Session 1: Aircraft emissions (Part 1), Talk

Export of aircraft exhaust ultrafine particles from Tokyo International (Haneda) Airport

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High concentrations of ultrafine particles (UFPs; diameter < 100 nm) have adverse effects on human health [1]. Jet aircraft emissions are significant sources of UFPs around airports and in the upper troposphere. However, the emissions and dispersion of UFPs originating from jet aircraft under real-world operating conditions are not well understood. The purpose of this study was to estimate the number flux of UFPs exported from Tokyo International (Haneda) Airport (HND) using mobile measurement data.

Mobile measurements were performed in the vicinity of HND on March 7 and 10 of 2022, February 18 and 19 of 2023, October 17 of 2024, and March 4 of 2025. A portable CPC (Model 3007, TSI) was mainly used for the measurements of polydisperse particle number concentrations (>10 nm). The basic performance of the CPC 3007 has been extensively evaluated using field measurement data obtained at Kobe Airport [2, 3]. A portable scanning mobility particle sizer (NanoScan, Model 3910, TSI) and an optical particle counter (HHPC 6+, Beckman Coulter) were temporarily used to estimate the particle number concentrations above the UFP size range. Furthermore, a carbon dioxide (CO_2) sensor (LI-840, Li-Cor) was temporarily used to derive the effective particle number emission indices (EIs). Here, the term “effective” includes the spatially and temporally averaged nonvolatile (combustion-generated) particles and volatile particles formed during plume expansion. The number flux of UFPs exported from HND can be estimated using the effective number EIs of UFPs and an emission inventory for CO_2.

Figure 1 shows an example time series of the number concentrations and size distributions of aerosol particles. The distance from the nearest runway to the observation point along the wind direction was ~1 km. The high particle number concentrations measured by the CPC were associated with the enhanced fraction of the smallest three size bins of the NanoScan (< 20 nm), indicating the significance of sub-20 nm particles in aircraft exhaust plumes exported from airports. The variability in the particle number concentrations and estimates of the number flux of UFPs are discussed in detail in the presentation.

Acknowledgments: This study was funded by the Environment Research and Technology Development Fund of the Ministry of the Environment (JPMEERF20205004, JPMEERF20245005) and by the Steel Foundation for Environmental Protection Technology.

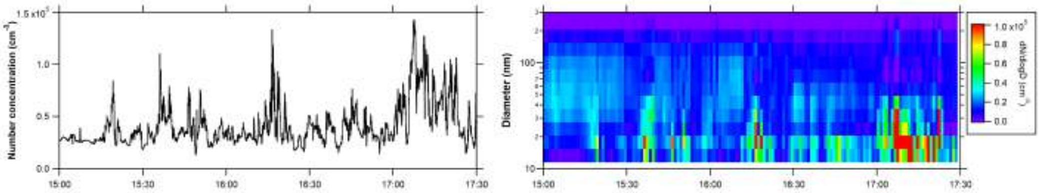

Fig. 1. Example time series of the number concentrations and size distributions of aerosol particles obtained in the vicinity of Haneda Airport on March 10, 2022.

[1] WHO global air quality guidelines, https://iris.who.int/handle/10665/345329; [2] N. Takegawa, *Aerosol Sci. Technol.*, **2023**, 57, 1087–1097; [3] N. Takegawa, Y. Murashima, and H. Sakurai, *Aerosol Air Qual. Res.*, **2025**, 25, 43.

