Manuscript: Preprint amt-2023-108

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

Response to Referee#1

The authors appreciate the overall positive response of the Referee #1 and we would like to thank for his/her constructive comments. In the following, the Referee suggestions (in bold) are in detail addressed (the author's responses are below in blue color).

The study performed by A. Almansa et al. presents an extension of the current operative method for calibrating the field Cimel instruments from AERONET by calibration transfer, allowing the existence of differences between channels wavelengths from primary and secondary instruments. This is not only useful for improving the transfer when small differences exist between the two channels to be transferred, but also to transfer the calibration from PFR-GAW radiometers, contributing to the traceability of measurements. Also, it allows to apply the cross calibration method to same Cimel models with different nominal channels, such as those from the AERONET-OC type. The results have been validated with standard Langley plots showing good results, and the issues raised have been also addressed.

English usage is also clear to my understanding, so I would not propose further need for native English revision.

My general recommendation for this manuscript is to be accepted, with minor changes.

General comments:

- The study would be an extension of a previous work from Fargion (2001), at least for the OC case, but I think the method has also some ideas in common from an older paper from Soufflet (1992). I think it merits to check for it, if the authors didn't do before.

Soufflet et al. (1992) presented a modified Langley method based on an iterative scheme suitable to perform the calibration transference under changeable aerosol conditions (in terms of type and load), which might occur during the day. Despite being proved to provide excellent results when applied to high AOD conditions in the case of dust storms, improving considerably the performance of the classical Langley calibration method, the authors of this paper think that the goal and physics behind this interesting calibration method are far from the basis of the LR method, presented in this manuscript. Moreover, this method has never been applied to the Cimel or the PFR photometers. In contrast, as we stated in the manuscript, LR method has been proved to be a suitable technique for transferring the calibration between instruments with different spectral bands (Cimels and PFRs) in addition to be a useful tool for detecting and correcting possible instrumental issues in our photometers. However, this reference will be added to the manuscript.

Specific comments:

- Why air mass is limited to minimum 2? Interval 2-5 is common for standard Langleys, but why limiting to air mass 2 in case of cross calibration? For this case, data around noon should be good, even if the airmass is smaller than 2 and some turbulence could make the measurements have higher variability, if this is the reason. Anyway, a comment could be included.

Yes, as the Referee states, the reason for this limitation is to minimize aerosol variability during the calibration process. If the spectral bands of the two instruments involved were identical, aerosol variability would have a limited impact on the cross-calibration, making data around noon usable without the need for the LR method. However, as the differences in spectral bands increase, aerosol variability has a more significant impact on the calibration results. For locations at low latitudes (latitude < 30º approximately), like Izaña, the optical airmass changes rapidly with time, especially during the summer. Thus, restricting the airmasses to the 2-5 range helps minimize aerosol variability. Including lower airmasses would extend the calibration time, thereby increasing the risk of encountering greater aerosol variability. Conversely, for higher latitude locations in the winter, such as Valladolid, optical airmasses lower than 2 are not even reached, leading to longer calibration times and an increased likelihood of encountering more aerosol variability.

We will add the following sentences in page 8 line 217: "In the same manner as the standard Langley method, we have restricted the optical air mass range from 2 to 5. This reduces the calibration time, especially in low-latitude areas, thereby minimizing the possibility of increased aerosol variability."

- Page 2, line 27: I think Campanelli et al (2012) would be more meaningful than Campanelli et al. (2004) reference here.

We agree with this comment. We will introduce this reference in the manuscript.

- Page 2, line 49: why some associated stations of PFR instruments are not part of GAW? What is the difference with full PFR-GAW stations?

GAW-PFR stations fulfil the GAW standards and are accepted by the WMO aerosol scientific advisory board. They are owned/calibrated/maintained by PMOD-WRC. Associated stations use PFR instruments belonging to host institutes, they are calibrated at PMOD-WRC and they are not contributing to GAW (it is up to the instrument owners to do so, by applying to GAW). Major requirements for participating in GAW are mentioned here: https://community.wmo.int/en/activity-areas/gaw/research-infrastructure/gaw-stations/procedure-station-inclusion-gaw-programme. There is an exception with the OHP (France) and Valladolid (Spain) stations. In both cases, the PFRs are owned/calibrated/maintained by PMOD-WRC and the main goal is the continuous comparison of PFRs with ACTRIS reference CIMEL instruments, as described in the manuscript.

- Page 3, line 81: it would be interesting to state main factors causing the higher uncertainty in the ratio cross-calibration.

