Manuscript: Preprint amt-2023-108

Title: The Langley Ratio method, a new approach for transferring photometer calibration from direct sun measurements

Response to Referee#2

The authors appreciate the generally positive response from Referee #2, and we would like to thank them for her/his constructive comments. Below, the Referee's suggestions (in bold) are addressed in detail (the authors' responses are provided below in blue).

This paper entitled present the Langley Ratio method for optimizing the calibration constants between two sun photometer that do not have the same spectral bands, although differences must be minimum. The method is great in advancing the optimization of sun-photometry, particularly between two different networks such as AERONET and GAW-PFR. Authors present the potentiality of the method and its applicability for detecting instrumental drifts. I recommend its publication, but before I have some issues that I would like the authors answer:

- **Authors claim the importance of different field-of-view (FOV) of the instruments. Can you quantify of this affect the Langley Ratio method.**

  To answer this question, we performed a simulation of irradiance using the radiative transfer code libRadtran (Mayer and Kylling, 2005; Emde et al., 2016), at different air masses (2, 2.5, 3, 3.5, 4, 4.5, and 5), different values of AOD at 500 nm (from 0.02 to 1), and two aerosol types, urban (fine particles predominance) and desert dust (coarse particles), for the different spectral bands and Field of Views (FOVs) of each instrument. To simulate the irradiance for each instrument, we followed the method for simulating circumsolar radiation as described in García et al. 2020. Once the irradiances were simulated, we applied the LR method to obtain the extraterrestrial irradiance of CE318, $E_{0,LR}$, using the PFR as the reference, and compared it with the extraterrestrial irradiance of CE318 using the standard Langley method, $E_{0,SL}$, obtained under low aerosol load conditions.

  The LR method was applied between the nearest pairs of spectral bands, namely 340/368, 380/368, 440/412, 500/500, 675/500, 870/862, 1020/862, and 1640/862. The results obtained are shown in Figure 1. In this figure, the relative difference of extraterrestrial irradiance, $(E_{0,LR}- E_{0,SL})/ E_{0,SL}$, is displayed on a logarithmic scale against the value of AOD at 500 nm, for the two types of aerosols and for each spectral band of CE318. We can see that $E_{0,LR}$ is always higher than $E_{0,SL}$ (except for urban aerosols and AOD_{500}>0.5 at 340 nm). We can also observe that urban aerosols have a lower impact than desert aerosols (except for bands 380 and 440 and AOD_{500}>0.4), and the difference increases with AOD_{500}, being greater for shorter wavelengths. In general, we can say that urban aerosols have a very low impact, whereas desert aerosols have a noticeable impact for moderate to high aerosol loads (from 0.1% to 1% for AOD_{500} between 0.1 and 1, depending on the spectral band).

However, it is important to admit that AOD uncertainty in large particles and high AODs due to FOV and forwards scattered light is much more important than the effect on the method.

