Answer to Referee #1 on: "*Characterization of filter photometer artefacts in soot and dust measurements – laboratory and ambient experiments using a traceably-calibrated aerosol absorption reference*"

We would like to thank the referee for the time invested in the review process of the manuscript and for the useful comments and remarks that will help improve our study. Below we reply to the referee comments. The text, added to the manuscript or significantly modified, is shown in blue.

1. **Abstract: The abstract is unclear about the purpose, methods, and key results. You can add content similar to Lines 40-55 to the abstract to explain why you conducted this study.**

   Taking into account this comment, we have modified the abstract, most importantly by introducing the following sentence at the start of the abstract:

   "We provide, for different aerosol types, reference values of the multiple scattering parameter, quantifying the artefact introduced by the interaction between the light, the particles and the filter."

2. **Introduction: The introduction is not clear for readers. How do you measure the absorption of soot and dust? What are the problems with current measurement methods? PTAAM-2λ provides reference data. I think these are your key points, but the information is spread across too many paragraphs and is not direct or clear for readers.**

   We have significantly rewritten the introduction so that it is clearly stated how we measured absorption and the problems with current methods. These changes are shown as tracked changes in the revised manuscript.

3. **For example, you can use clearer and simpler sentences to introduce that you will develop a novel method to measure dust using AE33, a measurement tool designed for black carbon (BC) (Lines 17-50).**

   As it was commented in the paragraph between 47-53, despite being designed for BC, filter photometers have been used in the past and are being used now for mineral dust. We don't introduce a novel method to measure dust using AE33, what we aim is to provide a better characterization of the artefacts related to the use of AE33 (and CLAP) for deriving the absorption of mineral dust. We have modified these paragraphs to better reflect this. The changes are shown as tracked changes in the revised manuscript.

   "The most widely used instrumentation to determine aerosol absorption coefficients, especially in ambient measurements, are filter absorption photometers (Moosmuller et al., 2009): aethalometers (Hansen et al., 1984; Drinovec et al., 2015), particle soot absorption photometers (PSAP; Bond et al., 1999), continuous light absorbing photometers (CLAP; Ogren et al., 2017) and the multi angle absorption photometers (MAAP; Petzold and Schonlinner, 2004). Their working principle (with some design variations) is based on the continuous accumulation of the aerosol sample on the filter, through which the attenuation of light in comparison with a blank filter is measured to derive absorption coefficients and the equivalent black carbon concentrations (eBC; Petzold et al., 2013). Filter photometers feature three main artefacts that influence and hinder the correct determination of the absorption coefficients. The first is the filter loading effect which can be corrected using assumptions (Bond et al., 1999; Weingartner et al., 2003; Collaud Coen et al., 2010), or measurements (Drinovec et al., 2015, 2017). The second is the amplification of absorption of light in the particles resulting from the scattering of light by the filter tape fibers, which is corrected by

introducing a multiplicative multiple-scattering parameter C, describing the enhancement of absorption by the scattering of light in the filter matrix (Arnott et al., 2005; Ogren et al., 2017; Drinovec et al., 2015). The third effect is the scattering of light by the particles embedded in the filter, reducing the transmission of light through the sample-laden filter due to scattering which is misinterpreted as absorption (Yus-Díez et al., 2021; Drinovec et al., 2022). The three artefacts are treated as separate, even though they are somewhat co-dependent, as shown in the light-transport models (Müller et al., 2014).

The filter loading effect results in the loss of sensitivity of the instrument due to the increase in the sample load in the filter (Bond et al., 1999; Weingartner et al., 2003). Multiple algorithms for the compensation of the filter loading effect have been developed for different filter photometer models (Bond et al., 1999; Virkkula et al.,2007; Weingartner et al., 2003; Drinovec et al., 2015; Ogren et al., 2017). The newest aethalometer models (AE33 and latest versions) feature a correction with an integrated compensation algorithm using online measurements of the filter loading effect (Drinovec et al., 2015). In addition, the physical properties of the sampled particles influence the multiple scattering of the collected particles within the filter (Weingartner et al., 2003; Lack et al., 2008; Virkkula et al., 2015; Drinovec et al., 2015; Yus-Díez et al., 2021), since particles with a higher single-scattering albedo produce an enhancement of the multiple scattering of light, increasing the apparent attenuation (Yus-Díez et al., 2021), and smaller particles have the ability of being deposited deeper inside the filter matrix, also enhancing the apparent attenuation measured by the filter photometers (Drinovec et al., 2022).

