

## Correspondence to Anonymous Referee #1

The authors thank the valuable comments and inputs from Anonymous Referee #1. This document contains the responses to each comment. The referee comments are in blue font, while the authors' responses are in black.

This publication highlights the effects of wood heating on air quality, which is important for our health and also for our climate. Experimental data were collected at a rural site where many wood-fired heating systems are in operation during the winter. Special attention will be given to particle properties that are relevant to the radiative forcing of these anthropogenic aerosols.

The work is important to the scientific community because it quantifies the existing particulate air pollution at this site and describes the properties of the particles that will allow

I recommend the paper for publication after the authors address the issues listed below.

One conceptual weakness in the interpreted data is the following:

An important metric used in the paper is PM<sub>1</sub>, which was calculated from the number-size distributions using density and shape assumptions. However, the size spectra were only recorded up to 600 nm (or 800 nm), and if one looks more closely at e.g. Figure 3f, one clearly has to assume that there is a substantial particle volume between 600 nm (800 nm) and 1000 nm. This does not seem to be taken into account and leads to a significant bias towards too low PM<sub>1</sub> values. As a first step, the measured size distributions should be extrapolated into this gap by making appropriate assumptions (log-normal surface distribution or volume distribution?). A discussion and estimation of the resulting errors is mandatory.

Another important problem is that eq 14 is wrong (see below).

Response: Thanks for your observations. The PM<sub>1</sub> mass concentrations at the main station (Retje village) were calculated from the particle number size distributions measured by the Tropos homemade MPSS (Tropos Ref. No. 1, Hauke-type medium DMA with a TSI CPC model 377). The instrument covers an actual mobility diameter range from 9.1 to 849.7 nm. In contrast, the PNSD at the background station was measured using a TSI MPSS (TSI Inc., DMA model 3081 with a TSI CPC model 3785), which covers a mobility diameter range from 11.8 to 593.5 nm. Table 1 displays the mobility diameter ranges covered by both instruments, which were erroneously named aerodynamic diameters initially; however, we have corrected the terminology in the table. It is important to highlight that the OA optical properties depending on the OA mass, are reported for the main station (village) only.

By definition, PM<sub>1</sub> is composed of particles with an aerodynamic diameter of less than 1  $\mu\text{m}$ . The TROPOS MPSS was designed to cover the PM<sub>1</sub> aerodynamic diameter range. From the mathematical relationship between mobility diameter ( $d_m$ ) and aerodynamic diameter ( $d_a$ ) (neglecting the slip correction), we have (Hinds, 1999):

$$d_a = \sqrt{\frac{\rho_p}{\chi * \rho_0}} * d_m, \quad (1)$$

Where  $\rho_p$  is the particle density,  $\chi$  is the shape factor, and  $\rho_0$  is the reference density (1 g  $\text{cm}^{-3}$ ). Due to the high load of organic aerosols in the study site, we assumed a particle density of 1.4 g  $\text{cm}^{-3}$  (Turpin and Lim, 2001). The shape factor was taken as 1 (spherical particles). Replacing these parameters in

equation 1, for an aerodynamic diameter of 1000 nm (PM<sub>1</sub>), the corresponding mobility diameter is 845.2 nm. The last demonstrates that the mobility diameter covered by the TROPOS MPSS PNSD contains PM<sub>1</sub>. Therefore, in our judgment, extrapolating the particle number size distribution is unnecessary.

Note: The PNSD measured in the background was used to calculate the differences in aerosol concentrations between the village and the background stations for the three atmospheric stability classes. Deltas in the number concentration ( $\Delta N$ ) were computed using ~600 nm as the upper limit of both size distributions for comparability. This information is indicated in the caption of Figure 4. The calculated  $\Delta OA$  was excluded from section 3.1 because, only in this case, a PM<sub>1</sub> mass concentration from the background station was used in the manuscript. However, considering the maximum mobility diameter covered by the instrument in the background station, it is unsuitable to calculate PM<sub>1</sub> and, consequently, OA.