Session 1: Aircraft emissions (Part 1), Talk

Dispersion of ultrafine particles originated from a medium-large international airport

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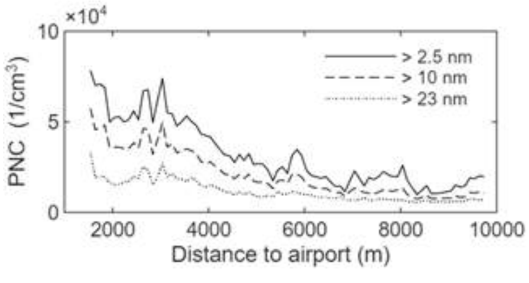
Ultrafine particles (UFPs), i.e. aerosol particles with a diameter smaller than 100 nm, are harmful to human health. As the emission and air quality regulations have mainly based on particle mass (e.g., $PM_{2.5}$), exposure to UFPs can still be high especially in urban areas. UFPs are suggested to be the most important contributor on premature deaths from air pollution in Europe in 2030 [1], highlighting the need to understand the sources and concentrations of UFPs in urban areas. Airports have been noted as important sources of UFPs (e.g. [2]). Long-term air quality impacts of airports as well as the characteristics and dispersion of the airport-originated UFPs are, however, not well understood: For example, the contribution of airports on 1–10 nm particles. Here [3], we measured airport-originated particles with the Aerosol and Trace-gas Mobile Laboratory (ATMo-Lab) near an international airport in Helsinki, Finland, February 2025. The ATMo-Lab was equipped with four condensation particle counters (CPC) with cut-off sizes of 2.5 nm, 4 nm, 10 nm and 23 nm, an electrical low pressure impactor (ELPI+), an AE33 Aethalometer, a Partector 2.1 Pro and CO_2 measurement. Driving measurement routes perpendicular to the airport (approx. 1–10 km) were driven so that the wind was blowing from the airport to the direction of the measurement routes. In addition, data from stationary air quality measurement sites 1-15 km away from the airport were utilised. At a site 1 km away, the particle size distribution was measured down to the size of 1.2 nm.

In the driving measurements [3], the downwind particle number concentration (PNC) exponentially increased when the distance to the airport decreased, and elevated PNC was still clearly observable 10 km away from the airport (Figure). The downwind PNC (> 2.5 nm) exceeded the WHO's definition for high short-term concentration (20 000 $1/cm^3$) 7–8 km away from the airport. Roughly 30 % of the airport-originated particles were smaller than 10 nm, and 70 % smaller than 23 nm. The effect of airport on black carbon or $PM_{2.5}$ was minimal. The airport was estimated to contribute to 500–5 000 $1/cm^3$ yearly increases of PNC (> 10 nm) 2–5 km away from the airport, showing the importance of UFPs near airports.

The study is part of GIANT (5582/31/2023) and METECH (3973/31/2025) -projects funded by Business Finland, participating companies and municipalities, as well as UNIC-project (Horizon Europe, 101192598). We thank all the collaborators in the measurement campaign.



[1] Hänninen, et al. (2025), Environment International. DOI: 10.1016/j.envint.2025.109657
[2] Keuken, et al. (2015): Atmospheric Environment, 104. DOI: 10.1016/j.atmosenv.2015.01.015
[3] Lepistö et al., in review (Environmental International).

Session 1: Aircraft emissions (Part 1), Talk

Ultrafine particle exposure from individual aircrafts approaching Innsbruck airport

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Aircraft engines produce emissions similar to those from other fossil fuel combustion sources, contributing to air pollution. In addition, they emit large numbers of ultrafine particles (UFPs) across a wide range of operating conditions. Studies have shown that exposure to UFPs can have adverse health effects, as these particles can enter the bloodstream and act as carriers of toxic substances (1). While there is no guideline level for UFP by WHO, an hourly Particle Number Concentration (PNC) above 20 000 particles/ccm is considered “high” (2). In this work we deployed a weather station, a microphone, two mobile UFP sensors and recently a fast CO2 sensor on the roof of a school building located approximately 1 km from the runway of the Innsbruck airport (in the direction of the city center to the East). The portable UFP sensors (Partector2 an Partector2 Pro from Naneos Particle Solutions GmbH, Switzerland) allows characterizing particle concentration and size virtually in real time. We carried out long term measurements over more than a year to capture the diurnal and seasonal impact of real-world aircraft specific UFP emissions. We observe UFP plumes with PNC of several hundred thousand particles/ccm of individual aircrafts approaching the airport prevailingly from the East as shown in Figure 1. As an example, in February 2024 PNC concentrations during the day exceeded the WHO “high” classification limit almost every day when wind speeds are less than 10 m/s. A comprehensive real-world dataset on aircraft-specific emissions will be presented, providing critical insights into plume dispersion during landing and take-off. This work was supported by OeAD Sparkling Science (Project Atemluft).

