



Supplement of

New insights into traffic emissions: the role of hydrocarbons and oxygenated organic species in traffic-derived aerosol

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Supplemental material

Table S1: Average chemical composition of aerosol measured during the campaigns. Black carbon (eBC) was measured with the aethalometer (AE33, Magee Scientific, Ljubljana, Slovenia) at 880 nm. PM₁ was measured with the FIDAS (Palas GmbH, Karlsruhe, Germany) and PM_{2.5} with the tapered element oscillating microbalance (TEOM 1405; Thermo Fisher Scientific, Waltham, US) in 2018. Ambient temperature and relative humidity were taken from the weather station located in Kumpula one kilometer from the street canyon site.

Measurement campaign	PM ₁ ($\mu\text{g m}^{-3}$)	Chemical species ($\mu\text{g m}^{-3}$)					Meteorology	
		OA	Sulfate	Nitrate	Ammonium	eBC	T (°C)	RH (%)
Spring 2018	7.9*	2.7	0.27	0.23	0.13	1.47	13	57
Summer-Autumn 2019	3.7	2.4	0.5	0.13	0.14	1.3	17	79
Winter 2022	4.6	2.0	0.62	0.63	0.39	0.72	-1.8	90
Spring 2024	4.0	2.7	0.62	0.55	0.30	0.49	4.2	79

*PM_{2.5}

Table S2: Elemental ratios of the PMF factors for the campaigns.

Campaign	Factor	O:C	H:C	N:C
Spring 2018	TrOA	0.196	1.82	7.63×10^{-3}
	HOA	0.065	2.22	3.04×10^{-4}
	SV-OOA	0.511	1.72	2.89×10^{-3}
	LV-OOA	0.950	1.54	3.17×10^{-3}
Summer-Autumn 2019	TrOA	0.160	1.76	1.4×10^{-2}
	HOA	0.082	2.05	1.54×10^{-4}
	SV-OOA	0.500	1.64	4.00×10^{-3}
	LV-OOA	0.710	1.60	5.20×10^{-3}
	LV-OOA-LRT	0.760	1.50	1.10×10^{-2}
	CoOA	0.250	1.86	9.20×10^{-2}
Winter 2022	TrOA	0.162	1.59	3.36×10^{-2}
	HOA	0.061	2.00	6.50×10^{-2}
	BBOA	0.165	1.84	9.72×10^{-3}
	SV-OOA	0.220	1.57	1.10×10^{-2}
	LV-OOA	0.657	1.34	4.94×10^{-2}
	LV-OOA (w/BB)	0.492	1.36	1.40×10^{-2}
Spring 2024	TrOA	0.179	1.70	1.76×10^{-2}
	HOA	0.074	2.10	7.26×10^{-3}
	SV-OOA	0.391	1.72	9.59×10^{-3}
	LV-OOA	0.743	1.51	1.9×10^{-2}
	unknown	0.752	2.51	1.77×10^{-2}

Table S3: Correlation of HOA, TrOA and SV-OOA with eBC and NO_x (Pearson R) for 1-hour averaged data. eBC was measured with the AE33 and NO_x with APNA 370 (Horiba).

Campaign	vs. BC			vs. NO _x		
	HOA	TrOA	SV-OOA	HOA	TrOA	SV-OOA
Spring 2018	0.42	0.47	0.38	0.47	0.45	0.32
Summer-Autumn 2019*	0.64 ^{0.61}	0.40 ^{0.32}	0.30 ^{0.31}	0.65 ^{0.62}	0.37 ^{0.30}	0.095 ^{0.13}
Winter 2022*	0.48 ^{0.82}	0.53 ^{0.35}	0.49 ^{0.21}	0.59 ^{0.83}	0.57 ^{0.44}	0.36 ^{0.23}
Spring 2024	0.73	0.47	0.54	0.78	0.42	0.27

*superscript values without the long-range transport episode/episodes

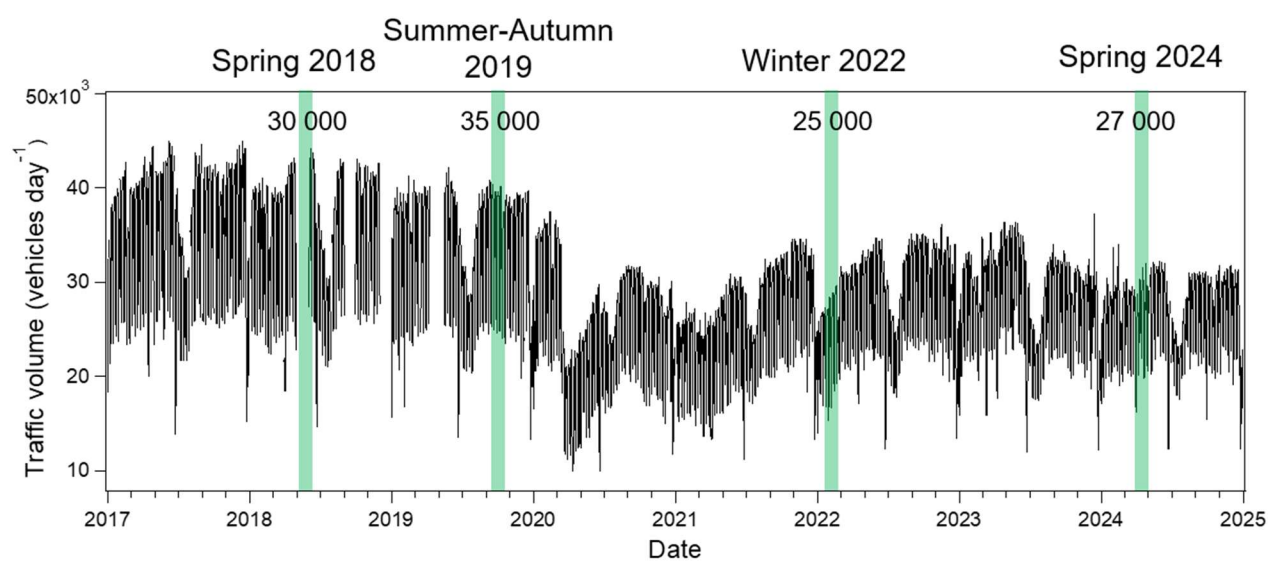


Figure S1: Traffic volumes in 2017–2024 at traffic counting site operated by the City of Helsinki. The durations of the campaigns are shown by green areas and average volumes during the campaigns by values on the top of the green areas.

