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Report guidance to produce eBC concentrations from NRT ACTRIS absorption measurements

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1. Introduction

This report pictures the methodology established to produce equivalent black carbon mass concentration (eBC) in near real-time (NRT) from absorption coefficients measured by online monitors, such as the Multi-Angle Absorption Photometer (MAAP) or the various Aethalometer models (e.g., AE33) installed at fixed observatory platforms. These instruments are referred here as Filter Absorption Photometers (FAPs).

As previously defined in the frame of pre-ACTRIS research studies (Petzold et al., 2013): when using FAPs, "equivalent black carbon (eBC) should be used instead of black carbon for data derived from optical absorption methods, together with a suitable MAC [i.e., Mass Absorption Efficiency, in m^2/g] for the conversion of light absorption coefficient into mass concentration".

The process followed within CAMS2.21a to determine such a suitable MAC value at the European scale has been described in milestone M21a.1.1.1 (2023). It notably resulted from the collaborative work of an ad hoc working group of European experts, before discussion was enlarged as also part of WP1 activities of the HE RI-URBANS project, considering synergies between this ACTRIS-related program (proposing and testing services for urban air quality) and CAMS2.21a. This whole process was also conducted in collaboration with the current activities of the European standardization body for ambient air quality on the establishment of equivalent methods for the measurement of elemental carbon deposited on filters (CEN/TC 264 working group 35, chaired by JP Putaud).

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2. Measurement principles

Figure 1 summarizes the workflow decided to produce eBC Level3 data products within ACTRIS for the purpose of CAMS2.21a activities, as explained in M21a.1.1.1 (2023). A complementary description of this workflow is given in this section.

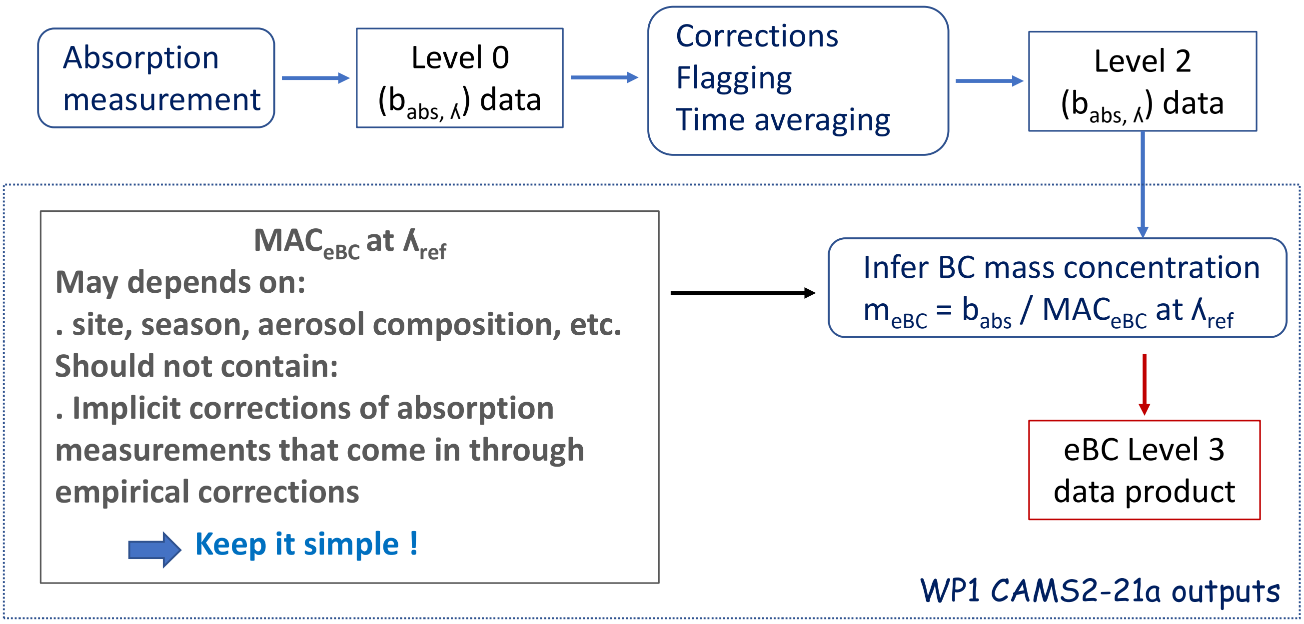

Figure 1: Workflow of the eBC level3 data product processing within CAMS21a.

