ATMD-2026-306

Interactive comment on "Impact of Spectral Aerosol Radiative Forcing at the Izaña Observatory during the August 2023 Extreme Wildfires" by Rosa D. García et al.

Referee #1

Reviewer recommendation: Accept with minor revisions

General comment:

The study by Garcia et al. captures a rare near-source wildfire event at a well-instrumented high-altitude observatory, providing valuable spectral radiative forcing data that is scarce in the literature. Due to the wide range of columnar, vertical, is situ aerosol and trace gas instrument at the Izaña Observatory (IZO) it is a comprehensive multi-instrument approach with rigorous methodology and significant results.

Specific comments

Missing aerosol absorption properties: The authors note (line 122) that AERONET inversion products (SSA, asymmetry parameter) were unavailable. This is a significant limitation since: SSA is crucial for distinguishing scattering vs. absorption effects. Without SSA, the conclusion that "scattering processes" dominate relies primarily on the positive diffuse forcing rather than direct measurement. Recommendation: Discuss this limitation more explicitly and consider whether MAAP absorption data could partially compensate.

Authors: The authors thank the referee for this comment. In order to provide useful information for the discussion on the predominance of the scattering capacity of the aerosols studied from spectral observations during the events selected in this work, the time series of the Single Scattering Albedo (SSA) at 637 nm has been included. This parameter was derived from data obtained with two surface instruments already described in this study: the Integrating Nephelometer and the MAAP. This information has been added to the final manuscript, as follows:

Lines 161-168:

> ***"The Single Scattering Albedo (SSA; ω0) was calculated following Valenzuela et al. (2015), by combining the total scattering coefficient (σscat (λ)) from the nephelometer and the absorption coefficient (σ_{abs} (λ)) derived from the MAAP measurements. The absorption coefficient was obtained by multiplying the eBC mass concentration by the mass absorption cross-section of 6.6 m2 g−1, with a correction factor of 1.05 applied to account for the shift in the MAAP light source wavelength (Mülleret al., 2011). SSA was then computed at 637 nm using:***
>
> $$\omega_0(\lambda) = \frac{\sigma_{scat}(\lambda)}{\sigma_{scat}(\lambda) + \sigma_{abs}(\lambda)}$$
>
> ***where $\sigma_{scat}(\lambda)$ was interpolated to 637 nm from the nephelometer measurements using the SAE, in order to match the MAAP absorption wavelength."***
>
> *Lines 332-334:*

*"…**This enhanced scattering capacity is consistent with the high SSA values obtained from the surface measurements (Fig. 5 in Sect. 4.1)**…"*

Besides, this information has been added as an additional time series in Fig. 5(c)