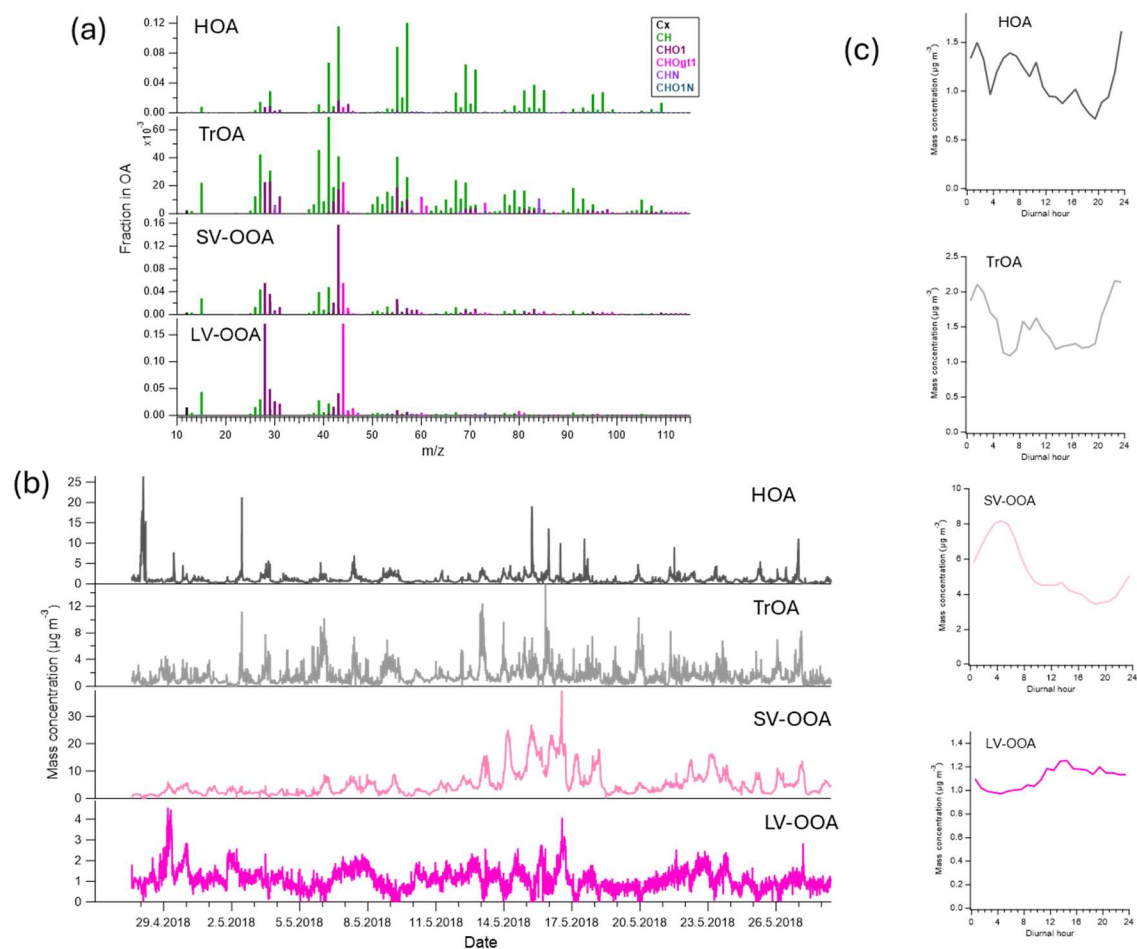


Figure S2: PMF results for the Spring 2018 data. Mass spectra (a), time series (b) and diurnal trends (c).