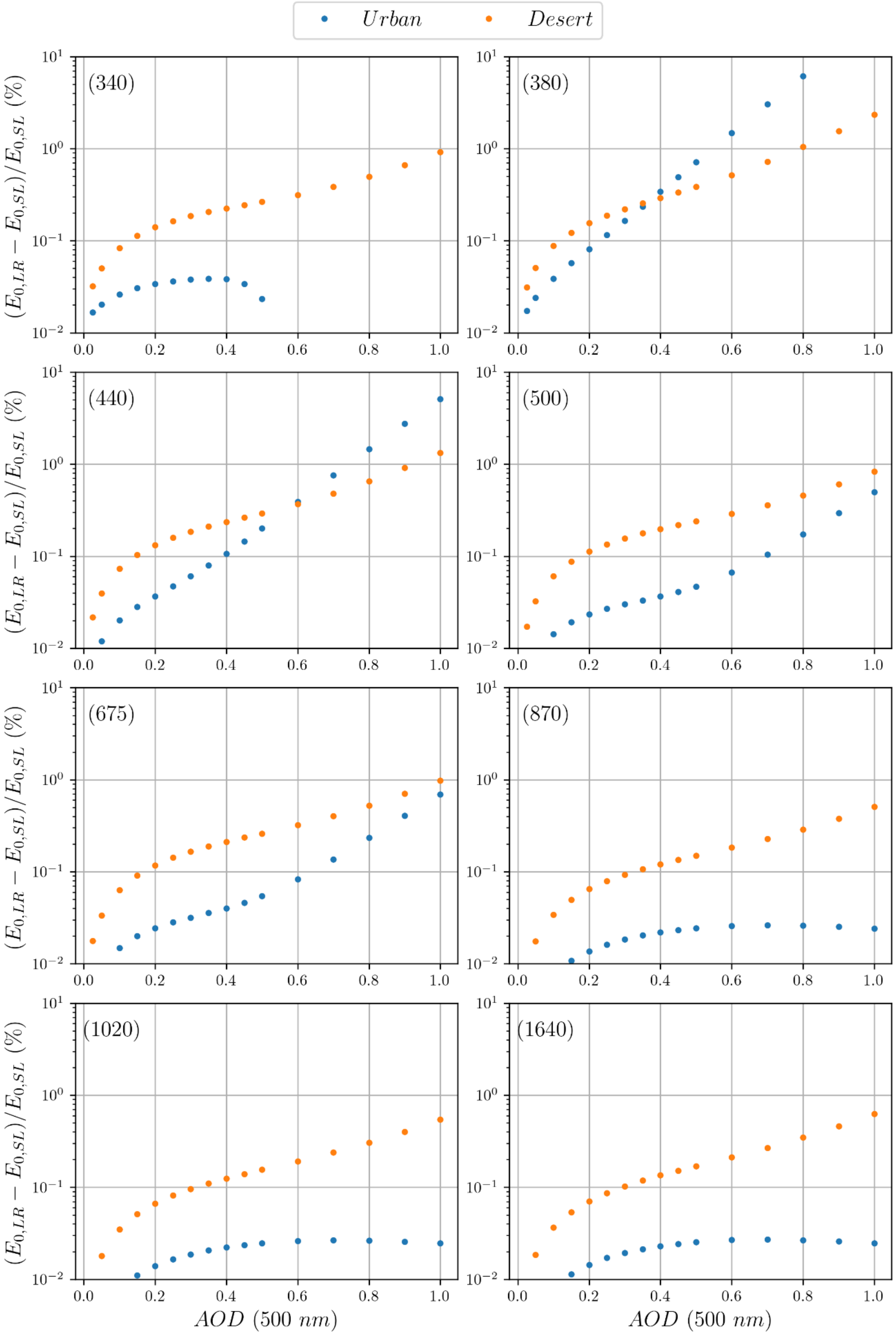

Figure 1: Relative difference between the extraterrestrial irradiance obtained with the LR method ($E_{0,LR}$) and the SL method ($E_{0,SL}$) against the AOD at 500 nm for two different types of aerosols: urban in blue and desert in orange, for each spectral band of the CE318. The irradiances were simulated using the LibRadtran radiative transfer code, taking into account the Field of Views (FOVs) of the CE318 and the

PFR. The LR method was applied between the closest Central Wavelength (CWL) pairs between the PFR and CE318, namely 340/368, 380/368, 440/412, 500/500, 675/500, 870/862, 1020/862, and 1640/862.

- **I miss an intercomparision between the Langley Ratio and the classical Langley methos. It could have been possible with instruments at Izaña.**

The authors did not consider this possibility because it is only possible to do it at IZO, and we wanted to show the results consistently for both stations. Furthermore, according to Toledano et al 2018, the standard Langley calibration for a single day in IZO has an uncertainty of 0.9%, so it is advisable to average at least 10 calibrations to achieve a lower uncertainty of 0.25%. However, following the referee's suggestion, we carried out the daily comparison of the LR method with the daily SL calibrations for the same time period presented in the article (from July 1, 2021, to December 31, 2022) for each channel of the CE318. The results of this comparison are shown in Figure 2 and Table 1. In this figure, the daily relative difference throughout the study period between calibrations is represented as $(V_{0,LR} - V_{0,SL}) / V_{0,SL}$ for each channel of the CE318, differentiating between morning (blue points) and afternoon (orange points). The grey crosses represent the relative differences where SL calibrations do not meet the criteria to consider the calibration as valid (see Toledano et al. 2018). We decided to include these results in the graph to show that on many days, it is not possible to perform a Langley calibration in IZO, particularly in summer due to Saharan dust intrusions. These data are not included in the calculation of the average and standard deviation of the differences presented in Table 1.