Concerning equation 14, we observed a typo wherein the term  $b_{abs}(950\text{ nm})$  was incorrectly stated instead of the correct notation  $b_{abs}(\lambda_1)$ . Nevertheless, we have corroborated and can confirm that the correct form of the equation  $b_{abs,BrC}(\lambda_1) = b_{abs}(\lambda_1) - b_{abs,BC}(\lambda_1)$  was used in our calculations. The equation has been rectified in the text. Please note that the equation numbering was updated throughout the entire manuscript, and equation 14 is now referred to as equation 12.

#### Specific comments (in order)

- Line 21: "more common in rural areas". Is this true? In some cities, wood is also used for heating and dominates air quality in winter.

Response: Agree. Wood burning is also common in cities and might be responsible for extreme pollution events during winter. However, existing studies need more attention to rural areas where wood burning can be the exclusive or predominant heating source during the colder period. For more clarity, we have rewritten this section in the abstract as follows:

"Existing studies that characterize wood-burning aerosol emissions in Europe primarily concentrate on urban and background sites and focus on BC properties. Despite the significant RWB emissions in rural areas, these locations have received comparatively less attention. The present scenario underscores the imperative for an improved understanding of RWB pollution, aerosol optical properties, and their subsequent connection to climate impacts, particularly in rural areas."

- Lines 40-44: RWB is also important for the health of the local population. This could be mentioned in the abstract. Out of curiosity, has there been an epidemiological study of health effects at the site? Could be informative.

Response: Unfortunately, there were no epidemiological studies on the site during the campaign. Nevertheless, we have included a mention of the risk to human health in the first paragraph of the abstract (line 18).

- Line 95, end of intro: Suggestion to add a few lines pointing out technical solutions to make wood burning cleaner (better certified stoves, appropriate fuel, burning conditions, electrostatic precipitators).

Response: We appreciate the suggestion and have incorporated a series of technical recommendations to mitigate wood-burning emissions in the Summary and Conclusions section, believing this is a more appropriate context to comment on this matter (lines 616 to 626).

- Lines 113-114: The difference in m a.s.l. is 200 m and contradicts the information in Fig. 1.

Response: Thanks for spotting the inconsistency. The main station was located at 715 m a.s.l., while the second station was at 815 m a.s.l.; we have updated Fig. 1.

- Line 163: "Contribution from fibers": Please be more precise. On the one hand directly, but probably also by condensation of semi-volatile gases on the fibers.

Response: Thanks for this observation. In effect, some studies report the condensation of semi-volatile gaseous species on the filter fibers as a source of enhanced light absorption. For instance, Weingartner et al. (2003) observed this effect on filter-based photometers during the first minutes of sample collection on a fresh filter spot after a tape advance. The authors suggest that the filter reaches an equilibrium with the gas phase after a short period, reducing the condensation artifact.

To be more precise, we have rephrased this paragraph as follows:

"Multiple studies point out that the scattering of light in filter-based absorption photometers is affected by the aerosol particles deposited on the filter matrix, their single scattering albedo (SSA), and the scattering within the filter fibers (Ajtai et al., 2019; Bernardoni et al., 2021; Collaud Coen et al., 2010; Drinovec et al., 2022; Saturno et al., 2017; Yus-Díez et al., 2021). Furthermore, some studies suggest that condensation of semi-volatile organic compounds on the filter might contribute to an apparent absorption enhancement (Cappa et al., 2008; Weingartner et al., 2003)."

- Lines 164-169: This is a can of worms and very unsatisfactory. On the one hand, a site-dependent empirical correction for multiple scattering effects in the filter (C) is used, and on the other hand, the harmonization factor is used. Both factors are determined empirically and influence each other. This makes it difficult to compare different instruments on different types of aerosols. A more thorough discussion is needed to disentangle the two factors (C and H). In addition: I also assume that C and H are wavelength dependent - correct? Please clarify.

Response: We acknowledge that using an additional correction factor might be confusing; however, the intention is to correct for previously observed overestimation of the light absorption coefficients calculated from AE33 measurements. In the following paragraphs, we try to provide further details and clarity; also, additional information was incorporated in the revised manuscript in the subsection "The Aethalometer AE33 and multiple scattering harmonization".

