

Author's response to referee #3

You can find our response below each comment.

General comment about language.

We included another co-author, who assisted with a large number of corrections in terms of English grammar, syntax and expression.

The authors use many acronyms in the document. A table summarizing the acronyms and their definitions would be useful for the readers.

Added a table of acronyms in the supplement.

I also recommend that the authors should write a few lines (e.g., in the introduction) about the novelty and the usefulness of their study.

Added at the end of the introduction:

“In previous studies intercomparisons (eg Kazadzis et al., 2023), the study of AOD differences was limited to the differences of AOD provided by each network. In the present study, we also separate the effect of the calibration approaches and the effect of the post-processing and instrument differences. We also include one campaign at each location with a duration of several months, which provided a significantly larger amount of data compared to the shorter campaigns that are more frequently organized. Finally, we include a detailed analysis of the ILP calibration method in relation to the aerosol properties and its sensitivity to all required input parameters.”

L18: “The major”. Do the authors mean “The main”? Furthermore, while the authors write here that AOD uncertainties are mostly due to the calibration method, in lines 22-23 they write that they did not find any association between the calibration performance and the variability in aerosol properties. This is confusing.

Changed to “main”.

The following are 2 separate issues. One finding is that the AOD uncertainties are mostly due to the calibration differences. Another finding is that we did not find any association between the calibration performance and the variability in aerosol properties. Probably the second finding is not understandable without the context in the main text, so we removed this sentence.

L19: “Underestimation of AOD compared to GAW-PFR”. The AOD from which network?

This refers to the ESR AOD. Rephrased to “underestimation of ESR AOD compared to GAW-PFR”.

L20: “Underestimation in the ILP calibration”. What is underestimated?

This refers to the systematically lower calibration constant (extraterrestrial signal) retrieved by ILP compared to the transferred calibrations using the PFR as reference. Rephrased to:

“underestimation of the calibration constant calculated with the ILP method compared to the calibration transfers using PFR as reference”.

L23: “variability in” instead of “variability of”?

No longer applicable.

L28-29: “between ... calibrations”. Do the authors mean the AOD retrieved the two methods?

The sc-AOD retrieved by the two methods and the calibration constant each case leads to. Rephrased to:

“between the retrieved sc-AOD nor a systematic increase in the ILP derived calibration constant when using the MRI pack for sc-AOD inversion instead of the Skyrad 4.2”.

L31: “AOD retrieved using ILP” instead of “ILP”

This sentence refers to the calibration methods (ILP and standard Langley) not the AOD.

L40: The phrase “the major driver” is not correct. It should be either “the main driver” or “a major driver”.

Replaced with “the main driver”.

L43: Delete “a”.

Reformulated to:

“can lead to a significant forcing”

L47-48: “AOD is ... of aerosols”. Please rephrase.

Rephrased from:

“AOD is an indicator of the total aerosol load in the atmosphere and its spectral dependence with the size of aerosols.”

to:

“AOD describes the overall effect of the total aerosol column on the attenuation of solar radiation, and is correlated with the total aerosol load in the atmosphere and its spectral dependence with the size of aerosols.”

L63: “Due to the differences ...”. Differences in what?

The differences are described in the previous 6 sentences. Rephrased to:

“Due to the differences among the main networks (i.e., AERONET, GAW-PFR, SKYNET) described above”.

L66: “of all types” instead “from all types”.

Rephrased to:

“includes all types of sun photometers”.

L69: “that the instrument” instead of “the instrument”.

Corrected.

L70-73: Please re-write clearer. Furthermore, the next sentence (“The conventionally ... instruments”) repeats the same things that the authors write in lines 70-73.