In general, we can say that the difference between both calibrations is low, especially for longer wavelengths, with average differences ranging from 0.08% to 0.68% and standard deviations ranging from 0.21% to 1.33%. These results are slightly different from those presented in the article (Figure 1 and Table 1). However, it is important to consider that the data population is different in each case, with 72 data points in the present study compared to 338 in the manuscript.

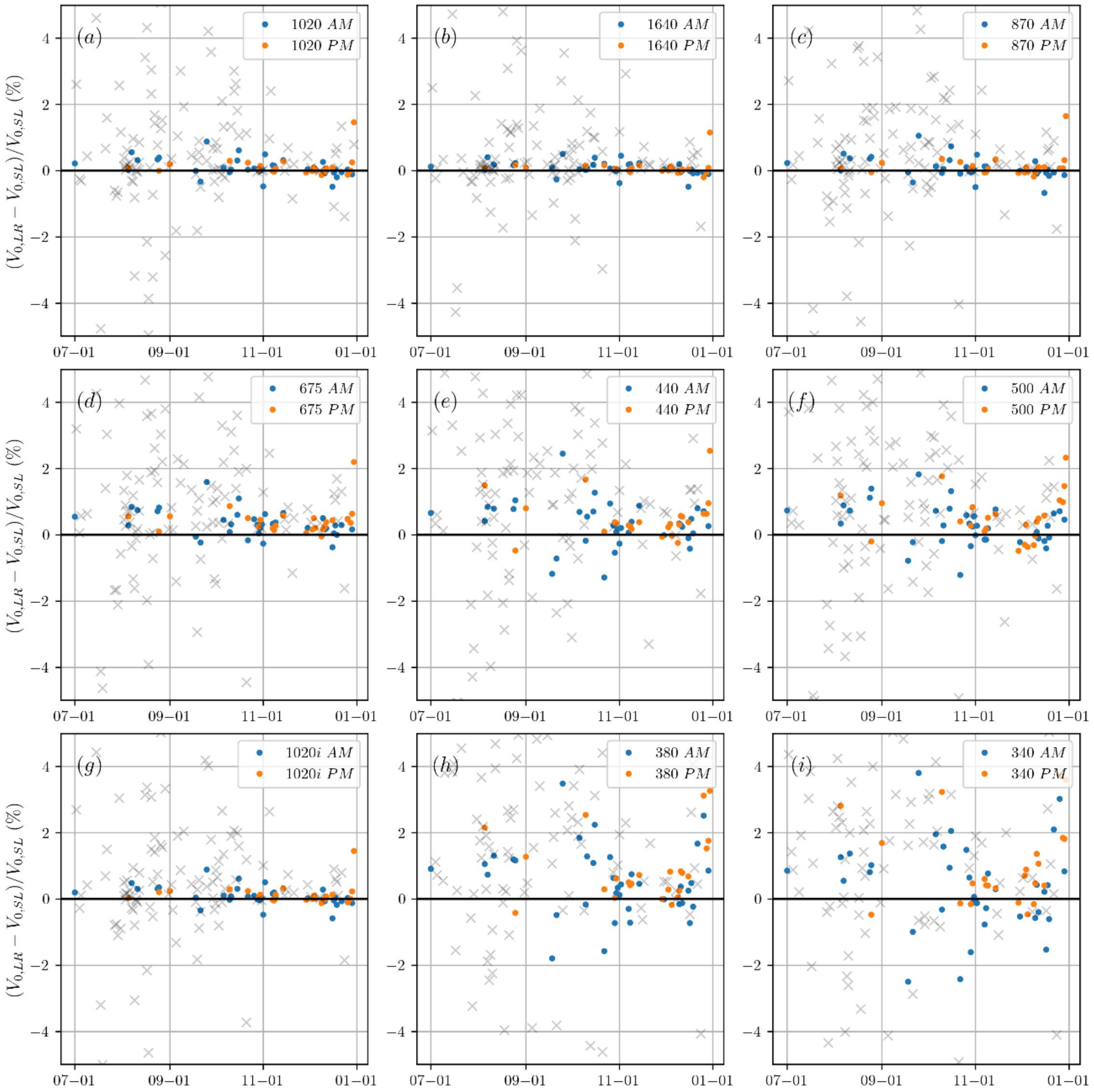

Figure 2: Daily relative differences between the extraterrestrial voltage obtained with the LR method ($V_{0,LR}$) and the SL method ($V_{0,SL}$) at IZO for a six-month period (from 07/01/2021 to 12/31/2021) for each spectral band of the CE318. Blue points represent morning data, orange points represent afternoon data, and grey crosses indicate data that does not meet the SL criteria described in Toledano et al 2018. The LR method was applied to the closest Central Wavelength (CWL) pairs between the PFR and CE318, specifically 340/368, 380/368, 440/412, 500/500, 675/500, 870/862, 1020/862, and 1640/862.

CE318 spectral band	**1640**	**1020**	**870**	**675**	**500**	**440**	**1020i**	**380**	**340**
$\overline{\Delta V_0}$(%)	0.08	0.11	0.11	0.38	0.39	0.40	0.11	0.68	0.62
$\sigma(\Delta V_0)$(%)	0.21	0.28	0.32	0.40	0.65	0.66	0.28	1.04	1.33

Table 1: Mean and standard deviation of the daily relative differences (in %) between the standard Langley calibration ($V_{0,SL}$) and the daily Langley ratio calibration ($V_{0,LR}$) at IZO for a six-month period (from 07/01/2021 to 12/31/2021) for the different CE318-TS spectral bands. The LR method was applied to the closest Central Wavelength (CWL) pairs between the PFR and CE318, specifically 340/368, 380/368, 440/412, 500/500, 675/500, 870/862, 1020/862, and 1640/862.

