https://doi.org/10.5194/egusphere-2026-3596
Preprint. Discussion started: 9 July 2026

Opinion: From Conversion Factors to Diagnostic Signals: Interpreting Response Ratios among eBC, EC, and rBC

Zefeng Zhang[1]
[1]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 metrics related to black carbon (BC). Building on the terminology framework of Petzold et al. (2013), this Opinion focuses on a practical question: how should empirical relationships among these metrics be represented and used? Conversion factors are often used for cross-metric harmonization, but their variability may also contain information on aerosol state and method response. We propose treating ratios such as eBC/rBC, eBC/EC, and EC/rBC as response ratios, namely derived diagnostic observables that can serve as empirical conversion factors when averaged for harmonization, but as indicators of changes in aerosol state and method response when retained as time-varying quantities. This dual role implies a practical equivalence trilemma: method specificity, state-independent numerical equivalence, and aerosol-state sensitivity cannot all be fully retained when cross-metric relationships are compressed into fixed conversion factors. The trilemma makes explicit a trade-off that the BC measurement community already navigates. It concerns cross-metric harmonization rather than within-method standardization or metrological traceability. We recommend transparent reporting of primary observables, conversion assumptions, and response-ratio time series in multi-method datasets. Retaining response-ratio variability alongside harmonized products would allow multi-method BC datasets to support both comparability and aerosol-state interpretation.

1 Introduction

Black carbon (BC) is 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 captures all of these attributes simultaneously, instruments based on different physical principles produce different BC-related mass concentrations (Slowik et al., 2007). Petzold et al. (2013) provided a landmark clarification by distinguishing three operationally defined metrics: equivalent black carbon (eBC), elemental carbon (EC), and refractory black carbon (rBC).

eBC is derived from optical absorption measurements and converted to a mass concentration via an assumed mass absorption cross-section (MAC). EC is defined by thermal-optical analysis and depends on a specified temperature protocol and charring correction scheme. rBC is measured by laser-induced incandescence and primarily reflects 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 yet empirically related operational metrics commonly reported

https://doi.org/10.5194/egusphere-2026-3596
Preprint. Discussion started: 9 July 2026

in mass-concentration units. Building on this terminology framework, a further question remains: how should the empirical relationships among these metrics be represented and interpreted?

This Opinion argues that cross-metric relationships should not be treated only as imperfect conversions among nominally equivalent quantities. Instead, their variability can also be used as diagnostic information. Shifting attention from using conversion factors only as fixed constants to also examining their variability provides a way to preserve information that is otherwise lost during harmonization.

The argument is analogous to the use of equivalent particle diameters in aerosol science. Mobility diameter, aerodynamic diameter, and optical diameter are not forced into a single universally correct particle size. Rather, their differences are often used to infer particle density, morphology, and optical properties (DeCarlo et al., 2004). Similarly, differences among eBC, EC, and rBC can be treated not only as obstacles to harmonization, but also as information on aerosol state and method response.

The contribution of this Opinion is threefold. First, it frames eBC, EC, and rBC as response-to-mass mappings rather than interchangeable estimates of a single directly measurable mass. Second, it defines response ratios such as eBC/rBC, eBC/EC, and EC/rBC as conditional quantities whose variability can be informative. Third, it formulates a practical equivalence trilemma that clarifies why fixed conversion factors necessarily compress state-dependent information.

2 Response-to-mass mappings and the equivalence trilemma

2.1 A unified mapping framework

We refer to eBC, EC, and rBC collectively as BC-related mass metrics because they are commonly reported in mass-concentration units, while emphasizing that each is produced by 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:

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

where S represents the multidimensional aerosol state, including BC core mass, size distribution, morphology, coating thickness, mixing state, and co-existing absorbing species; 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.

