



Determination of Aerosol Particle Organic Carbon (OC) by Aerosol Mass Spectrometry (AMS) and Thermo-Optical Transmission (TOT) Analysis: Spatial and Seasonal Differences

Shubhi Arora¹, Laurent Poulain¹, Radek Lhotka², Petr Vodička², Saliou Mbengue³, Petra Pokorná²,
Jaroslav Schwarz², Naděžda Zíková², Jakub Ondráček², Vladimír Ždímal^{2*}, Hartmut Herrmann^{1*}

¹Atmospheric Chemistry Department (ACD), Leibniz Institute for Tropospheric Research (TROPOS), Permoserstr. 15, Leipzig, 04318, Germany

²Institute of Chemical Process Fundamentals, Czech Academy of Sciences, Rozvojová 1/135, Prague, 16500, Czech Republic

³Global Change Research Institute of the Czech Academy of Sciences, 60300, Brno, Czech Republic

Correspondence to: Hartmut Herrmann (herrmann@tropos.de)

Abstract. Reliable quantification of organic carbon (OC) is essential for the comparability of long-term aerosol measurements across monitoring networks. A multi-site intercomparison of OC measurements was conducted at three Central European background stations, Melpitz (MEL), Frýdlant (FRY), and Košetice (NAOK), using aerosol mass spectrometry (AMS/ACSM) and thermal-optical transmission (TOT) methods (offline and semi-continuous). Semi-continuous and offline TOT measurements showed high consistency across sites and seasons, suggesting negligible influence of particle size differences on OC comparability. A pronounced seasonal contrast was observed between AMS derived OC (OC_{AMS}) and TOT based OC (OC_{TOT}). During summer, good agreement was found with $OC_{TOT}:OC_{AMS}$ slopes of 1.27 (MEL), 0.86 (FRY), and 0.83 (NAOK). In winter, AMS systematically underestimated OC, with slopes decreasing to 0.34 (MEL), 0.24 (FRY), and 0.63 (NAOK). The discrepancy increased under combustion dominated conditions and was associated with low organic aerosol to equivalent black carbon (OA:eBC) ratios ($\ll 5$), identifying a regime where OC_{AMS} and OC_{TOT} diverge substantially. Source dependent effects were evident, with the largest deviations observed at the coal influenced site (FRY) and during long-range transport events, while improved agreement coincided with higher OA:eBC ratios and enhanced secondary organic aerosol formation in summer. Evaluation of potential uncertainties (including pyrolytic carbon formation in TOT and AMS related limitations such as refractory organics and ionization efficiency) showed that no single factor explains the winter discrepancy, suggesting combined matrix and source effects. The results show that OA:eBC can serve as a practical indicator for OC_{AMS} - OC_{TOT} agreement and provide recommendations to improve OC quantification under winter combustion conditions.

1 Introduction

Organic carbon (OC) represents a major fraction of $PM_{2.5}$; when converted to organic matter (OM) using appropriate OM:OC ratios, it accounts for approximately 20-70% of $PM_{2.5}$, depending on regional sources and atmospheric conditions (Jimenez et al., 2009; Ng et al., 2010). Aerosols containing OC originate from a wide range of sources, including primary emissions from



fossil fuel combustion and biomass burning, as well as secondary formation from biogenic and anthropogenic precursors, and encompass a complex mixture of organic compounds with diverse chemical characteristics (Crippa et al., 2014). Accordingly, understanding the composition and quantity of OC is critical, and numerous measurement techniques have been developed to characterize OC in ambient aerosols (Fermo et al., 2006; Peltier et al., 2008; Cavalli et al., 2016). Large-scale atmospheric
35 monitoring networks such as ACTRIS (Aerosols, Clouds, and Trace gases Research Infrastructure), the European Monitoring and Evaluation Programme (EMEP), EPA's Chemical Speciation Network (CSN), the US-based Interagency Monitoring of Protected Visual Environments (IMPROVE), and the Global Atmosphere Watch (GAW) increasingly rely on multi-site as well as multi-instrument measurement strategies to reliably measure OC (Solomon et al., 2014; Laj et al., 2020; ACTRIS, 2023). These networks often employ a combination of thermo-optical transmission (TOT) analysis performed both offline and
40 online (semi-continuous EC/OC analyzers) across various sites to ensure comprehensive, time-resolved coverage (Massabo and Prati, 2021).

In Europe, thermal optical transmission (TOT) methods represent the standard approach for the determination of organic carbon (OC), measuring carbon fractions on collected aerosol filters by heating samples through defined temperature protocols (e.g., Cavalli et al., 2010; Panteliadis et al., 2015) and have been extensively applied in long-term measurements at Central
45 European background sites such as Melpitz (e.g., Spindler et al., 2010, 2013; Poulain et al., 2020). TOT methods may yield different OC values under varying environmental conditions due to factors such as charring correction and temperature-ramp design (Chow et al., 2001). In addition, sampling artifacts, such as adsorption of semi volatile organic compounds (SVOCs) or pyrolysis of OC into char, introduce further uncertainties (Yu et al., 2002). Without cross-validation, differences arising from calibration assumptions, sampling artifacts, and protocol-specific definitions can undermine the comparability of long-
50 term datasets and trend analyses (Vasilatou et al., 2025).

When OC concentrations are derived from aerosol mass spectrometer (AMS) measurements the comparison to TOT-derived data becomes complex. AMSs do not measure OC directly but instead infer it by applying OM:OC ratios to measured organic aerosol mass. The Aerodyne AMS, for example, detects non-refractory organic aerosol mass, and an assumed OM:OC ratio must be applied to estimate OC concentrations (Canagaratna et al., 2015). This conversion adds uncertainty, as OM:OC ratios
55 can vary depending on aerosol sources and their degree of oxidation, potentially introducing systematic biases when AMS-derived OC is compared to TOT measurements (Nault et al., 2023). These methodological differences have become identifiable through measurement intercomparisons, which have reported notable discrepancies between OC concentrations estimated by AMS and those obtained by traditional TOT methods (Takegawa et al., 2005; Docherty et al., 2011). Recent field studies have emphasized these issues - for instance, an intercomparison at two sites showed that while AMS and OCTOT measurements
60 correlated reasonably well, their agreement deteriorated under certain conditions, with seasonal differences in slope and correlation coefficients pointing to unresolved biases (Crenn et al., 2018). To date, however, most direct comparisons have been limited to individual locations or short-term campaigns, and comprehensive multi-site investigations, especially across different regions and seasons in Europe, remain scarce (Crenn et al., 2018). While some studies (e.g., Budisulistiorini et al.,



2014; Daellenbach et al., 2016) have reported reasonable agreement between AMS-OM and OCTOT, the consistency of such
 65 quantifications across broader spatial scales and varying meteorological conditions remains largely uncertain.
 Clearly, substantial uncertainties arise from methodological differences between TOT and AMS techniques, including
 detection principles, particle size cuts, vaporization efficiency, and the indirect OM-to-OC conversion required in AMS.
 Therefore, the present study presents a systematic multi-site, winter-summer evaluation of OC comparability between
 AMS/ACSM and TOT analysis, using both offline and semi-continuous online data from three Central European sites.
 70 Influencing factors such as sampling artifacts, aerosol composition, oxidation state (OSc), and source-specific variability are
 assessed. To place the OC analysis in a broader context, additional intercomparisons of brown carbon (BrC) are performed
 across all sites and seasons. The results clarify method uncertainties and could guide and support efforts toward harmonized
 OC quantification in long-term monitoring networks.

2 Methodology

75 2.1 Site Description

Measurements were conducted at three regional background stations: Melpitz (MEL; 51.5333°N, 12.9333°E, 86 m a.s.l.,
 Germany), Frýdlant (FRY; 50.9407°N, 15.0698°E, 366 m a.s.l., Czech Republic), and National Atmospheric Observatory
 Košetice (NAOK; 49.5734°N, 15.0805°E, 534 m a.s.l., Czech Republic). MEL is located northeast of Leipzig in a rural
 environment, FRY is situated near the tripoint of Germany, Poland, and the Czech Republic, and NAOK lies south of Prague
 80 in a predominantly agricultural and forested region (Fig. 1).



Figure 1: Locations of the three regional background measurement stations used in this study: MEL, Germany; FRY and NAOK, Czech Republic. The black lines illustrate their spatial relationship within Central Europe. Imagery © 2026 NASA, Map data © 2026 Google. Station locations and annotations added by the authors.



85

MEL and NAOK are well-established stations performing long-term physico-chemical aerosol measurement as part of, for example, ACTRIS and EMEP networks, whereas FRY served as a temporary measurement site equipped specifically for this project. At MEL, online instruments operated in a container connected to a PM₁₀ Anderson inlet (6 m a.g.l.) with a Nafion dryer (RH < 30%) and isokinetic splitter (WMO/GAW, 2016). At NAOK, the ACSM used a PM_{2.5} inlet, and the other online
90 instruments used PM₁₀ inlets (4 m a.g.l.), each followed by a Nafion dryer and isokinetic subsampling. At FRY, a similar PM₁₀ setup (4 m a.g.l.) with Nafion dryer and isokinetic flow division was applied. A detailed description of the sites, is provided in Horník et al. (2024) and Arora et al. (2026a). Briefly, all sites employed standardized sampling systems and instrumentation to enable consistent aerosol characterization across the network. Given the differing source influences and infrastructure setups across these sites, a standardized yet flexible sampling strategy was necessary to ensure intercomparability while capturing
95 regional variability.

2.2 Offline OC/EC Analysis

PM_{2.5} samples were collected at each station using high-volume DIGITEL DHA-80 samplers on pre-conditioned quartz fiber filters over 12-hours interval (from 06:00 to 18:00 and 18:00 to 06:00 UTC) during the winter (February 1st - March 20th, 2021) and summer (July 1st - August 30th, 2021) campaigns. The measurement periods were synchronized across all
100 instruments and sites, and the data coverage for OC/EC for each campaign is illustrated in Fig. S1-S2. Filters were heated at 105 °C for 24-hours, weighed before and after sampling using a microbalance (Mettler-Toledo AT 261) and conditioned for 48 hours at 20 ± 2 °C and 50 ± 5% relative humidity, following EMEP standards and ACTRIS quality control.

OC and EC concentrations were determined using TOT analysis following the EUSAAR-2 protocol (Cavalli et al., 2010). Filter punches (1.5 cm²) were analyzed with a laboratory instrument (Sunset Laboratory Model 5L, USA) equipped with a
105 flame ionization detector. The OC–EC split point was set automatically, and the transmittance method was applied for charring correction of OC. Carbon evolved before the split point (including charred OC) is reported as OC, whereas carbon evolved after the split point is classified as EC. Limit of Detection (LOD) was determined following the ACTRIS (2021) QA/QC protocol by calculating three times the standard deviation of the field blank filters plus their mean value (LOD = 3σ + mean). The resulting LODs were 0.05 µg m⁻³ for OC and 0.01 µg m⁻³ for EC. The relative standard uncertainty of the average OC
110 and EC concentrations was 12% and 18%, respectively (EN 16909:2017; ACTRIS 2021 QA/QC guidelines).

2.3 Online OC/EC Analysis

A semi-continuous TOT, OC/EC analyzer (Sunset Labs Model 4, Bauer et al., 2009) was used at all sites to measure OC. Each instrument was operated with a dedicated sampling inlet, with size cuts of PM_{2.5} at MEL and NAOK and PM₁ at FRY (flow rate 8 lpm) and by a carbon parallel plate denuder to eliminate the influence of gas-phase organics and thus prevent a positive
115 bias in OC measurements (Cheng et al., 2009). It operated with a 2-hour time resolution (4-h in NAOK) and used quartz fiber filters (16 mm diameter cuts). Analyses were performed using the shortened EUSAAR-2 protocol (Cavalli et al., 2010; Vodička



et al., 2015) and analyzed using a non-dispersive infrared detector. Automated optical corrections were applied to account for charring effects using continuous laser transmittance monitoring, and the OC-EC split point was determined automatically by RTCalc726 software provided by Sunset Lab. However, winter data for MEL are unavailable due to covid-19 restrictions preventing the installation of the instrument at this site. LOD values were $0.3 \mu\text{g m}^{-3}$ for OC and $0.2 \mu\text{g m}^{-3}$ for EC, with corresponding uncertainties of approximately 6% and 20 %, respectively (Bauer et al., 2009).

2.4 Non-Refractory Aerosol Composition

The chemical composition of non-refractory PM_{10} was measured using aerosol mass spectrometers (AMS/ACSM) at each station. MEL operated a high-resolution time-of-flight AMS (HR-ToF-AMS; DeCarlo et al., 2006), NAOK a time-of-flight aerosol chemical speciation monitor (ToF-ACSM; Fröhlich et al., 2013), and FRY a compact time-of-flight AMS (C-ToF-AMS; Drewnick et al., 2005). Instrument operating principles, data processing, quality control procedures as well as the time series showing data coverage of AMS/ACSM chemical species are described in Arora et al. (2026a). Organic aerosol (OA) concentrations were measured directly by AMS/ACSM instruments, while OC was derived using established elemental analysis approaches based on O:C and OM:OC ratios, which can be biased by vaporization inefficiencies and ion fragmentation (Canagaratna et al., 2015). To address such biases, Aiken et al. (2008) introduced the Aiken-Ambient (A-A) method, later refined into the Improved-Ambient (I-A) method (Canagaratna et al., 2015) to better account for composition-dependent systematic errors. At MEL, the availability of high-resolution mass spectra enabled the use of the I-A method for more accurate OM:OC estimation. AMS data were processed with the software packages Squirrel (version 1.65B) for Unit Mass Resolution (UMR) and Pika (version 1.25B) for High Resolution (HR) within Igor Pro (version 9.02, WaveMetrics, Inc.). Calculations were performed using the Igor Pika software, allowing time-resolved OM:OC ratios (Table S1) with improved ion-based correction. Data from the ToF-ACSM at NAOK were analyzed with Tofware package (version 3.2, Tofwerk and Aerodyne Research, Inc.). For FRY and NAOK, which used unit mass resolution (UMR) instruments, OC was estimated using the f_{44} signal (Org44/Org) based on the following empirical relationships:

$$\text{O:C} = 0.079 + 4.31 \times f_{44} \quad (1)$$

$$\text{OM:OC} = 1.29 \times \text{O:C} + 1.17 \quad (2)$$

$$\text{OC}_{\text{AMS/ACSM}} = \text{OA}_{\text{AMS/ACSM}} / \text{OM:OC} \quad (3)$$

These expressions allowed for OC_{AMS} estimation across the different AMS/ACSM instruments used in the study. The average f_{44} , O:C, and OM:OC ratios for all three stations in both seasons are summarized in Table S1. The PM_{10} mass concentrations of inorganic and organic species obtained from AMS/ACSM measurements typically have an uncertainty near $\pm 25 \%$ (Canagaratna et al., 2007).