We agree with referee comment. The main reason for the higher uncertainty in this method is that, in addition to the uncertainty introduced by the master calibration, we have also the uncertainty during the calibration transfer. The possible factors that can impact on the calibration transfer are: the differences in both spectral bands, the uncertainty in the synchronization of the measurements and the rest of instrumental uncertainties introduced from both instruments (dark current, instrumental noise, tracking, etc.).

We will add the following statement: “…, as the uncertainty depends on the uncertainty of the calibration transfer plus the calibration uncertainty of the master instrument.”

- Page 3, line 86: please add a brief meaning of the CE318-TV12-OC model as it has been introduced here for the first time in the paper.

The authors agree with the comment, we will add the following piece of text to complete the sentence: “…a modified version of the standard model CE318-T for satellite ocean colour (OC) validation…”

- Page 4 line 97: not sure the expression "the detectors are filtered" is correct in this case.

The authors agree with the comment, we will modify the sentence as follows: “The radiation reaching the detectors is filtered…”

- Page 4, line 103: do the collimator minimize stray light only when the sky radiance is measured?

We agree with the referee comment, the collimator is always reducing the stray light, but its influence is more important on the sky radiance as it is very low compared to the direct sun radiation. So, we will modify the end of the sentence like this: “…,which is specially necessary for sky radiance measurements near the solar aureole.”

- Page 8, line 214: In the standard Langley method, constant tau is assumed; variations of tau are caused by variations of aerosol burden mainly. In the LR, constant delta_tau is now assumed; what is the main factor for variations of delta_tau during the LR process? I assume AE is a main factor, but a short comment could be useful here.

We will answer this question by conducting a sensitivity analysis of $\Delta\tau_a$ with respect to AOD and AE.

The aerosol optical depth difference, $\Delta\tau_a$, can be written in terms of the master aerosol optical depth and the Ångström exponent, that is:

$$\Delta\tau_a = \tau_{\lambda_M,a} - \tau_{\lambda_F,a} = \tau_{\lambda_M,a} - \tau_{\lambda_M,a}\left(\frac{\lambda_F}{\lambda_M}\right)^{-\alpha}, \qquad (1)$$

where $\tau_{\lambda_M,a}$ is the aerosol optical depth from master instrument, $\tau_{\lambda_F,a}$ is the aerosol optical depth from field instrument and α the Ångström exponent.

We investigated the variability of Δτ$_a$ during the calibration process resulting from variations in $\tau_{\lambda_M,a}$ and α. Specifically, we expressed this variability in terms of standard deviation. To accomplish this, we considered various data sets with randomly normal distributed values for $\tau_{\lambda_M,a}$ and α. These values were characterized by specific averages and standard deviations. We performed 1000 evaluations of Equation 1 for each set of random values (every set has 10 values, the minimum number of data used for a LR calibration), denoted by $<\tau_{\lambda_M,a}>, \sigma(\tau_{\lambda_M,a}), <\alpha>$ and $\sigma(\alpha)$. Subsequently, we calculated the average and standard deviation of $\Delta\tau_a$.

The range of values we considered included four values for $<\tau_{\lambda_M,a}>$ (0.05, 0.1, 0.25 and 0.5), four values for $<\alpha>$ (0.1,0.5,1.0 and 2.0), 100 values for $\sigma\left(\tau_{\lambda_M,a}\right)$ (ranging from 1 to 20% relative to the average) and 100 values for $\sigma(\alpha)$ (ranging from 1 to 50% relative to the average). These values are consistent with the actual measurements obtained in Valladolid and IZO stations. The analysis has been focused on the CWL pair at 675/500 nm. The results are presented in Figure 1.