Rephrased from:

“There are different ways to calibrate a sun photometer. It can be accomplished either by using a co-located instrument as a reference, by laboratory calibration to the international system of units (SI) and use of satellite measurements for the top-of-the atmosphere or by using an indirect method to calibrate the instrument through the DSI at the ground. The conventionally used methods are the standard Langley plot method (SLP) (Shaw et al., 1973) and the calibration transfer from a reference instrument.”

to:

“There are different ways to calibrate a sun photometer. Conventionally, they are calibrated by the standard Langley plot method (SLP) (Shaw et al., 1973) and the calibration transfer from a reference co-located instrument. An alternative method is the laboratory calibration to the international system of units (SI). Under this alternative approach, we can use satellite measurements for the top-of-the atmosphere irradiance that are also in SI units.”

L85: Replace “One of the main differences are” with “One of the main differences between ... is”.

Rephrased to:

“One of the main differences between GAW-PFR with AERONET and SKYNET is correction for absorption due to nitrogen dioxide (NO₂) and water vapor (H₂O)”.

L91: “a Memorandum of Understanding” instead of “and Memorandum of Understanding”

Corrected.

L96: “using both,” instead of “both with”.

No longer applicable.

L118: “centered at” instead of “centered on”?

Corrected.

L141: “or diffuse sky radiance” instead of “and diffuse sky radiance”

Corrected.

L226: “the difference ... 1-2 nm”. Is there any reference that can be used to support this statement? Can the authors explain why the difference can be up to 2 nm?.

This was based on the observed differences of the central wavelength between the nominal wavelength and the one taken from the characterisation of the PFRs and CIMELs (available in the AOD files of those instruments). We removed this sentence from the manuscript.

L235: “differ in” instead of “differ on”.

Corrected.

L253: Larger than what?

Larger than in Davos. Rephrased to “larger in Rome compared to Davos”.

L266: add “were used” after “retrievals”.

Rephrased “For the SSA the AERONET level 1.5 retrievals”

to

“For the SSA, we used the AERONET level 1.5 retrievals”.

L282: Is there any reference for Eq. 8?

This equation was not taken from a particular literature reference. It’s the standard equation used by ESR.

L292-293: The manuscript is not clear at this point. Do the authors mean that the TOC from OMI overpasses is used in the PFR algorithm?

Yes. Rephrased from:

“TOC is taken OMI overpass (aura_omi_l2ovp_omto3_v8.5 <https://acd-ext.gsfc.nasa.gov/anonftp/toms/omi/data/overpass/>)”

to:

“The TOC used in the PFR algorithm corresponds to the OMI satellite product (aura_omi_l2ovp_omto3_v8.5 <https://acd-ext.gsfc.nasa.gov/anonftp/toms/omi/data/overpass/>)”.

L332: “number of retrievals” instead of “retrievals”

Corrected.

L366: “11 and 3”: please be consistent with the numbering

Corrected.

L373: Delete in that case”

Deleted.

L375: Using the same numbering in the supplement and in the main text is confusing. Please change the format of the numbering in the figures and tables in the supplement (e.g., Fig. S1, Fig S2, ..., Table S1, ...).

Corrected.

L407: “due to” instead of “due”.

Corrected.

L412: Changes in the instruments' performance?

Yes. Rephrased to:

“instruments' response”.

L414: “An ... 870 nm”: Please rephrase.

Rephrased from:

“An estimation of the uncertainty magnitude is evident in the coefficient of variation (CV%) of the daily ILP calibrations per month (Campanelli et al., 2023 preprint table 2a) which are between 0.18%-2.87% at 500 and 870 nm.”

to:

“The coefficient of variation (CV%) of the daily ILP calibrations per month (Campanelli et al., 2023 table 2a) is an estimate of the ILP monthly calibration uncertainties. The CV% for the ILP calibrations used in this study range between 0.18%-2.87% at 500 and 870 nm.”

Figures 2-4: It would help to somehow show the months at which each box corresponds

Added the months in a second horizontal axis (upper part of the graph).

L460-461: Please rephrase.

