https://doi.org/10.5194/egusphere-2026-2302
Preprint. Discussion started: 2 June 2026

Opinion: From Conversion Factors to Diagnostic Signals: Reframing the Relationships among eBC, EC, and rBC

Zefeng Zhang

School of Atmospheric Physics, Nanjing University of Information Science and Technology, Nanjing, China

Correspondence: Zefeng Zhang (zhangzf01@vip.163.com)

Abstract. Equivalent black carbon (eBC), elemental carbon (EC), and refractory black carbon (rBC) are widely recognized as distinct operationally defined BC-related metrics (Petzold et al., 2013). Building on this terminology, a further question remains: how should the empirical relationships among these metrics be characterized? In practice, these metrics are often connected through empirical conversions. For example, eBC depends on an assumed mass absorption cross-section (MAC), while cross-metric relationships such as eBC/rBC, eBC/EC, and EC/rBC are often used to compare or harmonize measurements. We define such cross-metric relationships as “response ratios”, which possess a dual identity: when treated as constants, they serve empirical harmonization; when treated as variables, they can serve as diagnostic observables sensitive to coating, aging, source type, non-BC absorption, and operational protocols. This leads to an “equivalence trilemma”: method specificity, universal numerical equivalence, and aerosol-state sensitivity cannot all be fully preserved simultaneously. Rather than challenging standardization, this trilemma clarifies what harmonization can and cannot retain. We recommend transparent reporting of primary observables and conversion assumptions, and retaining response ratios in multi-method datasets. Shifting attention from using conversion factors only as fixed constants to also examining their variability can help extract richer aerosol-state information from existing multi-method BC measurements.

1 Introduction

1.1 Terminological consensus: eBC, EC, and rBC are distinct metrics

Black carbon (BC) is not a single chemically defined substance but a class of carbonaceous aerosol characterized by strong light absorption, high-temperature refractoriness, thermal stability, and chain-like aggregate morphology (Bond et al., 2013). Because no single measurement principle can capture all of these attributes simultaneously, instruments based on different physical principles often produce markedly different "BC" mass concentrations (Petzold et al., 2013; Slowik et al., 2007). Petzold et al. (2013) provided a landmark clarification by distinguishing three operationally defined metrics:

- **eBC (equivalent black carbon):** derived from optical absorption measurements and converted to a mass concentration via an assumed mass absorption cross-section (MAC);

https://doi.org/10.5194/egusphere-2026-2302
Preprint. Discussion started: 2 June 2026

- **EC (elemental carbon):** defined by thermal-optical analysis and strictly dependent on a specified temperature protocol and charring correction scheme;
- **rBC (refractory black carbon):** measured by laser-induced incandescence, primarily reflecting the mass of refractory carbonaceous cores that incandesce under intense laser heating.

A key implication of this terminology framework is that eBC, EC, and rBC are best regarded not as interchangeable estimates of a single directly measurable “true BC mass”, but as distinct, operationally defined, yet empirically related BC-related metrics.

1.2 The unresolved issue: from terminological distinction to relationship characterization

Terminological distinction provides the necessary foundation, but it is not sufficient on its own. A further practical question remains: how should the empirical relationships among eBC, EC, and rBC be characterized? Even when it is accepted that eBC, EC, and rBC are different quantities, unresolved practical questions remain: What are the empirical relationships among them? Under what conditions do they converge? When do they diverge, and what does such divergence signify?

In atmospheric observations, eBC, EC, and rBC are not unrelated. They all respond to shared attributes of carbonaceous aerosols and therefore often show statistical correlations (Wu et al., 2025). Monitoring networks and field campaigns often report multiple BC-related metrics side by side, model evaluations require comparisons across metrics, and climate and health studies frequently need to merge or convert data obtained by different methods (Bond et al., 2013; Pileci et al., 2021; Tinorua et al., 2024; Wu et al., 2025). The scientific challenge, therefore, is neither to conclude that these metrics cannot be compared because they are different, nor to treat them as identical because they are correlated. A more accurate formulation is: **eBC, EC, and rBC are distinct but empirically related BC-related mass metrics. The task is not to deny their association or to force them into a single value, but to identify under what conditions their relationships change and to interpret what information such changes contain.**