2.5 Equivalent Black Carbon and Brown Carbon

150 Equivalent black carbon (eBC) was quantified at all sites using dual-spot aethalometers (AE33, Magee Scientific, Drinovec et al., 2015). Light absorption at seven wavelengths was obtained using default mass absorption coefficient (MAC) values provided by the manufacturer, and brown carbon (BrC) contributions were estimated based on wavelength-dependent absorption properties using the Ångström exponent approach (Sandradewi et al., 2008; Leskinen et al., 2020). A detailed description of the calculations is provided in Text S1.

2.6 Data Quality Assurance

155 Data quality was ensured through regular calibration and validation procedures. Mass closure between aerosol mass spectrometry and mobility particle size distribution measurements was assessed, and filter blanks were analyzed to correct for potential contamination. The QA/QC approaches closely followed the protocols described in Arora et al. (2026a).

3 Results

160 The TOT data, the AMS-derived OC estimates, and the aethalometer-based BrC data, were intercompared across the three sites (Table S2) to identify factors affecting their agreement, variability, and discrepancies. Variations associated with seasonal changes, emission source profiles, and methodological limitations were analyzed by comparing total carbon (TC), OC, and elemental carbon (EC) concentrations from offline and semi-continuous TOT methods, by assessing agreement/disagreement with AMS-derived OC estimates, and by quantifying the optical properties of BrC using aethalometer measurements. Observed patterns were examined in relation to air mass origin, aerosol aging, and source-specific combustion signatures, and
165 instrumental biases.

3.1 Intercomparison of offline and semi-continuous online TOT measurements

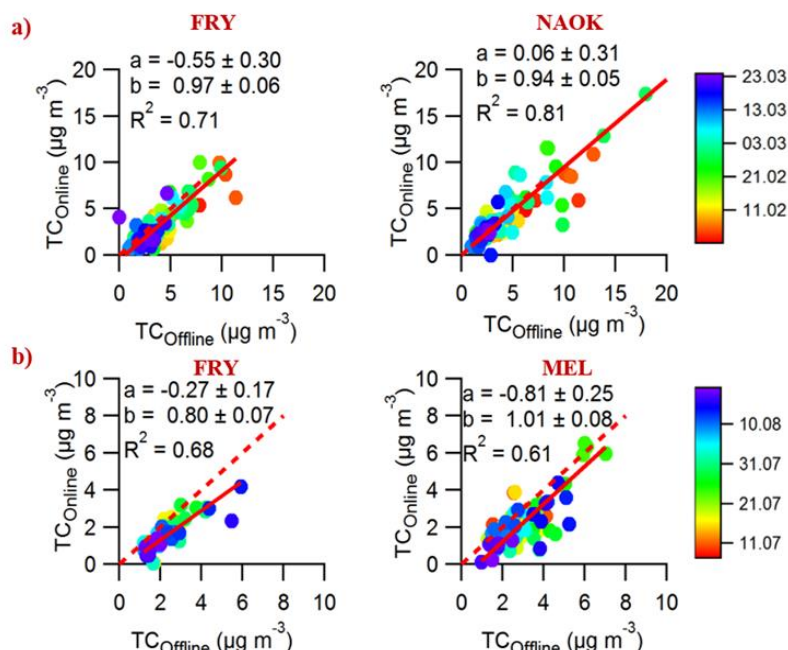
To evaluate internal consistency in the quantification of carbon sum parameters across sites and seasons, both offline and online TOT measurements were compared, enabling direct comparison of TC, OC, and EC (Fig. S1; Fig. S2). As pointed earlier, online TOT data were not available for all station-season combinations, therefore only the available cases are shown
170 in the following figures.

3.1.1 TC comparison

As shown in Fig. 2, for TC, winter comparisons at FRY (slope = 0.97 ± 0.06 , $R^2 = 0.71$) and NAOK (0.94 ± 0.05 , $R^2 = 0.81$) showed close agreement, similar to summer in MEL (1.01 ± 0.08 , $R^2 = 0.61$) and FRY (0.80 ± 0.07 , $R^2 = 0.68$). The color coding shows the course of time through the campaign and ensures that the points deviating from the 1:1 line were not confined



175 to a distinct period, but were distributed across the season. This suggests that the observed agreement/disagreement was not driven by a short-term episode or an obvious temporal drift.



180 **Figure 2: Comparison of TC winter and summer concentrations measured by semi-continuous (online) and filter-based (offline) TOT methods. Panel (a) shows winter measurements at FRY (left) and NAOK (right), while panel (b) shows summer measurements at FRY (left) and MEL (right). The dotted line represents the 1:1 line, the solid line represents the orthogonal distance fit of the data, b = slope and a = intercept. Course of time is in color for each season.**

These patterns are consistent with previous intercomparisons (Rigler et al., 2020; Bao et al., 2021), supporting the general reliability of Sunset-based TC measurements across deployment modes.

185 3.1.1 OC comparison

In the following, $OC_{Offline}$ refers to filter based offline TOT measurements, OC_{Online} to semi continuous online TOT measurements, and OCTOT is used only when referring collectively to both TOT based datasets. For OC, winter slopes at FRY (0.85 ± 0.06 , $R^2 = 0.71$) and NAOK (0.79 ± 0.06 , $R^2 = 0.66$) were close to unity. The summer results at MEL (0.80 ± 0.09 , $R^2 = 0.51$) and FRY (0.88 ± 0.12 , $R^2 = 0.62$) followed a similar pattern (Fig. 3), although the lower R^2 at MEL could be attributed to enhanced SOA production. The temporal color coding shows that deviations from the 1:1 line are not confined to specific periods, but occur throughout the campaign. Recent studies have also evaluated the comparability between OC_{Online} and $OC_{Offline}$. $OC_{Offline}$ measurements are often higher than OC_{Online} measurements due to positive artifacts from gas-phase adsorption, as observed in Italy (Malaguti et al., 2015) and California (Docherty et al., 2011), with reported discrepancies of 30-50%.

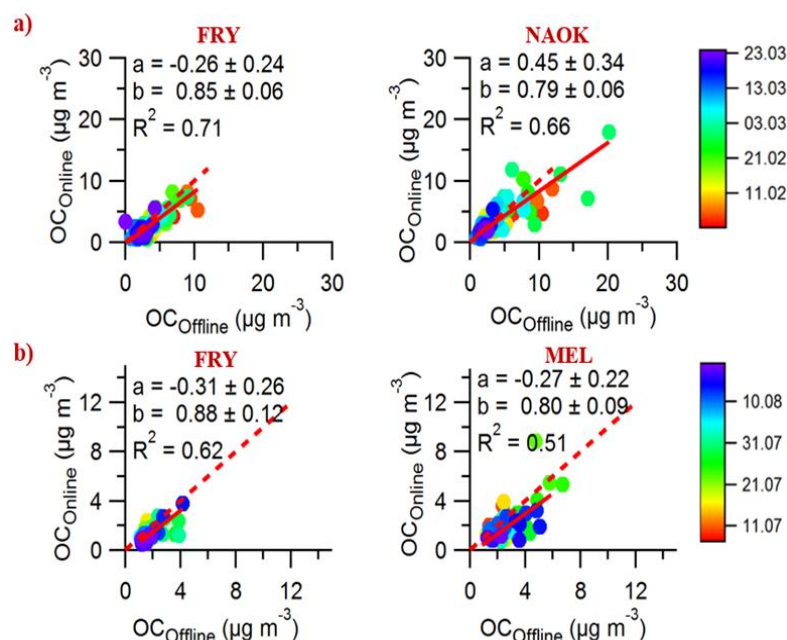


Figure 3: Comparison of OC winter and summer concentrations measured by semi-continuous (online) and filter-based (offline) TOT methods. Panel (a) shows winter measurements at FRY (left) and NAOK (right), while panel (b) shows summer measurements at FRY (left) and MEL (right). The dotted line represents the 1:1 line, the solid line represents the orthogonal distance fit of the data, b = slope and a = intercept. Course of time is in color for each season.

The magnitude of these artifacts was further assessed by Yttri et al. (2019), who found that the OC Back/OC Front ratio, a proxy for SVOC-related artifacts, was higher at MEL ($24 \pm 12\%$) than at NAOK ($12 \pm 4.4\%$). To mitigate such artifacts, the online OC/EC analyzer was equipped with a carbon parallel-plate diffusion denuder, which effectively reduces gas-phase interferences (Bauer et al., 2009). Multiple intercomparison studies for different TOT protocols (IMPROVE_A, NIOSH, and EUSAAR-2) yield highly correlated results ($R^2 > 0.96$), with typical protocol-related differences less than 10% (Cavalli et al., 2010; Bautista et al., 2015). These differences are consistent across urban and rural sites, indicating minimal site effects for OC. Overall, these intercomparisons show that OC measurements obtained using different TOT protocols are generally highly consistent.

3.1.1 EC comparison

In contrast to TC and OC, EC showed larger deviations between the online and offline measurements. As shown in Fig. 4, for EC, FRY (slope = 1.20 ± 0.05 , $R^2 = 0.85$) and NAOK (slope = 1.23 ± 0.07 , $R^2 = 0.74$) both showed strong correlations and slopes >1 , suggesting that the semi-online instrument reported slightly higher EC concentrations than the offline method, opposite to the tendency observed for OC where online values were generally lower. In summer, the correlations were somewhat weaker at MEL (slope = 1.26 ± 0.14 , $R^2 = 0.55$) and FRY (slope = 1.27 ± 0.11 , $R^2 = 0.68$), though the slopes remained consistently above one.

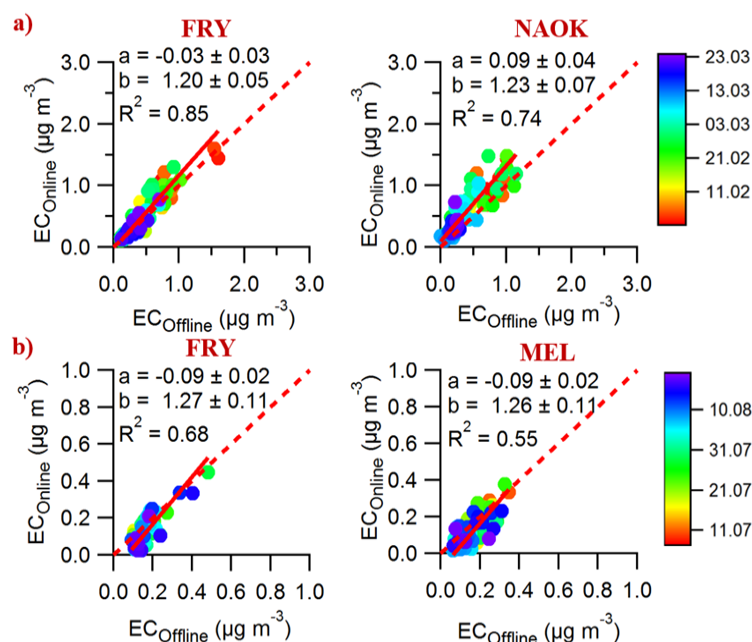


Figure 4: Comparison of winter and summer EC concentrations measured by semi-continuous (online) and filter-based (offline) TOT methods. Panel (a) shows winter measurements at FRY (left) and NAOK (right), while panel (b) shows summer measurements at FRY (left) and MEL (right). The dashed red line represents a 1:1 relationship. Course of time is in color for each season.

The agreement between the two methods was strong across sites and seasons, with only a slight positive bias in the semi-online Sunset. Such positive slopes likely reflect calibration or charring-correction differences between the online and offline protocols rather than systematic seasonal effects as they occur in both winter and summer measurements. Prior work (Karanasiou et al., 2020; Zhang et al., 2021) has shown high consistency between online and offline EC measurements (slopes ~0.91-1.04; $R^2 = 0.77-0.94$), with occasional deviations linked to optical saturation or denuder configurations. Overall, the offline and semi-online TOT measurements showed good agreement for TC and OC across sites and seasons, while EC showed a small but consistent positive bias in the semi-online data. These results suggest that the TOT datasets are sufficiently consistent to serve as a reference for the subsequent evaluation of OC derived from AMS/ACSM measurements.

3.2 Influence of the mass spectra resolution to OC_{AMS} estimation

Although both AMS and ACSM can estimate particulate OC concentrations, the HR-ToF-AMS allows OC to be derived using either UMR or high-resolution mass spectra. Therefore, before comparing OC_{AMS/ACSM} with the standardized method, the consistency between the HR and UMR approaches was evaluated at MEL (Fig. S3). In winter (Fig. S3a), the two methods were strongly correlated (slope = 1.08, $R^2 = 0.97$), indicating that the HR-derived OA values were on average 8% higher than from the UMR method. In summer (Fig. S3b), the correlation became even stronger compared to winter with slope = 0.96 and $R^2 = 0.99$, suggesting that HR-derived OA was 4% lower. These seasonal differences indicate that agreement between UMR and HR methods to a limited extent depend on OA composition and complexity. As the UMR OC estimation is primarily based



on the f44 contribution, its performance is sensitive to aerosol oxidation state and composition. The slightly larger winter deviation may be related to a higher contribution of less oxygenated primary OA, for which the f44 based O:C parameterization is known to be less accurate at low f44, whereas the closer summer agreement is consistent with a larger contribution of more oxygenated OA (Canagaratna et al., 2015). In addition, small systematic differences may arise because the UMR method cannot separate ions with the same m/z but different chemical composition, whereas HR analysis can resolve these signals (DeCarlo et al., 2006; Ulbrich et al., 2009). These limitations may bias UMR-derived OC estimates at all three sites. However, since the discrepancy between UMR and HR approaches remains within the uncertainty of the UMR method, similar behavior was assumed for FRY and NAOK. Resolution dependent uncertainties should therefore be considered when comparing $OC_{AMS/ACSM}$ with OC_{TOT} , particularly at sites such as FRY and NAOK where only UMR based data were available.

3.3 OC_{TOT} vs. OC_{AMS}

Inter-method biases varying across spatial and seasonal scales were assessed by comparing AMS derived OC data (OC_{AMS}) with OC from $PM_{2.5}$ filter measurements ($OC_{Offline}$) (Fig. 5). During winter, AMS systematically underestimated OC relative to the $OC_{Offline}$ at all stations, although the degree varied. Slopes at MEL ($R^2 = 0.78$, slope = 0.34) and FRY ($R^2 = 0.84$, slope = 0.24) diverged strongly from unity, while NAOK showed better agreement (slope = 0.63 ± 0.04 , $R^2 = 0.75$). The MEL results align with previous comparison of OC estimated from the Quadrupole ACSM with $PM_{2.5}$ daily filters over several winters (Poulain et al., 2020).