Rephrased from:

“ILP assumes a constant SSA as the inverse slope the linear fit (section 2.2.1) and the refractive index pre-assigned to specific value which potentially reduces the accuracy of the method. Here we present the AERONET SSA values and variability between the months of the campaigns (Fig. 3) at 440 nm (green) and 870 nm (red).”

to:

“The ILP method assumes a constant SSA as the inverse slope of the linear fit (section 2.2.1) and uses an a-priori refractive index (selected by the operator). These assumptions potentially reduce the accuracy of the method. Here we present the SSA values provided by AERONET and their variability during the campaign months (Fig. 3) at 440 nm (green) and 870 nm (red).”

L467: “was found” instead of “in”.

Rephrased from:

“Similarly, in Davos the largest variability in during QUATRAM III (DAV21), which also exceeds the Rome SSA variability.”

to:

“Similarly, the largest variability is during QUATRAM III (DAV21) in Davos, which also exceeds the Rome SSA variability.”

L483: As an additional indicator?

Added “additional”.

L511: “for both locations” instead of “both locations”

Corrected.

L513-514: Delete “and”

Replaced (Sections and tables S8-S10) with (Tables S8-S10)

L561: “% difference” instead of “%difference”

Corrected.

L562: and the transferred calibration?

Yes, added “transferred”.

L572: Delete “be”.

Corrected.

L578: “At ... Rome”: Please rephrase.

Rephrased from:

“At 870 nm the difference remains at least for 0.95%

Davos and 1.7% for Rome.”

to:

“At 870 nm the difference is at least 0.95% for Davos and 1.7% for Rome for all SA values used as input.”

L582: “at 870 nm it is” instead of “at 870 nm”.

Rephrased to “at 870 nm, results are”.

L606: “that there is a” instead of “the significance of the”

The systematic bias of the ILP calibration was clear already earlier (AOD and monthly calibrations). Here we show to what extent this appears to the daily ILPs (1 or 2 per day). The significance refers to the frequency of the bias’ appearance in the daily data.

Deleted this short sentence from the manuscript.

L618: “and thus it may show” instead of “it may show”.

Replaced “it” with “and”.

L625: “-0.004” instead of “-004”?

Corrected.

L716: in the PFR performance?

Rephrased to “changes in the PFR response”.

L730: "is" instead of ".is"

Corrected.

Significant modifications not requested by this referee:

As a response to the general comments of another referee we changed the order of the sections to improve the readability of the manuscript.

The methodology and the results are no longer the separate sections 2 and 3. Section 2 will now include only the parts of the preprint section 2 up to section 2.2.2. Each part of methodology starting from the preprint section 2.3 (methodology of the different sub-studies), will be now followed by the corresponding results directly in the next sub-section.

The modifications are the Table R1 below. We show each section of the pre-print to which section will correspond of the revised manuscript.

Table R1: The difference between the structure of the manuscript between the preprint and the revised version.

Preprint sections	Revised sections	Comments	Subject
2.3	3	3.1 methodology, 3.2 Results	Intercomparisons
3.1.1	3.2.1	-	Intercomparisons of AOD for different calibrations
3.1.2	3.2.2	-	Uncertainties
2.4	4	-	ILP error sources
2.4.1	4.1	4.1.1 methodology 4.1.2 results	Aerosol properties
3.2.1	4.1.2	-	Aerosol properties-results
3.2.2	4.1.2.1	-	AOD
3.2.3	4.1.2.2	-	SSA
3.2.4	4.1.2.3	-	AE
2.4.2	4.2	4.2.1, 4.2.2 and 4.2.3 the 3 sensitivity sub-studies. 4.2.1.1, 4.2.2.1 and 4.2.3.1 the methodology of each, previously merged in section 2.4.2. Added "Sub-study 1,2 or 3: in the corresponding titles (including the result sections below).	Sensitivity of ILP to input parameters
3.2.2.1	4.2.1.2	-	Results: Test one input as variable per case
3.2.2.2	4.2.2.2	-	Results: All input parameters variables
3.2.2.3	4.2.3.2	-	Results: Sensitivity tests

2.4.3	4.3	4.3.1 methodology 4.3.2 results	AOD and sc-AOD from sky radiance measurements
3.2.3	4.3.2	-	Results: AOD and sc-AOD from sky radiance measurements
4	5	-	Discussion
5	6	-	Conclusions

We also removed some sentences from the results and discussion that are not included in the minor comments of any referee to reduce the amount of information presented and fit the new format.

