there are many examples at other sites around the world to enrich the methodology and the discussion section as well. A reader could have the impression that this type of analysis has been only performed in Cuba.

Answer: Some more references concerning MODIS (or other sensors) aerosol studies in different

areas of the world have been now added in the manuscripts (i.e., Papadimas et al., 2009; Mishchenko, et al., 2010; Kahn et al., 2011; Bennouna et al., 2011, 2013; Witte et al., 2011; Gkikas et al., 2013; 2015; Levy et al., 2015). We have experience in this type of studies/analysis as can be seen by other published works for aerosol studies (Bennouna et al., 2011; 2013) or by other atmospheric components as water vapor (Vaquero-Martinez et al., 2017, <http://dx.doi.org/10.1016/j.jag.2017.07.008>; Vaquero-Martinez et al., 2018; <http://dx.doi.org/10.1016/j.rse.2017.09.028>). To our knowledge few studies or none have been made considering two criteria, two algorithms <http://dx.doi.org/10.1016/j.rse.2017.09.028> and two platforms, giving sometimes complicate patterns of comparisons between all these different cases or situations. The authors have not found any other comparison between MODIS and sun photometers in the Caribbean and only two conducted on islands at different latitudes and regions. This has been discussed at the end of Section 3.1.

- Despite being the most relevant contribution to the paper, the pyrheliometer description is missing. Therefore, please include at least some information about pyrheliometers spectral response, field of view (FOV) and calibration.
- Apparently, four pyrheliometers have been used in this study. However, only one of them (the one at Camagüey) has been used in the discussion. Please clarify the source of these discrepancies. If these three instruments don't provide reliable results, please do not include any mention of them in the paper.

Corrected: In answer to the two comments above the paragraph was erased and replaced by the section: “2.3.1 Direct normal irradiance measurements.” where the pyrheliometers used in Cuban stations are described and the process of manual measurements and computerized processing are briefly described, pointing to the appropriated references. Also the information about the pyrheliometer FOV and its estimated level of error are provided.

In addition the term “pyrheliometer” was replaced in the paper by “broadband pyrheliometer”

- Is the inclusion of single measurements in the discussion section really important? Personally, I am quite confused with the results section. Reducing the amount of approaches will improve the readability of the paper considerably.

Answer: The purpose of the comparison in this case is to test if single observations could be used for the determination of the aerosols climatology over land in Cuba

A new version of Figure 1 has been included to highlight the reasons for using L2 MODIS data instead L3. The sentence “The grid cell of 1° in latitude and longitude shown in red in figure 1 is an example of the limitations of the MODIS L3 products to represent land areas in the case of Cuba.” has been included on the 1st paragraph of the Section “2.4 Coincidence criteria for MODIS and Sun photometer measurements.”

We also rewrote the first paragraph of section: “2.4 Coincidence criteria for MODIS and Sun photometer measurements: “

- As I mentioned previously, the FOV of the pyrheliometer used in the present study is missing in the text but it is expected to be significantly different to the FOV of the sun photometer. Please include discussion on how to reconcile the two different pieces of information and the possible impact of the scattering radiation effect on pyrheliometer measurements as a result of the wider FOV.

Answer: The pyrheliometer FOV was included in the text. A paragraph was added at the end of section 2.3.2 describing the effect of the circumsolar radiation and our decision of not using DNI observations for the large solar zenith angles.

- The BAOD retrieval method is not described adequately. Equations and information about how the different terms have been calculated need to be included. García et al. (2015) is not an appropriate reference in this context.

Corrected: The reference (Garcia et al., 2015) was erased. The section “2.3.2 BOAD retrieval method.” Was included in the text. It describes the main retrieval equation and the parameterized variables. In addition, the main assumptions are described. The reader is referred to the original paper for details on the methods origin and assumptions.

Regarding the BAOD uncertainty estimation, if we look at the methodology presented in Gueymard et al. (1998), the total uncertainty in BAOD can conceptually be evaluated taking into account three sources of error (modelling, atmospheric inputs and experimental errors). I strongly suggest the authors perform a more rigorous estimation

of the BAOD uncertainty.