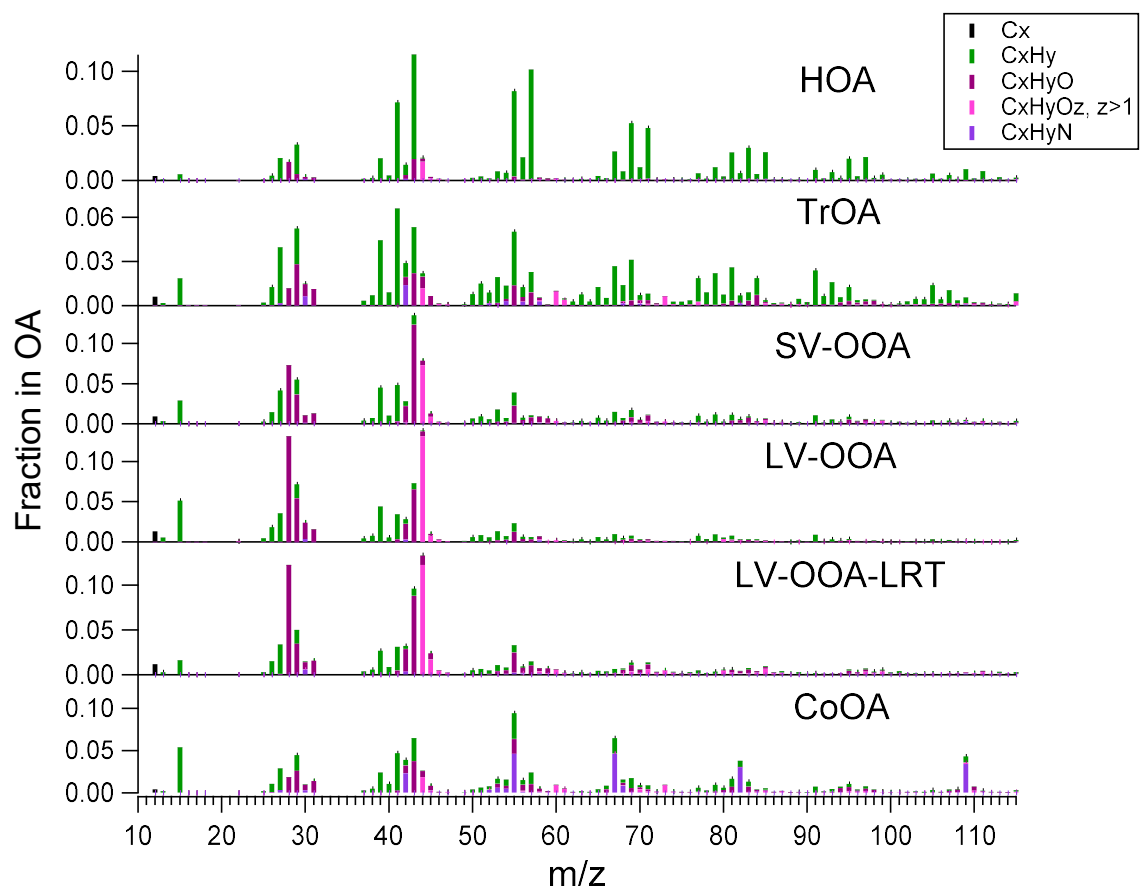


Figure S3: Mass spectra of the PMF factor for Summer-Autumn 2019 data (Saarikoski et al., 2023).

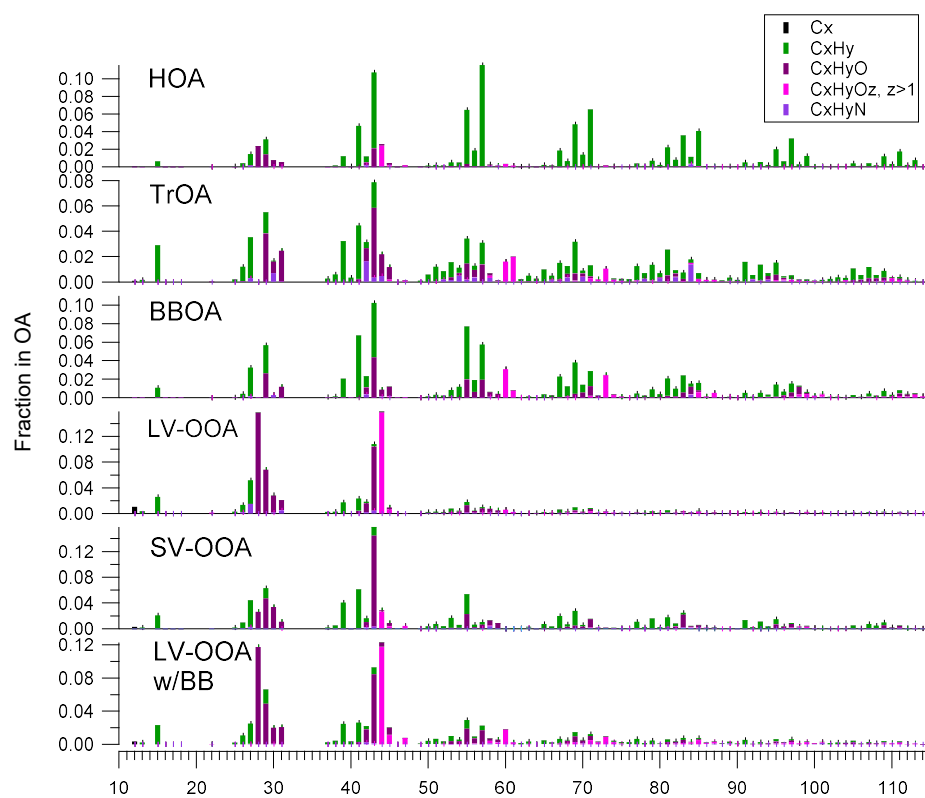


Figure S4: Mass spectra of the PMF factor for Winter 2022 data (Teinilä et al., 2025).