Using FAPs, the attenuation or transmission of light through a sample spot is continuously recorded by the instrument. This measurement can be performed at one or several wavelengths and may have different artifacts mainly due to the interference of the filter that will depend on the type and model of instrument used.

The MAAP device (Thermo Fisher Sci.) measures b_{abs} at a single wavelength, specified as wavelength of 670 nm, although its actual wavelength is 637 nm (Müller et al., 2011). The measurement considers online artifacts related to the presence of the filter tape by simultaneously measuring the intensity of light transmitted through the aerosol-laden filter tape and scattered from the filter point at different angles, and subsequently converts this data into b_{abs}. However, the MAAP production is discontinued and its use in the monitoring sites is decreasing.

The Aethalometer (Magee Sci.) measures the attenuation of light (b_{ATN}) passing through an aerosol-loaded filter tape at several distinct wavelengths (typically, 370, 470, 520, 590, 660, 880, and 950 nm for AE33 models). For the determination of eBC mass concentrations, the signal at 880 nm is commonly used because absorption due to other aerosol species than BC (mostly organic and iron oxide-containing aerosols) is negligible in the near-infrared region. Attenuation is due to both absorption and scattering of light. Moreover, multiple scattering effects may also occur within the filter fibers where particles are embedded. For Most recent AE33 and AE36 models correct online for this artefact by applying the so-called “dual spot” method (Drinovec et al., 2015). b_{ATN} shall then be divided by the filter multiple-scattering parameter (C_0) to determine b_{abs}:

$$babs = \frac{b_{ATN}}{C_0}$$

Eventually, it is necessary to apply harmonization factors as such those proposed by ACTRIS to ensure consistency between the various instrument types (Müller and Fiebig, 2018).

Whatever the used instrument, eBC can then be obtained dividing harmonized absorption coefficients (b_{abs}) by the Mass Absorption Cross section (MAC) that represents the actual efficiency of BC particles to absorb light, following:

$$eBC = \frac{b_{abs}}{MAC}$$

Various MAC values are proposed by the instrument manufacturers and included in their firmware, but they may lead to unsatisfactory agreement between the various types of devices. Indeed, the MAC value i) cannot be measured directly and ii) is known to vary with the chemical and physical properties of the absorbing particles, the choice of a “suitable MAC” value has been a subject of great debate within the scientific community. However, in the context of NRT data provision, it has been decided that eBC calculations should stay as simple and operational as possible (as presented in Figure 1).

Considering that BC is the main light absorbing particle in ambient air at wavelengths corresponding to the (near) infra-red (IR) region, the MAC of BC can be estimated from the measurements of b_{abs} (in m^{-1}) at a given near-IR wavelength (typically at 880 nm for multi-wavelength aethalometers) combined with the knowledge on black carbon-related mass concentration (BC_{proxy}) such as:

$$MAC_{BC,\lambda} = b_{abs,\lambda} / [BC_{proxy}].$$

The most common BC_{proxy} corresponds to Elemental Carbon (EC), which is already subject to regulatory measurements according to a well-defined standardized method in ambient air at the European scale (EN 16909, elaborated by CEN/TC 264). Co-located b_{abs} and EC measurements at various sites can then be used to determine an average (or median) MAC value across Europe, as previously proposed by Zanatta et al. (2016). Further investigations have been made in the frame of the present CAMS2.21a contract to consolidate this “overall MAC value”, as detailed in the following section.

3. Confirmation of the ACTRIS MAC value

Zanatta et al. (2016) took advantage on the combination of collocated b_{abs} and elemental carbon (EC) measurements at 9 regional background sites across Europe, in the frame of the ACTRIS-2 research project. It notably illustrated the variation of the MAC value (calculated at a given wavelength as $b_{abs,\lambda}$/EC) in relation with the coating of BC particles by inorganic and organic material. Nevertheless, it indicated relatively similar annual mean MAC values (around 10.0 m^2 / g), which was then considered as representative of the mixed boundary layer at European background sites. Further investigations shall include longer time periods and a comprehensive set of various European urban environments. These investigations have been mainly achieved in collaboration with IDEAE-CISC (Marco Pandolfi and Marjan Savadkoohi), first in the frame of the CAMS21a ad hoc working and then as a synergistical activity within the HE RI-Urbans project (WP1).