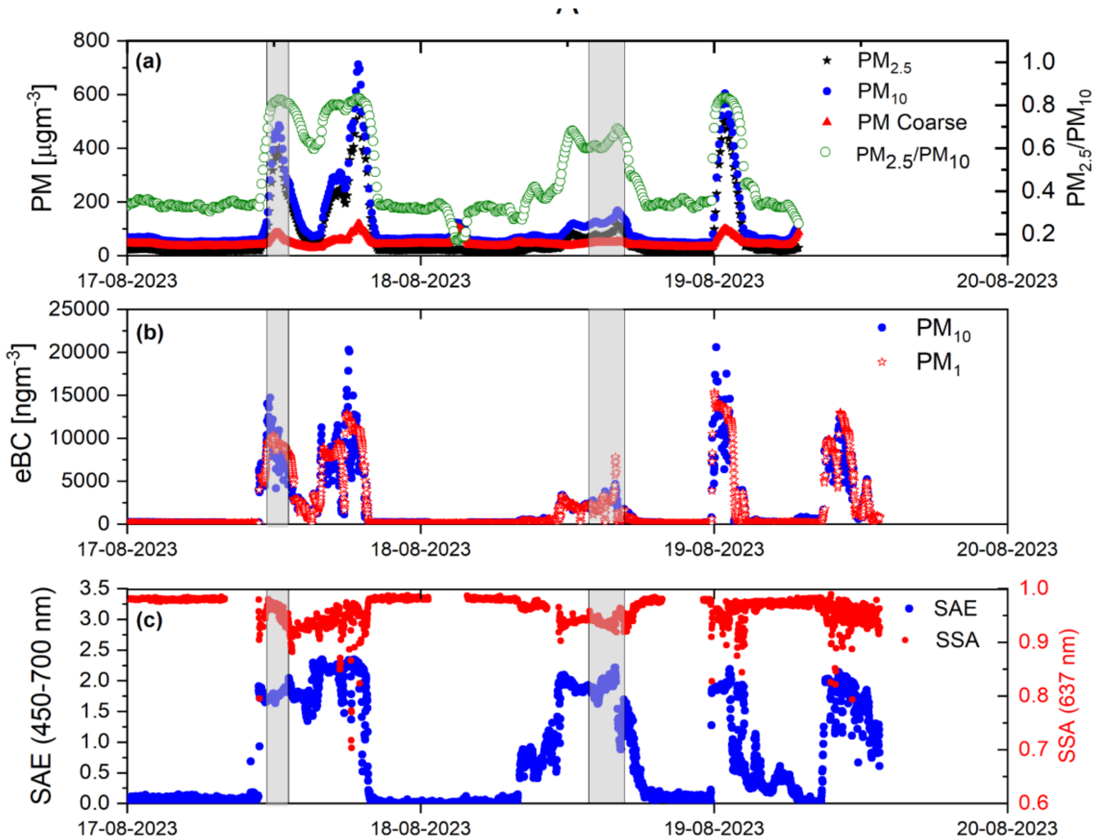


Figure 5.- *Time series of in situ aerosol measurements at IZO from 17 to 20 August 2023. (a) Mass concentrations of PM10 (black stars), PM2.5 (blue circles), coarse-mode PM (red triangles) and PM2.5/PM10 ratio (green dots, right axis). (b) Equivalent Black Carbon (eBC) concentrations for PM10 (blue circles) and PM1 (red stars) (c) SAE (450–700 nm; blue circles) and SSA (at 637 nm; red circles, right axis). Shaded areas indicate the periods corresponding to the maximum AOD values observed on 17 and 18 August.*

Limited temporal coverage: Analysis mostly focuses on two specific times (11:56 and 15:46 UTC). While understandable for detailed spectral analysis, a diurnal evolution of radiative forcing would strengthen the analysis. Recommendation: Consider adding a figure showing temporal evolution of integrated radiative forcing throughout the two days.
The comparison between 17 and 18 August would probably benefit from an analysis of measurement variability during each event.

Authors: Following the reviewer's recommendations, we have added the temporal evolution of the integrated radiative forcing throughout 17 and 18 August in Section 4.2 of the final manuscript.

Lines 367-373:

"In addition to the instantaneous spectral and band-integrated forcing values discussed above, the temporal evolution of the broadband shortwave radiative forcing was analysed over the two smoke-affected days in order to evaluate the diurnal behaviour of the aerosol perturbation (Figure 9). The time series shows a clear enhancement in the magnitude of the forcing during periods of strongest smoke influence, with the largest cooling occurring around local noon, when solar irradiance is at its maximum. On 17 August, the forcing exhibits a pronounced peak between approximately 11:30 and 13:30 UTC, coinciding with the period of highest aerosol loading observed at the station. On 18 August, the forcing remains significant over a broader time interval, with a maximum around 15:30 UTC, consistent with the later arrival of the densest smoke plume (Figure 4a)."