The internal algorithm of the AE33 uses the multiple scattering correction factor  $C$  to convert the attenuation change  $b_{ATN}(\lambda)$  into a light absorption coefficient  $b_{abs}(\lambda)$ , as follows (Magee Scientific, 2018):

$$b_{abs}(\lambda) = \frac{b_{ATN}(\lambda)}{C}, \quad (2)$$

Equation 2 is a condensed representation of the internal calculation. Here, the value of  $C$  is fixed in the instrument, and the instrument manual reports its value depends on the type of filter used during the measurements (Magee Scientific, 2018). Since the release of the AE33, three types of filter tapes have been available: M8020 (also called T60A20), M8050, and M8060. The filters M8020 and M8050 have been discontinued. Currently, users are advised to employ the newest filter, M8060, to minimize the unit-to-unit variabilities associated with the properties of the filter material. The M8060 filter tape has a corresponding  $C = 1.39$ , which is not site-dependent.

However, the multiple scattering in filter-based absorption photometers is not only filter-dependent since the sampled aerosol particles also contribute to light scattering in the filter fiber depending on their single scattering albedo (Collaud Coen et al., 2010; Saturno et al., 2017; Yus-Díez et al., 2021). To account for the aerosol effect, ACTRIS proposes to include an additional correction factor,  $H$  (Müller

and Fiebig, 2021). This “harmonization” factor attempts to harmonize the AE33 measurements with the MAAP measurements, which is treated as the closest to a reference for online aerosol light absorption measurements. The use of an additional correction for multiple scattering is recommended since it has been shown that the default  $C$  in the AE33 drives an apparent absorption enhancement resulting in overestimated values of  $b_{abs}(\lambda)$  and consequently, BC mass concentrations. This additional correction for absorption enhancement is imperative since the overestimation of absorption adds uncertainty to the calculated aerosol optical properties and simple forcing efficiency. The proposed harmonization factor is calculated as follows:

$$H = \frac{b_{abs}^{AE33,637\text{ nm}}}{b_{abs}^{MAAP,637\text{ nm}}}, \quad (3)$$

Where,  $b_{abs}^{AE33,637\text{ nm}}$  is the light absorption coefficient from the AE33 interpolated to 637 nm (using the measurements at 590 nm and 660 nm), and  $b_{abs}^{MAAP,637\text{ nm}}$  is the light absorption coefficient retrieved from the MAAP. ACTRIS has calculated a median value of  $H = 1.76$  for the AE33 using the filter tape M8060 based on measurements from multiple European sites, including background and urban stations (Müller and Fiebig, 2021). An AE33-MAAP harmonization factor is now used in recent studies involving AE33 measurements (see for example Pilz et al., 2022; Savadkoohi et al., 2023).

At TROPOS, we have performed parallel measurements using AE33 and MAAP in the laboratory and field campaigns, observing the AE33 measurements to be consistently higher than MAAP. For instance, in Melpitz, Germany, two sets of AE33-MAAP ran in parallel during one year. The data sets show an overestimation of the  $b_{abs}$  reported by the AE33 varying from 20 to 50 % (see Figure 1). The median values of  $H$  calculated for Melpitz during the one-year campaign were 2.25 (ranging between 1.74 (P.10) and 2.97 (P.90)) at Melpitz research station, and 1.87 (ranging between 1.15 (P.10) and 2.83 (P.90)) at Melpitz village station.