Filter photometers were designed for black carbon measurements (Gundel et al., 1984), however, the measurement was interpreted concurrently as a value of the absorption coefficient (Hansen et al., 1982, 1984). Eventually, filter photometers were also used to obtain the absorption coefficients for dust measurements (Fialho et al., 2005; Fialho et al., 2006; Di Biagio et al., 2017). The sensitivity of filter photometers depends on the depth at which particles are trapped in the filter matrix, which differs across filter photometer models and the aerosol particle size. This is taken into account by the MAAP using a simple radiative transfer model that takes into account the backscattering of light at two angles (Petzold and Schönlinner, 2004), or observed in other filter photometers as the dependence of the multiple-scattering parameter C on the single scattering albedo and the size of the particles (Yus-Díez et al., 2021; Drinovec et al., 2022). Therefore, in order to use the filter photometers, the measurement needs to be characterized with a representative sample and its artefacts quantified, which requires a better characterization for soot-like particles, mineral dust samples and ambient measurements where these two types of aerosol species appear simultaneously."

4. **Lines 211: Provide more details about Equation (9) in Yus-Díez et al. (2021).**

Following the referee advice, we have introduced a new paragraph explaining further the methods to obtain the scattering artefact, including explicitly the equation that is fitted - Eq. (9) in Yus-Díez et al. (2021). This can be found in the Section 2.3, eq. (3) and the paragraph just before it. It can be seen in the manuscript with the introduced changes.

"There are two main methods to obtain the scattering artefact, m_s: i. as the slope between the reported absorption by the filter photometers versus the measured scattering artefact for a non-absorbing material, such as quartz (Drinovec et al., 2022) or ii. by combining eqs. (1) and (2) with the definition of the single scattering albedo, SSA = bsp/(bsp + babs) and fitting the resulting equation, as shown in eq. (9) of Yus-Díez et al. (2021).

$$C = C_{ref} + m_s \cdot SSA/(1 - SSA) \quad (3)$$

Unlike in previous studies (e.g., Bernardoni et al., 2021; Yus-Díez et al., 2021), here we use as reference an instrument that does not suffer from the size and scattering artefacts – the PTAAM-2λ (Drinovec et al., 2022). As a consequence, we were able to determine the correction parameters without any additional artefacts from the reference absorption measurements. The pseudo-reference measurements used by Bernardoni et al. (2021) and Yus-Díez et al. (2021) were collected with with different filter photometers including polarimetric measurements with, PP_UniMI. With PP_UniMI and MAAP feature inversion algorithms that take into account the backscattering of light from the sample-laden filter to retrieve the absorption measurements, they are still subject to the main filter photometers artefacts. Here we use as reference an instrument that does not suffer from the size and scattering artefacts – the PTAAM-2λ (Drinovec et al., 2022). As a consequence, we were able to determine the filter photometer correction parameters without introducing additional artefacts from the (pseudo) reference measurements."

5. **Lines 181-182: Add sentences to emphasize that PTAAM-2λ provides reference data.**

We have modified the commented lines to introduce the referee suggestion:

"Here we present the analysis of filter photometer (AE33, CLAP and MAAP) artefacts from both laboratory and ambient campaigns, **using the traceably calibrated PTAAM-2λ as the aerosol absorption reference instrument**."

6. **Lines 272-274: This is a powerful conclusion, but how did you obtain it? Do you mean that the change is low, as shown in Table 3?**

Indeed, we mean that the difference is small between the values shown in Table 3 for the different event categories of the ambient measurements, the propane soot measurements and the literature values compared with. We have included further references to this table and rewritten slightly those lines to make it clearer, especially the sentence in question:

"Furthermore, the C did not vary significantly with the type of event affecting the site — urban background pollution, fresh urban pollution, a dust event, or globally transported wildfire smoke, with the differences in C values less than 20% at 450 nm and within 10% at 808 nm."

7. **Lines 317-319: This is a key point that should be included in the Introduction.**

We have modified the Introduction, lines 47-53 and 75-78, to highlight the point made in lines 317-319.

"Filter photometers were designed for black carbon measurements (Gundel et al., 1984), but the measurement was interpreted at the same time as one of the absorption coefficient (Hansen et al., 1982, 1984). Eventually, filter photometers were also used to obtain the absorption coefficients for dust measurements (Fialho et al., 2005; Fialho et al., 2006; Di Biagio et al., 2017). The sensitivity of filter photometers depends on the depth at which particles are trapped in the filter matrix, which differ across filter photometer models and the aerosol particle size. This is taken into account by the MAAP using a simple radiative transfer model that takes into account the backscattering of light at two angles (Petzold and Schönlinner, 2004), or observed in other filter photometers as the dependence of the multiple-scattering parameter C on the single scattering albedo and the size of the particles (Yus-Díez et al., 2021;

Drinovec et al., 2022). Therefore, in order to use the filter photometers, the measurement needs to be characterized with a representative sample and its artefacts quantified, which requires a better characterization for soot-like particles, mineral dust samples and ambient measurements where these two types of aerosol species appear simultaneously.