Technical comments

- **Abstract: In lines 1-2 you refer to ‘photometer’. I propose to specify ‘sun photometer’.**

We agree with the referee comment, we will change to sun photometer.

- **Line 44. Can you give the link to GAW-PFR network? Are the data publicly available?**

  Yes, the data is publicly available. You can download from the following URL:

  https://gawpfr.pmodwrc.ch/ or https://ebas-data.nilu.no/Default.aspx

- **Line 56. What is ACTRIS? Can you give the link?**

  Below we reproduce the definition provided in the ACTRIS web page (https://www.actris.eu/):

  "The Aerosol, Clouds and Trace Gases Research Infrastructure (ACTRIS) is the pan-European research infrastructure (RI) producing high-quality data and information on short-lived atmospheric constituents and on the processes leading to the variability of these constituents in natural and controlled atmospheres."

- **Line 65. 'Langley calibration technique', a reference is needed.**

  We agree with the referee comment. We will add the reference from Shaw, 1983.

  Shaw, G. E.: Sun photometry, Bull. Am. Meteorol. Soc., 64, 4–10,1983.

- **Line 66. What is the acronym 'SI?**

  We missed the acronym definition. SI is for International System of Units. We will add it in the text.

- **Instrumentation: Adding a table that summarizes the main characteristics of each instrument would be ideal. Actually, the authors use different CIMEL versions that have different bands. The reader might find easier the importance of the Langley Ratio technique.**

  We will add two tables, one for section 2.1 and another one for section 2.2 describing the CE318-T and the PFR photometers:

  Table 1: Main features of the CE318-TS and CE318-TV12-OC sun photometers used in this study.

