Author's response to:
RC#1 and RC#2 of Anonymous Referee #1 and #2
https://doi.org/10.5194/acp-2021-517-RC1;
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Jonas Witthuhn[1], Anja Hünerbein[1], Florian Filipitsch[2], Stefan Wacker[2], Stefanie Meilinger[3], and Hartwig Deneke[1]

[1]Leibniz Institute of Tropospheric Research (TROPOS), Leipzig, Germany
[2]German Weather Service (DWD), Meteorological Observatory Lindenberg, Tauche, Germany
[3]University of Applied Sciences Bonn-Rhein-Sieg, Sankt Augustin, Germany

Correspondence: Jonas Witthuhn (jonas.witthuhn@tropos.de)

Dear Referee #1 and Referee #2,

Thank you for carefully reading the manuscript and pointing out numerous technical corrections. The requested clarifications and references to ambiguities have also contributed to the improvement of the manuscript.

In order to separate the reviewer's comments and the author's response, we printed the comments in black and the response in blue.

Sincerely, on behalf of all authors

Jonas Witthuhn

Changes done to the manuscript:

- Technical corrections according to RC#1 and RC#2.
- Minor changes to improve wording and grammar.
- Figure 2: Revision and clarification of figure caption.
- Figure 7 and A4 to A7: Revised to improve readability.
- Figure (new) A1: added CAMS RA vs AERONET comparison for 2015.
- Table (new) A3: added new Table showing the percentage of days to be interpolated for the analysis in Sect.4.2.3.
- Sect. 2.3: Added clarification of used AERONET products.
- Sect. 3.3.2: added explanation of CAMS RA REari adjustment for the comparison to CSM derived REari and references to this explanation in Sect. 4.2.3.
- Sect. 4.1.1: Added description of how SSA at 550nm is calculated for the AERONET product.
- Sect. 4.2.1: Extended discussions about results with the Solis simple model.
- Sect. 4.2.2: Added possible explanations on the evaluation of simulated and measured DNI.
- Sect. 4.2.2: Added clarification on the explanation of Eq.(7)

Response to RC#1 of Referee #1:

We have added technical corrections suggested by Referee #1:

- L49: "spent" instead of "spend"
- L183: "analyses" instead of "analysis"
- L310: Delete “also”
- L395: “a RMSE” instead of “an RMSE”
- L490: “are” instead of “is”
- Tab 4: Please move the Table to section 4.2.2
  - In the latex document, the Table is already placed in the requested section. This issue might be resolved during final typesetting of the manuscript.
- L548: “irradiances” instead of “irradiance”
- Tab 5: Define the symbols for mean values (e.g., is he average for)
  - We added: "Annual average values are represented by an over-line".
- L599: “show” instead of “shows”
- Fig 7 and Tab 8: should be moved to the following section.
  - Again, the correct placement of the figures and tables will hopefully be resolved in the final typesetting.
- L617: “METSTAT” instead of “MESTAT”
- L643: “models” instead of “model”
- L673: Delete “models”
- Fig 10: “a station” instead of “an station”
- L684: “show” instead of “shows”
- L735: “in 2015”
- L739: Delete “in”
- L743: “means” instead of “mean”

– L835: “the use of simulations based on explicit radiative transfer simulations”: please rephrase

Thank you for pointing these corrections out. We have corrected the manuscript accordingly.

Apart from many technical corrections, Referee #1 pointed out some ambiguities and asked for comments from the authors. These comments are answered below:

– *L167: Have the authors used the Level 2 AERONET product?*

- Yes, the level 2.0 (quality assured) data is used in case of AOD and AE. For the inversion products, SSA and ASY, we had to fall back to level 1.5 (cloud-screened and quality controlled) data, as level 2.0 data was only available to a limited extent. In any case, the AERONET Version 3 database is used. We have improved the description of the used AERONET datasets accordingly.

– *L169: Do the authors refer to standard or to expanded uncertainty?*

- The uncertainties of SSA and ASY refer to the U27 lookup table results. These are provided with in the ancillary data of uncertainty estimates for each product and refer to one standard deviation. In the manuscript, we now use the term "standard uncertainty".

– *L384: Given that the AOD values are low over Germany, the authors have possibly used the Level 1.5 AERONET inversion products (which should be specified here).*

- Yes, this is correct. We now have added a statement about the used product level.

– *L488: In the case of MBE the AOD uncertainty is less significant than the AE uncertainty*

- We have rewritten this sentence accordingly: "For irradiance and REari, the major contribution to the MBE is the SSA uncertainty, and to the RMSE the AOD and SSA uncertainty of CAMS RA."