The three principal observation operators can be expressed schematically as

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

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

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

https://doi.org/10.5194/egusphere-2026-3596
Preprint. Discussion started: 9 July 2026

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

Metric	Primary measured response	Mapping form	Key assumptions or parameters	Main state sensitivities
eBC	Light absorption coefficient b_{abs}	$b_{\mathrm{abs}}/\mathrm{MAC}_{\mathrm{assumed}}$	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	Organic-carbon charring, protocol differences, mineral matrix, source type
rBC	Incandescence signal	Calibration-based mass retrieval	Calibration material, detection size range, extrapolation method	Core size range, morphology, calibration, detection efficiency

Optical instruments measure the light absorption coefficient b_{abs} and convert it to eBC via an assumed MAC:

$$\mathrm{eBC} = \frac{b_{\mathrm{abs}}}{\mathrm{MAC}_{\mathrm{assumed}}}. \tag{5}$$

The actual absorption can be decomposed as

$$b_{\mathrm{abs}} = M_{\mathrm{BC}} \cdot \mathrm{MAC}_{\mathrm{eff}}(S) + b_{\mathrm{abs}}^{\mathrm{non-BC}}(S), \tag{6}$$

where M_{BC} denotes a conceptual absorption-relevant BC core-mass term introduced for this decomposition; $\mathrm{MAC}_{\mathrm{eff}}(S)$ is the state-dependent effective MAC; and $b_{\mathrm{abs}}^{\mathrm{non-BC}}(S)$ accounts for absorption by non-BC species such as brown carbon and mineral dust.

Thermal-optical EC measurements separate carbonaceous aerosol into operational fractions through a prescribed temperature program and optical correction for charring. The resulting EC value is therefore protocol dependent. Laser-induced incandescence instruments infer rBC from the incandescence signal of refractory carbonaceous particles after calibration, but the result depends on calibration material, detection efficiency, and the measurable size range.

2.2 Response ratios

For two reported BC-related metrics M_i and M_j obtained from co-located and time-matched measurements of the same or comparable aerosol population, we define the response ratio as

$$R_{i/j} = \frac{M_i}{M_j}. \tag{7}$$

$R_{i/j}$ is a conditional quantity that depends on aerosol state, measurement principle, and data-processing assumptions. The three principal response ratios are

$$R_{\mathrm{eBC/rBC}} = \frac{\mathrm{eBC}}{\mathrm{rBC}}, \quad R_{\mathrm{eBC/EC}} = \frac{\mathrm{eBC}}{\mathrm{EC}}, \quad R_{\mathrm{EC/rBC}} = \frac{\mathrm{EC}}{\mathrm{rBC}}. \tag{8}$$

Table 2. The equivalence trilemma: a practical trade-off in cross-metric harmonization.

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

Response ratios have a dual role. When averaged over large datasets or fixed to literature values, they serve as empirical conversion factors for harmonization. When retained as time series and examined for conditional variability, they can carry information about changes in aerosol state and method response. Their interpretability depends on co-location, temporal alignment, size-cut consistency, and sufficient metadata.

2.3 The practical equivalence trilemma

Cross-metric harmonization often seeks numerical equivalence among eBC, EC, and rBC. However, three desirable goals cannot all be fully achieved by a single fixed conversion factor. These goals are: preserving method specificity, obtaining state-independent numerical equivalence, and retaining aerosol-state sensitivity.

The resulting practical equivalence trilemma clarifies an information trade-off. If method specificity and state-independent equivalence are prioritized, aerosol-state sensitivity is suppressed because response-ratio variability must be averaged out. If method specificity and aerosol-state sensitivity are retained, state-independent numerical equivalence is not possible because the ratios vary with aerosol state. If numerical equivalence and aerosol-state sensitivity are both imposed, the resulting quantity becomes a model-mediated product that no longer corresponds directly to any original method-specific metric.

This trilemma does not challenge the value of standardization within each measurement method. Rather, it highlights a limitation of cross-metric harmonization. Within-method standardization improves consistency, traceability, and comparability. Cross-metric conversion, by contrast, necessarily maps between quantities with different observation operators.