List of the deleted sentences:

- 1) 1.: 34 “In the following sections we report on results on the AOD retrievals of several instruments in different environments using different principles in their calibration methods. We also perform an investigation to explain the causes of differences.”
- 2) 1. 94: “During the period 2017-2021 a PFR was transported to Sapienza University in Rome, Italy once for each campaign for several weeks or months to measure AOD in parallel with one or more POMs and CIMEL (Table 1). Also, at least one POM was transported to Davos on 3 different periods as well (Table 1), where the WMO AOD reference (PFR-Triad) and a CIMEL are operated. The POMs were calibrated both with the ILP method and by calibration transfer using a PFR as a reference. There is already a publication under review showing calibration differences between several calibration methods (Campanelli et al., 2023).“ (added the period 2017-2021 to the previous sentence)
- 3) 1.:362 “Most of the times in the case of calibration transfer the median difference remains negative, but there are exceptions”
- 4) 1.:434 “As shown in section 3.1.1 the ESR dataset shows a systematic AOD underestimation compared to GAW-PFR and AERONET due to an underestimation in the calibration from the ILP method. However, this calibration difference varies significantly between the two locations and from month to month. Using the methods described in section 2.4 we attempted to explain why this underestimation happens and why it is systematically larger for Rome.”
- 5) 1.: 439 “Here we investigate whether there is any systematic difference between Davos and Rome on AOD, SSA and AE values or variability that could potentially be associated with the larger calibration differences in Rome for all months. We use AOD and AE from the PFR data during the half/full days of the ILP calibrations and SSA is from the AERONET data during the QUATRAM campaigns. We used monthly medians as the average level and monthly medians of the daily percentiles (5th,20th, 80th and 95th) as variability indicator as described in section 2.4.1.”
- 6) 1.:496 “As the available aerosol conditions during the campaigns show no indication of an explanation to the ILP underestimation and the differences between locations, we attempted to investigate the causes through a sensitivity study of the ILP. ILP uses six parameters as inputs: Real part of refractive index (RRI), Imaginary part of refractive index (IRI), Surface

albedo (SA), Total Ozone Column (TOC), Surface Pressure (P) and Solid View Angle (SVA). The first five are pre-selected and the last is provided by an in-situ calibration method. Therefore, there are discrepancies between the real atmospheric conditions under which the ILP is performed and the selected values.”

7) 1.:513 “Due to the small sensitivity at these three parameters, we do not include a more detailed analysis on them, but the comparisons are available in the supplement (sections and tables S8-S10). For the imaginary part of refractive index (IRI), surface albedo (SA) and solid view angle we observed cases of larger sensitivity.

In the Fig. 5-7 we can see the calibration differences between ILP runs and the calibration transfer from PFR for different conditions. The results correspond to the first sub-study described in section 2.4.2 where we study each parameter separately according to the observations of each site. The results correspond to all months of QUATRAM II.”

8) 1.:631 “Starting from the third column we show the median of all AOD differences, the percentage of differences within the WMO limits, the 5th and the 95th percentiles of AOD differences and the total number of measurements compared per location.”

9) 1.:638 “The sc-AOD median differences are negative at 500 nm and positive at 870 nm, which is in accordance with the sign of the calibration differences for most cases.”

10) 1.:686 “Also, in QUATRAM I (8/2017) the AOD at 500 nm is above 0.1, while in QUATRAM III (10/2021) below 0.05, but the calibration difference is smaller in QUATRAM I.”

11) 1.:717 “and changes in the instruments, but rather to the overall ILP uncertainty”