Ultimately, reference absorption measurements are required to measure the absorption coefficient and correct for the filter photometer artefacts. This is especially important since the new European Air Quality Directive (PE-CONS 88/24) requires the measurement of BC concentrations by optical absorption methods (European Commission, 2024). An often-used method to obtain the absorption coefficient, especially for laboratory experiments, is the extinction-minus-scattering method, which is usually performed by Cavity Phase Shift Extinction analyzers (CAPS; Massoli et al., 2010; Modini et al., 2021). Extinction-minus-scattering-obtained absorption coefficients are fairly robust and mainly feature low uncertainties, however for high single scattering albedo values, which are frequent in ambient measurements (Laj et al., 2020) and where the extinction is dominated by scattering, this methodology introduces very high uncertainties (Moosmüller et al., 2009; Singh et al., 2014),), especially when combined with imperfect nephelometer truncation error correction of the total scattering coefficient (Modini et al., 2021).

There are two main methods that provide direct measurements of the absorption coefficient and avoid artefacts introduced by filter photometers: photoacoustic spectrometry (PAS Arnott et al., 2003) and photothermal interferometry (PTI; Moosmüller and Arnott, 1996; Visser et al., 2020; Drinovec et al., 2022). Both are based on the heating of the aerosol sample by focusing light from an intensive source on it as it is drawn through a measurement chamber. The methods differ in the probe method: PAS uses an acoustic resonator and a microphone for detection, whereas PTI uses an interferometer and photodiodes. PAS can exhibit biases when the aerosol sample contains semi-volatile organic coatings or water, since the detected acoustic signal can be reduced by the latent heat of the material during evaporation of these substances upon heating (Arnott et al., 2003; Moosmüller et al., 2009). PTI and PAS have been found to agree when measuring soot particles coated with specific secondary organic matter (Kalbermatter et al., 2022). A novel traceably calibrated PTI instrument, the PTAAM-2λ (Haze Instruments, Slovenia) has been shown to provide accurate and precise aerosol absorption measurements for different aerosol particle compositions (Drinovec et al., 2022).

Filter photometers therefore require the use of a co-located reference absorption measurement for their calibration. Some studies have used either the extinction-minus-scattering method (Bond et al., 1999; Di Biagio et al., 2017) or another filter photometer, such as the tricolor absorption photometer (TAP) in Laing et al. (2020) or more sophisticated filter photometers that measure the backscattering of light from the filter such as the MAAP (Di Biagio et al., 2017; Yus-Díez et al., 2021) or the off-line Polar photometer of the University of Milano (PP_UniMI; Bernardoni et al., 2021; Ferrero et al., 2021). Indeed, the MAAP is used as the reference instrument in the Aerosol, Clouds and Trace Gases Research InfraStructure (ACTRIS; ECAC-CAIS, 2022) guidelines to harmonize absorption coefficients from the dual-spot multi-wavelength aethalometer, the AE33 (Drinovec et al., 2015), across the ACTRIS network. However sophisticated these methods are, none truly measure the absorption coefficient, and all add an additional layer of uncertainty. Recently, Drinovec et al. (2022) used a traceably calibrated instrument based on PTI, the PTAAM-2λ, to calibrate the AE33 and the CLAP and quantify their cross-sensitivity to scattering artefact for aerosol mixtures of fine soot and ammonium sulfate."

Answer to Referee #2 on: "*Characterization of filter photometer artefacts in soot and dust measurements – laboratory and ambient experiments using a traceably-calibrated aerosol absorption reference*"

We would like to thank the referee for the time invested in the review process of the manuscript and for the useful comments and remarks that will help improve our study. A detailed reply to the referee comments is provided below. The text, added to the manuscript or significantly modified, is shown in blue, with the bold text marked in places to show the additions.

General comments

- **The manuscript, in particular the introduction, is not providing all the necessary elements so that a non-fully expert reader can understand the problem and the chosen approach, as well the discussion of the results. I would encourage the authors to develop more in detail the different artefacts associated to filter-based measurements and the choice of the reference techniques.**

  Following the referee comment, we have significantly expanded and modified the Introduction and different parts of the text to make it more understandable and readable. Changes can be found in the tracked changes version of the document attached.