1.3 The analogy of equivalent particle diameters

This situation closely resembles the concept of equivalent diameters in aerosol science. Mobility diameter, aerodynamic diameter, optical equivalent diameter, and volume-equivalent diameter arise from different measurement principles and correspond respectively to electrical mobility, inertia, light-scattering cross-section, or geometric volume. Although these diameters can be converted into one another, the conversion factors are not universal constants but depend on particle effective density, shape factor, refractive index, and hygroscopicity (DeCarlo et al., 2004). In practice, the aerosol community does not seek to force all diameter definitions into a single "true" diameter; rather, it routinely uses the ratios among different diameters to infer particle density, morphology, or mixing state (DeCarlo et al., 2004).

BC measurements can be viewed from a similar perspective. eBC, EC, and rBC are empirically related, but their ratios—such as eBC/rBC, eBC/EC, and EC/rBC—should not be seen merely as "unstable conversion constants". They can also be regarded as potential diagnostic signals of aerosol state. In other words, **the variability of conversion factors may itself be scientifically informative, rather than merely an obstacle to harmonization.** Building on this analogy, we treat eBC, EC, and rBC as distinct response-to-mass mappings and discuss how cross-metric response ratios can be reframed from empirical conversion factors into diagnostic signals of aerosol state.

2 Response-to-mass mappings and the equivalence trilemma

2.1 A unified response-to-mass mapping framework

We refer to eBC, EC, and rBC collectively as BC-related mass metrics to emphasize that each is the result of a specific operational procedure that converts a physical or chemical response into a mass concentration. Each metric can be understood as a response-to-mass mapping, which can be written in the general form

$$M_i = H_i(S;\theta_i) + \epsilon_i \tag{1}$$

where S represents the multidimensional aerosol state (including BC core mass, size distribution, morphology, coating thickness, mixing state, organic matter, brown carbon, and mineral dust), H_i is the observation operator for method i, θ_i denotes the method-specific parameter set (such as the assumed MAC, thermal protocol, or calibration curve), and ϵ_i represents residual measurement or representation errors. eBC, EC, and rBC are the outputs of three typical observation operators:

$$eBC = H_{opt}(S; MAC_{assumed}, \lambda, correction) \tag{2}$$

$$EC = H_{therm}(S; protocol, split\ correction) \tag{3}$$

$$rBC = H_{inc}(S; calibration, size\ range) \tag{4}$$

Optical mapping. Optical instruments measure the light absorption coefficient b_{abs} and convert it to eBC via an assumed MAC: eBC = b_{abs} / $MAC_{assumed}$. However, the actual absorption can be decomposed as

$$b_{abs} = M_{BC} \cdot MAC_{eff}(S) + b_{abs}^{non-BC}(S) \tag{5}$$

where M_{BC} is an absorption-relevant BC core mass quantity (which may be approximated by rBC under suitable conditions), MAC_{eff}(S) is the state-dependent effective MAC, and ba_{bs}^{non-BC}(S) accounts for absorption by non-BC species such as brown carbon and mineral dust. Thus eBC is a composite quantity that embeds the assumed MAC, variations in the effective MAC, and non-BC absorption contributions.

Thermal-optical mapping. EC is strictly dependent on the temperature protocol and charring correction method (Schmid et al., 2001). Different protocols can lead to systematic differences in EC, which may be amplified under conditions of high organic carbon loading, substantial charring, or complex sample matrices.

Incandescence mapping. Laser-induced incandescence instruments, such as the Single Particle Soot Photometer (SP2), convert the incandescence signal to rBC mass via a calibration curve (Schwarz et al., 2006). rBC primarily reflects refractory core mass and is less directly sensitive to coating-induced optical enhancement than absorption-based methods, but its absolute concentration depends on the calibration material, the detectable size range (typically ~70–500 nm), and the method used to extrapolate mass outside that range (Pileci et al., 2021; Tinorua et al., 2024).