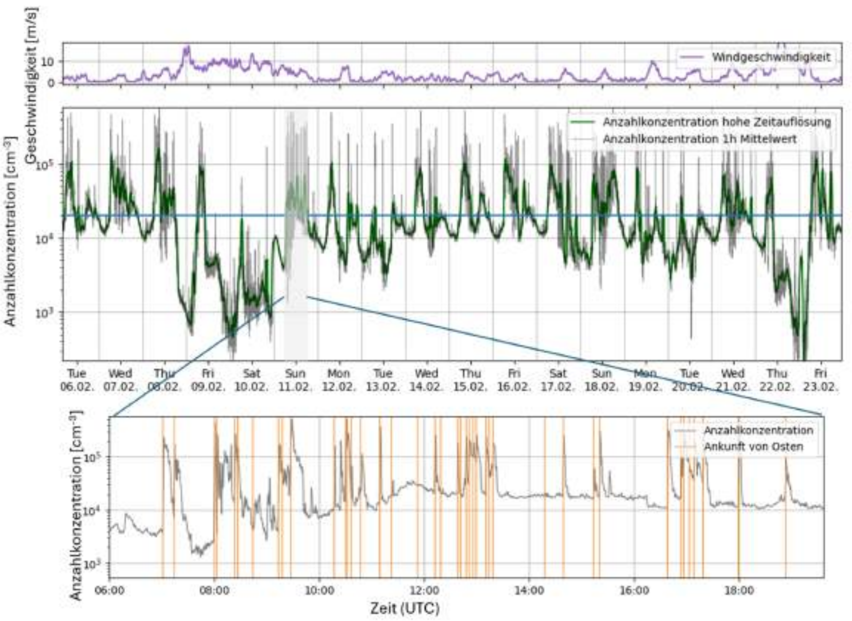

Figure 1: In-situ observations of PNC. Inset shows individual plumes associated with aircraft landing operations (1) European Aviation Environmental Report 2025, Doi: 10.2822/1537033 and references therein. (2) WMO (2021) WHO global air quality guidelines: particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide.

Impact of Seasonal Variations on Jet Engine Emissions from a Business Jet Running on Fossil and Sustainable Aviation Fuels

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Characterizing aircraft engine particle emissions is critical for assessing aviation's climate impact. While significant progress has been made in certifying large-thrust engines (>26.7 kN thrust), substantial data gaps remain for non-regulated, smaller engines. Furthermore, while the influences of fuel composition and ambient conditions are known to affect emissions, these factors are rarely quantified for smaller turbofans under varying seasonal conditions.

This study presents emission measurements from a Pilatus PC-24 aircraft equipped with Williams FJ44-4A turbofan engines. Using the Swiss Mobile Aircraft Emission Measurement System (SMARTEMIS), we measured the mass, number, and size distribution of non-volatile particles, as well as organic emissions, both at the engine exit and in the near-field (Figure 1). To isolate the effects of environmental variables and fuel properties, two campaigns were conducted: a "summer campaign" (August 2025) at elevated ambient temperatures and a "winter campaign" (January 2026) at low temperatures. Testing compared standard fossil kerosene against a 30% Hydroprocessed Esters and Fatty Acids (HEFA) blend.

Results indicate that a reduction in fuel aromatic content from 17.5 v% to 11.3 v% (corresponding to a +1 m% increase in hydrogen content), despite a small increase in naphthalene content from 0.57 v% to 1.09 v%, yielded a soot number reduction of up to 60 %. Notably, this reduction efficiency diminished as engine thrust increased. Beyond establishing the emission profile, this study demonstrates the particle reduction potential of small turbofan engines and provides unique empirical data on ambient temperature sensitivity, filling a critical knowledge gap that remains unresolved for larger engine classes.