- **Tables of results and plots in the main manuscript are generally missing consideration of uncertainties or statistical variability and this would be required for supporting data presentation, discussion and results**

  We appreciate the comment provided by the referee on the topic of measurement uncertainties and statistical variability. It should be noted that for the main results of the text, a range of the uncertainty and goodness of the results is given in the Figures in the supplementary where the fit where the value is obtained from is shown, as it is the upper and lower 95% confidence interval of the results in Tables S2 and S3. We have changed the tables and figures in the manuscript to include the uncertainties and better support the results.

  We have also modified the text of Section 3, where a bigger emphasis on the uncertainty of the C is introduced:

  "Table 3 shows the multiple-scattering parameter, C, after correcting the attenuation coefficients for the cross-sensitivity to scattering for each of the sample types. The values have been obtained for each of the sample groups as the slope of the orthogonal fit of the attenuation coefficients corrected for the cross-sensitivity to scattering $b_{atn\ -\ cor}$ (cf. eq. 1) vs. the reference absorption coefficients from the PTAAM-2l (cf. Figs. S8-S24). It should be noted that due to the effect of interpolation/extrapolation from/to the filter photometer or PTAAM-2l wavelengths the C values reported at the filter photometer wavelengths vs. the PTAAM-2l could vary. This effect is expected to be the highest for dust, since the AAE between 370 and 660 nm for dust is higher than between 660 and 950 nm. During the UGR ambient measurements, the uncertainty of the regression due to interpolation of the absorption coefficient to 637 nm using AAE derived from the measurements at the two PTAAM wavelength (450 and 808 nm) instead of the seven AE33 ones (307 - 950 nm) was 4%. The uncertainty of the fit is shown by the R^2 and 95% confidence interval range for each sample in Tables S2 and S3. This confidence interval is obtained by introducing the measurement error into the Deming regression fit by error propagation of the standard deviation and the instrument uncertainty."

  And:

  "Two types of soot were analyzed: propane (mean volume particle diameter, D_p, of 341 nm) and diesel soot (D_p of 177 nm), for which the C for the AE33 at 450/808 nm was 4.08/3.95 and

6.25/5.27, respectively (cf. Table 3). The CLAP featured C values at 450/808 nm of 5.10/4.26 for propane soot and 6.79/5.80 for diesel soot. These C values are consistent with the values found in Drinovec et al. (2022) for similar diesel and propane soot samples, between 5.3 and 3.2 at 532 nm, and between 4.2 and 2.6 at 1064 m, for 100 and 500 nm volume size mode, respectively. There are some differences due to the difference in the measuring wavelength and the different flow used in the compared studies for the AE33. Weingartner et al. (2003) studied the C values for an aethalometer AE30 (a prototype of the AE31), and comparison is limited to some extent, they found for soot C values around 2.14 for diesel soot at 450 and 660 nm. These values need to be interpreted with caution. The aethalometer model AE31 uses quartz filter tape, which features significantly higher (relative) C values when compared to different AE33 filter tapes, as shown in the original AE33 publication (Drinovec et al., 2015). Furthermore, Yus-Díez et al. (2021) showed important influence of the filter type in AE33 on the C parameter. The C value of 1.44 recalculated for the CLAP from parameters in Ogren et al. (2017), based on the experiments from Bond et al. (1999) on aerosol mixtures of pure nigrosin with pure ammonium sulfate using also a reference extinction minus scattering measurement, is clearly lower than the nigrosin and/or any soot mixture measured in this study and in Drinovec et al. (2022). Unlike for mineral dust samples, the goodness of the fit (Tables S2 and S3) was very good for both for both soot samples for the AE33 and the CLAP through-out the different wavelengths (R2 >0.95). Furthermore, Table S4 summarizes the C and m_s parameters following Ogren et al. (2017) and Bond et al. (1999) nomenclature, i.e. K1 and K2 parameters.

