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Atmospheric Measurement Techniques Discussions

Interactive comment on "Evaluation of satellite-based aerosol datasets and the CAMS reanalysis over ocean utilizing shipborne reference observations" *by* Jonas Witthuhn et al.

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Dear Editor and Reviewers,

We thank the editor and the three reviewers for their detailed reviews and thoughtful suggestions. We largely agree with their comments and have tried to address their concerns in the revised paper. In the following text, we give a point-by-point reply to the reviewer's comments. If changes are given in the answers with line, figure or table numbers, those numbers refer to the discussion article. Also the latexdiff file highlights the changes between the discussion article and the revised manuscript.

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

We highly appreciate the detailed comments and suggestions, which have helped to improve the manuscript.

Sincerely, on behalf of all authors

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Overview of changes made to the manuscript:

- Sect. 1:
  - The first three paragraphs have been merged to provide a shorter and more comprehensive introduction about why spectral aerosol observations over ocean are necessary.
- Sect. 2.1:
  - Included short description of MAN Microtops measurement protocol.
  - Included note of calibration procedures for GUVis and Microtops.
  - Included note of post processing in the GUVis introduction and restructured segments.
  - Rephrased the COMB dataset description.
- Sect. 2.2:
  - Added the wavelengths of the MODIS aerosol product.
  - Added note about referring to *MxD04* (MODIS) or *SEV_AER-OC-L2* (SEVIRI) when writing about MODIS or SEVIRI aerosol products.
  - Added a note on the increased side-scatter effect of non-spherical particles.
- Sect. 2.3:
  - Question accuracy of CAMS RA AOD under cloudy sky conditions.
- Sect. 3.1:
  - Change the thresholds of the aerosol classification method as suggested by Stefan Kinne. This effects all figures and tables related to aerosol type by changing number of datapoints but do not change the main conclusions.

  - Emphasize that the presented aerosol classification is an estimate of the dominant aerosol type of the current (mixed) aerosol situation.
- Sect. 4.2:
  - This section receives a major rework to account for changes in aerosol classification and the presentation of the statistics in Table 5., as well as to avoid several repetitions.
  - Added a note about the incompleteness of the analysis of the AOD variation between MODIS overpasses, and the additional value of high temporal resolution observations from SEVIRI, since morning and evening hours with potential aerosol growth are omitted.
- Sect. 4.3:
  - This section receives a rework due to Tables 6 and 7 are omitted or merged to Table 5 in the revised paper.
- Sect. 5:
  - Added a sentence that it has been shown, that the bias of SEVIRI AOD is dependend on AOD.
  - Reworded the paragraph about benefits of SEVIRI temporal resolution to emphasize more the targeted applications such as studies about aerosol plumes or frontal zones.
- Table 2 is updated due to the changes made to the aerosol classification.
- Table 4 is updated since outliers are no longer omitted from the calculation of GUVisE.
- Table 5 receives a major update as suggested by Stefan Kinne.

  - Results are presented for the comparison to MIC only.
  - The table focuses on 550 nm only.
  - The table includes the information about aerosol type and in case of CAMS RA additional information with and without AATSR.
- Figure 1 shows all aerosol types.
- Figure 3 shows all aerosol types.
- Figure 4 and similar Figures: added solid lines to connect the median values of each bin for clearer visualisation of the change in bias with increasing wavelength.
- All figures and tables are updated after changing the aerosol classification as suggested by Stefan Kinne.
- Minor changes and corrections to wording, grammar and typos throughout the manuscript as suggested by the reviewers.

Response to RC1 from Referee #4:

The paper discusses aerosol optical depth observations from ships. The calibration and retrieval techniques for a shadowband radiometer are revised to improve agreement with simultaneous sun-photometer measurements, removing a fractional bias. The new dataset is used to evaluate products from the MODIS and SEVIRI sensors. The former is, unsurprisingly, found to be more precise, but both overestimate the Angstrom exponent, with SEVIRI being out by up to an order of magnitude. The CAMS aerosol reanalysis is similarly evaluated, finding it eliminates much of the bias in the underlying MODIS data.

The paper is suitable for publication in this journal. Current satellite retrievals show significant disagreement as to the average AOD over remote ocean and the data provided by this study should be invaliable in resolving that discrepancy. I hope the authors can place their data in a publicy available repository âĂŤ I am eager to use it in the evaluation of my own satellite products!