These three mappings differ fundamentally in their physical basis and mathematical form (Table 1). Consequently, the ratios of their outputs—the response ratios defined below—are generally state-dependent, and a universal, state-independent conversion factor should not be presumed.

Table 1. Response-to-mass mappings of three BC-related metrics

Metric	Primary observable response	Mapping form	Key assumptions or parameters	Main state sensitivities
eBC	Light absorption coefficient babs*b*abs	$b_{abs}/MAC_{assumed}$	MAC, wavelength, filter correction method	Coating, aging, brown carbon, mineral dust, size, morphology
EC	Thermogram	Protocol-dependent carbon split	Temperature protocol, charring correction, split logic	OC charring, protocol differences, mineral matrix, source
rBC	Incandescence signal	Calibration curve	Calibration material, detection size range, extrapolation method	Core size range, morphology, calibration

2.2 The equivalence trilemma

When working with multiple BC-related metrics, researchers typically wish to achieve three goals simultaneously: **A. method specificity**—acknowledging that eBC, EC, and rBC are distinct; **B. universal numerical equivalence**—having stable conversion coefficients c_{ij} such that $M_i = c_{ij} M_j$; and C. aerosol-state sensitivity—retaining diagnostic information on how cross-metric relationships vary with aerosol state S, i.e.,

$$R_{ij} = \frac{M_i}{M_j} = g_{ij}(S) + \epsilon \tag{6}$$

These three goals cannot all be fully realized at the same time, giving rise to what we term an equivalence trilemma (Table 2). If one fixes conversion factors to achieve numerical equivalence, the state-dependent variability must be averaged out or neglected. If one preserves state sensitivity, the cross-metric ratios are necessarily conditional. If one constructs a unified product that adjusts for state, the result is a model-mediated quantity that no longer represents any single original method-specific metric.

This trilemma is not unique to BC measurements. In aerosol particle sizing, mobility diameter, aerodynamic diameter, and optical equivalent diameter also correspond to different observational responses. In practice, the field does not require these equivalent diameters to be numerically identical; instead, their relationships are used to infer effective density, shape factor, and mixing state. Analogously, response ratios among BC-related metrics should not be treated merely as harmonization residuals but can be viewed as diagnostic quantities shaped by both method-specific responses and aerosol state.

The trilemma can be concisely stated as: One should not expect universal, state-independent conversion factors among BC-related metrics without sacrificing either method specificity or aerosol-state information. Importantly, this trilemma does not diminish the value of instrument calibration and standardization, which ensure comparability within a given method. The trilemma focuses on cross-method relationships and aims to clarify the information trade-offs that harmonization strategies entail.

Table 2. The equivalence trilemma for BC-related metrics

Goals preserved	Goal weakened	Reason
A + B	C	To obtain stable conversion factors, the state-dependent variability in the ratios must be averaged out or neglected.
A + C	B	If response ratios vary with state, no single fixed conversion coefficient can apply across all conditions.
B + C	A	Constructing a state-adjusted unified product produces a model-mediated quantity that is no longer identical to any original method-specific metric.

3 Response ratios as diagnostic observables

3.1 Definition and dual identity

We refer to the ratios among different BC-related metrics collectively as response ratios, chiefly

$$\mathrm{R}_{\mathrm{eBC/rBC}} = \frac{\mathrm{eBC}}{\mathrm{rBC}}, \quad \mathrm{R}_{\mathrm{eBC/EC}} = \frac{\mathrm{eBC}}{\mathrm{EC}}, \quad \mathrm{R}_{\mathrm{EC/rBC}} = \frac{\mathrm{EC}}{\mathrm{rBC}}.$$

These are specific realizations of the general response ratio $\mathrm{R}_{ij} = \mathrm{M}_i / \mathrm{M}_j$ defined in Eq. (6). Response ratios possess a dual identity: when treated as constants, they serve empirical harmonization; when treated as variables, they become diagnostic observables that carry information about aerosol state. The core idea is that response ratios need not be viewed only as imperfect conversion factors; in an interpretive context, their variability can provide useful observational information.