Figure 2 is presenting the frequency distributions and related statistical parameters for MAC values at several European stations (Table 1), complementing previous analyses presented in Zanatta et al. (2016).

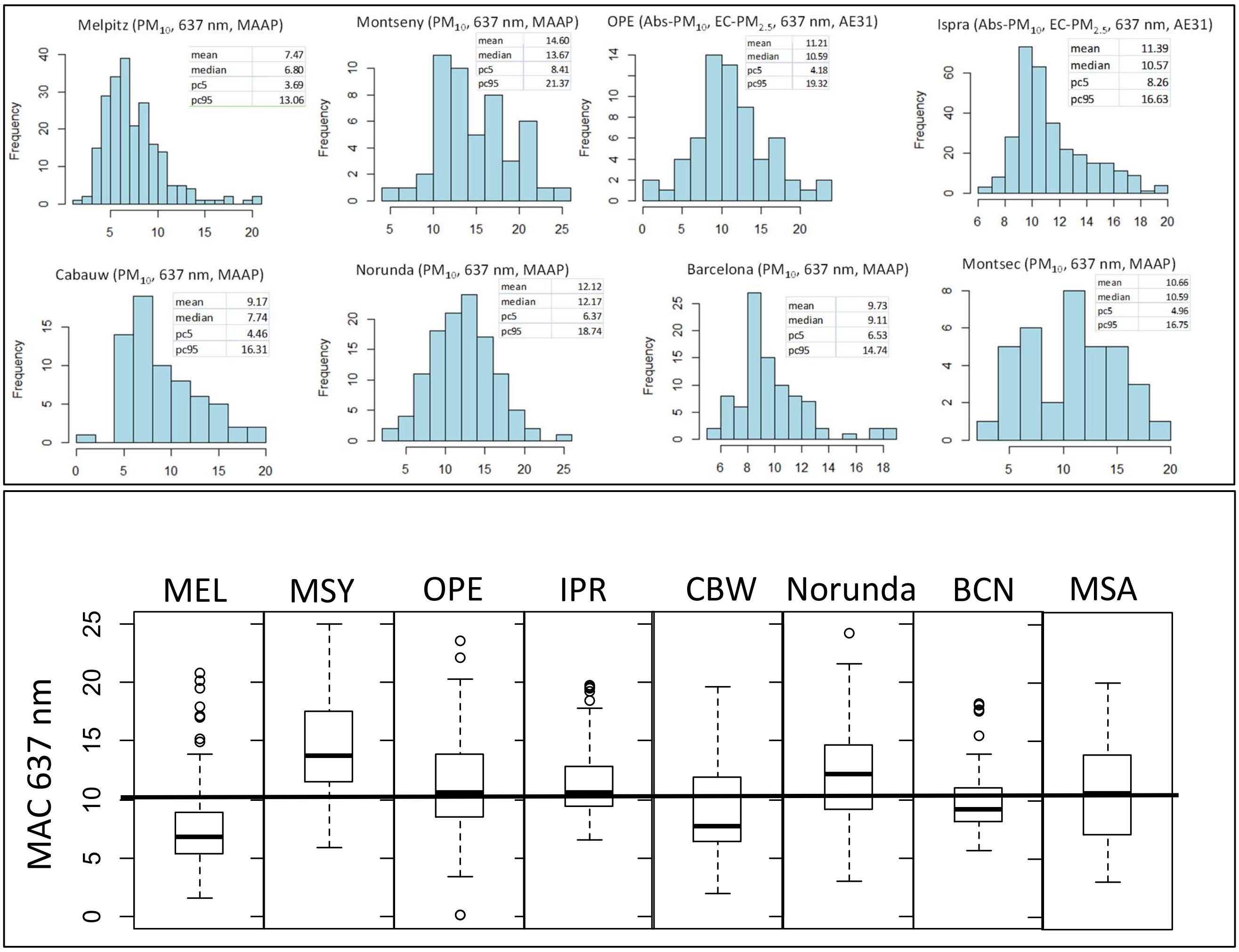

Figure 2: Frequency distributions, box-and-whisker plots, as well as mean, median and percentiles values obtained from MAC calculations at various European sites (CAMS2.21a ad hoc WG).