- Thank you for your recognition of the work in this paper. The processed data of all Polarstern cruises with the shadowband radiometer have been published at the PANAGEA data platform, where it can be freely accessed (without the need of a login): https://doi.pangaea.de/10.1594/PANGAEA.910535. We have also updated the link in the 'Data availability' section.

I have a few minor few comments that warrant the authors' attention:

- *Though I am fond of your analysis in Fig. 9, I disagree with the scope of your conclusions with respect to the information provided by SEVIRI.*
  - *By using the name of the sensor to refer to a specific dataset, you imply that your conclusions apply to all SEVIRI aerosol products. If one could produce*

a more accurate aerosol product from SEVIRI, that would provide useful information. You don't present sufficient evidence that all possible SEVIRI products provide minimal additional information.

- You are completely right. To be more specific, we have added the following text at the beginning of Sect.2.2 after the introduction of used satellite products: *"In the following text unless otherwise stated, the terms "MODIS aerosol products" or "MODIS retrieval" refer to the* MxD04_L2 *and* MxD04_3K *products, and similarly, the term "SEVIRI aerosol product" to the ICARE* SEV_AER-OC-L2 *aerosol product."*

– *Your wording is fairly definitive: 'only offer minor benefits compared to the use of polar-orbiting satellite platforms'. The circumstances where aerosol changes rapidly, such as plumes or the passing of a frontal system, are scientifically very interesting and exactly the sort of circumstances that geostationary imagery are absolutely vital in understanding. Geostationary observations might not add much to our understanding of the climatology of AOD, but this doesn't mean that they only provide minor benefits; they provide targeted benefits.*

- Thanks for pointing this out. We did not mean to disparage the value of geostationary measurements. As you have pointed out, this section was written with climatology studies in mind. To clarify this aspect, we have now reworded the paragraph in the conclusions section as follows: *"Hence, the better time resolution of SEVIRI and other geostationary satellite sensors offers minor benefits for climatological studies compared to the use of polar-orbiting satellite platforms, given its increased uncertainties. The SEVIRI AOD product provide valuable information on the temporal evolution of AOD when the aerosol changes rapidly. Specific cases with high temporal variability are dust storms, plumes of volcanic ash or the passing of frontal systems."*

– *You only evaluate the representivity of observations between the two MODIS overpasses. This omits the periods of boundary layer growth and collapse in the morning and evening, which current polar orbiting satellites do not observe.*

- That's indeed a limitation which deserves to be mentioned. For that reason, we have adopted your wording and added the following text at the end of Sect.4.2: *"We are aware that the analyses presented here do not provide a complete picture of the AOD variability over the full diurnal cycle. It was only possible to analyse the variability between daytime overpasses of MODIS. Continuous evaluation of the daily cycle of AOD are only possible with geostationary satellites such as SEVIRI."*

There is no need to perform additional analysis, but your conclusions should be reworded to be clearer about their breadth.

• *I am surprised by the repeated implications that laboratory lamp calibration is inadequate. Calibration in a controlled environment is usually held up as the gold standard of observational atmospheric science. Did the authors mean to imply that such calibrations are insufficient to produce a scientifically valid product(e.g. 'limited accuracy')?*
I would find that difficult to believe. I suspect what was meant is that there is an intrinsic difference between what a sun-photometer and shadowband radiometer measure. That limits the extent to which they could ever agree without additional correction methods, such as those outlined in this paper.

- You are right, the repeated use of the term 'lamp-based calibration' suggested that a calibration using a lamp was insufficient. This is indeed not true and not what we wanted to express in the text. Therefore we have removed the 'lamp-based' specification and now simply refer to 'calibration' in section 3.4 and 4.1. In

addition, we now give a short description of the calibration procedures of GUVis and Microtops in section 2. Nevertheless, several previous studies state that Langley-calibrations have a lower uncertainty than lamp-based calibartions. Hence, we think that it would be beneficial to also calibrate the GUVis instrument using the Langley-technique since this should lower the calibration uncertainty compared to a laboratory lamp-calibration (**??**).