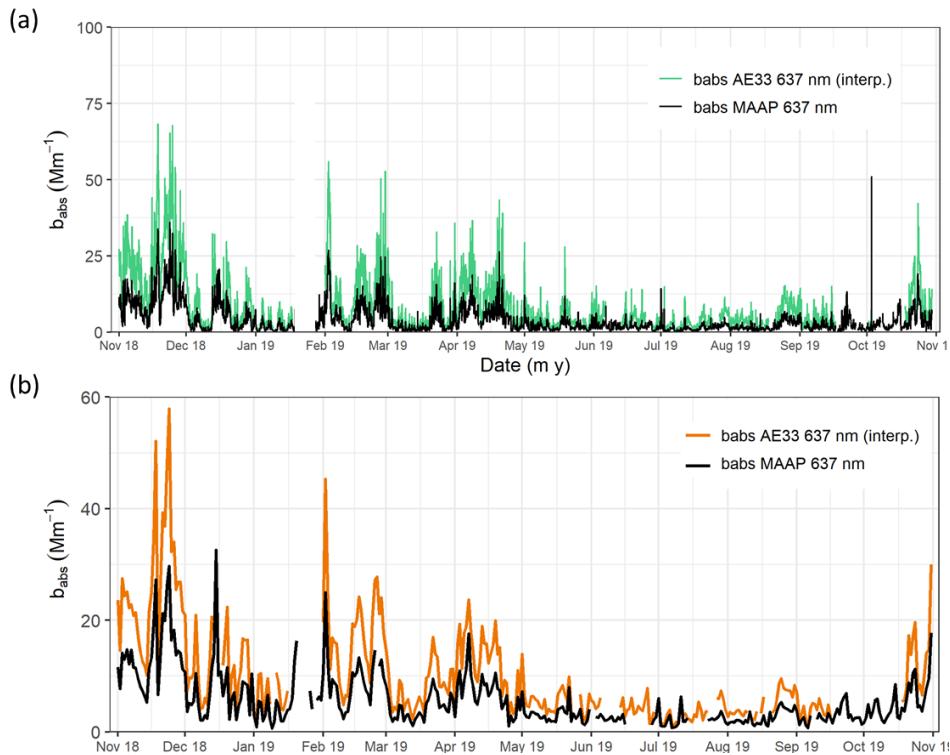


Figure 1: Time series of light absorption coefficient measurements from the AE33 and MAAP at (a) Melpitz research station and (b) Melpitz village station.

Due the absence of concurrent AE33-MAAP measurements in Loški Potok, we employed a value of  $H = 1.9$  obtained from measurements at Melpitz village during wintertime. Melpitz is a small village (~200 inhabitants) located in eastern Germany at 50 km from Leipzig. During the campaign, a measurement container was placed in the center of the village where residential wood burning is the main heating source during the coldest season (van Pinxteren et al., 2023). Although the  $H$  value for Melpitz-winter is slightly higher than the  $H$  recommended by ACTRIS, the difference between both is small, only 7 %.

The light absorption coefficients in the study site were harmonized as shown below:

$$b_{abs}(\lambda)^{Harm.} = \frac{b_{ATN}(\lambda)}{C*H} = \frac{b_{abs}(\lambda)}{H} \quad (4)$$

In our study,  $C$  and  $H$  are taken as wavelength-independent parameters. The spectral dependency of the light scattering corrections in the aethalometers has been investigated in a few studies with divergent results. For the AE33, Bernardoni et al. (2021) found no statistically significant change in  $C$  with wavelength. Yus-Díez et al. (2021) investigated the effective multiple scattering parameter ( $C$ ) defined as a function of the cross-sensitivity to scattering, the multiple scattering filter parameter, and the aerosol SSA. In three diverse environments, the authors observed no wavelength-dependency of  $C$  on the urban and regional stations, while they found variability in a mountaintop station. The variability in the remote mountain site was explained by the aerosols SSA: samples with low SSA (< 0.9) did not show a wavelength dependency in  $C$ , while the opposite was found in samples with high SSA (> 0.9). In Melpitz, Tropos measurements have shown that in winter, SSA < 0.9. For Loški Potok, the SSA estimated through Mie modeling did not exceed 0.9 (see Table 1).

**Table 1.** Aerosol SSA calculated for Loški Potok, Slovenia, using Mie modeling

Wavelength	Mean	P.10	P.90
370	0.47	0.42	0.55
470	0.49	0.41	0.59
520	0.53	0.44	0.63
590	0.56	0.47	0.65
660	0.61	0.53	0.7
880	0.65	0.57	0.73

Based on the previous findings and considering the mathematical definition of  $H$ , we have assumed that  $C$  and  $H$  do not exhibit spectral variation. Nevertheless, further investigation into this matter is needed but is beyond the scope of our study.

- Line 180, Table 1: What is the weighing procedure for PM10? The table is not complete. I am missing information on offline TCA, ion chromatography, levoglucosan. Was an impactor used in the SMPS that allows the correct correction for multiple charging? This is essential for correct volume determination. Why does one SMPS measure only up to 600 nm and the other up to 800 nm? However, the aerodynamic diameter is given. How was this converted?