Figure 1: Setup of the jet engine measurement during the summer campaign.

Session 2: Aircraft emissions (Part 2), Talk

Experimental study on the impact of HVO addition to Jet A-1 on non-volatile particulate matter emissions

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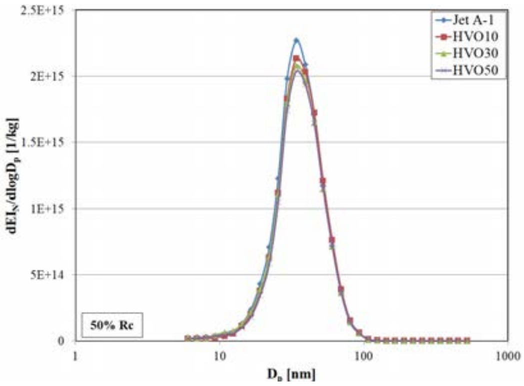
While Sustainable Aviation Fuels (SAFs) have been widely studied regarding their ability to lower particle emissions compared to conventional jet fuels, there is still a need to explore additional options for replacing traditional aviation fuels in the near future.One of the certified SAFs is HEFA-SPK (Hydroprocessed Esters and Fatty Acids Synthetic Paraffinic Kerosene), derived mostly from used cooking oil, waste and residues [1]. However, the production process is complex and requires advanced technologies, making large-scale implementation in aviation challenging in the short term. Currently, there is also well implanted Hydrotreated Vegetable Oil (HVO) which is dedicated to diesel engines, however the production process and physicochemical parameters are similar to HEFA-SPK. According to other researches, the HVO and HEFA-SPK are often used interchangeably in analyses [2].

This research focuses on analyzing the effect of adding HVO to Jet A-1 fuel and evaluating their impact on PM emissions from a laboratory-scale jet engine. HVO fuel was blended with Jet A-1 at a volumetric ratio of 10% (HVO10), 30% (HVO30) and 50% (HVO50) with the remainder consisting of Jet A-1. Also test were carried out with neat Jet A-1 fuel as a reference fuel. The experiments were conducted using a GTM 400 jet engine under four operational conditions: 10%, 30%, 50%, and 80% of maximum engine power.



For each tested engine operation point, emission indices such as nvPM Number Emission Index [1/kg] and nvPM Mass Emission Index [mg/kg], as well as Particle Size Distribution (PSD) of EI_N [1/kg] and EI_M [mg/kg] were presented. One of the results is that the addition of HVO to Jet A-1 led to a decrease in EI_N at 50% and 80% of the maximum thrust, with the highest value observed for neat Jet A-1 and the lowest for HVO50.

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Session 2: Aircraft emissions (Part 2), Talk

Physical and chemical properties of non-volatile and volatile nanoparticles emitted from turbofan jet engines

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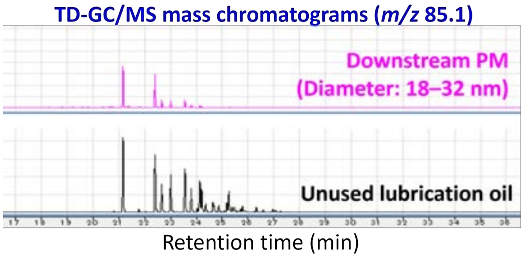
There is worldwide concern about the effects of aircraft exhaust particles on human health and the climate. The particle number concentrations in exhaust plumes of turbofan jet engines, which are commonly used in civil aviation, are generally dominated by volatile particles rather than nonvolatile particles (mostly soot). However, the mechanisms of emission and formation of volatile particles are unclear. We examined the exhaust particles from in-service commercial turbofan engines at the engine exit and 15 m downstream in a test cell at SR Technics, Zurich Airport. The target engines were PW4000 and CFM56. Real-time measurements of particle size distributions and gases (e.g., CO_2) were performed, as well as filter-based sampling, and subsequent high-resolution transmission electron microscopy and chemical analyses (e.g., organic species with thermal desorption gas chromatography/mass spectrometry (TD-GC/MS)). At the engine exit, the turbostratic (soot) particles were dominant, which mostly existed as agglomerates [1]. In downstream samples, the number of soot particles was <1% of the total number of particles analyzed. The remaining fraction predominantly contained trace amorphous, amorphous, and onion-like particles that partially contain graphene-like spherical layers. The microphysical structures of these three types of particles in aircraft exhaust plumes were newly identified. They were mainly single spherical particles with diameters of approximately 10−20 nm, suggesting that they were formed via nucleation and partial pyrolysis and were not significantly affected by coagulation with preexisting soot particles. The organic analysis revealed that the concentrations of lubrication oil markers (i.e., fatty acid esters of pentaerythritol, and tricresyl phosphate) in the bulk particulate samples were much higher downstream than at the engine exit. The results suggest that the hydrocarbons in downstream nanoparticles were mainly composed of lubrication oil (Fig).