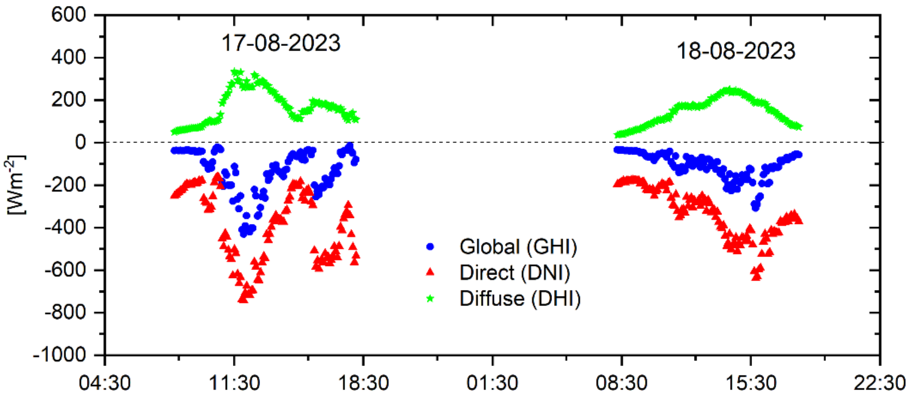


Figure 9.- *Temporal evolution of the radiative forcing components (blue: global (GHI), red: direct (DNI) and green: diffuse (DHI) radiation) at Izaña Observatory during the wildfire smoke events of 17 and 18 August 2023.*

Minor comments:

1. **Date/Time format**: format of date/time varies between figures (e.g. Fig. 3 and 4), consider aligning the format

Authors: Following the reviewer's recommendations, we have standardized all the figures using the same date/time format in the final manuscript.

2. **Add one or two more wildfire studies** and the values mentioned therein?

Authors: Yes, we have included several studies on wildfires that show results consistent with ours results:

Lines 241-244:

> *"...Figure 4c confirms this dominance, with data points from 17 and 18 August clustering in the region of high AE (> 1.5) and high FMF (> 0.8) (Figure 4c), indicative of fine-mode aerosols from biomass burning (Eck et al., 2001; O'Neill et al., 2023).* ***These values are similar to those reported by Masoom et al. (2023); Michailidis et al. (2024) for the extreme wildfires that occurred in Greece in August 2021 and 2023, respectively, as well as to those reported by Filonchyk and Peterson (2024) at the El Arenosillo site in southern Europe as a result of the 2023 Canadian forest fires."***

3. **Line 100**: "at the 4th position the shadow band stops at +5° **after** the solar disk" - Should this be "beyond" rather than "after"?

Authors: Corrected

4. **Line 222 and 232** – **reference to Masoom seems** somewhat repetitive, maybe add FMF value of Masoom to increase information value of second mention.

Authors: Following the reviewer's recommendations, we have added the FMF values reported in Masoom et al. (2023) in the final manuscript as follows:

Line 232:

> *"Simultaneously, AE > 2 on both days (2.06 on 17 August and 2.04 on 18 August) (see Table 1), indicating a predominance of fine-mode particles. These features are characteristic of biomass-burning aerosol intrusions and are comparable to those reported by Masoom et al. (2023) during the extreme wildfire episode in Greece in August 2021, where AOD values up to 3.6 at 500 nm, AE up to 2.4 (440–870 nm), **and fine-mode fraction (FMF) values around 0.98 were observed.** Therefore, the following study focuses on the events recorded on 17 and 18 August."*

5. **Table 1 and lines 259/260**: The PM2.5/PM10 ratio shows 0.81 for 17/08 and 0.66 for 18/08, but text (line 260) states "0.83 and 0.69", why is that?

Authors: The data in Table 1 correspond to the two events analysed in this study, during which the maximum AOD values were observed (grey-shaded areas in Fig. 4), whereas the values reported in the text (lines 255–260) correspond to the maximum in situ measurements (grey-shaded areas in Fig. 5). In any case, the paragraph has been updated as follows:

Lines 265-274:

> *"...The peaks on 17 August morning and 18 August afternoon (**shaded areas in Figure 5**) coincided with fire events identified from columnar properties (Figure 4). The elevated PM10 and PM2.5 concentrations within these periods indicate direct impacts from wildfire smoke plumes at the observatory, reaching maximum values of 485.19 and 167.80 µg m^{-3} for PM_{10} and 401.53 and 116.26 µg m^{-3} for PM2.5 (17 and 18 August). The eBC concentrations reached record values for the station (González et al., 2025) with **peaks** of 14.74 and 10.31 µg m^{-3} for the PM10 and PM1 size cuts on 17 August, and 4.69 and 7.81 µg m^{-3} on 18 August. Correspondingly, **the SAE, PM2.5/PM10 ratio, and SSA, which provide complementary information on aerosol size and optical properties, reached maximum values of 1.93, 0.83, and 0.98 on 17 August, and 2.21, 0.69, and 0.96 on 18 August, respectively. These values collectively confirm the dominance of fine, light-scattering wildfire originated particles during the selected events."***

6. **Reference list**: several times doi link wrong format: "https://doi.org/https://doi.org.." (remove one https://doi.org)

Authors: Corrected

Overall Assessment:

This is a valuable contribution documenting an extreme biomass burning event with rare spectral detail. The main scientific conclusions are sound, but the paper would benefit from a clearer discussion of limitations, particularly regarding missing SSA data. The multi-instrument approach is a major strength that validates the findings across independent measurement techniques. With the revisions outlined above the manuscript should be suitable for publication.