Response: A detailed description of the instrumentation and analytical methods used in the study is given in section 2.2 of the manuscript. We have included further details in this section to complement the missing information. Below, we answer each point addressed in this comment.

Filter samples of particulate matter  $PM_{10}$  were collected every 12 hours at the village station (06:00 to 18:00 and 18:00 to 06:00, local time) using a high-volume sampler (DHA-80, Digitel).  $PM_{10}$  mass concentrations were determined gravimetrically in the laboratory following the European Union standard EN 12341. The quartz fiber filters (150 mm diameter) were preheated before sampling for at least 24 hours at 105 °C to minimize blank values and frozen after sampling until their characterization in the laboratory; the weighing was done using a microbalance (AT261 Delta Range, Mettler-Toledo). The  $PM_{10}$  filters were analyzed to estimate the particle's chemical composition, including organic and elemental carbon (OC/EC), ions ( $NH_4^+$ ,  $Cl^-$ ,  $Na^+$ ,  $K^+$ ,  $Mg^{2+}$ ,  $Ca^{2+}$ ,  $NO^{3-}$ ,  $SO_4^{2-}$ , and  $C_2O_4^{2-}$ ), and levoglucosan. Mass concentrations of OC/EC were quantified following the EUSAAR-2 Protocol (Cavalli et al., 2010); ions were estimated using ion chromatography (Dionex ICS3000) of ultrapure water extracts (further details in Fomba et al., 2014), and levoglucosan was quantified using high-performance anion exchange chromatography coupled with an electrochemical detector (HPAEC-PAD, Iinuma et al., 2009).

The total carbon (TC) mass concentration at the village station was measured using an online Total Carbon Analyzer (TCA08, Magee Scientific). The dual-chamber instrument uses an online thermal method to quantify the total carbonaceous fraction in atmospheric aerosols. In one chamber, the sample is collected over a quartz fiber filter (47 mm diameter) and heated to 940 °C, transforming the carbon compounds into  $CO_2$ . The amount of  $CO_2$  is measured before and after combustion by a  $CO_2$  detector and later integrated to calculate the total carbon mass concentration. In parallel, the second chamber collects a new aerosol sample (sampling time adjustable from 20 min to 24 h). Both chambers alternate between sampling and analysis, enabling online functionality. Further details about the TCA are given in Rigler et al. (2020).

The Tropos MPSS did not employ pre-impactors. The multiple charge correction was done using a multiple-charge inversion routine to the raw mobility distributions described in Pfeifer et al. (2014). This information is mentioned in section 2.2.

The difference in the particle sizes covered the background MPSS (TSI Inc., DMA model 3081 with a TSI CPC model 3785) and the main-station MPSS (TROPOS Ref. No. 1, Hauke-type medium DMA with a TSI CPC model 3772) resides in the distinct high-voltage power supplies and the geometries of the DMA. The TSI MPSS uses a 10 kV high-voltage power supply and a TSI design DMA, which allows the instrument to reach a maximum particle size of ~600 nm. In contrast, the TROPOS MPSS uses a 12.5 kV high-voltage power supply, including a homemade TROPOS design DMA (Hauke-type).

Regarding the aerodynamic diameters mentioned in Table 1, we have corrected them to indicate that these are mobility diameters.

- Line 182, eq 2: why does it say "fraction in PM"? this is misleading because a fraction is unitless  
- the rest of the equation is not unitless...

Response: Many thanks for the observation; we have corrected the subscript to "PM."

- Line 188: Suggest writing  $PM_{0.8}$  or  $PM_{0.6}$  instead of  $PM_1$ .

Response: Considering our answer to the first comment of this review, we opted to maintain the terminology as  $PM_1$ .

- Line 210, Figure: I expect large systematic errors affecting the slope. Please discuss.

Response: The systematic error of the slope in Fig. 2 was calculated using error propagation, considering the contribution of individual uncertainties involved in the determination of  $PM_1$  (sampling

flow rate, volumetric diameter, and particle density) and  $PM_{10}$  (air sampling volume, reproducibility). The individual uncertainties are 17 % for  $PM_1$  and 10 % for  $PM_{10}$  (Hafkenscheid, 2013; Leiva et al., 2012). For a slope of 0.9, the resulting uncertainty is 15%. This is now described in the text (see lines 229 to 231). Also, further details have been included in section 3.3.