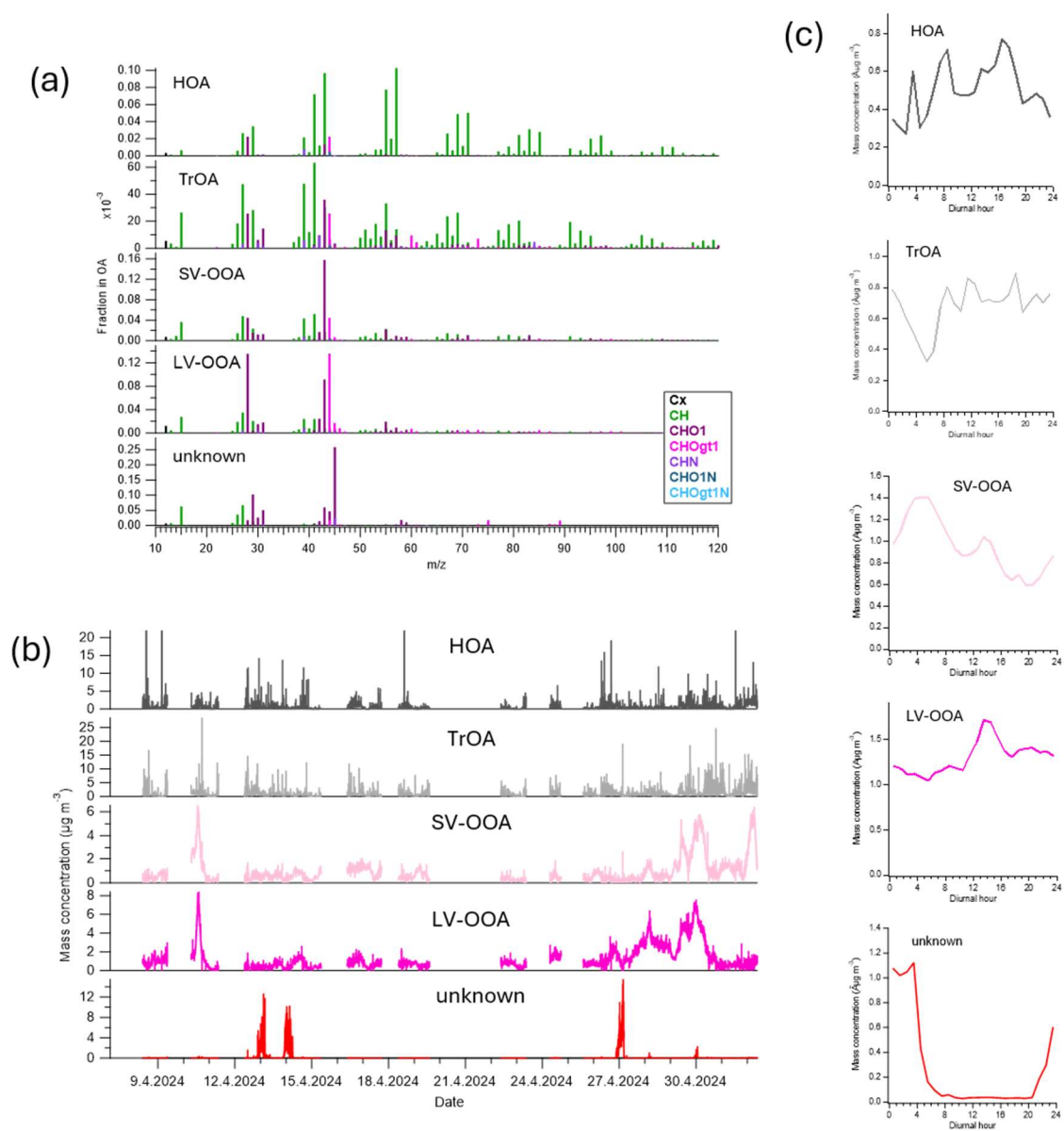


Figure S5: PMF results for Spring 2024 data. Mass spectra (a), time series (b) and diurnal trends (c).

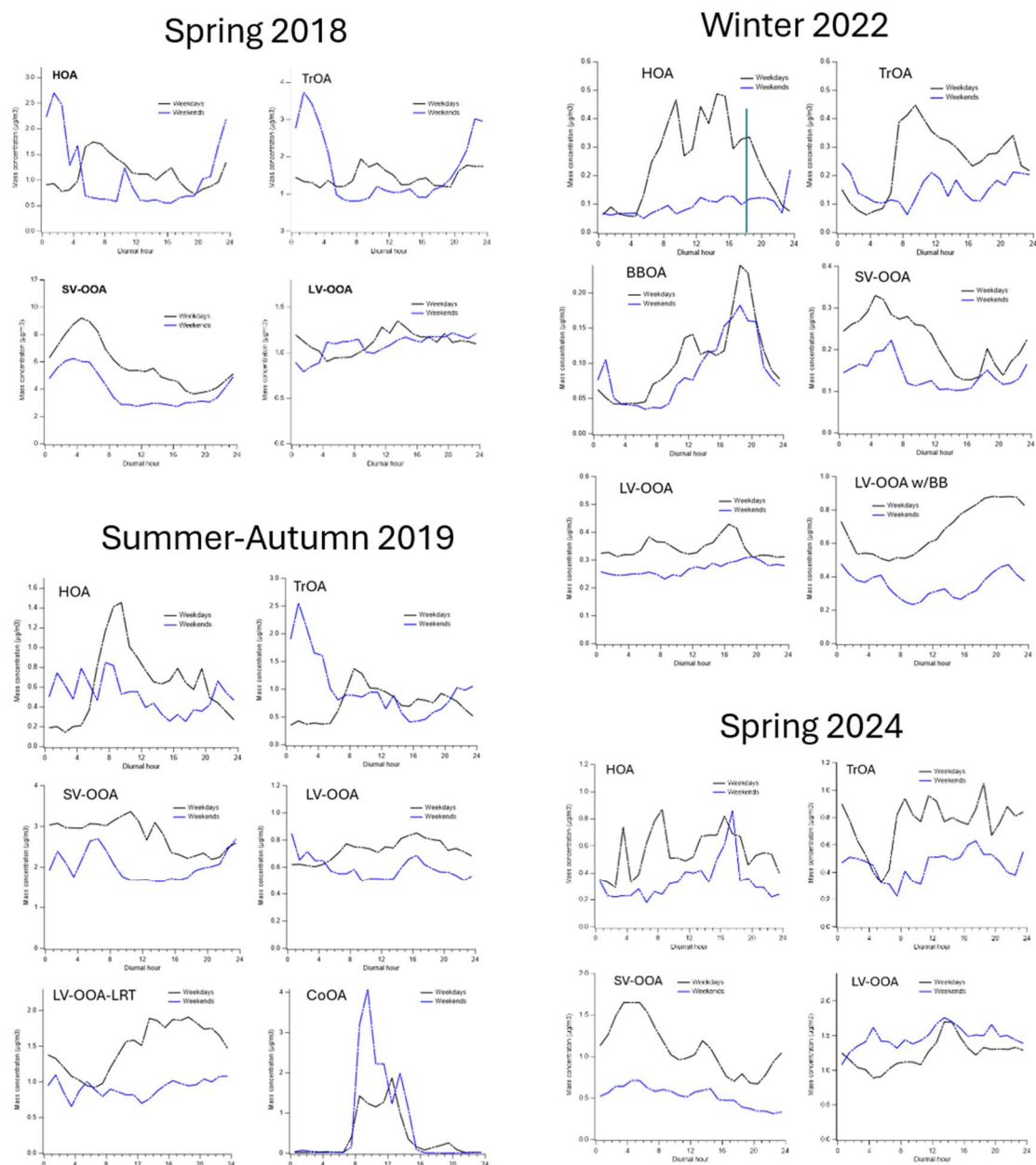


Figure S6: Average diurnal trends of the PMF factors during weekdays and weekends in Spring 2018, Summer-Autumn 2019, Winter 2022 and Spring 2024.