	CE318-TS	CE318-TV12-OC
Type of instrument	Standard version, Reference instrument in AERONET	Reference instrument in AERONET-OC (ocean color)
Type of observation	Automatic sun–sky tracking	Automatic sun–sky–sea tracking

Available standard channels	340, 380, 440, 500, 675 nm, 870, 1020, 1640 nm	400, 412.5, 442.5, 490, 510, 560, 620, 665, 779, 865, 937, and 1020 nm
FWHM	2 nm (340 nm), 4 nm (380 nm), 10 nm (VIS-NIR), 25 nm (1640 nm)	10 nm

Table 2: Main features of the CE318-TS and the GAW-PFR sun photometers used in this study

	CE318-TS	PFR
Type of instrument	Standard version, Reference instrument in AERONET	Standard version, Reference instrument in GAW-PFR
Type of observation	Automatic sun–sky tracking	Automatic continuous direct sun irradiance
Available standard channels	340, 380, 440, 500, 675 nm, 870, 1020, 1640 nm	368, 412, 500, 862 nm
FWHM	2 nm (340 nm), 4 nm (380 nm), 10 nm (VIS-NIR), 25 nm (1640 nm)	5 nm
FOV	1.3º	2.5º
Sun tracker	Robot specifically designed by CIMEL and controlled in conjunction with the radiometer	Any sun tracker with a resolution of at least 0.08º

- **Lines 110-112: There are more inversion techniques for obtaining aerosol microphysical properties. For example, check GRASP algorithm.**

  We agree with the referee comment, we will add the following references referring to GRASP:

  Dubovik, O., Lapyonok, T., Litvinov, P., Herman, M., Fuertes, D., Ducos, F., Torres, B., Derimian, Y., Huang, X., Lopatin, A., Chaikovsky, A., Aspetsberger, M., and Federspiel, C.: GRASP: a versatile algorithm for characterizing the atmosphere, in: SPIE, vol. Newsroom, 2014.

  Torres, B., Dubovik, O., Fuertes, D., Schuster, G., Cachorro, V. E., Lapyonok, T., Goloub, P., Blarel, L., Barreto, A., Mallet, M., Toledano, C., and Tanré, D.: Advanced characterisation of aerosol size properties from measurements of spectral optical depth using the GRASP algorithm, Atmos. Meas. Tech., 10, 3743–3781, https://doi.org/10.5194/amt-10-3743-2017, 2017.

- **Lines 113-114: A reference is needed for the statement about AOD uncertainties.**

We will add the reference from Eck et al. 1999.

Eck, T., Holben, b., Reid, J., Dubovik, O., Smirnov, A., Neill, Slutsker, I., and Kinne, S.: Wavelength dependence of the optical depth of biomass burning, urban, and desert dust aerosols, Journal of Geophysical Research: Atmospheres, 104, 31 333–31 349, https://doi.org/10.1029/1999JD900923, 1999.

- **Lines 114-117: Will the technique be used for ocean-color applications?**

  In our opinion, as the LR technique has been demonstrated to accurately transfer direct sun calibration from a standard CE318-T to a CE318-TV12-OC, it can be valuable for ocean color applications. This point has already been stated in the manuscript, specifically in Line 84 and Lines 397-400.

- **Lines 186-187: I do not understand why Langley technique requires long observational periods of one/two months. The same statement is in the introduction (Lines 76-77). Theoretically with one day of measurements during very clean and stable conditions at high altitude you have Langley calibration.**

  In principle, as the referee has pointed out, theoretically, under very pristine conditions, a Langley calibration should be sufficient for accurate instrument calibration. However, in reality, such extremely pristine conditions are not always attainable, even at Langley calibration sites like Izaña. In this regard, Toledano et al. (2018) conducted an analysis and determined that an individual Langley plot at Izaña has an uncertainty of approximately 0.9%. To reduce calibration uncertainty to below 0.25%, these authors concluded that 10 or more Langley plots should be averaged. Achieving such a number of Langley plots would require at least 10 days, assuming ideal conditions, but it can extend to one or two months depending on atmospheric conditions at Izaña, such as the presence of clouds or dust outbreaks, especially during the summer. Such period of observation is also important from the operational point of view, to ensure the stability of the photometers.