- Line 214: Is  $OA_{MPSS} = PM1$ ? please be consistent and use the same names.

Response: In this paragraph,  $OA_{MPSS}$  refers to the organic aerosol mass concentration calculated from the mass balance  $OA = PM_1 - eBC - InA$ . This enables the differentiation with the other estimated OA (or OC) mass concentrations, i.e., from the  $PM_{10}$  filters ( $OC_{filters}$ ) and the total carbon analyzer ( $OA_{TCA}$ ).

In the rest of the document,  $OA_{MPSS}$  is referred to as OA; we have indicated this in line 245.

- Line 222: Is it justified to assume that transmission, albedo, backscatter fraction are constant, i.e. not wavelength dependent? For which part of the electromagnetic spectrum is this true?

Response: In our calculation of the simple radiative forcing efficiency, the atmospheric transmission ( $\tau_{atm}$ ) and surface albedo ( $a_s$ ) were assumed wavelength-independent. The backscatter fraction ( $\beta$ ) was calculated as wavelength-dependent, as described further below.

The atmospheric transmission can be assumed wavelength-independent in certain spectral regions where atmospheric constituents such as gases and aerosols have minimal absorption or scattering. This is true for given bands; for instance, water vapor has a minimal absorption effect in some bands in the near-IR and IR regions. However, this assumption is not valid in other regions of the electromagnetic spectrum, such as the ultraviolet ( $\lambda \leq 320$  nm) or certain infrared bands where the atmospheric transmission can be highly wavelength-dependent. In summary, the wavelength dependence or independence of  $\tau_{atm}$  varies along the electromagnetic spectrum.

In our study, we have assumed a wavelength-independent  $\tau_{atm}$  since we intend to present a sensitivity analysis to represent the effect of including or neglecting the OA optical properties calculated from our field measurements. Additionally, using constant values of  $\tau_{atm}$  and  $a_s$  allow us to compare our results with other studies using a similar forcing efficiency model (e.g. Chen and Bond, 2010; Deng et al., 2022). The value of  $\tau_{atm}$  attempts to be representative of the variability given in the visible spectra and corresponds to the geometric mean of the average downward transmission (0.72) and the reflected upward transmission (0.87), as proposed by Chylek and Wong (1995) and Penner et al. (1992).

The surface albedo ( $a_s$ ) can be, in general, assumed as wavelength-independent when the properties of the surface do not change along the electromagnetic spectrum, i.e., the scattered light by the surface is the same or changes relatively little with the wavelength. This assumption is valid for natural surfaces like soil, deserts, and vegetation. Nevertheless, for vegetation, the surface albedo is primarily low in the visible spectrum and comparatively higher in the IR; it changes depending on the vegetation type and season. For snow, the albedo is strongly dependent on the surface conditions (age, cleanliness, roughness) and exhibits a wavelength dependency. In the spectral range from 500 to 800 nm, the albedo of fresh snow is nearly constant (~0.8 for ice-crystal snow, ~0.7 for large-grained wet snow) and decreases on the extremes of that range (0.5 to 0.8) (Iqbal, 1983). In our study, we used average albedos for fresh snow (0.8) and Earth average (0.19), representing diverse surface features and conditions. For the spectral range covered in our forcing efficiency calculations (370–880 nm), the approximations of the spectral dependence of albedo are frequently made, and we assume that the reflectivity of the surface remains reasonably constant. This assumption also enables comparability with other studies, such as Chen and Bond (2010).

The backscatter fraction  $\beta(\lambda)$  was taken as wavelength dependent and estimated by the mathematical relation with the asymmetry parameter  $g(\lambda)$  proposed by Sagan and Pollack (1967):

$$\beta(\lambda) = \frac{1}{2}(1 - g(\lambda))$$

The asymmetry parameter was modeled using core-shell Mie theory simulations. This information is described in section 2.4 of the manuscript.

- Line 292: Is it EC or BC (EC is present with lower time resolution)?