Authors: *We acknowledge the referee's comments.*

ATMD-2026-306

Interactive comment on "Impact of Spectral Aerosol Radiative Forcing at the Izaña Observatory during the August 2023 Extreme Wildfires" by García et al.

<u>Referee #2</u>

The manuscript "Impact of Spectral Aerosol Radiative Forcing at the Izaña Observatory during the August 2023 Extreme Wildfires" is clearly within the scope of the AMT/ACP inter-journal Special Issue "Sun-photometric measurements of aerosols: harmonization, comparisons, synergies, effects, and applications". The study makes extensive and appropriate use of sun-photometric observations (AERONET), complemented by high-quality spectral irradiance measurements and multi-instrumental aerosol and trace-gas observations. The scientific objective is well defined and addresses a timely and relevant topic: the spectral radiative effects of extreme biomass-burning aerosols under near-source conditions. The dataset is unique, the methodology is sound, and the analysis is thorough. The use of spectral irradiance measurements combined with radiative transfer simulations to quantify spectral radiative forcing and efficiency represents a valuable contribution to the existing literature, particularly given the scarcity of such detailed spectral studies. The structure is clear, the instrumentation and methods are well described, and the results are supported by comprehensive observational evidence. Studies of this kind are valuable as we are trying to demystify the radiative effect of wildfires on climate processes, and it is very rare to be able to have such extensive data of different types and instruments so close to the source of emissions.

<u>Authors:</u> We acknowledge the referee's comments.

I suggest to accept the manuscript for publication after the following minor revisions:

1. **Meteorological and Plume Characterization**

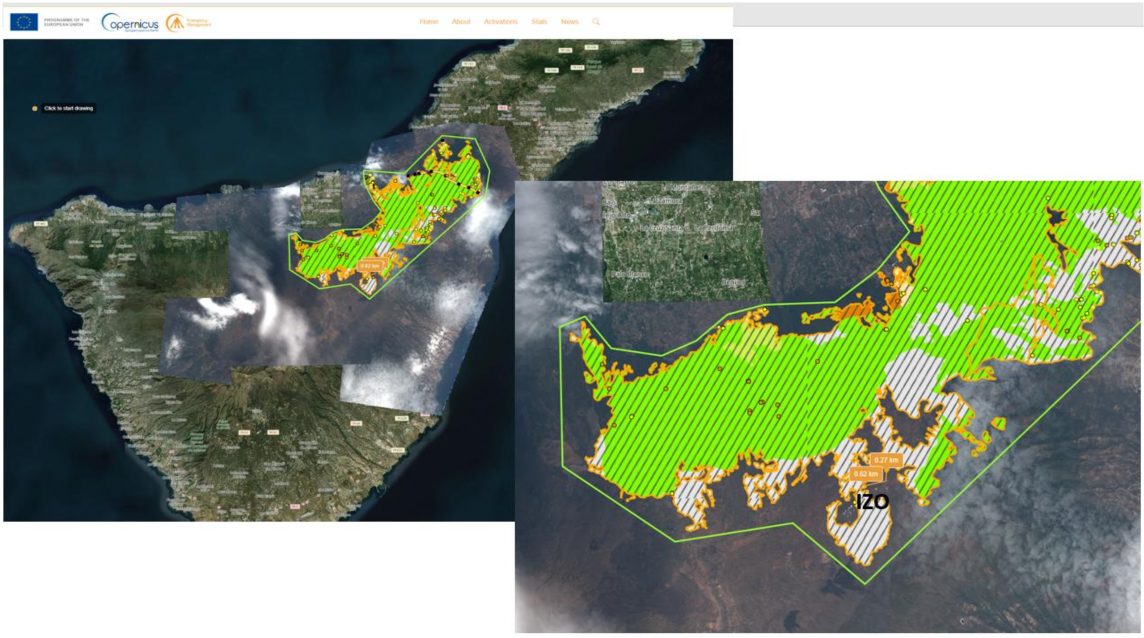
While Figure 1 provides a visual overview, more quantitative detail is needed regarding the meteorological conditions and the spatial relationship between the fire and the instruments.