3 Response ratios as diagnostic observables

3.1 MAC as an entry point

The mass absorption cross-section offers a useful entry point for understanding why response ratios carry aerosol-state information (Bond and Bergstrom, 2006). Recent synthesis work further highlights that "MAC" is not a single intrinsic constant but a method-conditional quantity that depends on both how absorption is measured and corrected and what BC mass reference is used. In particular, Asmi et al. (2025) review ambient-BC MAC values and summarize a taxonomy of BC-related metrics and measurement approaches (their Fig. 5), explicitly linking absorption measurements to different BC mass references (eBC-, EC-, or rBC-based). This aligns with our response-ratio framing: because observation operators and assumptions differ, fixed conversions between absorption-derived eBC and incandescence-/thermal-derived mass metrics are generally conditional rather than universal.

If rBC is treated, for illustrative purposes, as an operational approximation of the absorption-relevant refractory BC core mass after accounting for size-range and calibration effects, Eqs. (5) and (6) yield

$$R_{\mathrm{eBC/rBC}} = \frac{\mathrm{MAC}_{\mathrm{eff}}(S)}{\mathrm{MAC}_{\mathrm{assumed}}} + \frac{b_{\mathrm{abs}}^{\mathrm{non-BC}}(S)}{\mathrm{MAC}_{\mathrm{assumed}} \cdot \mathrm{rBC}}. \tag{9}$$

For this illustrative decomposition we use an operational identification $M_{\mathrm{BC}} \approx \mathrm{rBC}$ (SP2-derived rBC), which makes the assumptions behind Eq. (9) explicit. This identification is approximate and is subject to known rBC dependencies on calibration and detectable size range.

Equation (9) illustrates why eBC/rBC should not be presumed constant. Its variation can reflect the influence of coating and mixing state on absorption (Cappa et al., 2012; Zhang et al., 2018), atmospheric aging, additional absorption by brown carbon or mineral dust, source-dependent differences in initial MAC, and changes in size distribution and morphology.

Similar reasoning applies to eBC/EC and EC/rBC. eBC/EC can vary because optical absorption and thermal-optical carbon separation respond differently to coatings, non-BC absorbers, and source composition. EC/rBC can vary because thermal-optical EC depends on protocol-specific carbon evolution, while rBC depends on incandescence calibration and detectable refractory core size range. These ratios therefore need not be viewed only as imperfect conversion factors; they can also be interpreted as conditional response ratios.

3.2 Representative published examples

Published intercomparisons show that cross-metric relationships among BC-related measurements vary substantially across instruments, protocols, and aerosol regimes. Table 3 summarizes representative examples. The table is not intended as a quantitative meta-analysis. Rather, it illustrates that response-ratio variability is a recurring feature of multi-method BC measurements.

3.3 Potential diagnostic uses

Response ratios may be useful in several diagnostic contexts. Elevated eBC/rBC can indicate absorption enhancement due to coating or additional non-BC absorption. Large optical-to-core discrepancies can also flag dust or brown-carbon interference.

https://doi.org/10.5194/egusphere-2026-3596
Preprint. Discussion started: 9 July 2026

Table 3. Representative published examples of cross-metric and cross-response variability among BC-related measurements.