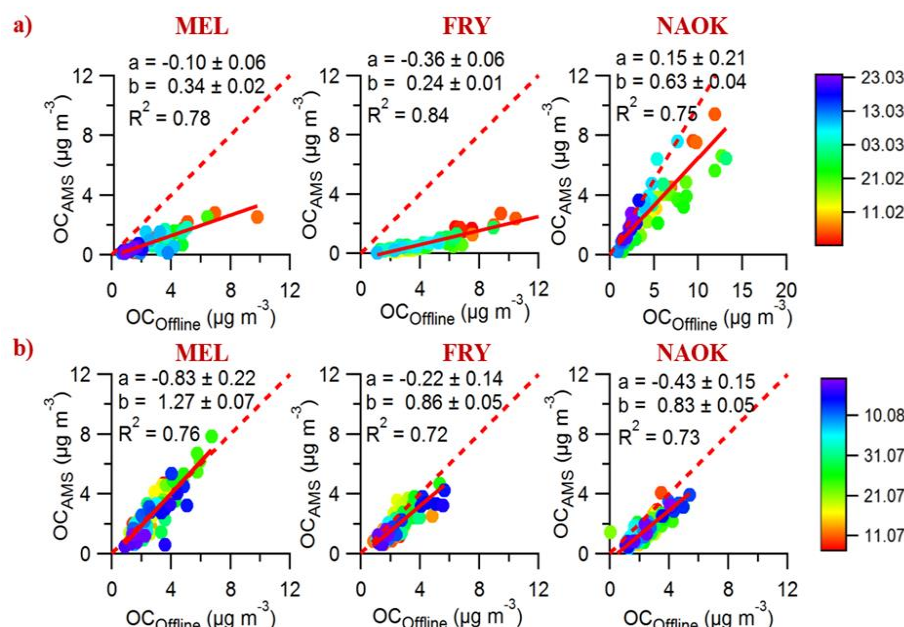


Figure 5: Comparison in winter (top) and summer (bottom) of OC_{AMS} (PM_1) with $OC_{Offline}$ ($PM_{2.5}$) at MEL, FRY, and NAOK. The dotted line represents the 1:1 line, the solid line represents the orthogonal distance fit of the data, b = slope and a = intercept. Course of time is in color for each season.



255 During summer, there was better agreement between OC_{AMS} and $OC_{Offline}$ at all stations (MEL: $R^2 = 0.76$, slope = 1.27; FRY: $R^2 = 0.72$, slope = 0.86; NAOK: $R^2 = 0.73$, slope = 0.83), with slopes generally nearer to the 1:1 line. However, MEL showed an overestimation of OC_{AMS} compared to $OC_{Offline}$. Correspondingly, the MEL results obtained with the HR-ToF-AMS are consistent with those reported from the ACSM in a previous study comparing daily $PM_{2.5}$ filters (Poulain et al., 2020), suggesting a reliable and reproducible OC estimation across instruments and years at this site. To test whether the discrepancy

260 between OC_{AMS} and TOT derived OC is influenced by temporal resolution, OC_{AMS} was additionally compared with higher time-resolution OC_{Online} data (Fig. 6), showing similar patterns as for the $OC_{Offline}$ comparisons.

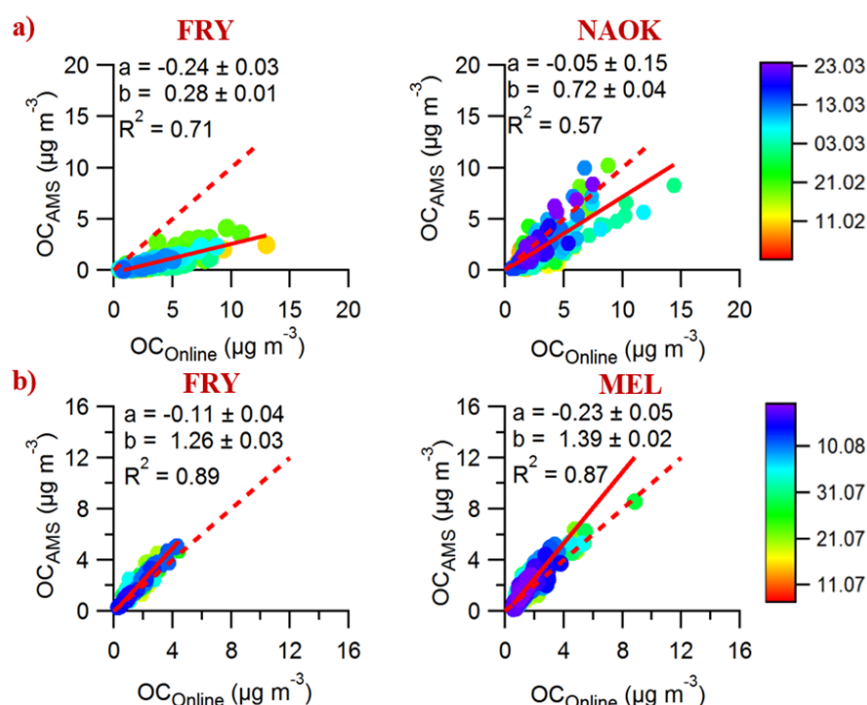


Figure 6: Comparison of winter and summer OC_{AMS} (PM_1) with OC_{Online} . Panel (a) shows winter measurements at FRY (left) and NAOK (right), while panel (b) shows summer measurements at FRY (left) and MEL (right). The dotted line represents the 1:1 line, the solid line represents the orthogonal distance fit of the data, b = slope and a = intercept. Course of time is in color for each season.

This contrasts with previous winter studies in Tokyo ($R^2 = 0.72$, slope = 1.14 ± 0.08 ; Kondo et al., 2007) and Las Vegas ($R^2 = 0.89$, slope = 0.91; Brown et al., 2019), where stronger correlations between the two methods were reported. At FRY, where both AMS and semi-online EC/OC analyzer used the same PM_1 size cut, size effects were excluded, confirming that winter discrepancies were not caused by mismatch in particle size. Summer intercomparisons (Fig. 6) followed a pattern similar to the $OC_{Offline}$ comparison. At FRY, correlations were strong ($R^2 = 0.89$) with a slope of 1.26, compared to $R^2 = 0.71$ and a slope of 0.28 in winter. At MEL ($R^2 = 0.87$, slope = 1.39), the online OC_{Online} was lower than the OC_{AMS} concentrations during summer. These summer results are consistent with previous findings in Tokyo ($R^2 = 0.87$, slope = 1.21; Kondo et al., 2007)



and Riverside, California ($R^2 = 0.53$, slope = 1.10 ± 0.15 ; Docherty et al., 2011), which also reported comparable agreement between TOT and AMS based OC.

Compared with these urban studies, far fewer OC intercomparisons are available for regional background or rural type environments. The most comparable measurements are those reported from northern France by Crenn et al. (2018). Although the sites were not rural, they represent urban background and coastal settings with aerosol characteristics closer to those at MEL, FRY, and NAOK than the heavily polluted megacities used in most previous comparisons. Crenn et al. observed clear seasonal behavior in OC_{AMS} to $OC_{Offline}$ regressions, with slopes of 0.68 in summer ($R^2 = 0.92$) and 0.61 in winter ($R^2 = 0.86$) at the urban background site, and 0.29 in summer ($R^2 = 0.50$) and 0.50 in winter ($R^2 = 0.82$) at the coastal site. They attributed these discrepancies mainly to the PM_1 to $PM_{2.5}$ size cut difference between AMS and TOT and also noted contributions from positive adsorption of SVOCs on filters, volatilization losses, uncertainties in the EC-OC split due to different thermal protocols, and the influence of high ambient relative humidity on AMS collection efficiency. The observed discrepancies between OC_{AMS} and OC_{TOT} were further assessed for source-specific influences, as discussed below.

3.4 Source Influence

The site and season dependent differences observed between AMS and TOT derived OC were examined for source-related factors like air mass origin and OA:eBC ratio. These factors can reflect differences in source composition and their role in observed variability. The potential influence of nearby emission sources was considered for each of the three measurement locations, as local contributions may affect the relative abundance and chemical characteristics of carbonaceous aerosol at the measurement sites.

3.4.1 Effects of Air Mass Origin on OC_{AMS} - OC_{TOT} Agreement

The strongest wintertime correlation between OC_{AMS} and OC_{TOT} was observed at NAOK; however, two distinct correlation regimes are apparent. While Fig. 5 shows the overall relationship between OC_{AMS} and $OC_{Offline}$, Fig. 7 separates this relationship according to air mass clusters, distinguishing periods dominated by long-range transport from the remaining clusters. Previous work has shown that air-mass origin at NAOK significantly influences both PM mass and its chemical composition (Arora et al., 2026a). Accordingly, the cluster classification from Arora et al. (2026a) was applied (Fig. S6). C1W represents long-range westerly transport from the North Atlantic across Western Europe, and C2W southwesterly flow from the Iberian Peninsula and Western Mediterranean. Although their mean trajectories do not extend into North Africa, the three major Saharan dust events (5-10 Feb, 21-26 Feb, and 2-4 Mar 2021) occurred during periods dominated by C1W or C2W, suggesting short-term synoptic variability not captured by average trajectories. Due to their association with dust events and increased OC_{AMS} - OC_{TOT} discrepancies, C1W and C2W were merged to represent a long-range transport regime and compared to the remaining clusters: C3W (North Atlantic via Scandinavia), C4W and C5W (eastern trajectories from northern Scandinavia and the Baltics across Eastern Europe), and C6W (Norwegian Sea across northern Germany).



During periods dominated by C1W and C2W, the slopes between OC_{AMS} and $OC_{Offline}$ were substantially below unity at all stations (MEL: 0.38, $R^2 = 0.86$; FRY: 0.12, $R^2 = 0.81$; NAOK: 0.48, $R^2 = 0.95$), suggesting pronounced underestimation by AMS (Fig. 7). In contrast, when the remaining clusters were grouped, the slopes increased (MEL: 0.51, $R^2 = 0.82$; FRY: 0.27, $R^2 = 0.91$; NAOK: 0.76, $R^2 = 0.83$), reflecting improved agreement between AMS and offline measurements, especially at NAOK, where the slope approached unity. A consistent pattern was observed in the OC_{Online} vs. OC_{AMS} comparison (Fig. S7), where the slopes during C1W and C2W remained markedly lower. In addition, OC_{Online} and $OC_{Offline}$ comparison shows no effects of the air mass origins (Fig. S8) as both datasets are based on the same TOT method further validating the discrepancies identified in Fig. 7. Moreover, C1W and C2W were characterized by relatively mild and ventilated conditions (Table S3), making inversion effects unlikely. Instead, these clusters correspond to faster (Table S3), long-range advection from Western Mediterranean, consistent with the presence of externally mixed or refractory aerosol (e.g., dust and fresh combustion products), thereby reinforcing that specific long-range transport conditions likely contributed to the observed OC_{AMS} underestimation relative to OC_{TOT} .

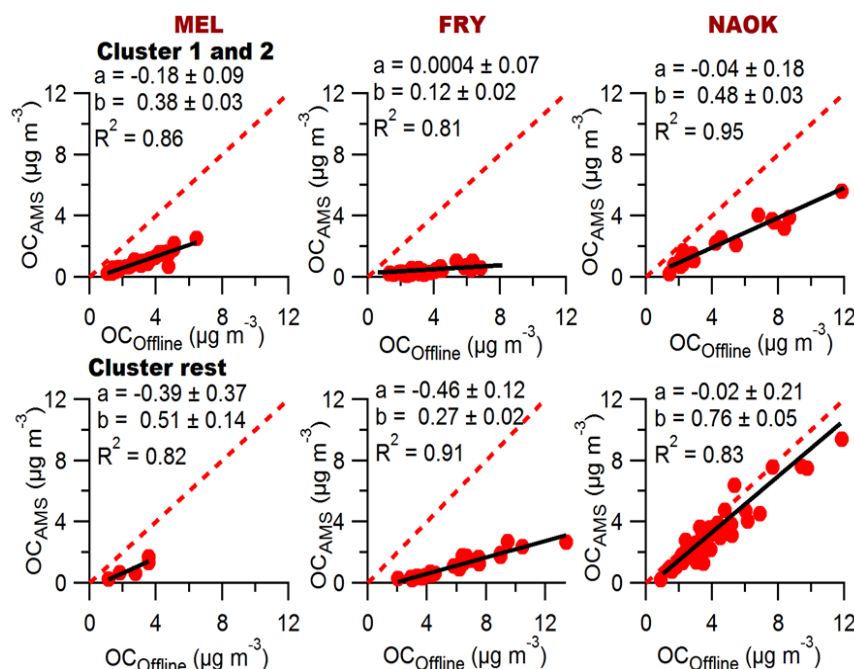


Figure 7: Comparison of OC_{AMS} (PM_1) with $OC_{Offline}$ ($PM_{2.5}$), illustrating the impact of clusters. Top panels represent Clusters 1 and 2, and bottom panels represent the rest of the clusters (3, 4, 5, and 6) for MEL, FRY, and NAOK stations during winter. The dashed red line indicates a 1:1 relationship, b = slope, and a = intercept.

One plausible explanation for the observed wintertime OC discrepancies is the enhanced influence of dust-laden air masses, as indicated by backward-trajectory analysis (Arora et al., 2026a). These clusters coincided with the three major dust events and were associated with larger discrepancies between OC_{AMS} and OC_{TOT} measurements, reflecting the known influence of mineral dust on both OC_{AMS} and OC_{TOT} quantification. Long-range transport of mineral dust introduces a significant fraction



of refractory organic material, which is not efficiently sampled by the AMS due to the aerodynamic lens cutoff and the standard vaporization temperature ($\sim 600^\circ\text{C}$) (Capes et al., 2008). As a result, systematic underestimation of OC by the AMS may occur, consistent with known biases for pyrolyzed OC fractions. Shen et al. (2019) similarly reported that the AMS is inherently limited in its ability to characterize refractory dust cores and that organic coatings associated with mineral dust may be underdetected, particularly when the organic mass fraction is low or the coating is thin. Furthermore, these authors noted that non-refractory species measured by AMS may originate from particles consisting of internally mixed non-refractory and refractory components, emphasizing that complex particle morphologies, common during dust events, can complicate AMS quantification.

In addition to AMS-related uncertainties, carbonate content from mineral dust may affect OC_{TOT} measurements, which can bias OC estimates upward (Koorneef et al., 2023; Wang et al., 2025). However, this effect is mainly relevant for coarse particles and is expected to be minor in the fine mode (Chen et al., 2021). Since air-mass origin cannot separate source from transport effects, the OA:eBC ratio is therefore examined as a bulk indicator of combustion influence and atmospheric processing, to assess whether these factors are associated with the discrepancies between OC_{AMS} and OC_{TOT} .

3.4.2 OA:eBC Ratio

As OC_{AMS} is derived from the AMS measured organic aerosol mass (OA) using the OM:OC ratio (Eq. 3), the OA:eBC ratio, defined as the mass of OA measured by the AMS divided by eBC from the aethalometer, acts as a proxy for dominant combustion sources; it is lower for traffic emissions and coal combustion and higher for biomass/wood burning (Lin et al., 2023). The ratio is also shaped by atmospheric processing, including condensation, evaporation, and aging, and was used to relate discrepancies between OC_{AMS} and OC_{TOT} to source characteristics, complementing the previously discussed cluster-based analysis.