- *I'm not convinced by the explanation in §4.2 of the narrow, highly biased observations of AOD ≃0.3 in Fig. 4 as I can't see why the choice of aerosol type would only affect one range of AODs. Are there an anomalously small number of collocations in those conditions or are they clustered in a small area? If you loosen your quality control conditions, does the distribution more closely resemble the typical behaviour?*

- Thanks to your comment, we recognize that the wording of these two paragraphs is misleading. We wanted to draw attention to the overestimation of satellite AOD during situations with low AOD values <0.4, where AOD ≃0.3. Panels (a) and (b) of Figure 4 show this overestimation most prominently. We referred to aerosol type with regards to GUVisE and COMB data, since both datasets consist mainly of cases with maritime and desert dust. Therefore the overestimation of AOD on the satellite side is strongly visible in panels (a) and (b) since we attribute it to limitation in the satellite retrivals, which requires parameterization of the surface reflection properties. We replaced these two paragraphs with the following text:
"*The SEVIRI retrieval shows an even stronger tendency to overestimate AOD in comparison to the MIC reference dataset. The bias of satellite AOD also shows a dependence on the magnitude of the AOD. A positive bias (overestimation) is mostly found in situations with AOD values below 0.5, and decreases for larger AOD. This behavior is most evident in Fig. 4 panel (a) and panel (b) as the reference datasets are GUVisE and COMB. A similar behavior also appears in the comparison to Microtops (panel (c)), although it is far less pronounced. Since the*

satellite instruments measure reflected radiance the reflecting properties of the ground used in the retrievals influence the retrieved AOD. Especially for clean atmosphere e.g. low AOD the influence of such parameters (e.g. surface albedo) is strong, since the values measured reflectance at TOA are close to the values of surface reflectance. For larger AOD values the uncertainty of those characterizations shrinks, therefore the overestimation of AOD decreases. Since GUVisE and COMB datasets contain more maritime and desert dust cases than the MIC, this behavior is strongly visible."

- *Are the outliers identified at page 11 (line 344) excluded from further analysis? That seems statistically suspect, as we expect large deviations to occur occasionally by random chance.*

- We indeed initially excluded outliers to produce the COMB dataset, where GUVis and MIC are combined. We saved the outliers for further analysis, but regarding the low number it does not change the results. You are right, the outliers should not be excluded for the regression to produce GUVisE. We have run the calculations again with included outliers. The results did not change much and do not affect our conclusions. You can check the differences by looking at Table 4 in the latexdiff file.

- *I found it strange that Fig. 1 implies that only maritime and dust aerosols were observed while Fig. 2 shows that mixed and continental were occasionally encountered as well.*

- In the discussion paper, we had restricted Fig.1 to show only maritime and desert dust, since the plot is already very crowded. Based on your comment, we have now updated Figure 1 to also show mixed and continental aerosol.

- *Fig. 7 is a compelling way to present the limitations in the retrieval of Angstrom exponent. In a future paper, it would be interesting to see a study of the impli-*

cations of your results on the Aerosol Index, which is widely used as a proxy for cloud condensation nuclei in studies of aerosol-cloud interactions.

- Thank you for this suggestion, a study considering the uncertainty of the AI would indeed be interesting.

- *At L540, is an increase from 0.90 to 0.92 really evidence of a 'clearly superior' product? That doesn't seem a particularly significant shift*

- We wanted to point out that CAMS RA performance is better than the performance of the SEVIRI product in all statistical measures considered here, even if 'clearly superior' might be misinterpreted to indicate a larger difference. We have now modified this sentence to: "*The CAMS RA outperforms the SERVIRI aerosol dataset in all presented statistical measures at least slightly (e.g., correlation 0.90 versus 0.92 or LOA of 0.13 versus 0.15).*"

- *On page 21, the EarthCARE lidar isn't itself that 'unique'. It's unique that said lidar is being flown collocated with an imager and radar.*

- An additional unique aspect is the high-spectral resolution lidar, which will be able to directly measure extinction, in contrast to CALIOP. We have now reworded the sentence as follows: "*The combination of both instruments on a single satellite and the use of a high-spectral resolution lidar enabling direct observations of the aerosol extincition at 355nm is a unique feature and will benefit scientific studies targeting aerosols including their radiative effects.*"

- *Your discussion about CAMS in §4.3 would be improved if you mention that the inputs to a reanalysis system must be bias corrected before input to ensure as table assimilation of the data. Hence, the reduction in bias is to be expected (but remains evidence of the utility of the CAMS product).*

- Thank you, we have now reworded the paragraph slightly to include this statement:
" *Further, the dependency of the bias on AOD reduced for the CAMS RA product as it shows low bias values for both low and high AOD values. This is expected since the MODIS AOD bias must be corrected before assimilation into the reanalysis product.*"