Response: In this section, we refer to EC mass concentrations estimated from thermo-optical methods on the PM<sub>10</sub> filters. The resolution is lower than BC since the sampling of the PM<sub>10</sub> filters was done every 12 hours.

- Line 300, Fig 3: the color for "unstable" is hard to distinguish, perhaps better in green. Fig 3b: At what wavelength was BC measured? Fig 3f: here the spectra go up to 850 nm. An additional plot of the volume size distribution would be helpful.

Response: Thanks for this observation. We have modified Fig. 3 using a different color palette. BC in Fig. 3b was calculated using absorption measured at 950 nm. The higher diameter in the size distribution measured by the Tropos MPSS is 849 nm.

- Line 327, caption Fig. 4: the black points (outliers) are not visible.

Response: Thanks for this observation; we have corrected the caption in Fig. 4.

- Line 332, Fig. 5: ditto

Response: Corrected.

- Line 335 and elsewhere: given the relatively large uncertainties, it makes no sense to give the values so precisely. Here 1100 mM<sup>-1</sup> would be appropriate.

Response: Following the recommendation, we have rounded the figures to two significant digits.

- Line 347, eq 12: This relationship is general and one could remove the BC here.

Response: We opted to keep BC in the equation (now Eq. 10) since the apportionment method requires two assumptions: (i) AAE<sub>BC</sub> = 1, and (ii) the total light absorption coefficient in the near IR is entirely attributed to BC.

- Line 351, eq 13: The exponent is an equation and therefore misleading. Just write -1 as the exponent.

Response: Agree. Equation 13 (now referred to as Eq. 11) has been corrected.

- Line 335, eq 14: I think this equation is clearly wrong. It should be:  $b_{abs} \cdot BrC(l1) = b_{abs}(l1) - b_{abs}(950) * (l1/950)^{-1}$ .

Response: Thanks for this important observation. Equation 14 (now referred to as Eq. 12) had a typo; the term  $b_{abs}(950 \text{ nm})$  was erroneously stated instead of the correct notation  $b_{abs}(\lambda_1)$ . Yet, we have corroborated and can confirm that the correct form of the equation  $b_{abs,BrC}(\lambda_1) = b_{abs}(\lambda_1) - b_{abs,BC}(\lambda_1)$  was used in our calculations.

- Line 366, Fig. 6: Will this figure change if eq. 14 is changed? Depending on this, it will also lead to an adjustment of the discussion (e.g. lines 369-377).

Response: Given that the correct equation was used in our calculations (see previous answer), the apportioned light absorption coefficients do not change, and neither do the contributions of BC and BrC shown in Fig. 6.

- Line 394: Will the "photochemical process" lead to an increase or decrease of AAE\_BrC?

Response: In our study, the  $AAE_{BrC, 370-590 \text{ nm}}$  decreased with increased atmospheric instability, which might be related to the mixing with external aerosol sources and aerosol aging/photochemical processes occurring during unstable conditions. The median  $AAE_{BrC, 370-590 \text{ nm}}$  were 3.9, 3.7 and 3.5 for strong inversion, weak inversion, and unstable atmosphere, suggesting a reduction in  $AAE_{BrC, 370-590 \text{ nm}}$  with increased photochemistry. In the literature, some studies suggest a decrease in light absorption in the near UV after aging and photobleaching. For instance, Deng et al., (2022) found comparatively lower BrC wavelength dependency during summer, and suggest that photobleaching and aerosol aging involved in the formation of secondary organic aerosol (SOA) might explain the reduced optical properties (including AAE), during summer time. In other study, Rana et al. (2020) found a reduction of at least 50 % in  $MAC_{BrC}$  after aging and transport of highly loaded BrC plumes in the Indo-Gangetic Plan. The lower MAC suggests a reduction in the light absorption at shorter wavelengths, reducing the wavelength dependency of BrC.

- Lines 403-420: Again, the problem with  $PM_1$ : How much does the missing volume affect the MAC values? I would like to see a presentation and discussion of the systematic errors.