Figure 8 shows the comparison of OC_{AMS} with $\text{OC}_{\text{Offline}}$ for all stations as a color-coded function of OA:eBC, an inverse dependency emerged. FRY showed the lowest OA:eBC ratio and deviated the most from the 1:1 line, whereas NAOK, with the highest ratio, was closest to unity. A comparable relationship was also found for OC_{AMS} versus $\text{OC}_{\text{Offline}}$ as a function of OA:EC (Fig. S10), supporting these results. A clear seasonal contrast was evident, with lower OA:eBC values in winter (MEL = 3.06, NAOK = 10.21, FRY = 1.12) than in summer (MEL = 21.97, NAOK = 18.44, FRY = 12.02). This seasonal pattern has been widely reported, as higher summer OA:eBC ratios are attributed to secondary organic aerosol (SOA) formation and reduced fossil fuel eBC emissions (e.g., Genberg et al., 2011; Heikkinen et al., 2020; Lin et al., 2023). For example, in Finland's boreal forest, approximately 80 % of summer aerosol is biogenic, yielding $\text{OA:eBC} > 10$ (Heikkinen et al., 2020). Similarly, at a rural site in southern Sweden, summer aerosol is dominated by biogenic organics ($\sim 80\%$), whereas winter is dominated by biomass burning (32 %) and fossil fuels (28 %) (Genberg et al., 2011). These findings are consistent with the present study, in which all stations exhibit $\text{OA:eBC} > 10$ during summer.

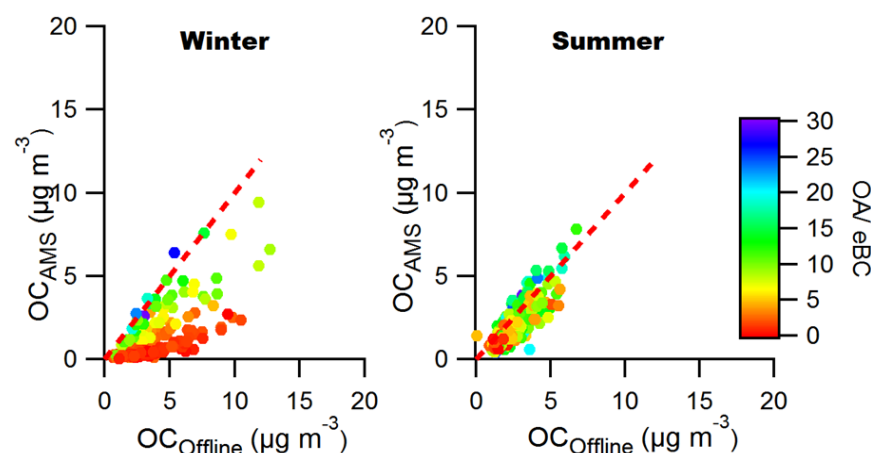


Figure 8: Comparison of OCAMS (PM₁) with OCOOffline (PM_{2.5}) as a function of OA:eBC ratio during winter and summer at all three stations combined.

OA:eBC ratios reported in the literature were also examined. At MEL, Atabaksh et al. (2023) from our laboratory found values of 4.50 in winter and 14.68 in summer, while Pokorna et al. (2022) reported 4.94 in winter and 12.42 in summer at NAOK. While the winter OA:eBC ratio at MEL aligns with prior studies, the values at NAOK in winter and summer are substantially lower than the present dataset. Although higher OA:eBC ratios in summer are generally expected, local sources can modify this trend. NAOK, for instance, shows an OA:eBC of 10.75 in winter, which is comparable to summer ratios at other sites, owing to strong wood burning influence (Schwarz et al., 2016; Pokorna et al., 2018). Lhotka et al. (2025) reported winter OA:eBC ratio of 4.70 at NAOK, whereas the present study recorded 10.75, reflecting short-term episodes of intense residential combustion. Comparable wintertime OA:eBC ratios (~11) have been observed at a rural Slovenian site dominated by residential wood combustion (Mosquera et al., 2024), consistent with the substantial OC emissions from smoldering wood combustion and subsequent formation of secondary organic aerosol (Heringa et al., 2011).

By contrast, at FRY, where coal combustion dominates, the winter OA:eBC ratio was lowest (1.12), consistent with typical coal burning values of 1.10 -1.30 due to higher eBC contribution (Bond et al., 2004; Lin et al., 2023). MEL, influenced by both coal and transported biomass burning, falls in between (OA:eBC = 3.06; Atabaksh et al., 2023). Overall, winter OA:eBC ratios reflect primary heating emissions, whereas summer ratios are governed by SOA formation. Exceptions such as NAOK, dominated by wood burning, demonstrate that source type, rather than season alone, ultimately determines OA:eBC variability. During winter, OA:eBC ratios below ~5 coincide with conditions where OC_{AMS} and OC_{TOT} are prone to substantial divergence. Under such conditions, OC values should be interpreted with caution. This relationship is season-specific, as higher summer OA:eBC ratios show no consistent link to the discrepancy. In addition to the influence of air mass origin and the OA:eBC ratio, potential TOT and AMS based uncertainties were identified and quantified to assess the key factors affecting the measurement agreement/disagreement.



3.5 Potential method uncertainties in OC determinations

380 The strong seasonal patterns and site-dependent variability observed in the agreement between OCAMS and measured OC indicate that several factors may contribute to the observed discrepancies. These likely include uncertainties related to instrument performance, biases introduced by sampling artifacts as well as potential aerosol matrix effects. Therefore, it is important to examine how these factors could contribute to the observed discrepancies and to what extent they influence the comparability of OC measurements across different sites and seasons.

385 3.5.1 Potential method uncertainties in OC determinations

TOT estimated from the EUSAAR-2 protocol described in Cavalli et al., 2018, is still known to be subject to artifacts that can affect the accuracy of OC measurements, although it represents a major improvement over older and less well-defined carbon sum parameter determination protocols. As in all available methods, a major source of uncertainty is formation of pyrolytic carbon (PC) during EC/OC analysis. During the inert He phase, part of the organic carbon can thermally decompose and form
390 PC. If left uncorrected, this artifact would bias OC low and EC high. The major progress introduced with EUSAAR-2 compared with earlier protocols is therefore the optical correction of this charring contribution during analysis. Using laser transmittance, the method tracks the return of the filter signal and assigns the pyrolyzed fraction back to OC, which substantially improves the determination of the OC and EC carbon sum parameters (Cavalli et al., 2018). PC production is composition dependent, with water soluble organic carbon (WSOC) rich aerosols from biomass burning, SOA, or low-rank coals such as lignite being
395 especially prone to charring (Yu et al., 2002). WSOC from residential solid fuel combustion has been shown to be light-absorbing and a major contributor to PC formation (Zhang et al., 2024), while removal of WSOC by water extraction prior to analysis can significantly reduce this artifact, with residual charring reported to decrease to <7 % of total EC after extraction and thereby affecting the OC-EC split (Zhang et al., 2012). Although such pretreatment is not part of the standard EUSAAR-2 protocol, its stepwise heating profile still substantially reduces pyrolysis artifacts, even in WSOC-rich samples (Haller et al.,
400 2021). At MEL, WSOC accounted for approximately half of the measured OC ($\text{WSOC/OC} \approx 50\%$), suggesting that a large fraction of OC was present in water-soluble form. Such values fall within the typical range reported for atmospheric aerosols, where WSOC commonly represents about 20-70% of OC and may reach 45-75% in biomass burning influenced particles (Mayol-Bracero et al., 2002; Chalbot et al., 2016). Seasonal comparison showed that WSOC concentrations and WSOC/OC ratios, determined from PM_{10} filter samples, were similar in winter ($\text{WSOC: } 1.72 \mu\text{g m}^{-3}$; $\text{WSOC/OC: } 51.6\%$) and summer
405 ($2.16 \mu\text{g m}^{-3}$; 50.8%), suggesting variations in WSOC abundance are unlikely to explain the observed OC discrepancies at this site. Comparable data were not available for FRY or NAOK.

The OC-EC split during TOT analysis represents the most sensitive step of the method, as it relies on this optical assignment of pyrolysis products to OC rather than EC. The PC fractions, also analyzed from $\text{PM}_{2.5}$ filter samples and expressed as a percentage of TC, were elevated during winter at all sites at FRY (35%, $1.97 \mu\text{g/m}^3$), MEL (34%, $1.52 \mu\text{g/m}^3$), and NAOK
410 (28%, $1.18 \mu\text{g/m}^3$), demonstrating known challenges in splitting PC from EC in TOT analysis (Chow et al., 2001; Yang & Yu,



2002). Thus, the high winter PC fractions suggest that the correction was particularly relevant under these conditions and likely improved the OC and EC determination compared with an uncorrected analysis. However, this correction still introduces some uncertainty because the optical signal cannot perfectly distinguish between charred OC formed during analysis and pre-existing EC in the sample, making the OC-EC split sensitive to the correction procedure (Yang & Yu, 2002). Malm et al. (2020) showed that this correction can overcompensate, leading to ~10% OC overestimation and ~60% EC underestimation, as part of the EC peak might be misclassified as OC. This does not imply that the PC correction is unsuitable. On the contrary, the optical correction is essential and represents a clear methodological improvement. The present results rather suggest that under winter combustion-dominated conditions, residual uncertainty in the corrected OC-EC split remains larger than in summer. Subtracting PC from winter OC improved correlations between OC_{AMS} and $OC_{Offline}$ (Fig. S4, slope: MEL = 0.61, FRY = 0.44, NAOK = 1.24), but the data still deviated strongly from the 1:1 line, showing that PC related effects contribute to, but do not fully explain, discrepancies between OC_{TOT} and OC_{AMS} . The improved summer agreement coincides with reduced PC fractions (range at all sites: ~18-22%, ~0.5-0.6 $\mu\text{g m}^{-3}$), fewer semi-volatile and refractory organics, and decreased combustion influence. Because NAOK already exhibited a lower PC fraction in winter compared with FRY and MEL, the seasonal decrease is most pronounced at MEL (15%) and FRY (17%), whereas NAOK (7%) shows a smaller reduction from winter to summer. Additional analysis of OC_{AMS} versus $OC_{Offline}$ as a function of PC/TC (Fig. S5) showed no dependence of the correlation on PC fraction. Overall, PC alone cannot explain the discrepancy and additional site and season-specific factors must be considered to fully reconcile OC_{AMS} with OC_{TOT} . Therefore, the practical implication is not to introduce matrix dependent split points, but rather to retain the standardized EUSAAR-2 correction procedure and to interpret OC-EC separation with increased caution for winter samples with high PC fractions and strong combustion influence. Under such conditions, reporting and discussing the magnitude of PC, the split behavior, and the associated uncertainty becomes especially important.

3.5.2 AMS

Although the AMS nowadays is a key instrument for direct quantification of organic aerosol mass and bulk chemical characteristics, the conversion of OM to OC introduces several challenges associated with AMS/ACSM techniques. These factors can collectively contribute to the underestimation of OC using AMS data. In the UMR approach, the O:C ratio is determined primarily from the f44 signal, which introduces additional uncertainty in OM:OC and therefore in OC_{AMS} , as discussed earlier in Section 3.2. While these uncertainties are primarily discussed for the AMS (which were deployed at MEL and FRY, the stations with the highest discrepancies), they also apply to ACSM measurements, as both instruments share the same vaporization and ionization principles although differences in instrument design and sensitivity may influence the magnitude of these effects. The most relevant sources of uncertainty, considered in this study, are listed below and are discussed individually in the following sections:

(i) Physical and instrumental uncertainties in detecting refractory and high molecular weight organic species.

The AMS measures non-refractory organic aerosol components, and therefore does not fully capture refractory organic material. Malmborg et al. (2019) showed that conventional AMS tends to underestimate refractory organic carbon (ROC),



particularly that corresponding to the OC3-OC4 (carbon fractions evolving at ≥ 450 °C) and PC from the EUSAAR-2 protocol, because rapid desorption at ~ 600 °C under high vacuum prevents complete volatilization of thermally stable structures. This bias is amplified when OC is associated with black carbon (BC) coatings. Ma et al. (2021) showed that AMS underestimates OC on BC-coated particles due to incomplete vaporization of ROC which prevents subsequent ionization and fragmentation under the default vaporization scheme as used on the instruments during this study. The A-A and I-A methods, optimized for this vaporization, may introduce bias, producing artificially higher oxidation ($fC_2H_3O^+/fCO_2^+$, O:C) ratios while excluding ROC that fails to vaporize completely. Correlations between OC_{AMS} vs. $OC_{Offline}$ regression residuals and the f_{44}/f_{43} ratio during both winter and summer at MEL (Fig. S14) showed only a weak, non-significant negative relationship ($r = -0.09$, $p = 0.46$; summer: $r = -0.17$, $p = 0.12$), suggesting that organic aerosol oxidation state did not significantly affect observed differences. Potential coating-based effects could not be directly assessed in this study due to the absence of Laser Vaporization AMS measurements, which improve detection of BC containing particles but may also enhance fragmentation of organic material because of higher vaporization temperatures.

Such vaporization limitations are particularly relevant for combustion related organic aerosols. Xu et al. (2020) found that polycyclic aromatic hydrocarbons (PAHs) and tarry organics in coal emissions often fragment into high m/z ions or fail to vaporize altogether, leading to underrepresentation of coal derived organics in AMS. Under laboratory conditions, they observed that $\sim 40\%$ of the organic signal from fresh coal combustion was associated to ions higher than m/z 150, reflecting the abundance of high molecular weight species. In the ambient MEL dataset, however, ions above m/z 150 accounted for only 2.3% of the organic signal in winter and 1.2% in summer, suggesting that high molecular weight ions represent only a minor fraction of the measured AMS organic spectra. Both coal combustion and residential wood burning are known sources of PAH rich organic aerosols containing large aromatic compounds that can contribute to high m/z fragments (Guerrero et al., 2019; Xu et al., 2020). The much lower ambient fraction therefore suggests that these compounds either fragment during AMS vaporization or alternatively, AMS may underestimate thermally stable larger molecular species such as polycarboxylic acids and humic-like substances (HULIS) (Paglione et al., 2014). These factors likely explain the low fraction of high m/z signal observed in the MEL winter data despite expected contributions from coal and wood combustion. Although no clear evidence of refractory or high molecular weight organics as a source of discrepancy was observed, complementary approaches should be considered when interpreting the data as these components are not directly captured by the AMS.