– *Table 3: It looks that the performance of the Solis simple model is generally better than that of the other models (at least regarding MBE and RMSE). Please comment.*

- "The Solis simple model is based on explicit radiative transfer simulations for selected situations." These include simulations with an AOD value of 0. Therefore, it is not surprising that ecRad and Solis simple agree well under pristine conditions (AOD=0). All other CSMs do not explicitly include a pristine case as implemented in Solis simple. "They are mostly optimized to represent the measured irradiance under natural conditions, which of course always contain some aerosol content." The explanation in Sect. 4.2.1 on this topic has been extended accordingly.

– *L565: Can the authors assume why the best agreement is found for the referred cases?*

- "These results can be explained for several reasons. First, the stronger solar radiation and the more absorbing aerosol in spring and summer lead to a mitigation of the systematic errors in the simulations (e.g. overestimation of absorption by

CAMS RA) and measurements. In addition, larger AOD values are observed in spring and summer and at more northerly stations, which reduces the deviations due to random errors. Furthermore, the input data of CAMS RA are collocated and altitude-corrected for this comparison, and the uncertainties of this method are larger over complex terrain and mountains towards the south. However, the differences in the various selection criteria are very small, so these are only hypotheses." This explanation has been appended to the manuscript.

– *L570: "except for winter and fall seasons". Any possible explanation?*

- "This could be due to the lower absorption properties of aerosol in winter and fall and generally lower AOD values in these seasons. Reduced absorption by aerosols leads to increased deviations due to overestimation of absorption in CAMS RA. Lower AOD values also mean a weaker radiation effect, making the simulation more prone to random errors." This explanation has been added to the manuscript.

– *L612 – 613: "To avoid ... surface albedo". I did not understand what the authors did here.*

- The default simulation using T–CARS rely entirely on the input data of the CAMS RA. This includes also the surface albedo. On the other hand, simulations done with the CSM purposely avoiding CAMS RA as input source and thus the high resolution surface albedo data form LSA SAF is used here. However, "for the comparison of surface REari to AERONET and CSM based simulations, the REari from the CAMS RA input is adjusted to avoid inconsistencies of different surface albedo used for the calculations. As Eq. (1) can be reformulated at surface level using the surface albedo (α_{sfc}) by:

$$\Delta F_{\mathrm{sfc}} = (1 - \alpha_{\mathrm{sfc}})(F^{\downarrow}_{\mathrm{sfc,aer}} - F^{\downarrow}_{\mathrm{sfc,pri}}), \tag{1}$$

the adjusted CAMS RA REari ($\Delta F'$) is calculated as follows:

$$\Delta F' = \frac{1 - \alpha'_{\mathrm{sfc}}}{1 - \alpha_{\mathrm{sfc}}} \Delta F_{\mathrm{sfc}}, \tag{2}$$

where α'_{sfc} denotes the requested surface albedo of either AERONET or LSA SAF as used for CSM simulations." This explanation has been added to Sect. 3.3.2 and subsequent references has been added to part of the text Referee#1 is referring to.

Response to RC#2 of Referee #2:

- We have changed the manuscript according to this technical corrections:
  - L15. Assymetrie -> assymetry
  - L53 Please provide the full abbreviation for ECOWAS, since it is not widely known
  - 691 te -> the

– Figure 2. It needs a little clarification. Some stations are missing the red dot and it is not clear their spot (eg Helgoland). Also, the symbol for sunshine duration is not comprehensible. How much sunshine duration is enough to get the symbol?

- We now have ensured, that all station labels and their corresponding dots are visible. As indicated by the figure caption, the sunshine duration is only shown for DWD stations, as it is calculated from the measured irradiance. Therefore, no values of sunshine duration are shown for AERONET stations. We have clarified the figure caption accordingly: "Map of Germany showing the locations of DWD and AERONET stations. The sunshine duration is calculated from the measured irradiance data at the DWD stations and shown as accumulated hours for the year 2015. On the map ..."

– Paragraph 2.3 It should be clarified which level aeronet product is used in the study, since the uncertainties are different between lv 1.5 and lv 2.0.

- Yes, we have clarified the used product levels. We use lv 2.0 for AOD and AE and lv 1.5 for SSA and ASY. See also the reply tho RC1 (https://doi.org/10.5194/acp-2021-517-AC1)

– L237 For future studies, it would be interesting to have a more hybrid threshold, as a percentage of sunshine hours, in order to keep the day in the dataset. Since probably 2 hours in summer months it would not be representative, and at winter even smaller periods might be, specially for Northern Germany. For now I think it would be useful to show the percentage or number of days that fulfilled the criterion, at each station, in order to understand the representativeness of the conclusions.