Meteorological Context: Please provide more specific synoptic or local meteorological data during the wildfire peaks. While the text mentions a heatwave and low humidity, a brief discussion or a supplementary panel showing wind direction/speed at the observatory level would better contextualize the plume's arrival.

<u>Authors:</u> We thank the reviewer for this suggestion. In the manuscript, we focused on the meteorological conditions recorded at the Candelaria station rather than at the Izaña Observatory, as the atmospheric situation at the onset of the wildfire was particularly relevant to the ignition phase. In contrast, the subsequent spread of the fire, which became very extensive across the island (more than 13000 hectares), was influenced by additional factors. In the insular context of Tenerife, the fire propagation was strongly related to the severe water stress of the vegetation following several months of very limited precipitation and persistent dryness. In addition, the frequency of typical trade-wind conditions during that period was unusually low. These trade winds normally help maintain a cooler and more humid environment in the forested areas, and their reduced occurrence likely contributed to the enhanced dryness of the vegetation and favoured the fire spread.

Plume Proximity: The manuscript states the fire occurred "only a few metres" from the spectroradiometer. Please provide a more precise estimate of the distance to the active fire front during the 17–18 August peak to support the "near-source" characterization.

Authors: The distance between the active fire front and the Izaña Observatory during the peak period from 17 to 18 August was approximately 270 meters to the North. The following figure shows the evolution of the affected area between the 17th and 18th of August 2023, resulting from pyrocumulonimbus activity over the extended burned areas of Tenerife (Canary Islands), based on the Copernicus Emergency Management Service Rapid Mapping analysis (https://rapidmapping.emergency.copernicus.eu/EMSR686, last access: 15 April 2024).

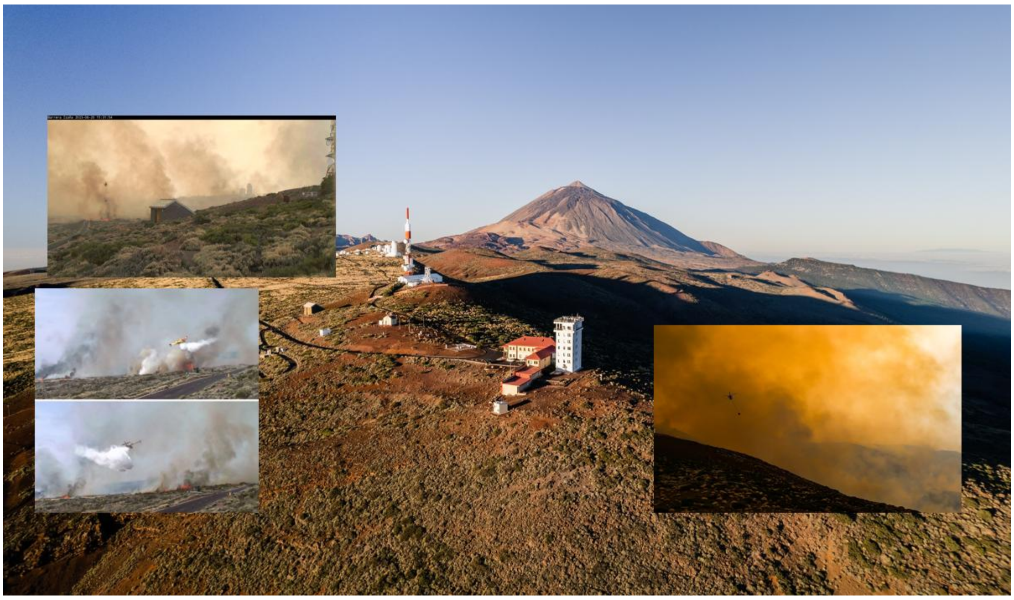


This distance has been added at the final manuscript as follows:

> *"...The extreme 2023 fire episode occurred* ***only ≈280 m north and 620 m east of*** *the spectroradiometer operating at IZO, providing a unique opportunity to directly observe the spectral radiative signal of fresh smoke under near-source conditions."*

Plume Height: You mention that the fresh smoke layer extended up to 4 km a.s.l. based on lidar observations. Given that the Izaña Observatory is located at 2400 m a.s.l., please explicitly discuss the fact that the observatory was effectively immersed within the smoke plume. This is crucial for interpreting the extremely high surface concentrations.