(ii) *Source dependent variability in the relative ionization efficiency (RIE) of organics, leading to uncertainties in organic mass quantification.*

Another potential source of uncertainty in OC_{AMS} quantification is variability in the relative ionization efficiency (RIE) of organics. While a default RIE of 1.4 is suitable for aged SOA, it can bias estimates for fresh POA from coal or biomass combustion, which have lower OSc values and different ionization behavior (Xu et al., 2018). Nault et al. (2023) demonstrated that POA with $OSc < -0.75$ can exhibit highly variable RIE_{OA} values with laboratory measurements of organic compounds ranging approximately 0.9-11.5 and mass spectra become dominated by high m/z fragments, some of which may be affected by reduced transmission efficiency at higher m/z . Intercomparison studies have shown that ACSM measurements become



increasingly uncertain at higher m/z . Variability between Q-ACSM instruments has been reported above m/z 98 (Crenn et al., 2015), and agreement between ACSM and AMS measurements is generally consistent only below this range (Fröhlich et al., 2013). Although the ToF-ACSM software applies mass-dependent transmission corrections, these adjustments cannot fully compensate for reduced transmission efficiency at high m/z . Consistent with this, the measured OSc of organics at MEL during winter was predominantly between -1 and 1 (Fig. S12), indicating the presence of fresh, less-oxidized POA likely subject to the same RIE variability and detection inefficiencies described above. A sensitivity test varying RIE values from 1 to 2 was performed to investigate this hypothesis (Fig. S11); however, the slope of OC_{AMS} versus $OC_{Offline}$ worsened, from 0.48 (RIE= 1) to 0.21 (RIE= 2). Moreover, volume closure analysis (Fig. S13) showed that the slope of $Volume_{AMS}$ versus $Volume_{SMPS}$ decreased substantially from 1.39 at RIE = 1 to 0.78 at RIE = 2 (compared to 0.92 at the original RIE = 1.4), suggesting that an underestimation of the organic mass concentration due to an incorrect organic RIE cannot explain the winter deviation between OC_{AMS} and OC_{TOT} values.

(iii) *Potential underestimation of organic oxygen content due to the incorrect attribution of organonitrates (ON) and organosulfates (OS) fragments to the inorganic nitrate and sulfate fractions.*

The misclassification of ON and OS as purely inorganic nitrate or sulfate represents another potential source of uncertainty. This can change the distribution of the oxygen atoms between the organic and inorganic fractions, introducing systematic bias into OM:OC estimates (Farmer et al., 2010; Day et al 2022). This phenomenon might not be negligible as Europe-wide study found that $34 - 44\%$ of fine particulate nitrate was derived from organic nitrates formed through nocturnal chemistry, even though the AMS would classify all of this as “nitrate” (Kiendler-Scharr et al., 2016). Using the HR mass spectra, the fraction of ON in particulate nitrate was calculated for MEL as:

$$pOrgNO_3_{frac} = \frac{(1 + R_{OrgNO_3}) \times (R_{measured} - R_{calib})}{(1 + R_{measured}) \times (R_{OrgNO_3} - R_{calib})} \quad (4)$$

yielding 35.5% during winter and 48.7% during summer. Although the fractional contribution was higher in summer, higher winter nitrate concentrations imply that the absolute organic nitrate concentration may be comparable or even larger during winter. The elevated winter proportion remains considerable given the lower photochemical production typically expected during colder months and falls within the range reported for Melpitz ($29-57\%$) in Kiendler-Scharr et al. (2016). AMS misclassification of ON/OS as inorganic nitrate or sulfate is expected to bias O:C downward by assigning organic oxygen to the inorganic fraction (Farmer et al., 2010). A lower O:C would reduce the OM:OC ratio (Eq. 2) and therefore increase OC_{AMS} for a given OA mass (Eq. 3); however, the relatively high O:C and OM:OC ratios observed here (Table S1) that a substantial fraction of oxygenated organics is already captured in the AMS signal. Therefore, even if ON/OS misclassification occurs, its effect would tend to increase rather than decrease OC_{AMS} , and cannot explain the systematic underestimation of OC_{AMS} relative to OC_{TOT} observed in winter. It is important to note that the estimation of ON requires HR mass spectra and was therefore only possible at MEL. These observations suggest that ON/OS misclassification is not a dominant factor in the observed OC discrepancy, although its influence on OM:OC estimates should be considered.



510 (iv) *Uncertainties in the f44 signal related to the so called Pieber effect (Pieber et al., 2016), which can cause apparent increases in measured organic signals unrelated to actual organic mass.*

Additionally, the so-called Pieber effect, can lead to overestimation of the CO_2^+ signal at m/z 44. It arises from the thermal decomposition of inorganic salts like ammonium nitrate on the AMS vaporizer, releasing reactive nitrogen species that oxidize deposited carbonaceous residues, producing CO and CO_2 unrelated to the sampled aerosol (Pieber et al., 2016). This non-organic CO_2^+ can be misattributed to organics, artificially enhancing the f44 signal and OA mass while potentially decreasing OCAMS due to higher O:C values entering the OM:OC conversion. Since the interference depends on carbonaceous residues accumulated on the vaporizer, its magnitude is instrument specific and influenced by measurement history. In this study, three different instruments with different sampling histories were used, making it unlikely that all sites would exhibit the same residue related behavior. Alternatively, if the vaporizer memory is very short, deposited residues would be rapidly removed and the artifact would become negligible. In either case, the Pieber effect is unlikely to produce a consistent OC bias across all sites.

Overall, the identified AMS related limitations do not appear as a single dominant source of bias in the ambient dataset, but rather suggests that OC_{AMS} quantification might become uncertain under combustion influenced conditions. In practice, this means that AMS derived OC should be interpreted in the context of aerosol composition, rather than treated as a standalone quantitative measure under all conditions. As refractory and chromophoric organic components are not fully represented in the AMS signal, BrC absorption was used to provide additional information on these fractions.

3.6 Influence of BrC

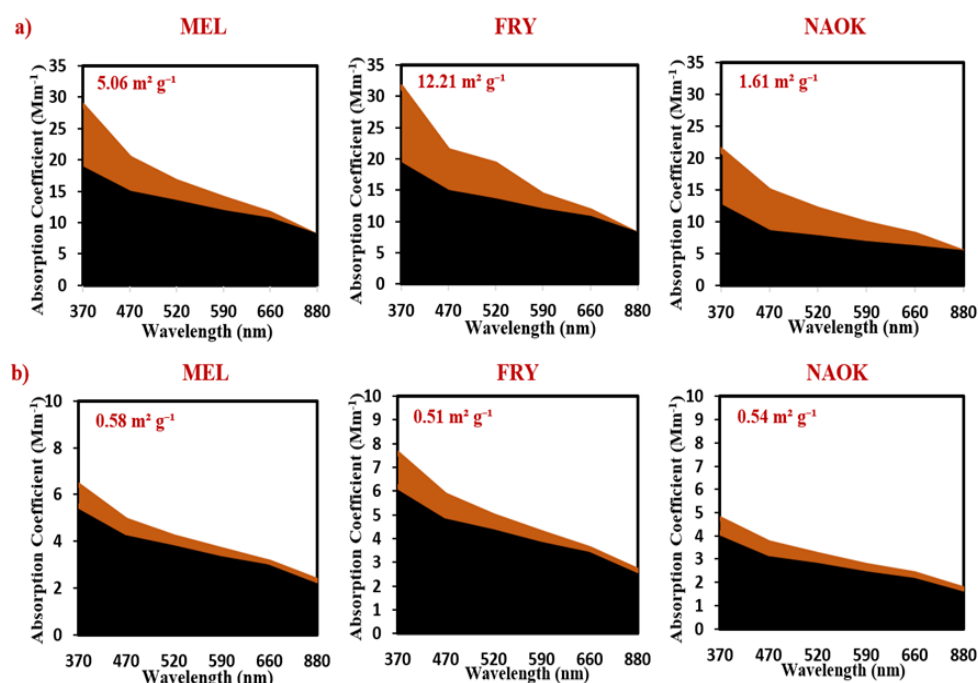
BrC represents the light absorbing fraction of organic carbon and therefore provides additional information on the chemical composition of OC beyond bulk OC concentrations (Laskin et al., 2015). Because BrC is commonly associated with combustion derived aromatic compounds, it may influence OC determination by affecting the optical correction used for the OC-EC split in TOT analysis (Andreae & Gelencsér, 2006) and by including thermally stable organic material that may not be fully detected by AMS (Malmberg et al., 2019), potentially contributing to discrepancies between OC_{TOT} and OC_{AMS} . To evaluate whether such chromophoric organic material was present in the aerosol, the light absorbing properties of BrC were examined across sites and seasons. BrC absorption provides insight into the aerosol radiative effects and source composition, therefore the absorption coefficient (b_{abs}) and the relative BrC contribution to total absorption was calculated (Fig. 9). While eBC dominated total absorption at longest wavelength of the visible light and near-IR spectrum, BrC contributed significantly at shorter wavelengths, showing strong seasonal and spatial variability. In summer, b_{abs} attributed to BrC at 370 nm was similar across sites: FRY ($1.38 \pm 3.04 \text{ Mm}^{-1}$), NAOK ($1.35 \pm 1.00 \text{ Mm}^{-1}$), and MEL ($1.29 \pm 3.54 \text{ Mm}^{-1}$), while in winter, they increased strongly without significant difference between the sites and slightly varied: FRY ($11.87 \pm 12.64 \text{ Mm}^{-1}$), MEL ($9.07 \pm 9.41 \text{ Mm}^{-1}$), and NAOK ($8.77 \pm 4.85 \text{ Mm}^{-1}$). At NAOK, Mbengue et al. (2021) reported BrC absorption of $12.84 \pm 9.34 \text{ Mm}^{-1}$ (winter) and $3.94 \pm 2.04 \text{ Mm}^{-1}$ (summer), consistent with the seasonal decrease observed here and linked to biomass burning and secondary formation, respectively. Similarly, Teich et al. (2016) reported BrC b_{abs} at 370 nm of 4.13 Mm^{-1}



(winter) and 0.84 Mm^{-1} (summer) at MEL, confirming higher winter absorption from primary emissions and lower summer values due to photochemical aging and biogenic influence.

545 Although NAOK showed the lowest winter $b_{\text{abs,BrC}}$, the corresponding $\text{MAC}_{\text{BrC},370}$ was substantially higher at FRY ($12.21 \pm 7.84 \text{ m}^2 \text{ g}^{-1}$) compared to NAOK ($1.61 \pm 0.81 \text{ m}^2 \text{ g}^{-1}$) and MEL ($5.06 \pm 4.75 \text{ m}^2 \text{ g}^{-1}$), indicating that BrC at FRY was considerably more light-absorbing per unit mass. This indicates that BrC at FRY was more light-absorbing per unit mass, consistent with enrichment in darker chromophores from coal combustion. This interpretation is supported by the lower OA:eBC ratio at FRY and by previous findings linking reduced OA:eBC to darker BrC (Pokhrel et al., 2017) and to

550 chromophore formation through pyrolysis (Donahue et al., 2015). In contrast, during summer, $\text{MAC}_{\text{BrC},370}$ values were lower and similar across sites (Table S2) indicating a more uniform BrC light-absorption efficiency. The comparable MAC values suggest that BrC was dominated by less-absorbing, secondary organic components formed through photochemical aging rather than by primary combustion sources.



555 **Figure 9: Winter (top) and summer (bottom) absorption coefficients (Mm^{-1}) attributed to eBC (black area) and BrC (brown area) at MEL, FRY and NAOK. The values in red represent $\text{MAC}_{\text{BrC},370}$ ($\text{m}^2 \text{ g}^{-1}$).**

Compositional evidence supports these interpretations. Mo et al. (2024) showed that coal combustion-derived HULIS in BrC are enriched in high-molecular-weight aromatics, which are resistant to photochemical degradation and exhibit strong light absorption, whereas biomass burning BrC contains more phenolic and unsaturated components with weaker absorption. At

560 FRY, elevated winter absorption at 520 nm points to tar-rich coal-derived BrC (Laskin et al., 2015), also consistent with Zhang et al. (2024), who identified coal-related organosulfates and fused aromatic structures extending BrC absorption into the visible range. The seasonal variability also reflects differences in aerosol composition. At MEL, Spranger et al. (2020) reported winter



WSOC and its HULIS fraction as being dominated by fresh biomass burning and coal emissions, while summer HULIS was more oxygenated, chemically homogeneous, and dominated by secondary formation. Overall, the distinct wintertime BrC profile at FRY, characterized by a high absorption coefficient, enhanced absorption at shorter wavelengths, and a low OA:eBC ratio, suggests the possible presence of refractory, coal-derived chromophores. However, this alone cannot explain the discrepancies between OC determined by AMS and TOT protocols, and targeted molecular-level analyses are required to confirm such a connection.

4 Conclusion

The present study provides a comprehensive multi-method intercomparison of carbonaceous aerosol measurements across three Central European background sites - MEL, FRY, and NAOK; using aerosol mass spectrometry (AMS/ACSM), TOT analysis (both online and offline), and aethalometer-based optical measurements. By evaluating methodological consistency and seasonal variability in OC quantification, the study addressed critical uncertainties in aerosol characterization and identified both potential systematic biases and site-specific influences. Across all stations, a pronounced seasonal pattern was observed with good agreement between the methods during summer (range of slopes and R^2), while the comparison deteriorated strongly in winter at every site. As similar results were obtained at all sites, an instrumental deficiency during winter was considered unlikely. Instead, potential sources of discrepancy related to the specific composition of the winter aerosol matrix were investigated. However, factors such as AMS uncertainties in RIE, the presence of high molecular weight organics, misclassification of ON, and pyrolytic artifacts in TOT analysis were individually considered, but none of them fully explained the discrepancies, demonstrating the multifaceted nature of the observed disagreement between the methods. Additionally, source-dependent factors such as OA:eBC ratios and air mass origins clearly influenced the degree of agreement. For instance, coal-dominated site FRY and long-range dust events during winter were associated with the largest discrepancies. In contrast, during summer, agreement between methods improved substantially, owing to the lower influence of combustion emissions, reduced pyrolytic interference, and the dominance of SOA formation. Distinct site-specific trends were evident in OA:eBC ratios, with NAOK exhibiting elevated ratios due to biomass burning, FRY showing the lowest ratios linked to coal combustion, and MEL presenting intermediate values indicative of mixed sources. Based on the measurements and analyses performed in this study, and with appropriate caution, the following recommendation and perspectives for further investigation are proposed for the determination of aerosol particle OC:

Recommendation

1. The applied intercomparison framework performs reliably under summer aerosol conditions but is affected by a strong matrix dependence in winter. During winter, the bias increases as the OA:eBC ratio decreases; thus, OC values particularly from the AMS should be interpreted with caution during winter, particularly when OA:eBC ratio value falls below 5.