- **The discussion on the discrepancies between the PTAAM and the MAAP is interesting and of potential relevance for the community. The authors identify as the limitation of the MAAP the reduced angular measurements, and the authors mention other more angular resolved instruments – such as for instance the PPUniMI – developed to overcome these issues. Does any other studies have provided comparison against those other instruments and how these investigations, if they exist, provide support to your analysis?**

  We identify the reduced angular measurements as a limitation of the instrument, as it has been shown when by Valentini et al. (2020) when they compared the results from the PP_UniMI with all the angles and using a MAAP-like set-up, or by Bernardoni et al. (2021) where they used both the PP_UniMI and the MAAP to obtain the C parameters for an ambient campaign in Milano. Similarly, Massabò et al. (2013) compared the lab built Multi-Wavelength Absorbance Analyzer (MWAA) with the MAAP and the University of Milano PP_UniMi**.** However, our manuscript is the first to report the comparison between a traceably calibrated direct reference absorption measurement (such as using the PTAAM-2l) and the MAAP, so we cannot reference previous studies. There is a comparison between indirect extinction-minus-scattering (EMS) measurement and MAAP (Romshoo et al., 2022) which shows a size dependent ratio between MAAP and EMS decreasing with volume mean diameter of the soot particles – for fresh soot the ratio is between 1.2 and 1.4 and around 1 for larger soot particles (all soot samples SSA<0.11). We have added this information and the reference to the manuscript text.

- **The text uses a lot of acronyms and the reading can result quite hard in some points also because many numbers (C for several instruments, aerosol types, wavelengths) are provided in the text. Please consider to introduce an acronym table and to simplify the text when possible to facilitate reading.**

  We acknowledge we introduce many acronyms through-out the manuscript, such as instrument names, abbreviation for measurements and variables, etc. Hence, we have checked the manuscript and eliminated the use of certain acronyms such as FP for filter photometers, or PM for particulate matter. Furthermore, we have introduced an acronym table as an appendix at the end of the manuscript (Appendix A).

Also, as the referee points out, the broad range of measurements for the C depending on the aerosol source, wavelength and instrument results into a text with many numbers. We have made the effort, when possible, to modify the text to facilitate the reading of the manuscript.

Specific comments

- **Lines 8-14: are the differences identified for C relevant within uncertainties**

  In accordance with the answer to the general comment #2, we have modified some sections of the manuscript to better capture the uncertainties of the results. The C differences identified in the abstract are relevant and are larger than the uncertainties.

- **Line 51: the C factor is mentioned but not introduced / explained**
  Line 52: this is relevant for all absorbing species, not only dust

  Both this and previous paragraphs were expanded to include these comments and are now modified:

  "The most widely used instrumentation to determine aerosol absorption coefficients, especially in ambient measurements, are filter absorption photometers (Moosmuller et al., 2009): aethalometers (Hansen et al., 1984; Drinovec et al., 2015), particle soot absorption photometers (PSAP; Bond et al., 1999), continuous light absorbing photometers (CLAP; Ogren et al., 2017) and the multi angle absorption photometers (MAAP; Petzold and Schonlinner, 2004). Their working principle (with some design variations) is based on the continuous accumulation of the aerosol sample on the filter, through which the attenuation of light in comparison with a blank filter is measured to derive absorption coefficients and the equivalent black carbon concentrations (eBC; Petzold et al., 2013). Filter photometers feature three main artefacts that influence and hinder the correct determination of the absorption coefficients. The first is the filter loading effect which can be corrected using assumptions (Bond et al., 1999; Weingartner et al., 2003; Collaud Coen et al., 2010), or measurements (Drinovec et al., 2015, 2017). The second is the amplification of absorption of light in the particles resulting from the scattering of light by the filter tape fibers, which is corrected by introducing a multiplicative multiple-scattering parameter C, describing the enhancement of absorption by the scattering of light in the filter matrix (Arnott et al., 2005; Ogren et al., 2017; Drinovec et al., 2015). The third effect is the scattering of light by the particles embedded in the filter, reducing the transmission of light through the sample-laden filter due to scattering which is misinterpreted as absorption (Yus-Díez et al., 2021; Drinovec et al., 2022). The three artefacts are treated as separate, even though they are somewhat co-dependent, as shown in the light-transport models (Müller et al., 2014).

  The filter loading effect results in the loss of sensitivity of the instrument due to the increase in the sample load in the filter (Bond et al., 1999; Weingartner et al., 2003). Multiple algorithms for the compensation of the filter loading effect have been developed for different filter photometer models (Bond et al., 1999; Virkkula et al.,2007; Weingartner et al., 2003; Drinovec et al., 2015; Ogren et al., 2017). The newest aethalometer models (AE33 and latest versions) feature a correction with an integrated compensation algorithm using online measurements of the filter loading effect (Drinovec et al., 2015). In addition, the physical properties of the sampled particles influence the multiple scattering of the collected particles within the filter (Weingartner et al., 2003; Lack et al., 2008; Virkkula et al., 2015; Drinovec et al., 2015; Yus-Díez et al., 2021), since particles with a higher single-scattering albedo produce an enhancement of the multiple scattering of light, increasing the apparent attenuation (Yus-Díez et al., 2021), and smaller particles have the ability of being deposited deeper inside the filter matrix, also enhancing the apparent attenuation measured by the filter photometers (Drinovec et al., 2022).