Analogous to the way relationships among equivalent diameters can constrain effective density and shape factor, response ratios such as eBC/rBC, eBC/EC, and EC/rBC can, under appropriate conditions, provide empirical clues to absorption enhancement, coating state, or method-specific biases.

3.2 State dependence of response ratios viewed through MAC

MAC offers a convenient entry point for understanding response ratios. When rBC is used as an approximation of the absorption-relevant BC core mass, Eq. (5) yields

$$\frac{\mathrm{eBC}}{\mathrm{rBC}} = \frac{\mathrm{MAC_{eff}(S)}}{\mathrm{MAC_{assumed}}} + \frac{\mathrm{b_{abs}^{non-BC}(S)}}{\mathrm{MAC_{assumed} \cdot rBC}} \tag{7}$$

Equation (7) shows directly why eBC/rBC should not be presumed to be constant. Its variation can reflect the influence of coating and mixing state on absorption, including possible lensing-driven absorption enhancement or limited enhancement (Cappa et al., 2012; Zhang et al., 2018), as well as atmospheric aging, additional absorption by brown carbon or mineral dust, source-dependent differences in initial MAC, and changes in size distribution and morphology. MAC, therefore, is not only a tool for harmonization; the variability of its effective value itself constitutes a composite response to aerosol state.

3.3 Observed variability in response ratios

Multi-method intercomparison studies indicate that response ratios exhibit systematic variability. From laboratory-controlled comparisons (Slowik et al., 2007) to recent multi-site field observations (Pileci et al., 2021), the data compiled by Wu et al. (2025) show that going from fresh emissions to aged aerosol, eBC/EC increases from roughly 0.81 to 1.17, eBC/rBC from roughly 0.94 to 2.14, and EC/rBC from roughly 1.32 to 1.60 (Table 3). In addition, Pileci et al. (2021) found that the median rBC/EC ratio varied from 0.53 to 1.29 across European sites, with a geometric standard deviation of 1.5.

Table 3. Example changes in response ratios between freshly emitted and aged aerosols

Response ratio	Fresh emissions	Aged aerosol	Direction of change
eBC/EC	~0.81	~1.17	Increase
eBC/rBC	~0.94	~2.14	Strong increase
EC/rBC	~1.32	~1.60	Moderate increase

https://doi.org/10.5194/egusphere-2026-2302
Preprint. Discussion started: 2 June 2026

These results indicate that differences in cross-metric ratios are not merely random measurement scatter; they exhibit reproducible systematic structure. This structure reflects differences among measurement methods in response mechanisms, size-range coverage, calibration assumptions, and operational protocols, while also potentially containing information on site conditions, source type, and aerosol aging state.

3.4 Potential diagnostic uses

No single response ratio can provide a definitive interpretation on its own; their value lies in being combined with other information.

Aging indicator. Under relatively stable source conditions and low non-BC absorption, a sustained increase in eBC/EC or eBC/rBC, together with evidence of air-mass aging time, elevated OC/EC ratio, and secondary organic aerosol formation, can qualitatively indicate coating accumulation and possible absorption enhancement (Cappa et al., 2012).

Empirical proxy for absorption enhancement. When non-BC absorption can be neglected, eBC/rBC may empirically reflect changes in the effective MAC and thus provide clues to coating-induced absorption enhancement. It should be stressed, however, that it is only an empirical proxy, not a rigorously calibrated absorption enhancement factor.

Flag for non-BC absorption interference. During dust or biomass-burning events, non-BC absorbing species can cause anomalously high eBC/rBC or eBC/EC values. Tinorua et al. (2024) reported from a two-year multi-method intercomparison at the Pic du Midi high-altitude station that springtime long-range dust transport could increase the deviation between AE33-derived eBC and SP2-measured rBC by up to a factor of about eight. When such high response ratios are accompanied by elevated absorption Ångström exponent (AAE) values and dust tracers, they can serve as interference flags.