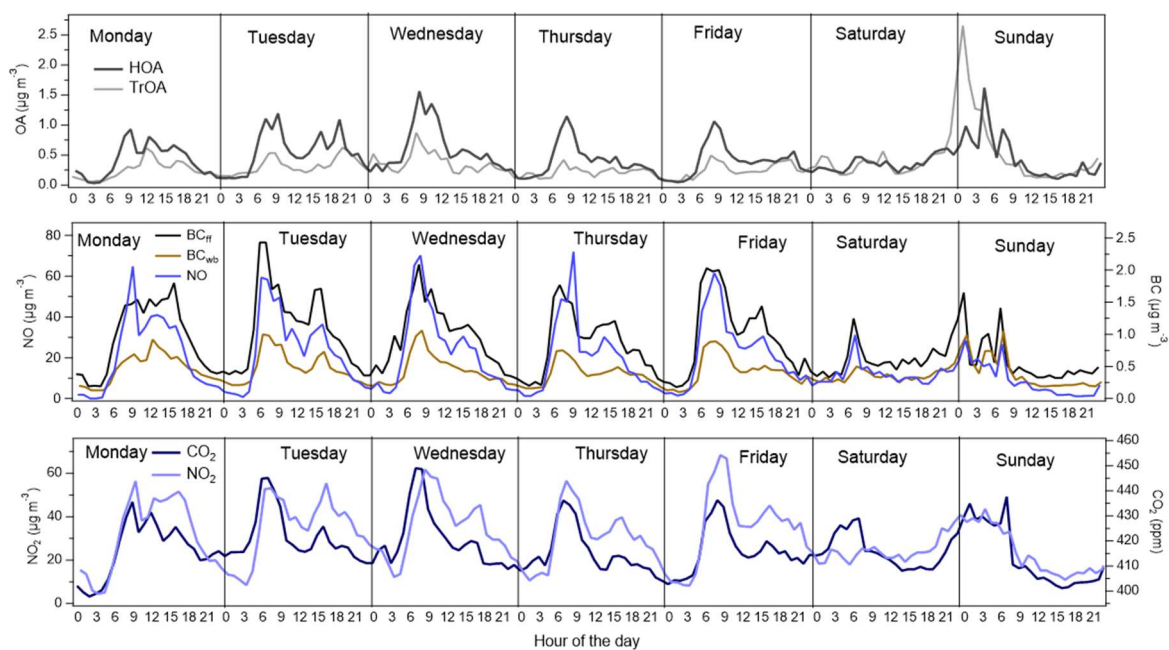


Figure S7: Average diurnal trends of HOA, TrOA, BC_{ff}, BC_{wb}, NO, CO₂, and NO₂ at different days of the week during Summer-Autumn 2019 campaign. Black carbon from fossil fuel combustion (BC_{ff}) and black carbon from wood burning (BC_{wb}) was measured with the aethalometer (AE33; see details in Saarikoski et al., 2024).