Answer: According to table 3 in Gueymard, (1998) for PW = 5 cm with an error of $\pm 20\%$ in the PW value, the magnitude of the possible absolute error in BAOD is between 0.0145 and 0.0325. The first value is estimated for an instrumental error of $\pm 0.5\%$ and the second for $\pm 3\%$.

We used PW from sunphotometer at Camagüey because of its lower error than PW from reanalysis data. At the other 3 sites we have only PW from reanalysis data. The differences between monthly mean PW from sun photometer and reanalysis at Camagüey (estimated for 2008 to 2015) are in the order of 1% for the wet season (November to April) and 8% in the rainy season (May to October). Then the magnitudes of the possible error in BAOD produced by the PW differences between the sun photometer and the reanalysis are inside the estimated total error in the determination of the BAOD, 10^{-2} .

SPECIFIC COMMENTS:

P2, Abstract: Please quantify the main results including some numbers in the Abstract.

Corrected: The abstract was rewritten including more details and numerical values.

P3, .57: Is the small mass of aerosols an important issue related to the role of atmospheric constituents in weather and climate?

Corrected: The reviewer is right; the aerosols mass is not relevant for the research described in the paper. The sentence has been changed to ... "Atmospheric aerosols play an important role in weather and climate."

P3, . 78: Antuña-Marrero et al. (2016) does not seem an adequate reference.

Answer: We consider that is an adequate reference because it describes the aerosol research conducted at Camaguey. Nevertheless, we added the URL <http://www.goac.cu/uva/> to provide additional information on this subject.

P5, .117-123: I think this MODIS calculus chain is not relevant in this manuscript.

Answer: In the author's opinion, considering the broad and diverse audience of this journal, at least a simple explanation of the MODIS calculus chain is necessary.

P5, .129-131: This information is missing in the Introduction and would be better in the introductory part.

Corrected: The following sentence was modified and moved to the introduction: "We used the combination of both Terra and Aqua and DB and DT algorithms to evaluate the reliability of the satellite AOD and AE retrievals for selecting the most appropriate data set to derive the climatology of both aerosol parameters in Cuba."

P6, .140-147: It does not seem relevant to me for this study.

Corrected: The sentence was erased. The following was modified: "The Camagüey sun photometer, installed under an agreement between the University of Valladolid (UVA), Spain, and the Meteorological Institute of Cuba (INSMET) for joint aerosols research, contributes to the Aerosol Robotic Network (AERONET) of NASA (Antuña et al., 2012)".

P6, .148-155: Information about sun photometer nominal wavelengths is required.

Corrected: The following sentence was added: "In general, Cimel sun photometers nominal wavelengths are 340, 380, 440, 500, 675, 870, 935, 1020 and 1640 nm. In some cases, the 1640 nm is replaced by a 1240 nm."

P6, .159: Please refer to Angstrom Law and reference this law accordingly.

Corrected. The sentence is now: "Applying the Ångström power law we converted the single sun photometer AOD measurements at 500 nm wavelength to AOD at 550nm, (AOD_{SP}) making use of the AE_{SP} from the same measurement."

P6. L. 159: Please, include in this section the information required about PWV calculation using the sun photometer.

Answer: We consider it is not necessary to include in the paper the information required about PWV calculation using the sun photometer. We neither include information on how reanalysis derives PWV. The PWV is used to derive the BAOD it is not subject of the comparison. References are provided.

P6. I. 161: Please, clarify the method and include equations as well.

Corrected: The section "2.3.2 BOAD retrieval method." Was included in the text. It describes the main retrieval equation and the parameterized variables. In addition, the main

assumptions are described. The reader is referred to the original paper for details on the methods origin and assumptions.

P7. I. 167: What does “That-free” mean? Is it a typo?