  Filter photometers were designed for black carbon measurements (Gundel et al., 1984), however, the measurement was interpreted concurrently as a value of the absorption coefficient (Hansen

et al., 1982, 1984). Eventually, filter photometers were also used to obtain the absorption coefficients for dust measurements (Fialho et al., 2005; Fialho et al., 2006; Di Biagio et al., 2017). The sensitivity of filter photometers depends on the depth at which particles are trapped in the filter matrix, which differs across filter photometer models and the aerosol particle size. This is taken into account by the MAAP using a simple radiative transfer model that takes into account the backscattering of light at two angles (Petzold and Schönlinner, 2004), or observed in other filter photometers as the dependence of the multiple-scattering parameter C on the single scattering albedo and the size of the particles (Yus-Díez et al., 2021; Drinovec et al., 2022). Therefore, in order to use the filter photometers, the measurement needs to be characterized with a representative sample and its artefacts quantified, which requires a better characterization for soot-like particles, mineral dust samples and ambient measurements where these two types of aerosol species appear simultaneously."

- **Lines 67-68: it is not clear why the EMS method is more relevant for laboratory than field measurements, please explain**

  Extinction-minus-scattering (EMS) works well for low SSA samples. Ambient samples, especially at different background sites, frequently feature high SSA, and, when combined with imperfect nephelometer truncation error correction, increase the uncertainty of EMS above 100% (Modini et al., 2021). We have modified the aforementioned sentence to:

  "A well-established method to obtain the absorption coefficient, especially for laboratory experiments, is the extinction-minus-scattering method, which is usually performed by Cavity Phase Shift Extinction analyzers (CAPS; Massoli et al., 2010; Modini et al., 2021). Extinction-minus-scattering-obtained absorption coefficients are fairly robust and mainly feature low uncertainties, however for high single scattering albedo values, which are frequent in ambient measurements (Laj et al., 2020), where the extinction is dominated by scattering, this methodology introduces very high uncertainties (Moosmüller et al., 2009; Singh et al., 2014), especially when combined with imperfect nephelometer truncation error correction of the total scattering coefficient (Modini et al., 2021)."

- **Line 75: the MAAP was already introduced in line 39**

  We mention the MAAP again in line 75 to demonstrate its application as an ACTRIS pseudo-reference in addition to the line 39, where it was introduced.

- **Line 82: the nephelometer is mentioned without any indication of which quantity is measured with this instrument**

  We have modified the paragraph as follows:

  "We use absorption coefficients, measured by the novel PTAAM-2λ, and the scattering coefficients, measured by the integrating nephelometer Aurora 4000, to fully quantify the artefacts of widely deployed filter photometers: the AE33, the CLAP and the pseudo-reference MAAP. For this purpose, we have performed chamber experiments with a wide variety of aerosol types during a laboratory campaign, as well as ambient measurements in a polluted urban background atmosphere in Granada (Spain)."

- **Line 95: please recall how the soot are produced (combustion conditions) and their main properties (chemical, physical)**

  We have modified the first paragraph in the section to:

  "Different samples of dust and soot-like aerosolized particles were measured in this study (cf. Table 1). Mineral dust, which is the most abundant aerosol compound in the atmosphere by mass,

with poorly constrained influence on the climate, features a small net cooling effect (Kok et al., 2023). BC particles, which are aggregate structures of graphene layers originated from the incomplete combustion of fossil fuel (Bond and Bergstrom, 2006), feature very high mass absorption cross-section values, and as such are the most important aerosol climate forcer (Bond et al., 2013; Szopa et al.,2021). Samples with high BC content: Euro-3 engine diesel soot and propane soot (Drinovec et al., 2022) were sampled. In addition, pure quartz dust (Sigma-Aldrich 342890-100G) was used as a purely scattering dust reference sample. Fig. S1 shows the CLAP filter spots as a visual reference for the different samples."

- **Line 104: if a reference exists for the dust generation device, please cite it (manufacturer)**

  It is an in-house device. It follows the same procedure as the one described in Moosmüller et al. (2012).