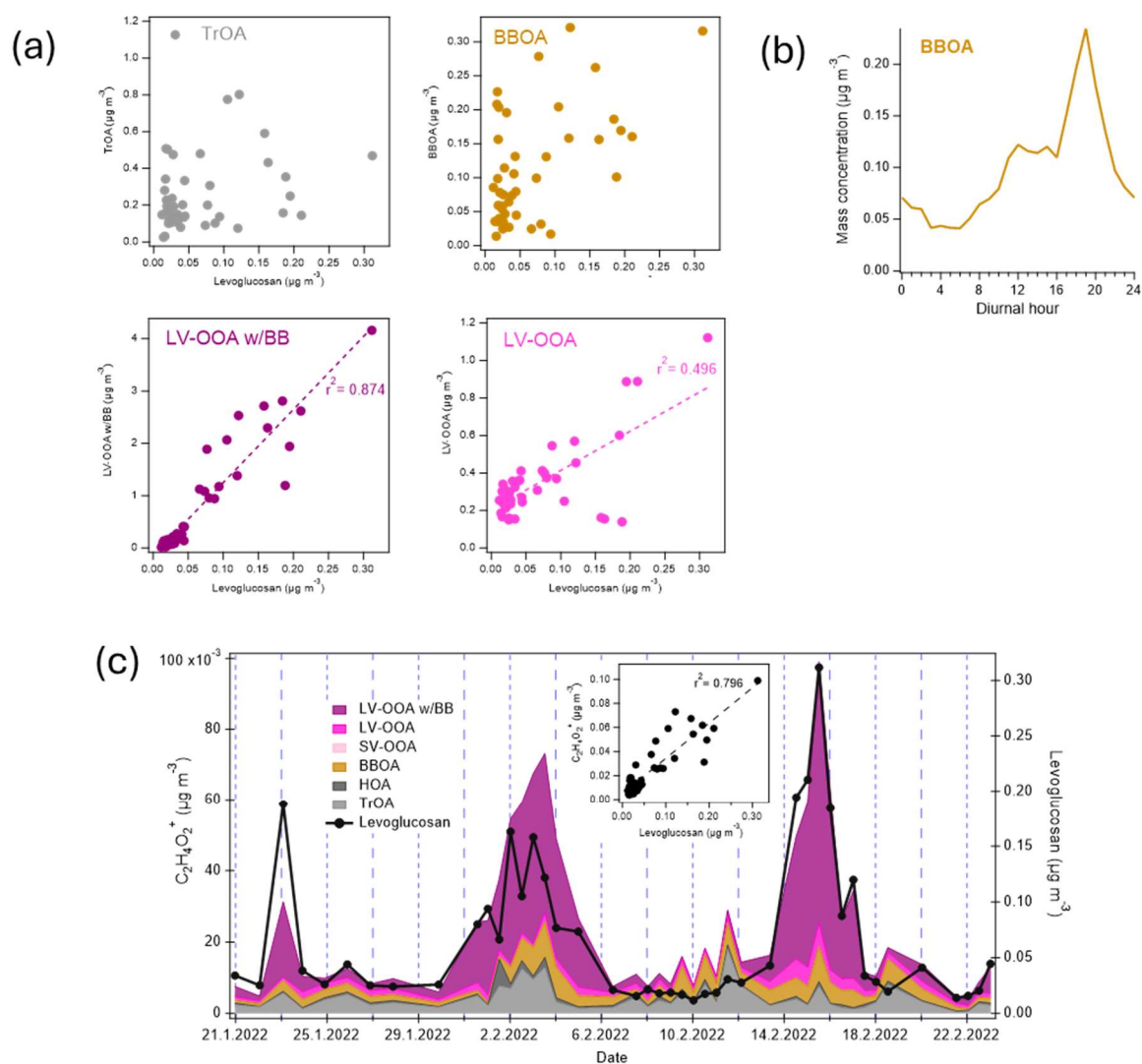


Figure S8: Correlation of selected PMF factors with the levoglucosan concentrations (a), the diurnal trend of BBOA (b), and the time series of $\text{C}_2\text{H}_4\text{O}_2^+$ divided into PMF factors (left y-axis) and the time series of levoglucosan (right y-axis, analyzed from the PM_{10} filter samples) (c) during winter 2022 campaign. The details of PM_{10} sampling and levoglucosan analyses have been given in Teinilä et al. (2025).

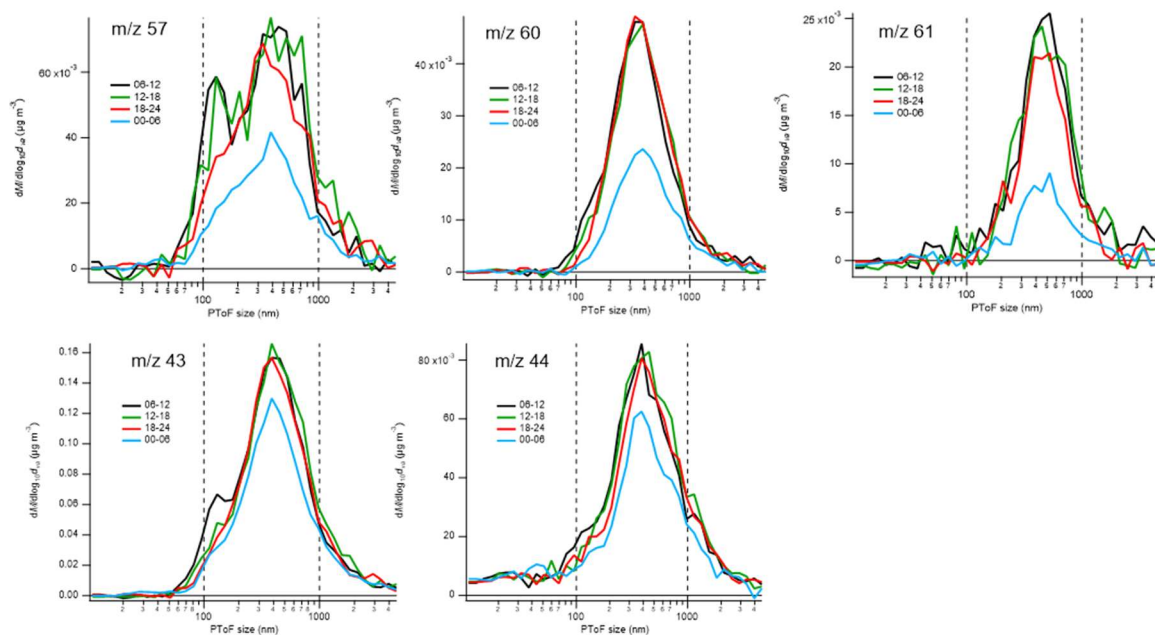


Figure S9: Average mass size distributions for m/z 57, 60, 61, 43 and 44 at different times of the day in Winter 2022. Only weekdays are included.

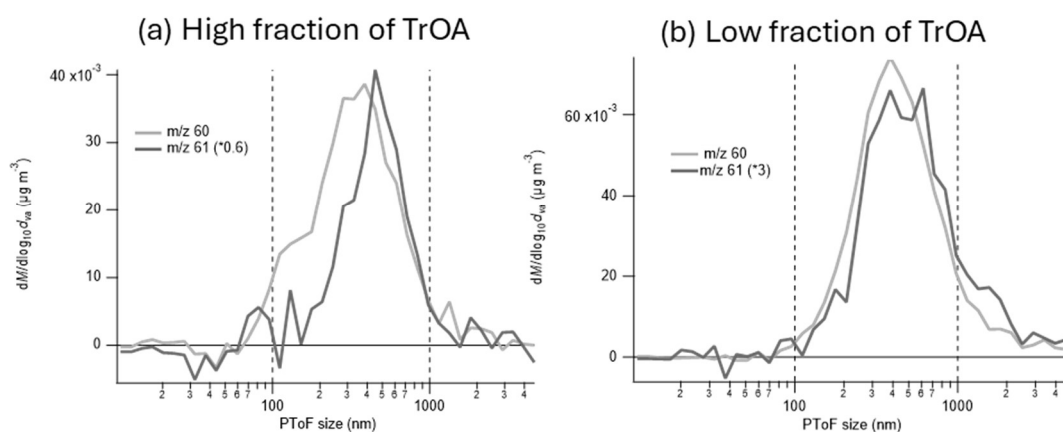


Figure S10: Average mass size distributions for m/z 60 and 61 during the periods of high (a) and low fraction (b) of TrOA in OA for Winter 2022 data.