Parameters requiring further investigation



- 595 1. PC formation and charring in TOT analysis may contribute to uncertainties in winter OC determination. Although PC
correction alone does not explain the discrepancy between OC_{TOT} and OC_{AMS} , elevated PC fractions during
combustion dominated periods indicate that charring effects may influence the OC-EC split and warrant further
targeted investigation.
- 600 2. OC_{TOT} provides a more stable reference for absolute OC levels due to its standardized thermal-optical protocol,
whereas OC_{AMS} is better suited for resolving temporal variability and composition; wintertime OC trend analyses in
monitoring networks are therefore recommended to be anchored primarily to TOT based OC, with AMS based OC
used in a complementary way.
- 605 3. Site-specific source composition should be treated as an explicit uncertainty factor. Conditions influenced by coal
combustion, mineral dust, long-range transported aerosol, or any overlap between these regimes require particular
caution; under such conditions, quantitative use of OC_{AMS} without co-located OC_{TOT} should be avoided, or at least
treated as providing only a lower bound for OC.
- 610 4. Since neither OM:OC parameterization, RIE assumptions, PC correction, nor ON/OS misclassification fully explain
the winter discrepancies, future intercomparisons should include explicit quantification and targeted analysis of
refractory and thermally stable organics (OC3-OC4, HULIS, BC-coated organics, BrC etc.) to close the mass balance
between AMS and TOT under winter combustion and dust conditions.
5. The present analysis is based on the EUSAAR-2 thermal optical protocol. Given known differences in temperature
programs and OC-EC split definitions, comparable intercomparisons should be performed for other widely used
protocols (e.g., NIOSH 5040, IMPROVE_A) to assess the transferability of the observed OC_{AMS} - OC_{TOT} discrepancies
across methods.
- 615 Future work should focus on the applicability of winter aerosol measurements for calculating OC from AMS/ACSM data
according to the equations published by Canagaratna et al. (2015). Moreover, intercomparisons should be extended to other
European regions with diverse emission regimes, and harmonized correction and calibration frameworks for consistent long-
term monitoring should be developed. Combining such intercomparison results with source apportionment and air mass
analysis would strengthen links to climate and health models.

620 **Code and data availability**

The data used in this study are publicly available at <https://doi.org/10.5281/zenodo.19681493> (Arora et al., 2026b).

Supplement link

The link to the supplement will be included by Copernicus, if applicable.



Author contributions

625 Author contributions. SA designed the study, performed the data analysis, and prepared the manuscript. LP, RL, PV, SM, PP, JS, NZ, JO, HH and VZ contributed to data collection, processing, and interpretation. HH and VZ supervised the study. All authors contributed to the discussion of the results and reviewed the manuscript.

Competing interests

630 Hartmut Herrmann is a member of the editorial board of Atmospheric Measurement Techniques. He was not involved in the editorial handling of this manuscript. The authors declare no further competing interests.

Disclaimer

635 Copernicus Publications remains neutral with regard to jurisdictional claims made in the text, published maps, institutional affiliations, or any other geographical representation in this paper. While Copernicus Publications makes every effort to include appropriate place names, the final responsibility lies with the authors. Views expressed in the text are those of the authors and do not necessarily reflect the views of the publisher.

Acknowledgements

The authors thank the staff at the Melpitz, Frýdlant, and Košetice stations for their support during the measurement campaigns.

Financial support

640 Financial support for this study was provided by the TRACE project, jointly funded under the German-Czech Collaboration Program of the DFG under grant no. 431895563 and HE 3086/40-1 and GAČR under grant nos. 431895563 and 20-08304J, respectively. Additional support was provided by ACTRIS-CZ (LM2023030), funded by the Ministry of Education, Youth and Sports of the Czech Republic and under ACTRIS-D by the German BMFTR (01LK2001A).

References

645 ACTRIS: ACTRIS QA/QC guidelines for carbonaceous aerosol measurements – Version 1.0, Aerosol, Clouds and Trace Gases Research Infrastructure (ACTRIS), <https://doi.org/10.5281/zenodo.5574653>, 2021.
Aiken, A. C., DeCarlo, P. F., Kroll, J. H., Worsnop, D. R., Huffman, J. A., Docherty, K. S., Ulbrich, I. M., Mohr, C., Kimmel, J. R., Sueper, D., Sun, Y., Zhang, Q., Trimborn, A., Northway, M., Ziemann, P. J., Canagaratna, M. R., Onasch, T. B., Alfarra, M. R., Prevot, A. S. H., Dommen, J., Duplissy, J., Metzger, A., Baltensperger, U., and Jimenez, J. L.: O/C and OM:OC ratios



- of primary, secondary, and ambient organic aerosols with high-resolution time-of-flight aerosol mass spectrometry, *Environ. Sci. Technol.*, 42, 4478–4485, <https://doi.org/10.1021/es703009q>, 2008.
- Andreae, M. O. and Gelencsér, A.: Black carbon or brown carbon? The nature of light absorbing carbonaceous aerosols, *Atmos. Chem. Phys.*, 6, 3131–3148, <https://doi.org/10.5194/acp-6-3131-2006>, 2006.
- Arora, S., Poulain, L., Lhotka, R., Schwarz, J., Vodička, P., Mbengue, S., Zíková, N., Ondráček, J., Pokorná, P., Zdímal, V., and Herrmann, H.: Tracing local and long-range aerosol emission areas using multi-method and multi-site analyses in Central Europe, *Atmos. Environ.*, 367, 121733, <https://doi.org/10.1016/j.atmosenv.2025.121733>, 2026a.
- Arora, S., Poulain, L., Lhotka, R., Vodička, P., Mbengue, S., Pokorná, P., Schwarz, J., Zíková, N., Ondráček, J., Zdímal, V., and Herrmann, H.: Data for: Determination of Aerosol Particle Organic Carbon (OC) by Aerosol Mass Spectrometry (AMS) and Thermo-Optical Transmission (TOT) Analysis: Spatial and Seasonal Differences, Zenodo, <https://doi.org/10.5281/zenodo.19681493>, 2026b.
- Atabakhsh, S., Poulain, L., Chen, G., Canonaco, F., Prévôt, A. S. H., Pöhlker, M., Wiedensohler, A., and Herrmann, H.: A 1-year aerosol chemical speciation monitor (ACSM) source analysis of organic aerosol particle contributions from anthropogenic sources after long-range transport at the TROPOS research station Melpitz, *Atmos. Chem. Phys.*, 23, 6963–6988, <https://doi.org/10.5194/acp-23-6963-2023>, 2023.
- Bao, M., Zhang, Y.-L., Cao, F., Lin, Y.-C., Wang, Y., Liu, X., Zhang, W., Fan, M., Xie, F., Cary, R., Dixon, J., and Zhou, L.: Highly time-resolved characterization of carbonaceous aerosols using a two-wavelength Sunset thermal–optical carbon analyzer, *Atmos. Meas. Tech.*, 14, 4053–4068, <https://doi.org/10.5194/amt-14-4053-2021>, 2021.
- Bauer, J. J., Yu, X.-Y., Cary, R., Laulainen, N., and Berkowitz, C.: Characterization of the Sunset semi-continuous carbon aerosol analyzer, *J. Air Waste Manage. Assoc.*, 59, 826–833, <https://doi.org/10.3155/1047-3289.59.7.826>, 2009.
- Bautista, A. T., Pabroa, P. C. B., Santos, F. L., Quirit, L. L., Asis, J. L. B., Dy, M. A. K., and Martinez, J. P. G.: Intercomparison between NIOSH, IMPROVE_A, and EUSAAR_2 protocols: Finding an optimal thermal–optical protocol for Philippines OC/EC samples, *Atmos. Pollut. Res.*, 6, 334–342, <https://doi.org/10.5094/APR.2015.037>, 2015.
- Bond, T. C., Streets, D. G., Yarber, K. F., Nelson, S. M., Woo, J., and Klimont, Z.: A technology-based global inventory of black and organic carbon emissions from combustion, *J. Geophys. Res.-Atmos.*, 109, D14203, <https://doi.org/10.1029/2003JD003697>, 2004.
- Brown, S., Minor, H., O’Brien, T., Hameed, Y., Feenstra, B., Kuebler, D., Wetherell, W., Day, R., Tun, R., Landis, E., and Rice, J.: Review of Sunset OC/EC instrument measurements during the EPA’s Sunset Carbon Evaluation Project, *Atmosphere*, 10, 287, <https://doi.org/10.3390/atmos10050287>, 2019.
- Budisulistiorini, S. H., Canagaratna, M. R., Croteau, P. L., Baumann, K., Edgerton, E. S., Kollman, M. S., Ng, N. L., Verma, V., Shaw, S. L., Knipping, E. M., Worsnop, D. R., Jayne, J. T., Weber, R. J., and Surratt, J. D.: Intercomparison of an Aerosol Chemical Speciation Monitor (ACSM) with ambient fine aerosol measurements in downtown Atlanta, Georgia, *Atmos. Meas. Tech.*, 7, 1929–1941, <https://doi.org/10.5194/amt-7-1929-2014>, 2014.



- Canagaratna, M. R., Jimenez, J. L., Kroll, J. H., Chen, Q., Kessler, S. H., Massoli, P., Hildebrandt Ruiz, L., Fortner, E., Williams, L. R., Wilson, K. R., Surratt, J. D., Donahue, N. M., Jayne, J. T., and Worsnop, D. R.: Elemental ratio measurements of organic compounds using aerosol mass spectrometry: Characterization, improved calibration, and implications, *Atmos. Chem. Phys.*, 15, 253–272, <https://doi.org/10.5194/acp-15-253-2015>, 2015.
- Capes, G., Johnson, B., McFiggans, G., Williams, P. I., Haywood, J., and Coe, H.: Aging of biomass burning aerosols over West Africa: Aircraft measurements of chemical composition, microphysical properties, and emission ratios, *J. Geophys. Res.-Atmos.*, 113, D00C15, <https://doi.org/10.1029/2008JD009845>, 2008.
- Cavalli, F., Viana, M., Yttri, K. E., Genberg, J., and Putaud, J.-P.: Toward a standardised thermal-optical protocol for measuring atmospheric organic and elemental carbon: the EUSAAR protocol, *Atmos. Meas. Tech.*, 3, 79–89, <https://doi.org/10.5194/amt-3-79-2010>, 2010.
- Cavalli, F., Alastuey, A., Areskoug, H., Ceburnis, D., Čech, J., Genberg, J., Harrison, R. M., Jaffrezo, J. L., Kiss, G., Laj, P., Mihalopoulos, N., Perez, N., Quincey, P., Schwarz, J., Sellegri, K., Spindler, G., Swietlicki, E., Theodosi, C., Yttri, K. E., and Putaud, J. P.: A European aerosol phenomenology – 4: Harmonized concentrations of carbonaceous aerosol at 10 regional background sites across Europe, *Atmos. Environ.*, 144, 133–145, <https://doi.org/10.1016/j.atmosenv.2016.07.050>, 2016.
- Cesari, D., Merico, E., Dinoi, A., Marinoni, A., Bonasoni, P., and Contini, D.: Seasonal variability of carbonaceous aerosols in an urban background area in Southern Italy, *Atmos. Res.*, 200, 97–108, <https://doi.org/10.1016/j.atmosres.2017.10.004>, 2018.
- Chalbot, M. C. G., Brown, J., Chitranshi, P., Gamboa da Costa, G., Pollock, E. D., and Kavouras, I. G.: Water-soluble organic matter in atmospheric aerosols: Insights from molecular characterization, *Atmosphere*, 7, 73, <https://doi.org/10.3390/atmos7060073>, 2016.
- Chan, T. W., Huang, L., Leaitch, W. R., Sharma, S., Brook, J. R., Slowik, J. G., Abbatt, J. P. D., Brickell, P. C., Liggio, J., Li, S.-M., and Moosmüller, H.: Observations of OM:OC and specific attenuation coefficients (SAC) in ambient fine PM at a rural site in central Ontario, Canada, *Atmos. Chem. Phys.*, 10, 2393–2411, <https://doi.org/10.5194/acp-10-2393-2010>, 2010.
- Chen, P., Kang, S., Abdullaev, S. F., Safarov, M. S., Huang, J., Hu, Z., Tripathi, L., and Li, C.: Significant influence of carbonates on determining organic carbon and black carbon: A case study in Tajikistan, Central Asia, *Environ. Sci. Technol.*, 55, 2839–2846, <https://doi.org/10.1021/acs.est.0c05876>, 2021.
- Cheng, Y., He, K. B., Duan, F. K., Zheng, M., Ma, Y. L., and Tan, J. H.: Positive sampling artifact of carbonaceous aerosols and its influence on the thermal-optical split of OC/EC, *Atmos. Chem. Phys.*, 9, 7243–7256, <https://doi.org/10.5194/acp-9-7243-2009>, 2009.
- Chow, J. C., Watson, J. G., Crow, D., Lowenthal, D. H., and Merrifield, T.: Comparison of IMPROVE and NIOSH carbon measurements, *Aerosol Sci. Technol.*, 34, 23–34, <https://doi.org/10.1080/02786820119073>, 2001.
- Crenn, V., Sciare, J., Croteau, P. L., Verlhac, S., Fröhlich, R., Belis, C. A., Aas, W., Äijälä, M., Alastuey, A., Artiñano, B., Baisnée, D., Bonnaire, N., Bressi, M., Canagaratna, M., Canonaco, F., Carbone, C., Cavalli, F., Coz, E., Cubison, M. J., and Favez, O.: ACTRIS ACSM intercomparison – Part 1: Reproducibility of concentration and fragment results from 13 individual