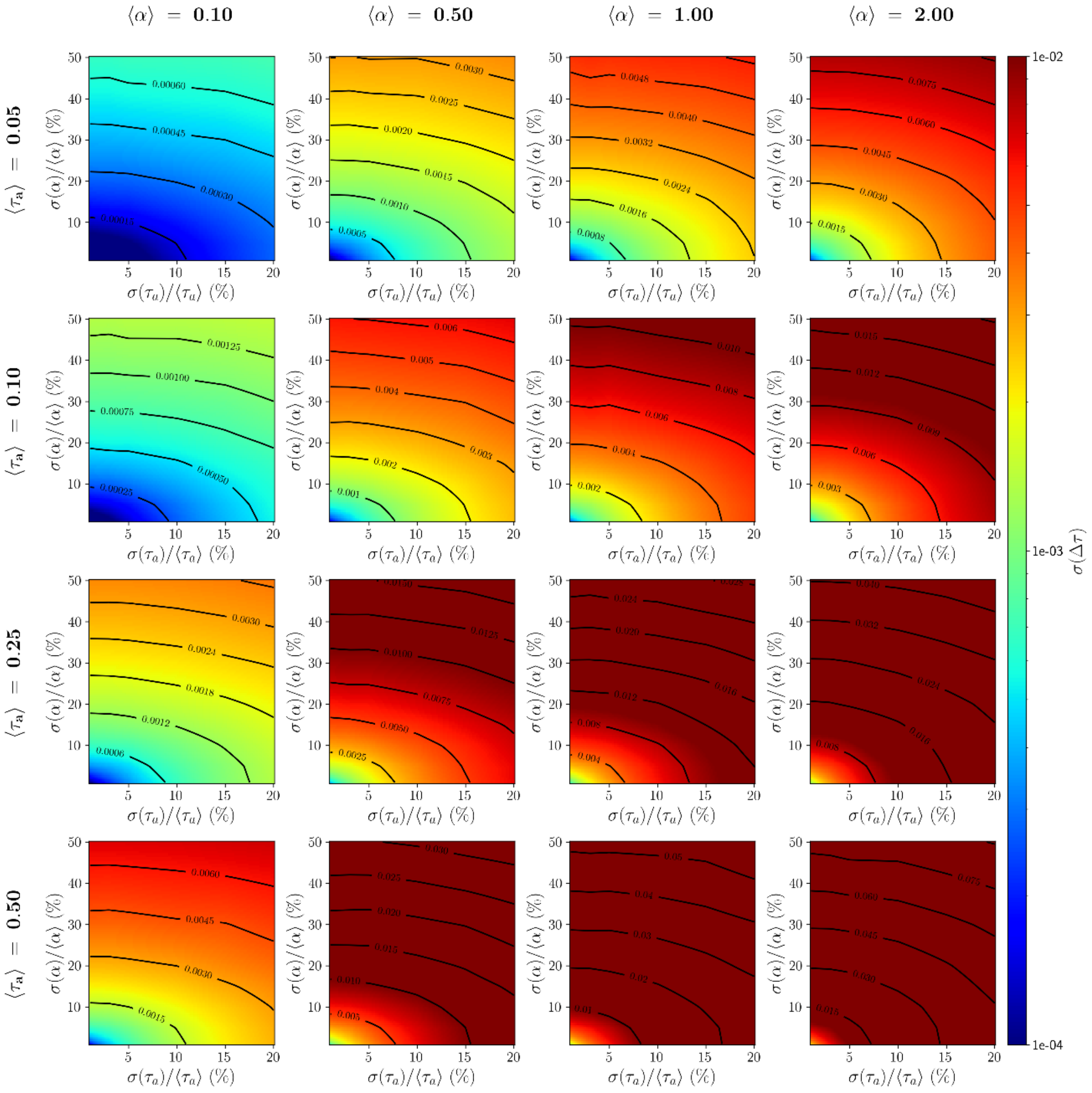

Figure 1: Colormaps representing Δτ$_a$ variability as σ(Δτ$_a$) as a function of the standard deviations of τ$_a$ and α relative to their averages ($\sigma(\tau_{\lambda_M,a})/<\tau_{\lambda_M,a}>$ and σ(α)/⟨α⟩) for a set of average values of $\tau_{\lambda_M,a}$ and

α (⟨α⟩ = 0.1, 0.5, 1.0, and 2.0) and ($< \tau_{\lambda_M,a} >$ = 0.05, 0.1, 0.25, and 0.5) for the 675/500 CWL pair. Panels from left to right correspond to increasing ⟨α⟩ values, and panels from top to bottom correspond to increasing ($< \tau_{\lambda_M,a} >$ values. σ($\Delta\tau_a$) is displayed on a logarithmic color scale, where bluer shades indicate lower variability, and redder shades indicate higher variability.

In Figure 1, the variability of $\Delta\tau_a$ is represented on a color map, showing the standard deviation of $\Delta\tau_a$ (σ($\Delta\tau_a$)), plotted against the standard deviations of $\tau_{\lambda_M,a}$ and α relative to their averages ($\sigma(\tau_{\lambda_M,a}) / < \tau_{\lambda_M,a} >$ and σ(α)/⟨α⟩) for various average values of $\tau_{\lambda_M,a}$ and α ($< \tau_{\lambda_M,a} >$ and ⟨α⟩), resulting in a total of 16 subfigures. Panels from left to right correspond to increasing ⟨α⟩ values, and panels from up to down correspond with increasing $< \tau_{\lambda_M,a} >$. The variability in $\Delta\tau_a$ (σ($\Delta\tau_a$)) is displayed on a logarithmic color scale, where bluer shades indicate lower variability and redder shades indicate higher variability. As a reference, we will assess the results with respect to a threshold σ($\Delta\tau_a$) value of 0.001 (green color), which corresponds approximately to the middle of the color scale in Figures 1 and 2 of the preprint paper.