- The number of days which, according to our criterion, are sufficient for the CSF is listed in Table 1. At L237 we added a reference to the Table.

– L289 Since AERONET inversion products have a large gap around noon, how this interpolation take place in that case?

- If the gap is larger than 90 minutes from the CAMS RA timestamp, then no valid pairing is found and the data of this timestamp is not considered in the comparison

– L364 The median value is from all data, per station or seasonal per station?

- Referring to Figure 3, the median value is shown for all AERONET data points of AOD, AE, SSA, or ASY. No seasonality or different stations are considered here.

– Paragraph 4.1.1. How AERONET SSA is transferred to 550nm? If it through interpolation, a higher uncertainty should be considered. Also, I think it is important to provide a statistic of how many cases are misconsidered, due to the CAMS RA cut off at 1.5 AE.

- The AERONET SSA is calculated using the inversion product. We are using the provided absorption AOD (AAOD) and extinction AOD at 440 nm and the absorption AE (AAE) and extinction AE to calculate AOD and AAOD at 550 nm using the Ångström relation (Eq.(2)). With this, the SSA is calculated by 1-(AAOD/AOD). Oppositely, the CAMS RA SSA is calculated at 550 nm from mass mixing ratios provided in the model level dataset using the aerosol optical properties' dataset. To test the influence of the AE cut off, we reproduced Figure 3 but excluding all data pairs (for SSA and ASY) of AERONET and CAMS RA if AERONET AE > 1.6. This reduces the number of datapoints for the comparison of SSA and ASY from 19132 to 11682, which means that approximately 40 % of cases are possibly influenced by this AE cut off. However, the results did not change much. For SSA, excluding cases of AE > 1.6, the RMSE increases from 0.07 to 0.08 (see Figure 1). In the manuscript we added the statement on how the AERONET SSA at 550 nm is derived and a possible higher uncertainty. Also, we added a sentence indicating that about 40% of cases are possibly influenced by the AE cut off.

– L397 I think that the explanation is not sufficient in order to consider the uncertainty of CAMS RA ASY. Relative error is more appropriate term for this quantity.

- We agree, but as this is not a relative quantity, we now use the term "standard error" instead of uncertainty.

– L399. I suggest to show these results in the Appendix, for the inclusiveness of the study.

- We have now added the results for the year 2015 as figure in the appendix. In the updated manuscript, this will be Fig. A1.

– L523 Linke turbidity is not widely known term. Please provide a definition.

- We now have added the following reference and definition to the Appendix section A2 and a corresponding reference at L523: "Louche et al. (1986), which defines the Linke turbidity as the ratio of the optical depth of the atmosphere to the optical depth of a pristine atmosphere, excluding aerosols and water vapour."

– L547 it should be explained in detail, why this inequality is the appropriate measure for the agreement.

- Here, the standard deviation of two predictions for the same observation are compared. As the reference data is the same for both predictions (pristine or with aerosols), the metric introduced in L547 is similar as comparing the coefficient of variation (relative standard deviation) of both estimates. Therefore, a lower relative standard deviation indicates a higher level of agreement of simulation and observation. As the simulation with aerosols is expected to show the higher level of agreement, the metric is defined in the way, that positive values of $\Delta\sigma$ indicate a better agreement if aerosols are considered. We agree, that the way Eq. (7) is introduced should be clarified. In the manuscript, we edited Eq. (7) to

$$\Delta\sigma = \sigma\left(F_{\mathrm{pri}} - F_{\mathrm{obs}}\right) - \sigma\left(F_{\mathrm{aer}} - F_{\mathrm{obs}}\right), \tag{3}$$

and in the text an explanation similar to this answer is added in the same paragraph.

– Figure 7 and 8. I guess, specially in winter, a lot of days have been interpolated, please provide some statistics about these cases.

- Yes, a lot of days had to be interpolated during the year and especially in winter to fill the gaps caused by cloudy days, which do not meet the CSF criterion. This is also indicated by Table 1, where the absolute number of days available for CSF are shown. We have now added Table A3 in the appendix, to show the relative number of days to be interpolated for the results in Sect. 4.2.3 (including Fig. 7 and 8). In the first paragraph of Sect. 4.2.3 we have added: "Note, numerous days had to be interpolated in order to fill the gaps in the CSM simulations caused by cloudy days which do not meet the CSF criteria (see Table 1 and Table A3).".