- **Equation 3: Is difficult to follow unless you define each of the variable. Same happens for Equation 4.**

  We agree with the referee comment, we will clarify it, by changing the text from line 188:

  Due to the scarcity of locations with Langley conditions, the typically high costs associated with shipping equipment to such remote areas, and the long time required to conduct this calibration, alternative methods have been developed (Soufflet et al. 1992; Schmid et al. 1998; Holben et al. 1998; Fargion et al. 2001). Specifically, transferring calibration from a Langley-calibrated reference instrument ($V_{0,\lambda}^{M}$), referred to as the "master," to uncalibrated instruments ($V_{0,\lambda}^{F}$), known as "field" instruments, conducted in more accessible facilities offers a practical solution for calibrating multiple instruments simultaneously. In this regard, AERONET applies the method exposed by Holben et al. 1998 and extended by Fargion et al. 2001, where the calibration of the field instrument, $V_{0,\lambda}^{F}$, is determined by calculating the ratio between equation 1 applied to the field instrument and equation 1 applied to the master instrument for measurements that are both coincident in time and within the same spectral band. Consequently, this ratio can be expressed in terms of quasi-coincident ratios between raw direct sun measurements from the master (V_{λ}^{M}) and the field instrument (V_{λ}^{F}) as follows:

$$V_{0,\lambda}^{F} = \frac{V_{\lambda}^{F}}{V_{\lambda}^{M}} \cdot V_{0,\lambda}^{M},$$

- **Equation 5: It is not clear to me how do you compute the differences in aerosol optical depth.**

  The differences in aerosol optical depth are calculated as follows:

$$\Delta\tau_{a} = \tau_{\lambda_{m},a} - \tau_{\lambda_{f},a} \approx \tau_{\lambda_{m},a} - \left(\frac{\lambda_{f}}{\lambda_{m}}\right)^{-\alpha} \cdot \tau_{\lambda_{m},a} \approx \tau_{\lambda_{m},a} \cdot \left(1 - \left(\frac{\lambda_{f}}{\lambda_{m}}\right)^{-\alpha}\right),$$

  where α is the Ångström exponent. Therefore, $\tau_{\lambda_{f},a}$ is estimated from $\tau_{\lambda_{m},a}$ and α, which are calculated from the master instrument

- **Section 5.1. It is important to know the ranges of AODs you have during the measurement periods.**

  The AOD ranges at 500 nm are between 0.008 and 0.583 for IZO (with an average of 0.093) and between 0.017 and 0.845 (average of 0.123) at Valladolid.

  This information will be added in the manuscript.

- **Line 263: Why limiting to airmasses 2-5**

  The primary reason for this limitation is to reduce the calibration duration and, consequently, minimize aerosol variability. Data beyond airmass 5 are affected by heightened errors in determining optical airmass due to the Earth's spherical shape, in addition to a lower signal-to-noise ratio. Conversely, data below an airmass of 2 change slowly with solar zenith angle, which means it takes longer for the airmass to change. Consequently, this extended period increases the likelihood of encountering greater aerosol variability.

- **Figure 1: How do you explain the outliers in the Figure? Particularly those above 2%. Why positive values predominate?**

  As depicted in Figure 1 of the manuscript, it is evident that most of the higher discrepancies in V_0 result from greater variability in Δτ, especially in $\Delta\tau_a$, as aerosols constitute the most variable component within the observed spectral bands. Nevertheless, several other factors can influence the final outcome, including potential inadequate cloud filtering, the absence of correction for temperature effects in the UV bands of the CE318, or the field of view (FOV) effect. Regarding the prevalence of positive values, we attribute it to the FOV in combination with the increase in AOD. The FOV causes the V_0 value obtained with the LR method to increase as AOD rises, as illustrated in Figure 1 of this document.

- **Section 5.3. I do not understand relative differences if you are using the standard Langley calibration. Who is your reference?**

  We assume the referee is referring to the results presented in Figure 4 of the manuscript. In this figure, we depict the relative difference in V_0 between the ratio cross calibration and the standard Langley, as well as between the LR (AM and PM) and the standard Langley. In all cases, the standard Langley calibration serves as the reference.