Authors: The authors have no doubt that the Izaña Observatory was enveloped by the smoke plume. This is also demonstrated by the different techniques used throughout the manuscript to corroborate this finding, including both column-integrated and in situ measurements. The following figure shows the location of the different instruments used in this study and their close proximity to each other.



2. **Clarification of Measurement Levels (Sections 2.3.3, 2.3.4, and 2.3.5)**

It should be explicitly stated in the headings or introductory sentences of these sections that the TEOM , MAAP , and Integrating Nephelometer measurements represent ground-level (in-situ) concentrations at the observatory.

Authors: Done

These surface-level observations should be discussed in direct relation to the plume height mentioned earlier (4 km a.s.l.) to clarify that these are not column-integrated values but point measurements within the plume layer.

Authors: The authors understand that some confusion may arise from the description of the event due to the combination of remote sensing and in situ techniques. For this reason, we have added an introductory sentence at the beginning of line 248*:*

> *“**This local event was also characterised using in situ surface measurements, complementing remote-sensing observations**. PM10 and PM2.5 concentrations experienced...”*

After this line, in situ surface measurements are described up to line 264, where a direct comparison between in situ and column-integrated results becomes necessary (acknowledging the intrinsic complications associated with this type of comparison). In particular, we believe that the information explicitly referred to by this referee corresponds to the text between lines 273 and 277. We have modified this paragraph to clarify this distinction:

> *“...**The consequence of this pronounced aerosol layering above the station is that surface observations detected the arrival of smoke-dominated air masses, whereas column-integrated observations indicated the dominance of coarser desert dust particles.**”*

3. **AERONET Data and Retrieval Limitations (Lines 116–121)**

Data Levels: The manuscript clarifies that Level 2.0 data was used for 17 August, but Level 1.0 was required for 18 August because the extreme aerosol load was misclassified as clouds by the AERONET algorithm. This has been done in other studies as well, when we "know" that the cloud flagging is off. But some discussion on the uncertainties introduced by this choice should be provided.

Authors: As is well known, Version 3 Level 1.5 represents near-real-time automatic cloud screening and automatic instrument anomaly quality control, including several procedures designed to detect not only clouds but also potential instrument anomalies. Pre-field and post-field calibrations, as well as temperature characterisation, are applied only when the data reach Level 2.0. This means that quality assurance is guaranteed only for Level 2.0 data. This information will never be accessible to the station in the case that the measurements were erroneously filtered, as is the case in the present study. There are many examples in the literature showing that the quality control procedures implemented operationally within the AERONET algorithm can fail under extreme circumstances, as was the case for the events described in this study.

Since it is impossible to compare products that were not generated, and the specific reasons why the different steps of the complex automatic quality control implemented in AERONET Version 3 failed are also unknown, the only way to truly assess the consistency of the measurements from both events is to perform an intercomparison with another independent instrument that measured during both events: the EKO MS-711 grating spectroradiometer, which was measuring simultaneously with the Cimel during the two events. The results show a high level of consistency between the measurements from both instruments during the two events, ruling out the presence of any instrumental problem or anomaly in the Cimel that could have led to the rejection of these data by the quality control algorithm (see Figure).