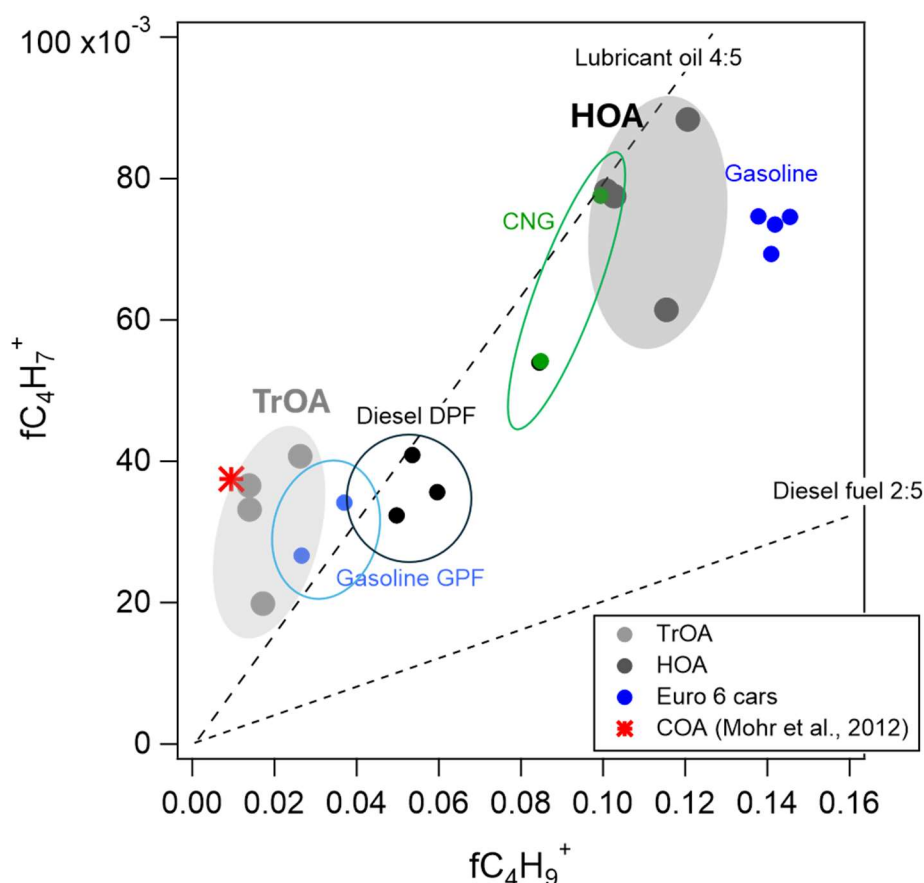


Figure S11: Scatter plots of $fC_4H_7^+$ (at m/z 55) and $fC_4H_9^+$ (at m/z 57) for TrOA and HOA in four campaigns. Additionally, $fC_4H_7^+$ and $fC_4H_9^+$ are shown for the OA from Gasoline car (without GPF), CNG car, Gasoline car with GPF, Diesel car with DPF and CNG car measured in laboratory conditions. All cars are Euro 6 level passenger cars. See details of the car measurements in Saarikoski et al. (2024). Dashed lines present the ratio for lubricant oil and diesel fuel (Canagaratna et al., 2004). GPF = gasoline particulate filter, DPF = diesel particulate filter, CNG = compressed natural gas. For comparison, $fC_4H_7^+$ and $fC_4H_9^+$ were also presented for OA from cooking (COA, Mohr et al., 2012).

Source apportionment for Spring 2018 data

The SP-AMS dataset collected in spring 2018 at the Helsinki supersite was analyzed with a positive matrix factorization (PMF) algorithm (CU AMS PMF tool v. 2.08D, Paatero and Tapper, 1994; Ulbrich et al., 2009) to identify sources and organic aerosol (OA) types. Prior to PMF analysis, the SP-AMS data were processed with ToF AMS HR Analysis 1.200 in Igor Pro 8.04. High-resolution (HR) data were averaged to 10-minute intervals, resulting in a dataset of 4440 data points.

PMF was run from 2 to 9 factors. Solutions with 6 and 7 factors were inconclusive, while the 4-factor solution provided the most reasonable results. The factors were identified as hydrocarbon-like OA (HOA), traffic-related OA (TrOA) semi-volatile oxygenated OA factor (SV-OOA), and low-volatility oxygenated OA factor (LV-OOA). Corresponding mass spectra, time series and diurnal profiles are given in Fig. S2. In the 3-factor solution, TrOA was not resolved and was split between HOA and LV-OOA. In the 5-factor solution, the additional factor presented a combination of LV-OOA and SV-OOA, and the TrOA contribution decreased from 17 to 15%

compared to the 4-factor solution. Solutions with 8 and 9 factors did not yield any additional information as HOA was split into two factors.

The chemical characteristics of TrOA varied with the number of factors. The hydrogen-to-carbon ratio (H:C) remained relatively stable, whereas the oxygen-to-carbon ratio (O:C) was smallest in the 5-factor solution and largest in the 8-factor solution (Fig. S12). The relative contributions of $\text{C}_2\text{H}_4\text{O}_2^+$ (at m/z 60), $\text{C}_2\text{H}_5\text{O}_2^+$ (at m/z 61) and $\text{C}_3\text{H}_5\text{O}_2^+$ (at m/z 73) in TrOA also changed, with the highest fractions observed in the 8-factor solution. Regarding diurnal trends, TrOA exhibited the clearest morning peak in the 4-factor solution, although its highest concentrations occurred at night across all solutions (Fig. S13).

The 4-factor solution was further evaluated for rotational ambiguity by varying f_{peak} and for robustness using bootstrapping and multiple seeds. These tests confirmed that the 4-factor solution was stable.