- *In Fig. 3, is the sharp transition from maritime to dust aerosol at 0.18 a true feature of your data (which would be concerning) or a feature of plotting the orange points over the blue ones? If the latter, perhaps add some transparency, so the transition is easier to see?*

- The points overlap only slightly, since the AOD on the x-axis is an average value. The sharp transition originates from the aerosol classification method we are using. Based on **?**, and the suggestions of Stefan Kinne (see reviewer comment RC3) we chose the following thresholds to identify aerosol types: maritime background (AOD < 0.15), mineral dust transport (AE < 0.5, AOD > 0.15), continental transport (AE > 1, AOD > 0.15), and mixed (0.5 < AE < 1, AOD > 0.15) type. Therefore, the sharp transition is a result of the method. We are aware that this empirical classification of aerosol type has limitations. While a better aerosol classification based on more complex methods could be developed, we content that for the purpose of our study, this simple empirical approach is sufficient.

- *In point (ii) of the appendix, you change the method for filtering perturbed observations. What motivated this choice? In undergraduate labs, I teach my students to throw out any observation for which the method was suspect as making a correction involves a number of assumptions. Why do you feel the need to keep some corrupted observations here?*

- We found that the former filter criterion was too strict in excluding data from the whole sweep. Since we are only interested in the direct irradiance, it is sufficient

to have good observations of the global irradiance before and after the sweep, and the moment when the shadowband fully shades the diffusor, and right before or after the shadow falls on the diffuser. A full sweep needs 40 seconds and during most of the time, the shadowband shades some part of the sky nowhere close to the sun. In the former (strict) filter method, the whole sweep was skipped if too large variations occured during a sweep. Now the algorithm focuses only on the relevant parts of the sweep (when the shadowband is close to the sun) to assess whether it should be skipped or not. We have found that this new filter works well for identifying perturbed scenarios while providing stable data even during short sunny periods.

I also include some technical comments and corrections. P1L2 means line 2 of page1.

- *P1L16 similar performances for both datasets*
- Done.
- *P2L39 e.g. from ships are available*
- Done.
- *P2L57 Does 'earth' need to be capitalized?*
- The AMT guidelines on capitalization leave the decision in particular for 'earth' to the authors, as long as it is consistent. So we leave it as is. Instead we corrected 'Earth' > 'earth' at L21, L31 and L33.
- *P3L79 complex, non-spherical shape*
- Done.

- *P4L109 These findings are understood in the context of the results found for the SEVIRI aerosol product to observe*
- Done.
- *P4L119 Add a space after the comma.*
- Done.
- *P4L124 are publicly available*
- Done.
- *P5L133 reference: the sunphotometer*
- Done.
- *P8L251 of $\pm$30min have been used*
- Done.
- *P9L257 distance angle less than 0.2°*
- Done.
- *P9L272 the analyses are*
- Done.
- *P10L303 Perhaps add 'to ensure the' after 'compensated for'? It means something slightly different but is what I think you meant to say here.*
- Done, thanks for the suggestion.
- *P12L373 Add a space after 'Table'.*

- Done.

- *P16L513 The wrong style of reference is used.*

- Done.

- *P16L518 I don't know what you meant to say by 'follow up'.*

- What is meant hear are overlapping pixels of MODIS images from consecutive Terra & Aqua scans. In the text we replaced 'follow up' with this description:
  "*To further investigate this point, MODIS collocations with the shipborne datasets are used to serve as random samples to study the AOD variability between successive overpasses. For each pixel of a MODIS image the corresponding SEVIRI AOD for every available SEVIRI image between overlapping MODIS images of consecutive Terra and Aqua overpasses was acquired to calculate the AOD variation.*"
  We did this also to other occurrences of 'follow up' in this paragraph.

- *P20L627 has channels only at*

- Done.

- *P20L640 products can provide a*

- Done.

- *P21L672 with the next few years collocated with an imager and radar.*

- Done.

- *Tab.5 collocated data points. Listed*

- Done.

- *Fig.1 The aerosol classification method*

- Done.

- *Fig.8 requirement for simultaneous . . . figure also shows CAMS RA*

- Done.

Please also note the supplement to this comment:
https://www.atmos-meas-tech-discuss.net/amt-2019-321/amt-2019-321-AC1-supplement.pdf

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