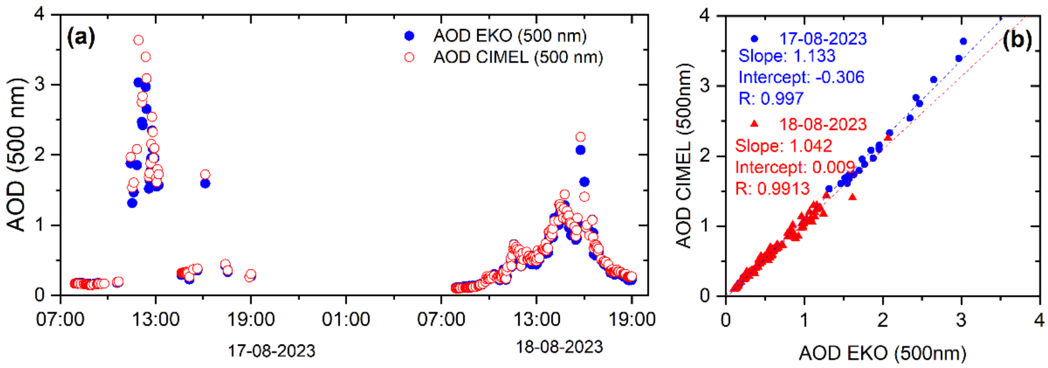


Figure.- (a) Time series of aerosol optical depth (AOD) at 500 nm measured by EKO (blue) and CIMEL (red) instruments on 17–18 August 2023. (b) Scatterplot AOD measured by CIMEL versus AOD EKO, including linear regression fits for each day.

Methodological Limitations: Please expand the discussion on the limitations of AERONET retrievals during such extreme events. Specifically, how does the use of Level 1.0 data (without final calibration or full quality control) impact the uncertainty of the AOD and AE values presented in Table 1?

Authors: As described above, the authors have presented arguments to ensure that the measurements performed during the first event (Level 1.0) were not affected by any instrumental issues that could compromise their quality. What has not been clarified until this point is the extent to which these Level 1.0 AOD values may differ from those measured the following day (Level 2.0) as a result of post-processing related to calibration drift during station operation. Considering that the calibration drift observed in photometers—such as the reference photometers of the network operated at Izaña—is expected to be low (on the order of 2%). In the specific case of the AERONET photometer used in this study, the mean inter-channel variation amounts to only 0.27%. Taking into account that the information presented in this section is used solely for a qualitative description of the event, we consider that the impact of this assumption does not have a direct consequence on the objective of the study, which is to investigate the impact of Spectral Aerosol Radiative Forcing at our station during a specific event.

Cloud Flagging: Could you specify if the Level 1.0 data points used were those specifically flagged as "cloudy" in the standard Version 3 algorithm? Confirming that these "clouds" were actually the dense wildfire plume would strengthen the justification for using Level 1.0 data.

<u>*Authors:*</u> As stated previously, the authors do not have information on the specific reasons why the various steps of the complex automatic quality control implemented in AERONET Version 3 failed for the near-real-time Level 1.5 AOD products. However, the high level of consistency between the EKO and Cimel measurements shown above rules out any instrumental problem or anomaly in the Cimel that could have led to the rejection of these data by the quality control algorithm, ensuring the presence of clouds (from fire) as the reason for rejecting this data.

4. **Inversion Products and SSA Hypothesis.**

The authors state that inversion products (SSA and asymmetry parameter) were unavailable due to insufficient data, which is very reasonable given the non homogenity of the skies during the event.

Since spectral Single Scattering Albedo (SSA) significantly influences the final radiative effect, please discuss in detail the specific hypotheses or fixed values used for these parameters in your radiative transfer simulations.

A sensitivity analysis or a comparison with literature-based SSA values for fresh biomass-burning smoke (e.g., from the referenced 2021 Greece fires) would add robustness to the radiative forcing calculations.

<u>*Authors:*</u> *In this study, the radiative forcing due to the presence of the wildfire smoke plume was determined using the equation:*

$$\Delta F(\lambda, SZA) = F^{\downarrow A}(\lambda, SZA) - F^{\downarrow C}(\lambda, SZA)$$

where $F^{\downarrow A}$ represents the downward irradiance at the surface in the presence of atmospheric aerosols, while $F^{\downarrow C}$ corresponds to the irradiance expected under clean or pristine atmospheric conditions, obtained from radiative transfer simulations. Therefore, the SSA values are not taken into account in the simulations.

The influence of the SSA and sensitivity analysis or a comparison with literature-based SSA values for fresh biomass-burning smoke is beyond the scope of this study. This will be addressed in a future study.