Source apportionment for Spring 2024 data

The SP-AMS dataset collected in spring 2024 at the Helsinki supersite was analyzed with a positive matrix factorization (PMF) algorithm (CU AMS PMF tool v. 2.08D, Paatero and Tapper, 1994; Ulbrich et al., 2009). Before the PMF analysis, the SP-AMS data were processed with ToF AMS HR Analysis 1.26E in Igor Pro 8.04. PMF was run applied to the HR dataset at its original 1-minute time resolution, consisting of 20 100 data points. PMF was tested with 2 to 8 factors. The 5-factor solution provided the most reasonable interpretation. The factors were identified as HOA, TrOA, SV-OOA, LV-OOA, and a fifth factor of unknown origin. Mass spectra, time series and diurnal trends for these factors are shown in Fig. S5. The unknown factor appeared in three distinct 6–8 hour peaks during the nights of Fri-Sat (12-13 April), Sat-Sun (13-14 April) and Fri-Sat (26-27 April). Its mass spectrum was dominated by signals for CHO^+ (at m/z 29) and $\text{C}_2\text{H}_5\text{O}^+$ (at m/z 45) indicating a generally oxygenated composition. The source of this factor could not be conclusively determined, but possible explanations include emissions from a nearby restaurant, given its occurrence on weekend nights, or road maintenance activities, as streets were being cleaned of winter sand during that period.

In the 3-factor solution, HOA and TrOA were separated, but OOA remained undivided, and the unknown factor was absent. In the 4-factor solution, the unknown factor appeared, but OOA was still grouped as one factor. In these solutions, TrOA contributions were higher (28 and 25%, respectively) compared to the 5-factor solution (18%). In the 6-factor solution, OOA split into three sub-factors, redistributing contributions from SV-OOA and LV-OOA. Further splitting occurred in the 7-factor solution, and in the 8-factor solution, where the eighth factor gained mass from both HOA and LV-OOA.

Compared to spring 2018 data, TrOA characteristics varied more noticeably with factor number in spring 2024 data. While H:C ratios remained rather stable across all solutions, the oxygen to carbon (O:C) ratios decreased as the number of factors increased (Fig. S12). $f_{\text{C}_2\text{H}_4\text{O}_2^+}$, $f_{\text{C}_2\text{H}_5\text{O}_2^+}$ and $f_{\text{C}_3\text{H}_5\text{O}_2^+}$ in TrOA increased almost linearly with factor number (Fig. S12). Diurnal patterns of TrOA were consistent across all solutions, although its absolute concentration varied (Fig. S13).

The 5-factor solution was further investigated for rotational freedom via f_{peak} variation and accuracy using bootstrapping and multiple seeds. These tests showed that the 5-factor solution was robust and stable.

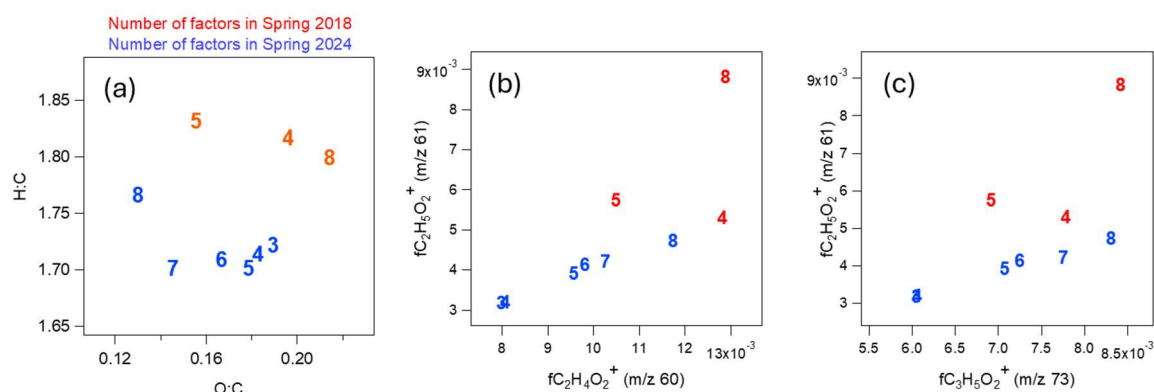


Figure S12: Elemental composition of TrOA (a), the relationship of $\text{fC}_2\text{H}_5\text{O}_2^+$ to $\text{fC}_2\text{H}_4\text{O}_2^+$ (b) and $\text{fC}_2\text{H}_5\text{O}_2^+$ to $\text{fC}_3\text{H}_4\text{O}_2^+$ (c) according to the number of PMF factors.

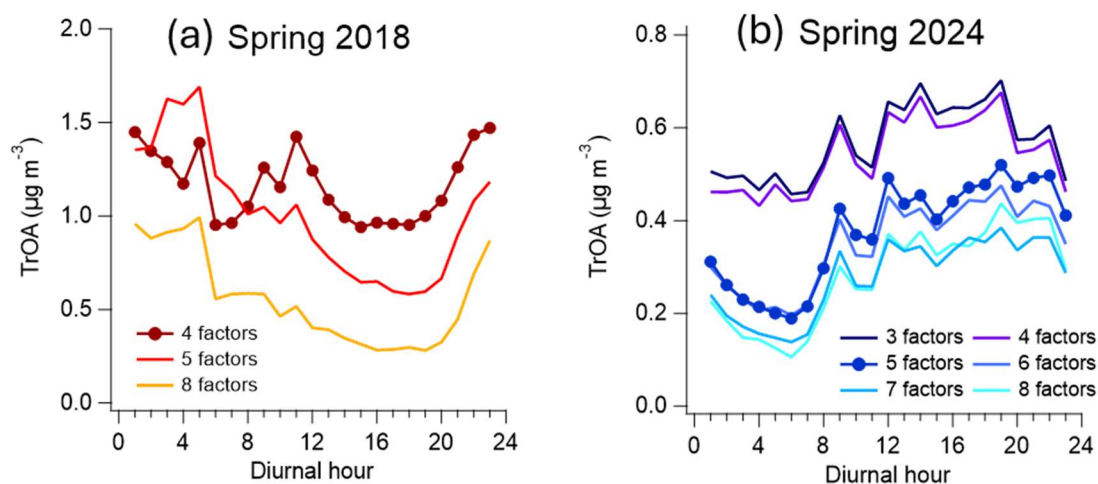


Figure S13: The diurnal trend of TrOA in Spring 2018 (a) and Spring 2024 (b) with the number of PMF factors.

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