Mean MAC value calculated from the MAC median values obtained at the 8 stations was: 10.16 ± 2.24 m^2/g. The median values of the medians was: 10.58 ± 2.24 m^2/g.

Alternatively, mean and median MAC values can be calculated using all the MAC values from the 8 stations together. The frequency distribution of MAC values from all the stations is reported in Figure 3, conforming a good agreement with previous results (with MAC value around 10 m^2/g at 637nm).

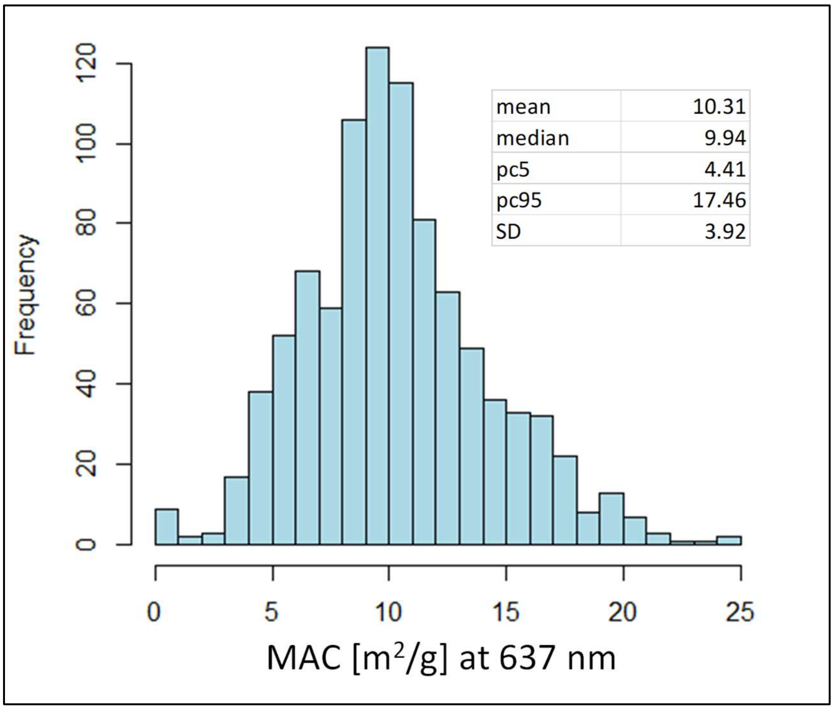

Figure 3: Frequency distributions of the MAC values obtained when pooling sites together (CAMS2.21a ad hoc WG).

Table 1: description of the stations used for the calculations presented in Figures 2 and 3.

Station	type	Country	Instrument
Melpitz	rural background	Germany	MAAP
Montseny	regional background	Spain	MAAP
Observatoire Pérenne de l'Environnement	rural background	France	Aethalometer (AE31)
Ispra	rural background	Italy	Aethalometer (AE31)
Cabauw	rural background	The Netherlands	MAAP
Norunda	rural background	Sweden	MAAP
Barcelona	urban background	Spain	MAAP
Montsec	remote/mountain station	Spain	MAAP

Complementary results, including additional sites and/or periods, have then been obtained in the frame of RI-Urbans activity, which is synthetized in Table 2 taken from Savadkoohi et al. (2024).

Table 2
Site-specific experimental MAC values for 22 monitoring sites obtained as the ratio of the b_{abs} to EC mass concentration at the instrument specific wavelengths AE 880 nm; MAAP 637 nm.