Study	Context and metrics	Reported variability	Diagnostic interpretation
Schmid et al. (2001)	International carbon round-robin; carbon fractions including EC across protocols and laboratories	Inter-laboratory and protocol-dependent differences of order tens of percent	Operational choices, including thermal protocol and charring correction, affect EC comparability.
Pileci et al. (2021)	European field campaigns; rBC/EC	Campaign-dependent ratios spanning roughly a factor of two, with campaign median rBC/EC values about 0.5–1.3	rBC–EC relationships are campaign- and method-condition dependent, reflecting site conditions, SP2 size range, extrapolation, and EC protocol.
Kalbermatter et al. (2022)	Laboratory soot with controlled secondary organic coating; black-carbon and aerosol-absorption instruments	Instrument responses varied with the amount of secondary organic coating	Coating can modify absorption-instrument response and complicate fixed conversions.
Tinorua et al. (2024)	High-altitude observatory; AE33 eBC, SP2 rBC, and Sunset EC	AE33-derived eBC was overestimated by up to about a factor of 8 during dust-influenced periods	Large optical-to-core discrepancies may flag dust-related interference and limitations of optical correction factors.
Wu et al. (2025)	Systematic review; eBC/EC, eBC/rBC, and EC/rBC	Review-averaged fresh-to-aged ratios: eBC/EC $\sim$0.81 to $\sim$1.17; eBC/rBC $\sim$0.94 to $\sim$2.14; EC/rBC $\sim$1.32 to $\sim$1.60	Review synthesis suggests systematic fresh–aged shifts in response ratios caused by aging, coating, and technique-dependent response.

The table is intended as a set of representative examples rather than a quantitative meta-analysis.

Variations in EC/rBC can reveal differences between thermal-optical protocol response and incandescence-based refractory-core detection. Changes in eBC/EC may reflect shifts in source influence, aging state, or the relative importance of absorbing organic material.

These qualitative interpretations are consistent with the process-level view that the light-absorbing behaviour of carbonaceous aerosol evolves substantially over its atmospheric lifecycle. Liu et al. (2020) review how emission conditions, chemical aging and secondary processing, mixing with co-emitted and secondary species, and interactions with hydrometeors can modify the size, composition, hygroscopicity, and optical properties of light-absorbing carbonaceous aerosol (including both BC and BrC). Within our response-ratio framing, such lifecycle processes provide concrete mechanisms through which $\mathrm{MAC_{eff}}(S)$ and non-BC absorption contributions can change, thereby driving time variability in ratios such as eBC/rBC and eBC/EC. These process-level mechanisms provide the physical basis for treating response ratios as diagnostic signals rather than mere conversion constants.

The diagnostic value of response ratios does not imply that every change in a ratio has a unique physical interpretation. Instead, response ratios should be interpreted conditionally, together with information on site type, source influence, size cut, wavelength, instrument configuration, calibration, thermal protocol, and co-measured aerosol properties.

4 Implications for reporting, harmonization, and interpretation

4.1 Distinguish primary observables from derived metrics

A practical reporting strategy should separate primary observables from derived BC-related mass metrics. For optical measurements, the absorption coefficient, wavelength, filter correction scheme, and assumed MAC should be reported. For thermal-optical EC, the thermal protocol and split correction method should be specified. For laser-induced incandescence rBC, calibration material, detectable size range, and extrapolation assumptions should be described.

This distinction is important because eBC, EC, and rBC are not direct raw observations. They are derived quantities produced by observation operators. Reporting the assumptions behind these operators allows response ratios to be interpreted rather than treated as unexplained discrepancies.

4.2 Re-analyse existing multi-method datasets

Existing multi-method datasets provide an opportunity to evaluate the diagnostic value of response ratios without requiring new instruments. A practical workflow would include recovering primary observables where possible, computing response ratios from co-located and time-aligned measurements, stratifying the ratios by aerosol regime or source influence, and interpreting anomalies using available metadata.

Such re-analysis would allow the community to ask whether response-ratio variability is random, method-specific, or systematically linked to aerosol state. This approach is especially useful for datasets that include optical absorption, thermal-optical carbon, laser-induced incandescence, particle size, chemical composition, or source-tracer information.

4.3 Treat harmonized products as model-mediated quantities

Harmonized BC products are useful and often necessary for long-term trends, model evaluation, and policy assessment. However, when fixed conversion factors are used, the resulting product should be regarded as a model-mediated quantity. It is not identical to any single original metric and may not preserve state-dependent information contained in the original multi-method differences.

This does not diminish the value of harmonization. Rather, it suggests that harmonized products and response-ratio information should be reported together when possible. The harmonized product supports comparability, while the response ratios preserve information on the conditions under which the conversion is valid or unstable.