This work was supported by the Environment Research and Technology Development Fund (JPMEERF20205004 and JPMEERF20245005) of the Ministry of the Environment, Japan, the Scientific Exchanges Grant of the Swiss National Science Foundation (IZSEZ0_198063), and the Swiss Federal Office of Civil Aviation (FOCA) Projects (AGEAIR SFLV 2017-030 and AGEAIR 2 SFLV 2018-048).

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Session 2: Aircraft emissions (Part 2), Talk

SOURCE FFR: Recent activities within the UFP exposure study in the Frankfurt Rhine-Main region

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Over the past years, the emissions and impacts of ultrafine particles (UFP) have received increased attention, especially in densely populated and urbanized areas close to a widespread highway net and large airports, like the Frankfurt Rhine-Main region. The project SOURCE FFR (*Study On Ultrafine Particles in the Frankfurt Airport Region, https://www.ultrafeinstaub-studie.de/en/*) was commissioned by the Umwelt- und Nachbarschaftshaus (UNH) in order to provide a scientific basis for further discussions. The study is divided into an UFP exposure study presented here and an impact study which started in September 2025.

Since Frankfurt Airport is one prominent source of UFP in the region, two emission measurement campaigns were performed at four different positions on the airport apron. Part of this data was used to obtain real-world emission indices (EI's) by assigning measured exhaust plumes to specific aircraft. These EI's contain emission information of both non-volatile and total particle number concentrations and are used as an input for the dispersion modelling after the clustering of the data according to aircraft engine types.Aside from UFP emissions directly at the airport, a public concern is the potential for the transportation of UFP in the downward direction via the wake vortices generated by aircraft on the glide paths. This question was assessed by performing wake vortex predictions considering wind conditions prevailing in 2019 and the respective traffic mix of Frankfurt Airport. Results indicate only a minor contribution of wake vortices to the ambient particle concentrations close to the airport and no significant influence on the surrounding area.

To characeterize the spatial and temporal distribution of UFP (number size distributions among other parameters) in the study area, immission measurements were carried out at ten locations in both upwind and downwind locations, considering the most prevalent wind directions. While particle sizes in some cases allow for conclusions to be drawn on UFP sources, further information is needed for a clear source apportionment. Taking advantage of the characteristic compounds present in aircraft engine oils, comprehensive chemical analyses facilitated the identification of aircraft-related emissions despite the manifold UFP sources in the area (e.g. ground traffic, industry, domestic fuel etc.). The quantification of these engine oils in particle filter samples provides valueable insight into the distribution and dispersion of the emissions within the studied area.

The dispersion modelling aims for an accurate and detailed description of air qualitiy parameters in both time and space. It relies on both emission measurement results provided by the project consortium and emission data of third-party providers as input parameters. Results of the aforementioned immission measurements serve as a validation target to investigate the quality of the model output. This presentation aims to give an overview on the project by showing selected results (emission measurements, vortex modelling, chemical characterisation).