- Quadrupole Aerosol Chemical Speciation Monitors (Q-ACSM) and consistency with co-located instruments, *Atmos. Meas. Tech.*, 8, 5063–5087, <https://doi.org/10.5194/amt-8-5063-2015>, 2015.
- Crenn, V., Chakraborty, A., Fronval, I., Petitprez, D., and Riffault, V.: Fine particles sampled at an urban background site and an industrialized coastal site in Northern France – Part 2: Comparison of offline and online analyses for carbonaceous aerosols, *Aerosol Sci. Technol.*, 52, 287–299, <https://doi.org/10.1080/02786826.2017.1403008>, 2018.
- Crippa, M., Canonaco, F., Lanz, V. A., Äijälä, M., Allan, J. D., Carbone, S., Capes, G., Ceburnis, D., Dall’Osto, M., Day, D. A., DeCarlo, P. F., Ehn, M., Eriksson, A., Freney, E., Hildebrandt Ruiz, L., Hillamo, R., Jimenez, J. L., Junninen, H., Kiendler-Scharr, A., Kortelainen, A. M., Kulmala, M., Laaksonen, A., Mensah, A. A., Mohr, C., Nemitz, E., O’Dowd, C., Ovadnevaite, J., Pandis, S. N., Petäjä, T., Poulain, L., Saarikoski, S., Sellegri, K., Swietlicki, E., Tiitta, P., Worsnop, D. R., Baltensperger, U., and Prévôt, A. S. H.: Organic aerosol components derived from 25 AMS data sets across Europe using a consistent ME-2 based source apportionment approach, *Atmos. Chem. Phys.*, 14, 6159–6176, <https://doi.org/10.5194/acp-14-6159-2014>, 2014.
- Cuesta-Mosquera, A., Glojek, K., Močnik, G., Drinovec, L., Gregorič, A., Rigler, M., Ogrin, M., Romshoo, B., Weinhold, K., Merkel, M., Van Pinxteren, D., Herrmann, H., Wiedensohler, A., Pöhlker, M., and Müller, T.: Optical properties and simple forcing efficiency of the organic aerosols and black carbon emitted by residential wood burning in rural central Europe, *Atmos. Chem. Phys.*, 24, 2583–2605, <https://doi.org/10.5194/acp-24-2583-2024>, 2024.
- Daellenbach, K. R., Bozzetti, C., Křepelová, A., Canonaco, F., Wolf, R., Zotter, P., Fermo, P., Crippa, M., Slowik, J. G., Sosedova, Y., Zhang, Y., Huang, R.-J., Poulain, L., Szidat, S., Baltensperger, U., El Haddad, I., and Prévôt, A. S. H.: Characterization and source apportionment of organic aerosol using offline aerosol mass spectrometry, *Atmos. Meas. Tech.*, 9, 23–39, <https://doi.org/10.5194/amt-9-23-2016>, 2016.
- Day, D. A., Campuzano-Jost, P., Nault, B. A., Palm, B. B., Hu, W., Guo, H., Wooldridge, P. J., Cohen, R. C., Docherty, K. S., Huffman, J. A., De Sá, S. S., Martin, S. T., and Jimenez, J. L.: A systematic re-evaluation of methods for quantification of bulk particle-phase organic nitrates using real-time aerosol mass spectrometry, *Atmos. Meas. Tech.*, 15, 459–483, <https://doi.org/10.5194/amt-15-459-2022>, 2022.
- DeCarlo, P. F., Kimmel, J. R., Trimborn, A., Northway, M. J., Jayne, J. T., Aiken, A. C., Gonin, M., Fuhrer, K., Horvath, T., Docherty, K. S., Worsnop, D. R., and Jimenez, J. L.: Field-deployable, high-resolution, time-of-flight aerosol mass spectrometer, *Anal. Chem.*, 78, 8281–8289, <https://doi.org/10.1021/ac061249n>, 2006.
- Docherty, K. S., Aiken, A. C., Huffman, J. A., Ulbrich, I. M., DeCarlo, P. F., Sueper, D., Worsnop, D. R., Snyder, D. C., Peltier, R. E., Weber, R. J., Grover, B. D., Eatough, D. J., Williams, B. J., Goldstein, A. H., Ziemann, P. J., and Jimenez, J. L.: The 2005 Study of Organic Aerosols at Riverside (SOAR-1): instrumental intercomparisons and fine particle composition, *Atmos. Chem. Phys.*, 11, 12387–12420, <https://doi.org/10.5194/acp-11-12387-2011>, 2011.
- Donahue, N. M., Hildebrandt Ruiz, L., Paciga, A. L., Cerully, K., Tritscher, T., Presto, A. A., Gasparini, R., Dommen, J., and Pandis, S. N.: Aging of secondary organic aerosol from small aromatic VOCs: Changes in chemical composition, mass yield, volatility and hygroscopicity, *Atmos. Chem. Phys.*, 15, 8301–8313, <https://doi.org/10.5194/acp-15-8301-2015>, 2015.



- Drewnick, F., Hings, S. S., DeCarlo, P., Jayne, J. T., Gonin, M., Fuhrer, K., Weimer, S., Jimenez, J. L., Demerjian, K. L.,
750 Borrmann, S., and Worsnop, D. R.: A new time-of-flight aerosol mass spectrometer (TOF-AMS) – Instrument description and
first field deployment, *Aerosol Sci. Technol.*, 39, 637–658, <https://doi.org/10.1080/02786820500182040>, 2005.
- Drinovec, L., Močnik, G., Zotter, P., Prévôt, A. S. H., Ruckstuhl, C., Coz, E., Rupakheti, M., Sciare, J., Müller, T.,
Wiedensohler, A., and Hansen, A. D. A.: The “dual-spot” Aethalometer: An improved measurement of aerosol black carbon
with real-time loading compensation, *Atmos. Meas. Tech.*, 8, 1965–1979, <https://doi.org/10.5194/amt-8-1965-2015>, 2015.
- 755 Fermo, P., Piazzalunga, A., Vecchi, R., Valli, G., and Ceriani, M.: A TGA/FT-IR study for measuring OC and EC in aerosol
samples, *Atmos. Chem. Phys.*, 6, 255–266, <https://doi.org/10.5194/acp-6-255-2006>, 2006.
- Fröhlich, R., Cubison, M. J., Slowik, J. G., Bukowiecki, N., Prévôt, A. S. H., Baltensperger, U., Schneider, J., Kimmel, J. R.,
Gonin, M., Rohner, U., Worsnop, D. R., and Jayne, J. T.: The ToF-ACSM: A portable aerosol chemical speciation monitor
with TOFMS detection, *Atmos. Meas. Tech.*, 6, 3225–3241, <https://doi.org/10.5194/amt-6-3225-2013>, 2013.
- 760 Genberg, J., Hyder, M., Stenström, K., Bergström, R., Simpson, D., Fors, E. O., Jönsson, J. Å., and Swietlicki, E.: Source
apportionment of carbonaceous aerosol in southern Sweden, *Atmos. Chem. Phys.*, 11, 11387–11400,
<https://doi.org/10.5194/acp-11-11387-2011>, 2011.
- Guerrero, F., Yáñez, K., Vidal, V., and Cereceda-Balic, F.: Effects of wood moisture on emission factors for PM_{2.5}, particle
numbers and particulate-phase PAHs from Eucalyptus globulus combustion using a controlled combustion chamber for
765 emissions, *Sci. Total Environ.*, 648, 737–744, <https://doi.org/10.1016/j.scitotenv.2018.08.057>, 2019.
- Haller, T., Sommer, E., Steinkogler, T., Rentenberger, C., Wonaschuetz, A., Kasper-Giebl, A., Grothe, H., and Hitznerberger,
R.: Investigation of structural changes of atmospheric aerosol samples during two thermal–optical measurement procedures
(EUSAAR2, NIOSH870), *Atmos. Meas. Tech.*, 14, 3721–3735, <https://doi.org/10.5194/amt-14-3721-2021>, 2021.
- Heikkinen, L., Äijälä, M., Riva, M., Luoma, K., Dällenbach, K., Aalto, J., Aalto, P., Aliaga, D., Aurela, M., Keskinen, H.,
770 Makkonen, U., Rantala, P., Kulmala, M., Petäjä, T., Worsnop, D., and Ehn, M.: Long-term sub-micrometer aerosol chemical
composition in the boreal forest: Inter- and intra-annual variability, *Atmos. Chem. Phys.*, 20, 3151–3180,
<https://doi.org/10.5194/acp-20-3151-2020>, 2020.
- Heringa, M. F., DeCarlo, P. F., Chirico, R., Tritscher, T., Dommen, J., Weingartner, E., Richter, R., Wehrle, G., Prévôt, A. S.
H., and Baltensperger, U.: Investigations of primary and secondary particulate matter of different wood combustion appliances
775 with a high-resolution time-of-flight aerosol mass spectrometer, *Atmos. Chem. Phys.*, 11, 5945–5957,
<https://doi.org/10.5194/acp-11-5945-2011>, 2011.
- Horník, Š., Pokorná, P., Vodička, P., Lhotka, R., Sýkora, J., Arora, S., Poulain, L., Herrmann, H., Schwarz, J., and Ždímal, V.:
Positive matrix factorization of seasonally resolved organic aerosol at three different central European background sites based
on nuclear magnetic resonance Aerosolomics data, *Sci. Total Environ.*, 916, 170303,
780 <https://doi.org/10.1016/j.scitotenv.2024.170303>, 2024.
- Jimenez, J. L., Canagaratna, M. R., Donahue, N. M., Prevot, A. S. H., Zhang, Q., Kroll, J. H., DeCarlo, P. F., Allan, J. D., Coe,
H., Ng, N. L., Aiken, A. C., Docherty, K. S., Ulbrich, I. M., Grieshop, A. P., Robinson, A. L., Duplissy, J., Smith, J. D., Wilson,



- K. R., Lanz, V. A., and Worsnop, D. R.: Evolution of organic aerosols in the atmosphere, *Science*, 326, 1525–1529, <https://doi.org/10.1126/science.1180353>, 2009.
- 785 Karanasiou, A., Panteliadis, P., Perez, N., Minguillón, M. C., Pandolfi, M., Titos, G., Viana, M., Moreno, T., Querol, X., and Alastuey, A.: Evaluation of the semi-continuous OCEC analyzer performance with the EUSAAR2 protocol, *Sci. Total Environ.*, 747, 141266, <https://doi.org/10.1016/j.scitotenv.2020.141266>, 2020.
- Kau, D., Greiling, M., Kirchsteiger, B., Göndör, A., Herzig, C., Limbeck, A., Eitenberger, E., and Kasper-Giebl, A.: Thermal–optical analysis of quartz fiber filters loaded with snow samples – determination of iron based on interferences caused
790 by mineral dust, *Atmos. Meas. Tech.*, 15, 5207–5217, <https://doi.org/10.5194/amt-15-5207-2022>, 2022.
- Kiendler-Scharr, A., Mensah, A. A., Friese, E., Topping, D., Nemitz, E., Prevot, A. S. H., Äijälä, M., Allan, J., Canonaco, F., Canagaratna, M., Carbone, S., Crippa, M., Dall'Osto, M., Day, D. A., De Carlo, P., Di Marco, C. F., Elbern, H., Eriksson, A., Freney, E., Hao, L., Herrmann, H., Hildebrandt, L., Hillamo, R., Jimenez, J. L., Laaksonen, A., McFiggans, G., Mohr, C., O'Dowd, C., Otjes, R., Ovadnevaite, J., Pandis, S. N., Poulain, L., Schlag, P., Sellegri, K., Swietlicki, E., Tiitta, P., Vermeulen,
795 A., Wahner, A., Worsnop, D. R., and Wu, H.-C.: Ubiquity of organic nitrates from nighttime chemistry in the European submicron aerosol, *Geophys. Res. Lett.*, 43, 7735–7744, <https://doi.org/10.1002/2016GL069239>, 2016.
- Kondo, Y., Miyazaki, Y., Takegawa, N., Miyakawa, T., Weber, R. J., Jimenez, J. L., Zhang, Q., and Worsnop, D. R.: Oxygenated and water-soluble organic aerosols in Tokyo, *J. Geophys. Res.-Atmos.*, 112, D01203, <https://doi.org/10.1029/2006JD007056>, 2007.
- 800 Koorneef, G. J., De Goede, R. G., Pulleman, M. M., Van Leeuwen, A. G., Barré, P., Baudin, F., and Comans, R. N.: Quantifying organic carbon in particulate and mineral-associated fractions of calcareous soils – A method comparison, *Geoderma*, 436, 116558, <https://doi.org/10.1016/j.geoderma.2023.116558>, 2023.
- Laj, P., Bigi, A., Rose, C., Andrews, E., Lund Myhre, C., Collaud Coen, M., Lin, Y., Wiedensohler, A., Schulz, M., Ogren, J. A., Fiebig, M., Glien, J., Mortier, A., Pandolfi, M., Petäjä, T., Kim, S.-W., Aas, W., Putaud, J.-P., Mayol-Bracero, O., and
805 Zikova, N.: A global analysis of climate-relevant aerosol properties retrieved from the network of Global Atmosphere Watch (GAW) near-surface observatories, *Atmos. Meas. Tech.*, 13, 4353–4392, <https://doi.org/10.5194/amt-13-4353-2020>, 2020.
- Laskin, A., Laskin, J., and Nizkorodov, S. A.: Chemistry of atmospheric brown carbon, *Chem. Rev.*, 115, 4335–4382, <https://doi.org/10.1021/cr5006167>, 2015.
- Lhotka, R., Pokorná, P., Vodička, P., Zíková, N., Chen, G. I., Prévôt, A. S. H., Mbengue, S., Schwarz, J., and Ždímal, V.:
810 Influence of meteorological conditions and seasonality on PM₁ and organic aerosol sources at a rural background site, *Atmos. Environ.*, 344, 121028, <https://doi.org/10.1016/j.atmosenv.2025.121028>, 2025.
- Lin, C., Ceburnis, D., Vaishya, A., Trubetskaya, A., Tan, Y., Wang, T., Smith, W., Johnson, R., Xu, W., Monaghan, R. F. D., O'Dowd, C., and Ovadnevaite, J.: Air quality–climate forcing double whammy from domestic firelighters, *npj Clim. Atmos. Sci.*, 6, 101, <https://doi.org/10.1038/s41612-023-00427-x>, 2023.