Sites	FAPs	Site-specific MAC [m^2g^{-1}], AE 880 nm; MAAP 637 nm	Number of observations
BCN_UB	MAAP	9.6 ± 2.6	1035
GRA_UB	MAAP	10.4 ± 3.3	391
ROC_UB	AE21	7.2 ± 2.8	1390
ATH_UB	AE33	6.1 ± 4.0	1244
MAR_UB	AE33	5.1 ± 1.7	120
DDW_UB	MAAP	10.4 ± 4.1	179
LND_UB	AE22	8.8 ± 2.6	1565
BER_TR	AE31-AE33	5.7 ± 3.5	350
ZUR_UB	AE33	4.9 ± 2.3	338
ROM_UB	AE33	8.8 ± 3.1	43
MLN_UB	MAAP	11.2 ± 6.5	1142
PRG_UB	MAAP	14.0 ± 3.7	296
UMH_UB	AE33	7.3 ± 2.1	136
HEL_TR2	MAAP	12.4 ± 4.7	38
LEJ_TR1	MAAP	13.8 ± 4.6	164
DDN_TR	MAAP	9.6 ± 2.6	181
LND_TR	AE22	9.7 ± 1.8	1856
ATH_SUB	AE33	10.1 ± 2.3	513
PAR_SUB	AE31-AE33	5.5 ± 3.0	2190
SMR_RB	MAAP	7.3 ± 4.7	432
IPR_RB	MAAP	10.8 ± 4.4	3945
PAY_RB	AE31-AE33	12.4 ± 4.1	494

All these results confirmed the accuracy of a mean value of 10 m^2/g for MAC value (at 637nm) at the European scale.

4. Open-source software to be used for NRT eBC calculation

The software implemented at the ACTRIS Data Centre (DC) In Situ unit for deriving the eBC mass concentration is based on the algorithm described above. The software uses fully corrected aerosol particle light absorption coefficient data as input, which may originate from all commonly used filter absorption photometer types. This includes not just Multi-Angle-Absorption-Photometers (MAAP) and Model 33 aethalometers (AE33), but also older filter absorption photometers, e.g Model 31 aethalometers (AE31) or particle soot absorption photometers (PSAP) and derived designs. The details of corrections applied to the data depends on instrument manufacturer and model, but always results in comparable aerosol particle light absorption coefficient data.
The calculation of the eBC mass concentration, as well as the associated MAC value, always refers to a light wavelength of 637 nm. In case the instrument doesn't provide the aerosol particle light absorption coefficient at this wavelength directly, the software interpolates the value from the values at the 2 neighbouring wavelengths by using the Ångström exponent method. In case the instrument only measures at 1 wavelength which differs from 637 nm, the aerosol particle light absorption coefficient is shifted to this wavelength assuming an Ångström exponent of 1.
The software is maintained in 2 versions which differ only in the data format they accept as input. The educational version is targeted towards the ACTRIS Virtual Research Environment (VRE), and uses NetCDF formatted data as provided by the ACTRIS Data Portal as input. The other version is the production version used in the real-time data production chain, and uses EBAS NASA Ames 1001 formatted data as input. This format is currently used throughout the ACTRIS In Situ data production chain. The software can be openly accessed online:

- Educational version
- Production version.

Both software versions are available under the GNU-AGPL-3.0 license. This license is not to be confused with the Creative Commons by Attribution 4.0 International (CC-BY-4.0) license which is governing the use of ACTRIS data.

5. Conclusions

As part of this RI-Urbans activity, 20 additional sites (mainly urban ones) could be investigated for their MAC values calculated from the comparison of optical and elemental carbon measurements and using different methodologies. Results obtained are in good agreement with those previously obtained by Zanatta et al. (2016) and by further investigation by Marco Pandolfi at regional background sites, notably suggesting that the MAC value of 10 m²/g (at 637 nm) can reasonably be considered as the median annual mean value representative of rural and urban European environments and therefore as the value to be used to calculate ACTRIS eBC level 3 data product.

The whole procedure to generate such eBC level 3 data product in NRT has been developed in a comprehensive open-source software (using Python scripts) implemented at ACTRIS DC and openly available.

Finaly, it has been decided that ACTRIS should continue to work actively on the establishment of complementary methodologies like a CEN/TC264 standard for aerosol absorption and data workflow to produce another type of level 3 data, accounting for the MAC variations in time and space and to reduce the uncertainty of the current eBC estimate.

6. References

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