Corrected. The sentence is now: *“The cloud-free condition in the line of sight to the sun is satisfied selecting DNI measurements with a clear line of sight between the pyrheliometer and a region of 5° around the sun (GOAC, 2010).”*

P7, .179-183: This is not the place to describe the PWV retrieval using sun photometry. In addition, García et al. (2015) does not seem an adequate reference for this methodology.

Answer: We are sorry but we do not agree with this comment. This is the right place for this explanation, because we are describing how we derived the PWV to be used in the algorithm described by Gueymard (1998) to derive BAOD. We already did this as it is described in García et al. (2015)

P7, . 182: Is Barja et al. (2015) the only reference for this type of analysis?

Answer: Yes, it is the only reference about deriving PWV from reanalysis for Cuba. It includes a comparison of those PWV with the ones measured by sun photometer and GPS at Camagüey.

P7, . 182-183: Gueymard et al. (1998) pointed to instrumental errors and PWV estimation as the main limiting factors of this method. So, the uncertainty of this type of methodology is linked to the uncertainty on these factors. Please include details on these sources of error.

Answer: According to table 3 in Gueymard, (1998) for PW = 5 cm with an error of $\pm 20\%$ in the PW value, the magnitude of the possible absolute error in BAOD is between 0.0145 and 0.0325 . The first value is estimated for an instrumental error of $\pm 0.5\%$ and the second for $\pm 3\%$.

We used PW from sun photometer at Camagüey because of its lower error than PW from reanalysis data. At the other 3 sites we have only PW from reanalysis data. The differences between monthly mean PW from sun photometer and reanalysis at Camagüey (estimated for 2008 to 2015) are in the order of 1% for the wet season (November to April) and 8% in the rainy season (May to October). Then the magnitudes of the possible error in BAOD produced by the PW differences between the sun photometer and the reanalysis are inside the estimated total error in the determination of the BAOD, 10^{-2} .

P7, . 185-187: It sounds better in the Introduction. Take into account that many references in the literature using the MODIS Level 2 in these types of comparisons exist. Please remove this sentence.

Corrected: The sentence “.In response to it, we used the MODIS L2 product instead of L3 used commonly for this type of studies.” Has been erased.

We consider the paragraph should remain in this section. In addition, we modified the whole paragraph to express clearly the goals we pursue: *“Obtaining enough satellite measurements for climatological studies at insular states represent a challenge with respect to the typical amount of data available over continental regions, like US, Europe and China for example. The reason in general is the little areal extension of islands. In addition, in the case of Cuba its particular narrow latitudinal, elongated longitudinal extensions and the vicinity of the sea makes the MODIS L3 product not suitable for climatological studies. In response to it, we plan to use the MODIS L2 product to produce the aerosols climatology for Cuba instead of L3 used commonly for this type of studies. In that sense is absolutely necessary to validate the single MODIS L2 with the single sun photometer measurements.”*

P8, . 208: Why these two periods?

Corrected: There was a typo regarding the first period. It is 2001-2015 and not 2011-2015; it was corrected. The sentence was rewritten for clarity: *“It shows the amount of data available or the entire period 2001 to 2015, when pyrheliometer measurements at Camagüey are available and 2008 to 2014, the period of the available sun photometer measurements.”*

P12, . 315-319: What about the maximum in summer?

Answer: We added the description of the statistics for the summer: *“In summer, RMSE and MAE show their maximum values associated to the maximum values of the AOD resulting from the arrival of Saharan dust to Cuba transported across the Atlantic. The BIAS is negative in summer for both Terra and Aqua AOD, showing the fact that AODt and AODa measurements have higher magnitudes than AODSP.”*

P12, . 315-323: Figure 3 > Figure 4? Please revise figure numbers and table captions.

Corrected: The captions were corrected and the figure revised.

P. 17, . 461: This is not a reference but an URL.

Corrected: The URL was referred directly in the text and eliminated from the reference list.

Figures 3 and 6: Please add diagonal lines. I also suggest including some statistics in the figures. Mixing tables and figures could help to improve comprehension.

Corrected. Figures 3 and 6 contains now the density plots. The least squares linear fit is also shown and drawn, together with the number of cases.