In the figure 1, as expected, we can see that an increase in any of the different parameters ($< \tau_{\lambda_M,a} >, \sigma(\tau_{\lambda_M,a}), < \alpha >$ and $\sigma(\alpha)$) leads to an increase in the variability of $\Delta\tau_a$. In general, we can say that for very low values of ⟨α⟩ (<=0.1) and $< \tau_{\lambda_M,a} >$ (<=0.1), σ($\Delta\tau_a$) remains below 0.001, regardless of the variability in $\tau_{\lambda_M,a}$ and α (within the study range). For high values of ⟨α⟩ (>=1) and $< \tau_{\lambda_M,a} >$ (>0.1), σ($\Delta\tau_a$) is almost always greater than 0.001 (except in unrealistic cases where the variability in $\tau_{\lambda_M,a}$ and α is extremely low). For the rest of the intermediate cases, σ($\Delta\tau_a$) would have values below or above 0.001 depending on the variability in $\tau_{\lambda_M,a}$ and α.

In view of the numerical results, we can say that $\tau_{\lambda_M,a}$ and α have a similar influence on the variability of $\Delta\tau_a$. However, it is true that generally, according to the measurements, α tends to be more variable than $\tau_{\lambda_M,a}$. Therefore, we can conclude that α is the factor that most influences the variability of $\Delta\tau_a$.

This analysis will be extended to the variability of V_0 obtained using the LR method to address referee 3 question #7, and it will be included as a supplementary material in the final manuscript.

- Page 8, equation 6: has been ancillary data used in this equation? or AERONET derived terms for the master instrument? (both tested sites).

To calculate the optical depth due to Rayleigh scattering and gas absorption (mainly O_3 and NO_2) we employ the formulas provided in Giles et al. (2019). The ancillary quantities for pressure and gases concentrations are provided in the AERONET data files.

- Page 8, line 229-230: I think it would be clearer if in this sentence it is stated that tau_F,a is estimated using the Angstrom law using data from the master AOD spectrum (or I assume it is how it has been done).

The referee is right, we have used the spectral AOD data from the master to estimate $\tau_{f,a}$. Then we have added the following text: "…from the master AOD spectrum…"

- Page 9, line 267-268: Then no postcalibration and interpolation has been used to get the V_0,SL for the two photometers?

We have not included post-calibration nor any interpolation of the calibration constants of the master's instruments. This aligns with the typical procedure within the AERONET network for producing final, quality-assured Level 2.0 products. However, as pointed out by Toledano et al. (2018), Cimel masters, such as the instruments employed in this study, exhibit an extraordinarily high level of temporal stability, with an expected degradation of only -0.07% per year. Based on these findings, we can consider the degradation of our master instrument's calibration over a period of six months to be negligible. Consequently, our dataset maintains a quality level suitable for the objectives of this paper, which is to demonstrate the effectiveness of the method in obtaining calibration constants within the operational AERONET uncertainty.

Reference: Toledano, C., González, R., Fuertes, D., Cuevas, E., Eck, T. F., Kazadzis, S., Kouremeti, N., Gröbner, J., Goloub, P., Blarel, L., Román, R., Barreto, Á., Berjón, A., Holben, B. N., and Cachorro, V. E.: Assessment of Sun photometer Langley calibration at the high-elevation sites Mauna Loa and Izaña, Atmos. Chem. Phys., 18, 14555-14567, https://doi.org/10.5194/acp-18-14555-2018, 2018.

- Page 14, line 340: "tracking problems" make me think of technical problems appearing during tracking. I thknk the authors refer to the general lack of continuous tracking during the measurement sweep, ending on UV wavelengths. Maybe the authors should reformulate somehow the expression, for example "tracking limitations"?

We agree with the referee comment, we will change the text to "…tracking limitations".

- Page 15, line 357: what is the measurement time required for a triplet/individual sweep when the pointing is adjusted before each single specxtral measurement?

The pointing adjustment takes just a fraction of a second, so in total this adjustment adds around 1 or 2 seconds to the standard measurement sequence sequence (about 15 seconds in total for all 10 channels in the filter wheel).

References suggested:

V. Soufflet, C. Devaux, and D. Tanré. Modified langley plot method for measuring the spectral aerosol optical thickness and its daily variations. Appl. Opt., 31(12):2154–2162, 1992.

M. Campanelli et al. (2012) Monitoring of Eyjafjallajökull volcanic aerosol by the new European Skynet Radiometers (ESR) network, Atmospheric Environment 48, doi:10.1016/j.atmosenv.2011.09.070.