– Figure 11 I suggest to use a different color scheme, since it is difficult to see the differnces at the stations. Also use a larger font on the map.

- We agree, that for the annual mean values in Fig. 11 the color scheme could be spread out in order to enhance the visibility of details and comparison to observations at the stations. However, the color scheme is chosen to be fixed for Figures 11 and A4 to A7 in order to enhance the comparability of annual and seasonal means. Therefore, we would like to stick to the given color scheme for the revision of the manuscript. However, we increased the font size and station markers to improve the readability of the figures.

– Figure 12 Please explain how the classification of aerosols was made. It is nowhere to be found in the manuscript.

- The aerosol classification is taken from the CAMS RA dataset. We have integrated the mass fraction of each aerosol type, taken directly from the model level data (see Bozzo et al., 2020). In addition, we have combined all size bin limits in order to simplify the pie charts to 5 aerosol types.

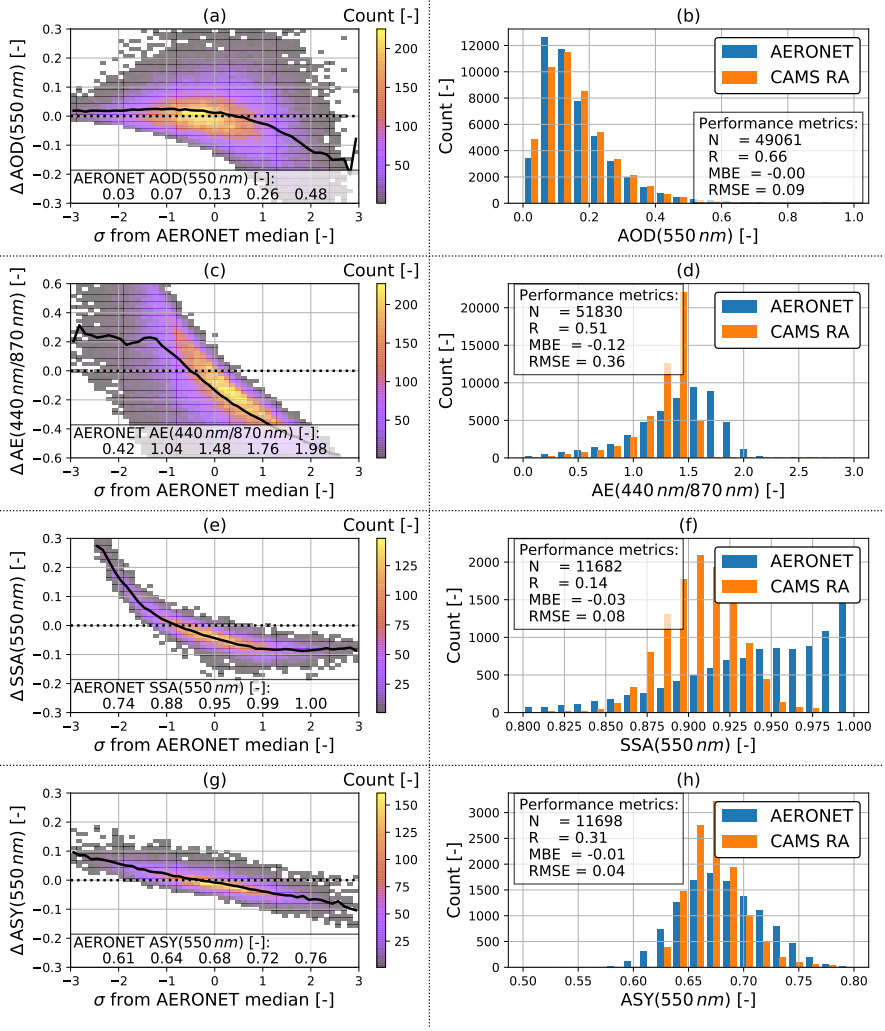

Figure 1. This figure is the same as Fig 03 in the manuscript, except, cases of AERONET AE>1.6 are dropped for the comparison of SSA and ASY. Although the cases possibly influenced by the AE cut off by CAMS RA are about 40% of the total dataset, the influence on SSA and ASY is minor.

References

Bozzo, A., Benedetti, A., Flemming, J., Kipling, Z., and Rémy, S.: An aerosol climatology for global models based on the tropospheric aerosol scheme in the Integrated Forecasting System of ECMWF, Geoscientific Model Development, 13, 1007–1034, https://doi.org/10.5194/gmd-13-1007-2020, 2020.

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