4.4 Use-dependent treatment of response ratios

The appropriate treatment of response ratios depends on the scientific objective. If the objective is to produce a comparable long-term dataset, averaging response ratios into empirical conversion factors may be appropriate. If the objective is to understand aerosol processes, source influence, aging, coating, or non-BC absorption, the variability of response ratios should be retained.

In this view, response ratios are not merely conversion factors; they can also serve as diagnostic signals. The same quantity can therefore have different roles depending on whether the analysis prioritizes harmonization or interpretation.

5 Conclusions

Building on the terminology framework of Petzold et al. (2013), this Opinion argues that the empirical relationships among eBC, EC, and rBC deserve explicit attention. The main conclusions are as follows.

eBC, EC, and rBC are distinct but empirically related BC-related mass metrics. Their relationships should be characterized through conditional variability rather than assumed universal equivalence.

These metrics represent different response-to-mass mappings. Because their observation operators depend on different physical responses and assumptions, fixed cross-metric conversion factors necessarily compress state-dependent information.

The resulting practical equivalence trilemma clarifies an information trade-off in harmonization: method specificity, state-independent numerical equivalence, and aerosol-state sensitivity cannot all be fully preserved in a single fixed conversion.

Response ratios such as eBC/rBC, eBC/EC, and EC/rBC have a dual role. They support empirical conversion when averaged, and provide diagnostic information on coating, aging, source influence, and non-BC absorption when their variability is retained. Response ratios appear unstable only when judged as universal constants; interpreted conditionally, their variability becomes the information of interest.

The diagnostic patterns proposed here should be tested across existing multi-method datasets and refined where necessary. The practical step is to retain the information already present in multi-method differences as response-ratio variability, rather than averaging it away during harmonization. Multi-method BC datasets contain more information than any single harmonized product can preserve, provided that response ratios are retained together with the metadata needed to interpret them. In this sense, response-ratio variability plays a role analogous to differences among equivalent particle diameters: it is not merely an obstacle to harmonization, but can also be a source of diagnostic information.

Code availability. No software code was developed for this Opinion article.

Data availability. No new datasets were generated or analysed for this Opinion article.

Author contributions. Zefeng Zhang conceived and wrote the paper.

Competing interests. The author declares that there is no conflict of interest.

190 *Acknowledgements.* 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 article.

Financial support. This work was supported 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

Asmi, E., Sipkens, T. A., Saturno, J., Backman, J., Vasilatou, K., Weingartner, E., Keller, A., Ciupek, K., Müller, T., Suja, A. B., Mocnik, G., Drinovec, L., Eleftheriadis, K., Gini, M. I., Nowak, A., and Corbin, J. C.: Mass absorption cross-section of ambient black carbon aerosols – a review, npj Clim. Atmos. Sci., 9, 16, https://doi.org/10.1038/s41612-025-01288-2, 2025.

Bond, T. C. and Bergstrom, R. W.: Light absorption by carbonaceous particles: An investigative review, Aerosol Sci. Technol., 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., and 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. Technol., 38, 1185–1205, https://doi.org/10.1080/027868290903907, 2004.

Kalbermatter, D. M., Močnik, G., Drinovec, L., Visser, B., Röhrbein, J., Oscity, M., Weingartner, E., Hyvärinen, A.-P., and Vasilatou, K.: Comparing black-carbon- and aerosol-absorption-measuring instruments – a new system using lab-generated soot coated with controlled amounts of secondary organic matter, Atmos. Meas. Tech., 15, 561–572, https://doi.org/10.5194/amt-15-561-2022, 2022.

Liu, D., He, C., Schwarz, J. P., and Wang, X.: Lifecycle of light-absorbing carbonaceous aerosols in the atmosphere, npj Clim. Atmos. Sci., 3, 40, https://doi.org/10.1038/s41612-020-00145-8, 2020.

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.

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., 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.

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. Technol., 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.