Response: We have included uncertainty calculations in the revised manuscript using error propagation. To estimate the  $MAC_{OA}$  uncertainty, we considered the individual contributions of the OA mass concentration and BrC light absorption coefficients. The propagated error of the OA mass includes the uncertainty derived from the  $PM_1$  mass calculation and accounts for contributions from the sampling flow rate, the volumetric diameter, the diffusion efficiency corrections, and the particle density. The  $PM_1$  uncertainty was assumed to be 17 % based on the calculations of Buonanno et al. (2009) and the instrument intercomparison in the laboratory. Furthermore, the contribution of the individual uncertainties of the eBC and inorganic species mass concentrations were included in the calculations. The resulting uncertainty for the  $MAC_{OA, 370 \text{ nm}}$  is 46 %. An extended description of the uncertainty estimation is now given in the new section 3.3 of the revised manuscript.

- Line 429: Regarding the measurement conditions: How were the particles sampled to the instruments (sampling conditions, at what temperatures and thus relative humidities were the particles measured)?

Response: Nafion®Permapure air dryers (length=1.5 m) were used to keep the relative humidity of the AE33 and MPSS samples below 40 %. The instruments operated under ambient room temperature. For  $PM_{10}$ , the filters were preheated before sampling for at least 24 hours at 105 °C to minimize blank values and frozen after sampling until their characterization in the laboratory. The conditions of sampling and analysis are described in section 2.2 of the manuscript (see lines 155 to 158).

- Line 450: The beta should be a\_s.

Response: Many thanks for noticing this error; we have corrected it.

- Line 453: I have recalculated the RF values in Fig. 9 graphically and get about 20% lower values. Please check the integration. Note that in Fig. 9 the wavelengths are not equidistant as shown!

Response: We have corroborated manually and in R our calculations to obtain RF and found similar values in both cases. The RF is calculated as the area under the curve formed by the median SFE at each wavelength, applying the trapezoidal rule for uneven intervals. The results are still the same as those reported in the manuscript. We have adjusted Fig. 9 to show the accurate distances among the wavelengths in the x axis.

- Line 460,461: two times: inverse square meter

Response: The units are given as  $\text{W m}^2 \text{ nm}^{-1}$ .

- Line 466: the lensing effect was not described before. Have you compared the  $\text{MAC}_{\text{BC}}$  with literature values? Should it be higher in this study?

Response: Thanks for the observation. The lensing effect was briefly mentioned in the introduction; however, further details have been included in the revised manuscript (see lines 76 to 77). Typical  $\text{MAC}_{\text{BC}}$  values fall in the range of 5 to  $15 \text{ m}^2 \text{ g}^{-1}$  for wavelengths between 500 and 880 nm and exhibit an inverse relationship with wavelength (Bond and Bergstrom, 2006; Feng et al., 2021; Mbengue et al., 2021). At 550 nm, Bond and Bergstrom (2006) suggest that BC has a reliable MAC of  $7.5 \pm 1.2 \text{ m}^2 \text{ g}^{-1}$ . Tropos' measurements at the village of Melpitz yielded a  $\text{MAC}_{\text{BC}, 880 \text{ nm}}$  of  $6.5 \text{ m}^2 \text{ g}^{-1}$ , using harmonized light absorption coefficients. The calculated  $\text{MAC}_{\text{BC}, 950 \text{ nm}}$  for Loški Potok, was  $6.7 \text{ m}^2 \text{ g}^{-1}$ , which remains within the range of previously reported values and is similar to  $\text{MAC}_{\text{BC}}$  for Melpitz. For Loški Potok, the  $\text{MAC}_{\text{BC}}$  could be comparatively lower than other studies because of the high wavelength for which it is reported and the introduction of the harmonization of the light absorption coefficients. We know a fraction of previous studies has not considered additional corrections for the aerosol scattering contribution on filter-based absorption photometers.

- Line 470, Table 3: The min and max values are not very meaningful because they depend on the choice of the averaging interval. Better would be e.g. quantiles

Response: We respectfully prefer to maintain min and max values; however, we have included percentiles 10 and 90 in Tables 3 and 4.

- Line 489, 490: Consider (again) the number of significant digits. Put the units after the whole expression: e.g:  $71 \pm 56 \text{ ug/m}^3$ .

Response: We have adjusted our figures to keep two significant digits. Also, we have changed the position of the units.

## References

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