- **Lines 110-123: as volumetric quantities, if the absorption coefficient measurements are all reported to the same temperature and pressure (i.e. Standard Temperature and Pressure) or not should be mentioned. If not, is the difference in T and p reference affecting the comparison and to what extent?**

  We have included the following text at the first paragraph of section 2 for clarification purposes:

  "To allow comparison between the instruments, all measurements are reported in the same conditions of standard temperature and pressure (T=273.15 K and P=1013.25)."

- **Line 133: size instrumentation is introduced but some more details on the type of measured diameter and potential corrections applied to the data should be mentioned**

  We have modified the commented text to provide a more detailed description of the size instrumentation used:

  "Aerosol particle size distribution measurements were performed using an optical particle spectrometer (GRIMM 11-D) for mineral dust samples, which measures the number of particles in 31 bins for bins with an optical diameter size ranging from 0.253 to 35.15 µm. The particle size distribution for soot-like particles (diesel and propane) was measured with a scanning mobility parameter sizer (TSI model 393L75), which measures the number of particles in 64 bins for particle mobility diameters ranging from 15.12 to 982.17 nm Given the differences in the size range and type of diameter reported by each instrument, comparison for particle size dependence is performed in a qualitative manner."

- **Line 137: if the Teri (2022) correction scheme requires information on the complex refractive index of the aerosols to be applied, the hypothesis used should be explained**

  We have introduced the following text for clarification:

  "The instrument was set to measure total and back-scattering coefficients and angular truncation errors were corrected applying Teri et al. (2022) correction schemes using the scattering Ångström exponent for the size distribution and refractive indexes used by Anderson and Ogren (1998) and Müller et al. (2011b)."

- **Lines 167-169: not clear what is the "compensation scheme" used – lease give more details**

  We have modified the commented paragraph for clarification:

  "Using a constant multiple scattering parameter to compensate the artefacts of the filter photometer measurements under scenarios with high single scattering albedo, samples have been shown to introduce a large overestimation of the absorption coefficients measured with

aethalometers (Yus-Díez et al., 2021). To compensate for this cross-sensitivity to scattering of the filter photometers, we have applied the approach proposed by Yus-Díez et al. (2021) for the AE33, CLAP and MAAP, with a more detailed description provided below."

- **Lines 178-180: please provide more explanation as I am not sure this could be clear for non-fully expert readers**

  We have modified the paragraph to:

  "The pseudo-reference measurements used by Bernardoni et al. (2021) and Yus-Díez et al. (2021) were collected with different filter photometers including polarimetric measurements with PP_UniMI. While PP_UniMI and MAAP feature inversion algorithms that take into account the backscattering of light from the sample-laden filter to retrieve the absorption measurements, they are still subject to the main filter photometers artefacts. Here we use as reference an instrument that does not suffer from the size and scattering artefacts – the PTAAM-2λ (Drinovec et al., 2022). As a consequence, we were able to determine the filter photometer correction parameters without introducing additional artefacts from the (pseudo) reference measurements."

- **Section 3.1 misses discussion about laboratory soot experiment**

  The soot-like particles feature single scattering albedo values below the threshold above which the scattering parameter becomes important, therefore no correction for the cross-sensitivity to scattering is necessary and therefore performed.

  We have modified the beginning of this section to comment on this in the main text:

  "During the laboratory experiments we analyzed soot-like and dust samples. The soot-like particles feature single scattering albedo values below the threshold above which the scattering parameter becomes important, therefore no correction for the cross-sensitivity to scattering is necessary and therefore performed (Yus-Díez et al., 2021). We analyzed the filter photometer scattering cross-sensitivity artefact by measuring quartz as a reference sample for purely scattering mineral dust."

- **Fig 2 caption: "random sample" to replace with more specific sample identification**

  "Morocco Surface Random sample" is the published name of the sample given in González-Romero et al. (2023), and we have chosen to keep the same name. We have introduced further clarification to avoid possible confusion with its label.

  "a) Example of the typical time evolution for a resuspended mineral dust sample, during the measurement of the Saharan desert sample, "Morocco Surface random", Table 1, and described in further detail in González-Romero et al. (2023) - the attenuation coefficient (batn) of the AE33 and CLAP, and the PTAAM-2λ absorption coefficient, and b) the temporal evolution of the absorption from the PTI, the absorption Ångström Exponent, and the multiple-scattering parameter for 2 Saharan dust event days during the campaign in Granada (time in UTC). Note the logarithmic scale on the y-axis.".