Session 2: Aircraft emissions (Part 2), Talk

A “2^{nd}” (> 150 nm) Size Mode in Aircraft Gas Turbine Engine Exhaust, New Analysis

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We have been pursuing this project for several years, and last year we reported our progress at the 28th ETH-Nanoparticles Conference. That presentation focused on detailed experimental observations but did not yet offer a theoretical interpretation. In this presentation, we introduce new analyses that provide fresh insight into the mechanisms responsible for the formation of the second mode.

Piston-engine exhaust particle size distributions (PSD) typically exhibit three modes: a 3-30 nm nucleation mode of semi-volatile material, a 30-300 nm soot mode of carbonaceous aggregates, and a coarse mode of larger mechanically generated particles from oil atomization and surface re-entrainment. Measuring PSDs from commercial aircraft gas-turbine engines is much more challenging than with piston engines due to more extreme conditions: exhaust temperatures up to 900 °C, near-Mach-1 velocities. The long sampling lines required suppress nucleation-mode formation. Turbine-engine soot aggregates are smaller (15-50 nm GMD), and coarse particles were not expected given limited exhaust–surface interactions and the absence of piston rings. Nevertheless, under some conditions—particularly at low soot concentrations—we observed a distinct “2nd mode” of particles larger than ~150 nm. Daily zero checks and step-change tests showed no evidence that these particles were due to sampling-system particle shedding.

These results were obtained during the EPA/USAF VARIAnT 1–4 measurement campaigns, designed to refine methods for quantifying non-volatile aircraft-engine particles. The findings reported here draw on VARIAnT 3 and 4, using a GE J-85 turbojet and Libby Welding GT-05 and LGT-60 turbine start carts operated across a range of conditions and fuels. Particle size, concentration, and composition were measured with multiple instruments.

PSD measurements employed SMPS, EEPS, and DMS500 systems, supplemented by Aerodyne CAPS PMSSA extinction/scattering measurements in both campaigns and miniSPLAT single-particle mass spectrometry in VARIAnT 4. The 2^{nd} mode was quantified using volume above 150 nm (V150) and a bimodal lognormal fit of soot mode and 2^{nd} mode. V150 and the fitted volume in the 2^{nd} mode, V_{2nd}, were well correlated. With the J-85, V_{2nd}/V_{total} ratios approached 50% in some tests and generally decreased with increasing engine load and total mass emissions. The mode was far more pronounced for the J-85 than for the start carts.

Its formation also coincided with increased single-scattering albedo and the appearance of particles with distinct compositions and morphologies in the miniSPLAT data.

Session 2: Aircraft emissions (Part 2), Talk

Characterizing Aviation Contributions to Particulate Matter near Zurich Airport using Chemical Composition and Source Apportionment

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Aircraft emissions are a major source of particulate matter (PM) and ultrafine particles (UFP) during takeoff, landing, taxiing, and idling, degrading air quality near airports. With global air traffic projected to grow by ~4.2% annually and potentially doubling by 2040 (IATA, 2023a), aviation-related PM represents an increasing public health concern due to its links to respiratory and cardiovascular effects. Airport emissions contribute to both primary and secondary PM and can influence air quality well beyond airport boundaries, with impacts observed up to 18 km downwind (Hudda et al., 2012). Within the APPROPRIATE project, a month-long field campaign was conducted in fall 2022 at a downwind site ~1 km east of Zürich Airport, using LToF-AMS and EESI-LToF to characterize real-world aircraft emissions. PMF analysis of LToF-AMS data resolved nine PM□.□ factors (Figure 1), including two oxygenated organic aerosol (OOA) factors, primary combustion-related components (HOA and COA), two biomass burning factors, a nitrogen-containing organic aerosol (NOA), an organic nitrogen–rich factor, and an event-related factor. Compared to the seven factors resolved by Lu et al. (2019, ACP), two additional factors were identified: one showing strong correlations with aircraft lubrication oil markers (Yu et al., 2012), indicating a distinct primary aviation-related organic aerosol source, and another dominated by organonitrates. The event-related factor contributed 46.8% during the first campaign week (28 October–3 November) and 14.4% over the full sampling period. Ongoing integration of complementary molecular- and gas-phase measurements will further refine source attribution and improve separation of airport emissions from other anthropogenic and biogenic influences.