Ancillary source identification. Particles from different sources—such as traffic emissions and biomass burning—differ in light-absorption properties, and their AAE values can show systematic differences (Sandradewi et al., 2008). Combined with air-mass back trajectories and chemical tracers, differences in response ratios can provide additional constraints for source apportionment.

3.5 From error analysis to signal characterization

A conventional intercomparison asks: "Why do different methods give inconsistent BC values?" A more scientifically productive question is: "What patterns do these inconsistencies show? What can they tell us?" The shift advocated here is thus from "making all metrics agree" to "identifying under what conditions response ratios change and what such changes signify". Only when good intra-method comparability is ensured do cross-method response ratios acquire reliable scientific interpretability.

https://doi.org/10.5194/egusphere-2026-2302
Preprint. Discussion started: 2 June 2026

4 Implications for reporting, harmonization, and interpretation

Building on the framework outlined above, we offer the following practical suggestions.

Distinguish primary observables from derived metrics. Data reporting should clearly separate directly measured primary response quantities (such as b_{abs}, thermograms, and incandescence signals) from the mass metrics obtained through assumptions and calibrations (eBC, EC, rBC). For optical methods, the absorption coefficient, wavelength, filter correction method, and adopted MAC value should be reported. For thermal-optical methods, the temperature protocol and charring correction approach should be specified. For SP2, the calibration material, detection size range, and extrapolation method should be stated.

Report conversion assumptions transparently. All BC-related mass metrics depend on specific conversion assumptions. For eBC, the key information is the adopted MAC value and its source. For EC, it is the thermal protocol type. For rBC, it is the calibration material and size range. These metadata should ideally become standard components of BC-related datasets, consistent with ongoing efforts to improve the metrological traceability and standardization of BC aerosol metrics, such as the EURAMET STANBC project.

Retain and analyze response ratios. When multiple BC instruments are operated at the same site, response ratios should be reported and analyzed as auxiliary variables, rather than being collapsed into a single harmonized concentration. For sites that already conduct multi-method observations, computing and analyzing response ratios adds almost no extra measurement cost yet can provide rich information on aerosol processes—a logic that parallels the way relationships among equivalent diameters are used to infer particle properties. The time series of these ratios can be examined jointly with the AAE, OC/EC ratio, size distribution, and air-mass trajectories to distinguish instrument effects from genuine changes in aerosol state.

Treat harmonized products as model-mediated quantities. Unified BC products constructed for model evaluation are not direct observations but model-mediated quantities. Their uncertainty encompasses not only instrument measurement errors but also state-dependent variability in conversion factors, MAC assumptions, and protocol differences. When fixed conversion factors are used, their origin and domain of applicability should be explicitly stated, and sensitivity analyses under different conversion assumptions should be provided where possible.

Consider application-specific objectives. For long-term trend monitoring and archival data products, fixed conversion factors may often be necessary to preserve the internal consistency of time series, provided their limitations are transparently stated. For atmospheric process studies, multiple metrics and their response ratios should be retained, allowing the differences themselves to become objects of analysis. For model evaluation, observation operators corresponding to specific measurement methods should be used rather than treating all BC-related metrics as if they represent the same model variable.

5 Conclusions

Building on the terminology framework of Petzold et al. (2013), this Opinion examines how the empirical relationships among eBC, EC, and rBC can be characterized. The main conclusions are:

1. **Terminological distinction is a starting point, not an endpoint.** eBC, EC, and rBC are distinct but empirically related BC-related mass metrics, each responding to a different facet of the same complex aerosol state. The scientific task is to identify the conditional dependence of their relationships.
2. **The three metrics can be understood in a unified way as different response-to-mass mappings.** Because the mappings differ in their physical basis and mathematical form, universal, state-independent cross-metric conversion factors should not be presumed.
3. **BC-related metrics face an equivalence trilemma.** Method specificity, universal numerical equivalence, and aerosol-state sensitivity cannot all be fully preserved. Fixing conversion factors compresses state information; retaining state sensitivity requires accepting that conversion relationships are conditional. The analogous tension in aerosol particle sizing—where different equivalent diameters are used diagnostically rather than forced into uniformity—illustrates that the systematic structure of cross-method differences can have diagnostic value.
4. **Response ratios are not merely conversion factors; they can also serve as diagnostic signals.** Ratios such as eBC/rBC, eBC/EC, and EC/rBC can, in an interpretive context, reflect information on coating, aging, source, and non-BC absorption.
5. **This perspective complements, rather than challenges, standardization.** Standardization ensures intra-method comparability; we argue for additionally retaining and interpreting the aerosol-state information embedded in cross-method differences. Analogous to the way aerosol science exploits differences among equivalent particle diameters to infer particle properties, BC measurements can exploit the differentiated responses among eBC, EC, and rBC while preserving the value of harmonization. In this view, cross-metric relationships are not merely obstacles to harmonization but can also serve as tools for diagnosing aspects of aerosol state.

Author contributions

Zefeng Zhang conceived and wrote the paper.

Competing interests

The author declares that there is no conflict of interest.

Acknowledgments

During the preparation of this work, the author used AI-assisted language editing tools for language polishing and structural editing. After using these tools, the author reviewed and edited the content as needed and takes full responsibility for the content of the published article.

Financial support

This work was supported jointly by the National Natural Science Foundation of China (grant no. 41005071) and the National Key Research and Development Program of China (grant no. 2016YFA0602003)..

References

Bond, T. C. and Bergstrom, R. W.: Light absorption by carbonaceous particles: An investigative review, Aerosol Sci. Tech., 40, 27–67, https://doi.org/10.1080/02786820500421521, 2006.

Bond, T. C., Doherty, S. J., Fahey, D. W., Forster, P. M., Berntsen, T., DeAngelo, B. J., Flanner, M. G., Ghan, S., Kärcher, B., Koch, D., Kinne, S., Kondo, Y., Quinn, P. K., Sarofim, M. C., Schultz, M. G., Schulz, M., Venkataraman, C., Zhang, H., Zhang, S., Bellouin, N., Guttikunda, S. K., Hopke, P. K., Jacobson, M. Z., Kaiser, J. W., Klimont, Z., Lohmann, U., Schwarz, J. P., Shindell, D., Storelvmo, T., Warren, S. G., and Zender, C. S.: Bounding the role of black carbon in the climate system: A scientific assessment, J. Geophys. Res.-Atmos., 118, 5380–5552, https://doi.org/10.1002/jgrd.50171, 2013.

Cappa, C. D., Onasch, T. B., Massoli, P., Worsnop, D. R., Bates, T. S., Cross, E. S., Davidovits, P., Hakala, J., Hayden, K. L., Jobson, B. T., Kolesar, K. R., Lack, D. A., Lerner, B. M., Li, S.-M., Mellon, D., Nuaaman, I., Olfert, J. S., Petäjä, T., Quinn, P. K., Song, C., Subramanian, R., Williams, E. J., and Zaveri, R. A.: Radiative absorption enhancements due to the mixing state of atmospheric black carbon, Science, 337, 1078–1081, https://doi.org/10.1126/science.1223447, 2012.

DeCarlo, P. F., Slowik, J. G., Worsnop, D. R., Davidovits, P., and Jimenez, J. L.: Particle morphology and density characterization by combined mobility and aerodynamic diameter measurements. Part 1: Theory, Aerosol Sci. Tech., 38, 1185–1205, https://doi.org/10.1080/027868290903907, 2004.

Petzold, A., Ogren, J. A., Fiebig, M., Laj, P., Li, S.-M., Baltensperger, U., Holzer-Popp, T., Kinne, S., Pappalardo, G., Sugimoto, N., Wehrli, C., Wiedensohler, A., and Zhang, X.-Y.: Recommendations for reporting "black carbon" measurements, Atmos. Chem. Phys., 13, 8365–8379, https://doi.org/10.5194/acp-13-8365-2013, 2013.