- **Line 254: as it is absorption, then scattering is also used for EMS calculation with CAPS, to be mentioned**

  We have modified the sentence to include the comment:

  "Di Biagio et al., (2017) performed a similar study, albeit for an aethalometer AE31 (Magee Scientific, USA) which has been shown to have C values higher than those of the AE33 (Drinovec et al., 2015; Savadkoohi et al., 2023), where they (Di Biagio et al., 2017) measured reference dust

absorption using the extinction-minus-scattering method using a CAPS PMex and a nephelometer (model 3563, TSI Inc.) at 450 nm and the extrapolated MAAP absorption coefficients at 660 nm."

- **Lines 256-257: the fact that the C found in the present analysis using PTAAM data is lower than previous studies using MAAP observations as reference absorption is not in contradiction with the discussion in sect. 3.3?**

  Indeed, the C from Di Biagio et al. (2017) for dust at 660 nm, which they find using MAAP as reference, is higher than the one found in our study (Sect. 3.3). We attribute the higher values compared with Di Biagio et al. (2017) on the different aethalometer model AE31 with the quartz filter tape. The AE31 quartz tape features significantly higher C values when compared to different AE33 filter tapes, as shown in the original AE33 publication (Drinovec et al., 2015). Furthermore, Yus-Díez et al. (2021) show important influence of the filter type in AE33 on the C parameter. We have incorporated this in the text – see answer below.

- **Lines 265-269: would add comparison with soot data from Weingartner et 2003**

  We have introduced the following statement:

  "Weingartner et al. (2003) studied the C values for an aethalometer AE30 (a prototype of the AE31), and comparison is limited to some extent, they found for soot C values around 2.14 for diesel soot at 450 and 660 nm. These values need to be interpreted with caution. The aethalometer model AE31 uses quartz filter tape, which features significantly higher C values when compared to different AE33 filter tapes, as shown in the original AE33 publication (Drinovec et al., 2015). Furthermore, Yus-Díez et al. (2021) show important influence of the filter type in AE33 on the C parameter."

- **Lines 279-281: is this because urban air masses are dominant?**

  Indeed, this is our interpretation, supported by the PSD separation between the two types of events, as can be seen in Fig. S2b. We have modified the last sentence in the paragraph to make the message clearer:

  "It is the combination of the absorbing soot-like particles **(in the fine mode)** and the **coarser** dust particles present during the campaign that influenced the C, but the **small** changes of their relative contribution **(cf. Fig S2b)** did not have an effect on the resulting C values."

- **Sect 3.2: the comparison with the literature indicate both higher and lower values when referring to different aerosol types and photometer models. The conclusion of the comparison is not clear then, and would suggest to develop this point so that a clear message is delivered.**

  We appreciate the comment. Hence, at the end of the section we have introduced a paragraph to provide a summary of the results and a clear message. Furthermore, we have introduced a new section where we provide a summary and comparison on the multiple scattering values and harmonization factors: Section 4.

  "In brief, this section showcases the variation of the multiple scattering parameter for different aerosol types: mineral dust, soot-like particles and ambient urban aerosol. We have found that the key parameter is the source-dependent particle size, with smaller particles showcasing much higher values of the multiple scattering parameter C. Therefore, the comparison of our results with the literature showcases the impact of the variability introduced by different sources (and therefore size). When comparing these values with the previously published ones, it is important to take int account the use of different filter material in different (or same) filter photometer models. In this regard, this study provides a focused and in-detailed analysis of the behavior of

the C parameter for different aerosol types with different particle size ranges in two most-used filter photometers –the Aethalometer AE33 and the CLAP."

- **Line 299: how much the differences in diameter definition can influence the results and their interpretation?**

  We have modified the first paragraph of this subsection, where this comment applies to provide an approximate indication of the expected shift.

  "The conversion of the optical diameter to the mobility diameter would require assumptions on the complex refractive index, density, and most importantly, shape of mineral dust, as shown in Huang et al. (2020), which falls beyond the scope of this manuscript. Huang et al. (2020) showed that, for different assumptions of the complex refractive index and particle shape, optical diameters are on average 56% lower than geometric, which in turn are a 45% lower than aerodynamic diameters. Following the same assumptions on particle density and sphericity used to convert the UGR APS aerodynamic to mobility diameters, will result in an overall shift by ~ 1.7 of the diameters, thus resulting in a higher effective diameter, i.e., a positive shift of the corresponding data points in Fig. 5 in the x-axis."

- **Lines 364-369: would be good to have a reference for the results in relation to the stanBC campaign**

  We can't provide a reference since the stanBC campaign manuscripts is still under preparation and results showcasing this comparison have not been featured in any conference/workshop presentation. If the stanBC campaign paper is submitted during our review phase, we intend to quote the manuscript in the public repository.

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