- 815 Ma, M., Rivellini, L.-H., Cui, Y., Willis, M. D., Wilkie, R., Abbatt, J. P. D., Canagaratna, M. R., Wang, J., Ge, X., and Lee, A. K. Y.: Elemental analysis of oxygenated organic coating on black carbon particles using a soot-particle aerosol mass spectrometer, *Atmos. Meas. Tech.*, 14, 2799–2812, <https://doi.org/10.5194/amt-14-2799-2021>, 2021.
- Malaguti, A., Mircea, M., La Torretta, T. M. G., Telloli, C., Petralia, E., Stracquadanio, M., and Berico, M.: Comparison of online and offline methods for measuring fine secondary inorganic ions and carbonaceous aerosols in the central Mediterranean area, *Aerosol Air Qual. Res.*, 15, 2641–2653, <https://doi.org/10.4209/aaqr.2015.04.0240>, 2015.
- 820 Malm, W. C., Schichtel, B. A., Hand, J. L., and Prenni, A. J.: Implications of organic mass to carbon ratios increasing over time in the rural United States, *J. Geophys. Res.-Atmos.*, 125, e2019JD031480, <https://doi.org/10.1029/2019JD031480>, 2020.
- Malmberg, V. B., Eriksson, A. C., Török, S., Zhang, Y., Kling, K., Martinsson, J., Fortner, E. C., Gren, L., Kook, S., Onasch, T. B., Bengtsson, P.-E., and Pagels, J.: Relating aerosol mass spectra to composition and nanostructure of soot particles, *Carbon*, 142, 535–546, <https://doi.org/10.1016/j.carbon.2018.10.072>, 2019.
- 825 Massabò, D. and Prati, P.: An overview of optical and thermal methods for the characterization of carbonaceous aerosol, *Riv. Nuovo Cimento*, 44, 145–192, <https://doi.org/10.1007/s40766-021-00017-8>, 2021.
- Mayol-Bracero, O. L., Guyon, P., Graham, B., Roberts, G., Andreae, M. O., Decesari, S., Facchini, M. C., Fuzzi, S., and Artaxo, P.: Water-soluble organic compounds in biomass-burning aerosols over Amazonia: 1. Characterization by NMR and GC-MS, *J. Geophys. Res.-Atmos.*, 107, 8047, <https://doi.org/10.1029/2001JD000522>, 2002.
- 830 Mbengue, S., Zikova, N., Schwarz, J., Vodička, P., Šmejkalová, A. H., and Holoubek, I.: Mass absorption cross-section and absorption enhancement from long term black and elemental carbon measurements: A rural background station in Central Europe, *Sci. Total Environ.*, 794, 148365, <https://doi.org/10.1016/j.scitotenv.2021.148365>, 2021.
- Mo, Y., Li, J., Zhong, G., Zhu, S., Cheng, Z., Tang, J., Jiang, H., Jiang, B., Liao, Y., Song, J., Tian, C., Chen, Y., Zhao, S., and Zhang, G.: The sources and atmospheric processes of strong light-absorbing components in water soluble brown carbon: Insights from a multi-proxy study of PM_{2.5} in 10 Chinese cities, *J. Geophys. Res.-Atmos.*, 129, e2023JD039512, <https://doi.org/10.1029/2023JD039512>, 2024.
- 835 Nault, B. A., Croteau, P., Jayne, J., Williams, A., Williams, L., Worsnop, D., Katz, E. F., DeCarlo, P. F., and Canagaratna, M.: Laboratory evaluation of organic aerosol relative ionization efficiencies in the Aerodyne aerosol mass spectrometer and aerosol chemical speciation monitor, *Aerosol Sci. Technol.*, 57, 981–997, <https://doi.org/10.1080/02786826.2023.2223249>, 2023.
- 840 Ng, N. L., Canagaratna, M. R., Zhang, Q., Jimenez, J. L., Tian, J., Ulbrich, I. M., Kroll, J. H., Docherty, K. S., Chhabra, P. S., Bahreini, R., Murphy, S. M., Seinfeld, J. H., Hildebrandt, L., Donahue, N. M., DeCarlo, P. F., Lanz, V. A., Prévôt, A. S. H., Dinar, E., Rudich, Y., and Worsnop, D. R.: Organic aerosol components observed in Northern Hemispheric datasets from aerosol mass spectrometry, *Atmos. Chem. Phys.*, 10, 4625–4641, <https://doi.org/10.5194/acp-10-4625-2010>, 2010.
- 845 Paglione, M., Kiendler-Scharr, A., Mensah, A. A., Finessi, E., Giulianelli, L., Sandrini, S., Facchini, M. C., Fuzzi, S., Schlag, P., Piazzalunga, A., Tagliavini, E., Henzing, J. S., and Decesari, S.: Identification of humic-like substances (HULIS) in oxygenated organic aerosols using NMR and AMS factor analyses and liquid chromatographic techniques, *Atmos. Chem. Phys.*, 14, 25–45, <https://doi.org/10.5194/acp-14-25-2014>, 2014.



- Panteliadis, P., Hafkenscheid, T., Cary, B., Diapouli, E., Fischer, A., Favez, O., Quincey, P., Viana, M., Hitzengerger, R.,
850 Vecchi, R., Saraga, D., Sciare, J., Jaffrezo, J. L., John, A., Schwarz, J., Giannoni, M., Novak, J., Karanasiou, A., Fermo, P.,
and Maenhaut, W.: ECOC comparison exercise with identical thermal protocols after temperature offset correction –
instrument diagnostics by in-depth evaluation of operational parameters, *Atmos. Meas. Tech.*, 8, 779–792,
<https://doi.org/10.5194/amt-8-779-2015>, 2015.
- Peltier, R. E., Weber, R. J., and Sullivan, A. P.: Investigating a liquid-based method for online organic carbon detection in
855 atmospheric particles, *Aerosol Sci. Technol.*, 41, 1117–1127, <https://doi.org/10.1080/02786820701777465>, 2007.
- Pieber, S. M., El Haddad, I., Slowik, J. G., Canagaratna, M. R., Jayne, J. T., Platt, S. M., Bozzetti, C., Daellenbach, K. R.,
Fröhlich, R., Vlachou, A., Klein, F., Dommen, J., Miljevic, B., Jiménez, J. L., Worsnop, D. R., Baltensperger, U., and Prévôt,
A. S. H.: Inorganic salt interference on CO₂⁺ in Aerodyne AMS and ACSM organic aerosol composition studies, *Environ.*
Sci. Technol., 50, 10494–10503, <https://doi.org/10.1021/acs.est.6b01035>, 2016.
- 860 Pokhrel, R. P., Beamesderfer, E. R., Wagner, N. L., Langridge, J. M., Lack, D. A., Jayarathne, T., Stone, E. A., Stockwell, C.
E., Yokelson, R. J., and Murphy, S. M.: Relative importance of black carbon, brown carbon, and absorption enhancement from
clear coatings in biomass burning emissions, *Atmos. Chem. Phys.*, 17, 5063–5078, <https://doi.org/10.5194/acp-17-5063-2017>,
2017.
- Pokorná, P., Schwarz, J., Krejci, R., Swietlicki, E., Havránek, V., and Ždímal, V.: Comparison of PM_{2.5} chemical composition
865 and sources at a rural background site in Central Europe between 1993/1994/1995 and 2009/2010: Effect of legislative
regulations and economic transformation on the air quality, *Environ. Pollut.*, 241, 841–851,
<https://doi.org/10.1016/j.envpol.2018.06.015>, 2018.
- Pokorná, P., Zíková, N., Vodička, P., Lhotka, R., Mbengue, S., Holubová Šmejkalová, A., Riffault, V., Ondráček, J., Schwarz,
J., and Ždímal, V.: Chemically speciated mass size distribution, particle density, shape and origin of non-refractory PM₁
870 measured at a rural background site in central Europe, *Atmos. Chem. Phys.*, 22, 5829–5858, <https://doi.org/10.5194/acp-22-5829-2022>, 2022.
- Poulain, L., Spindler, G., Grüner, A., Tuch, T., Stieger, B., Van Pinxteren, D., Petit, J.-E., Favez, O., Herrmann, H., and
Wiedensohler, A.: Multi-year ACSM measurements at the central European research station Melpitz (Germany) – Part 1:
Instrument robustness, quality assurance, and impact of upper size cutoff diameter, *Atmos. Meas. Tech.*, 13, 4973–4994,
875 <https://doi.org/10.5194/amt-13-4973-2020>, 2020.
- Rigler, M., Drinovec, L., Lavrič, G., Vlachou, A., Prévôt, A. S. H., Jaffrezo, J. L., Stavroulas, I., Sciare, J., Burger, J., Kranjc,
I., Turšič, J., Hansen, A. D. A., and Močnik, G.: The new instrument using a TC–BC (total carbon–black carbon) method for
the online measurement of carbonaceous aerosols, *Atmos. Meas. Tech.*, 13, 4333–4351, <https://doi.org/10.5194/amt-13-4333-2020>, 2020.
- 880 Sandradewi, J., Prévôt, A. S. H., Szidat, S., Perron, N., Alfarra, M. R., Lanz, V. A., Weingartner, E., 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.



- Sauvage, S., Cornacchia, C., and Gagliardi, S.: Deliverable 9.3: Report on the results of the flagship actions, ACTRIS IMP, Horizon 2020 Research and Innovation Framework Programme (Grant Agreement No. 871115), <https://www.actris.eu>, 2023.
- 885 Shen, X., Saathoff, H., Huang, W., Mohr, C., Ramisetty, R., and Leisner, T.: Understanding atmospheric aerosol particles with improved particle identification and quantification by single-particle mass spectrometry, *Atmos. Meas. Tech.*, 12, 2219–2240, <https://doi.org/10.5194/amt-12-2219-2019>, 2019.
- Schwarz, J., Cusack, M., Karban, J., Chalupníčková, E., Havránek, V., Smolík, J., and Ždímal, V.: PM_{2.5} chemical composition at a rural background site in Central Europe, including correlation and air mass back trajectory analysis, *Atmos. Res.*, 176–177, 108–120, <https://doi.org/10.1016/j.atmosres.2016.02.017>, 2016.
- 890 Solomon, P. A., Crumpler, D., Flanagan, J. B., Jayanty, R. K. M., Rickman, E. E., and McDade, C. E.: U.S. National PM_{2.5} chemical speciation monitoring networks – CSN and IMPROVE: Description of networks, *J. Air Waste Manage. Assoc.*, 64, 1410–1438, <https://doi.org/10.1080/10962247.2014.956904>, 2014.
- Spindler, G., Brüggemann, E., Gnauk, T., Grüner, A., Müller, K., and Herrmann, H.: A four-year size-segregated characterization study of particles PM₁₀, PM_{2.5} and PM₁ depending on air mass origin at Melpitz, *Atmos. Environ.*, 44, 164–173, <https://doi.org/10.1016/j.atmosenv.2009.10.015>, 2010.
- Spindler, G., Grüner, A., Müller, K., Schlimper, S., and Herrmann, H.: Long-term size-segregated particle (PM₁₀, PM_{2.5}, PM₁) characterization study at Melpitz – Influence of air mass inflow, weather conditions and season, *J. Atmos. Chem.*, 70, 165–195, <https://doi.org/10.1007/s10874-013-9263-8>, 2013.
- 900 Spranger, T., Van Pinxteren, D., and Herrmann, H.: Atmospheric “HULIS” in different environments: Polarities, molecular sizes, and sources suggest more than 50 % are not “humic-like”, *ACS Earth Space Chem.*, 4, 272–282, <https://doi.org/10.1021/acsearthspacechem.9b00299>, 2020.
- Takegawa, N., Miyazaki, Y., Kondo, Y., Komazaki, Y., Miyakawa, T., Jimenez, J. L., Jayne, J. T., Worsnop, D. R., Allan, J. D., and Weber, R. J.: Characterization of an Aerodyne aerosol mass spectrometer (AMS): Intercomparison with other aerosol instruments, *Aerosol Sci. Technol.*, 39, 760–770, <https://doi.org/10.1080/02786820500243404>, 2005.
- 905 Teich, M., Van Pinxteren, D., Wang, M., Kecorius, S., Wang, Z., Müller, T., Močnik, G., and Herrmann, H.: Contributions of nitrated aromatic compounds to the light absorption of water-soluble and particulate brown carbon in different atmospheric environments in Germany and China, *Atmos. Chem. Phys.*, 17, 1653–1672, <https://doi.org/10.5194/acp-17-1653-2017>, 2017.
- Ulbrich, I. M., Canagaratna, M. R., Zhang, Q., Worsnop, D. R., and Jimenez, J. L.: Interpretation of organic components from positive matrix factorization of aerosol mass spectrometric data, *Atmos. Chem. Phys.*, 9, 2891–2918, <https://doi.org/10.5194/acp-9-2891-2009>, 2009.
- Vasilatou, K., Iida, K., Kazemimanesh, M., Olfert, J., Sakurai, H., Sipkens, T. A., and Smallwood, G. J.: Aerosol physical characterization: A review on the current state of aerosol documentary standards and calibration strategies, *J. Aerosol Sci.*, 183, 106483, <https://doi.org/10.1016/j.jaerosci.2024.106483>, 2025.



- 915 Vodička, P., Schwarz, J., Cusack, M., and Ždímal, V.: Detailed comparison of OC/EC aerosol at an urban and a rural Czech background site during summer and winter, *Sci. Total Environ.*, 518–519, 424–433, <https://doi.org/10.1016/j.scitotenv.2015.03.029>, 2015.
- Wang, X., Kang, S., Hu, Z., Zhang, C., Yan, F., Chen, P., and Wang, Y.: Significant impact of carbonates on the concentration and light absorption properties of black carbon in Lanzhou, northwest China, *Atmos. Pollut. Res.*, 16, 102473, <https://doi.org/10.1016/j.apr.2025.102473>, 2025.
- 920 Xu, W., Lambe, A., Silva, P., Hu, W., Onasch, T., Williams, L., Croteau, P., Zhang, X., Renbaum-Wolff, L., Fortner, E., Jimenez, J. L., Jayne, J., Worsnop, D., and Canagaratna, M.: Laboratory evaluation of species-dependent relative ionization efficiencies in the Aerodyne aerosol mass spectrometer, *Aerosol Sci. Technol.*, 52, 626–641, <https://doi.org/10.1080/02786826.2018.1439570>, 2018.
- 925 Xu, W., He, Y., Qiu, Y., Chen, C., Xie, C., Lei, L., Li, Z., Sun, J., Li, J., Fu, P., Wang, Z., Worsnop, D. R., and Sun, Y.: Mass spectral characterization of primary emissions and implications in source apportionment of organic aerosol, *Atmos. Meas. Tech.*, 13, 3205–3219, <https://doi.org/10.5194/amt-13-3205-2020>, 2020.
- Yang, H. and Yu, J. Z.: Uncertainties in charring correction in the analysis of elemental and organic carbon in atmospheric particles by thermal/optical methods, *Environ. Sci. Technol.*, 36, 5199–5204, <https://doi.org/10.1021/es025672z>, 2002.
- 930 Yttri, K. E., Simpson, D., Bergström, R., Kiss, G., Szidat, S., Ceburnis, D., Eckhardt, S., Hueglin, C., Nøjgaard, J. K., Perrino, C., Pizzo, I., Prevot, A. S. H., Putaud, J.-P., Spindler, G., Vana, M., Zhang, Y.-L., and Aas, W.: The EMEP Intensive Measurement Period campaign, 2008–2009: Characterizing carbonaceous aerosol at nine rural sites in Europe, *Atmos. Chem. Phys.*, 19, 4211–4233, <https://doi.org/10.5194/acp-19-4211-2019>, 2019.
- Yu, J. Z., Xu, J., and Yang, H.: Charring characteristics of atmospheric organic particulate matter in thermal analysis, *Environ. Sci. Technol.*, 36, 754–761, <https://doi.org/10.1021/es015540q>, 2002.
- 935 Zhang, L., Li, J., Li, Y., Liu, X., Luo, Z., Shen, G., and Tao, S.: Comparison of water-soluble and water-insoluble organic compositions attributing to different light absorption efficiency between residential coal and biomass burning emissions, *Atmos. Chem. Phys.*, 24, 6323–6337, <https://doi.org/10.5194/acp-24-6323-2024>, 2024.
- Zhang, X., Trzepla, K., White, W., Raffuse, S., and Hyslop, N. P.: Intercomparison of thermal–optical carbon measurements by Sunset and Desert Research Institute (DRI) analyzers using the IMPROVE_A protocol, *Atmos. Meas. Tech.*, 14, 3217–3231, <https://doi.org/10.5194/amt-14-3217-2021>, 2021.
- 940 Zhang, Y. L., Perron, N., Ciobanu, V. G., Zotter, P., Minguillón, M. C., Wacker, L., Prévôt, A. S. H., Baltensperger, U., and Szidat, S.: On the isolation of OC and EC and the optimal strategy of radiocarbon-based source apportionment of carbonaceous aerosols, *Atmos. Chem. Phys.*, 12, 10841–10856, <https://doi.org/10.5194/acp-12-10841-2012>, 2012.