Pileci, R. E., Modini, R. L., Bertò, M., Yuan, J., Corbin, J. C., Marinoni, A., Henzing, B., Moerman, M. M., Putaud, J. P., Spindler, G., Wehner, B., Müller, T., Tuch, T., Trentini, A., Zanatta, M., Baltensperger, U., and Gysel-Beer, M.: Comparison of co-located refractory black carbon (rBC) and elemental carbon (EC) mass concentration measurements during field campaigns at several European sites, Atmos. Meas. Tech., 14, 1379–1401, https://doi.org/10.5194/amt-14-1379-2021, 2021.

Sandradewi, J., Prévôt, A. S. H., Weingartner, E., Schmidhauser, R., Gysel, M., and Baltensperger, U.: Using aerosol light absorption measurements for the quantitative determination of wood burning and traffic emission contributions to particulate matter, Environ. Sci. Technol., 42, 3316–3323, https://doi.org/10.1021/es702253m, 2008.

Schmid, H., Laskus, L., Abraham, H. J., Baltensperger, U., Lavanchy, V., Bizjak, M., Burba, P., Cachier, H., Crow, D., Chow, J., Gnauk, T., Even, A., ten Brink, H. M., Giesen, K.-P., Hitzenberger, R., Hueglin, C., Maenhaut, W., Pio, C., Carvalho, A., Putaud, J.-P., Toom-Sauntry, D., and Puxbaum, H.: Results of the "carbon conference" international aerosol carbon round robin test stage I, Atmos. Environ., 35, 2111–2121, https://doi.org/10.1016/S1352-2310(00)00493-3, 2001.

Schwarz, J. P., Gao, R. S., Fahey, D. W., Thomson, D. S., Watts, L. A., Wilson, J. C., Reeves, J. M., Darbeheshti, M., Baumgardner, D. G., Kok, G. L., Chung, S. H., Schulz, M., Hendricks, J., Lauer, A., Kärcher, B., Slowik, J. G., Rosenlof, K. H., Thompson, T. L., Langford, A. O., Loewenstein, M., and Aikin, K. C.: Single-particle measurements of midlatitude black carbon and light-scattering aerosols from the boundary layer to the lower stratosphere, J. Geophys. Res., 111, D16207, https://doi.org/10.1029/2006JD007076, 2006.

Slowik, J. G., Cross, E. S., Han, J.-H., Davidovits, P., Onasch, T. B., Jayne, J. T., Williams, L. R., Canagaratna, M. R., Worsnop, D. R., Chakrabarty, R. K., Moosmüller, H., Arnott, W. P., Schwarz, J. P., Gao, R.-S., Fahey, D. W., Kok, G. L., and Petzold, A.: An inter-comparison of instruments measuring black carbon content of soot particles, Aerosol Sci. Tech., 41, 295–314, https://doi.org/10.1080/02786820701197078, 2007.

Tinorua, S., Denjean, C., Nabat, P., Pont, V., Arnaud, M., Bourrianne, T., Dias Alves, M., and Gardrat, E.: A 2-year intercomparison of three methods for measuring black carbon concentration at a high-altitude research station in Europe, Atmos. Meas. Tech., 17, 3897–3915, https://doi.org/10.5194/amt-17-3897-2024, 2024.

Wu, B., Wu, Z., Dou, J., Yao, Z., Shen, X., Wang, A., Li, L., and Hao, X.: A systematic review of the variability of freshly-emitted and aged black carbon based on various measurement techniques, Sci. Total Environ., 958, 177872, https://doi.org/10.1016/j.scitotenv.2024.177872, 2025.

Zhang, Y., Zhang, Q., Cheng, Y., Su, H., Li, H., Li, M., Zhang, X., Ding, A., and He, K.: Amplification of light absorption of black carbon associated with air pollution, Atmos. Chem. Phys., 18, 9879–9896, https://doi.org/10.5194/acp-18-9879-2018, 2018.

EURAMET: Standardisation of Black Carbon aerosol metrics for air quality and climate modelling, STANBC project, available at: https://www.euramet.org/climate-and-ocean-observation/projects/project-details/project/standardisation-of-black-carbon-aerosol-metrics-for-air-quality-and-climate-modelling, last access: 8 June 2026.