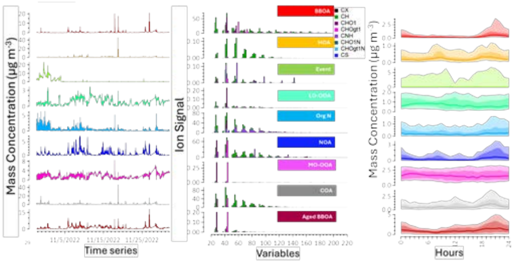

Figure 1. Factor solution for 2022 campaign with factor time series, factor profiles and diurnal variation

This work was supported by the Swiss Federal Office of Civil Aviation (SFLV 2020-080). We acknowledge the support from ZHAW, EMPA, Frithjof Siegerist (SRTechnics), and the City of Kloten.

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Emissions from fuel operated auxiliary heaters of passenger cars

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Due to road transport emissions being significant source of both direct particle emissions and precursors of secondary particles in addition to other harmful substances such as carbon monoxide, nitrous oxides and being major contributor to global warming due to high carbon dioxide emissions, there have been both national and international efforts to restrict and reduce emissions from vehicles. However current regulations mostly account for direct engine emissions an approach which omits auxiliary sources of combustion emissions if they are emitted by heater unit separated from the engine. These separate heating devices are called auxiliary heaters (AH). AHs are typically installed into gasoline and diesel vehicles in colder climates to both provide additional comfort to passengers and improve operation of the engine by preheating it before driving, which would otherwise suffer from reduced performance and increased wear and tear due to the cold started engine.

However AHs have in been observed to produce significant amount of emissions relative to more strictly regulated engine emissions with single 30 minute preheating cycle with fuel operated AH producing as much PN23 emissions as 20 or 97 kilometers of driving for diesel and gasoline fueled AHs respectively if driving would produce as much PN23 as is allowed by regulation.[1] Benefits of preheating with AH to driving emissions were have been found to be smaller than expected with no observable reductions in PN emissions and only minor reductions in PM in some cases,[2] so fuel operated AHs have mostly negative effect on the total emissions of vehicle with AHs installed due to additional direct emissions generated by AH. Preheating with AHs were found to have neglible benefits to fuel economy during driving and if fuel consumed during the preheating is accounted for fuel operated AHs increased overall fuel consumption of driving 13.8 km after preheating by around 30 %.[2] In addition to relatively high direct emissions AHs were observed to produce one to three orders of magnitude greater secondary particle emissions compared to direct emissions.[3] Current AHs lack emission aftertreatment devices comparable to those used to mitigate engine emissions and by accounting AH emissions as part of regulated vehicle emissions would provide appropriate incentive to both vehicle and heater manufacturers to optimize heaters to mitigate their emissions.

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Session 4: Emissions: aftertreatment / real world operation / alternative fuels, Talk

Influence of Lubricant Ash Content on DPF-Performance in Medium-Speed Diesel Engines

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Medium-speed marine diesel engines have only recently been equipped with diesel particulate filters (DPF), despite their relevance for particle emission reduction. While DPF technology has been successfully applied to smaller high-speed marine engines comparable to off-road machinery, early attempts on large medium-speed engines were not successful [1]. More recently, vessels operating medium-speed engines equipped with combined DPF and selective catalytic reduction (SCR) systems have entered service, achieving unprecedentedly low emissions for this engine class [2].

As heavy-duty, megawatt-scale medium-speed marine diesel engines typically operate for several thousand hours per year, downtime associated with DPF ash cleaning can become a critical operational parameter. Even when switching from heavy fuel oil to marine distillate fuels, sulfur levels remain higher than in on-road applications. This also applies to partial substitution with bio-, waste-derived, or synthetic distillates with reduced CO_2 footprint. To ensure sufficient corrosion protection, marine lubricating oils therefore require elevated base numbers. Consequently, lubricating oil formulation and oil consumption rate become the dominant factors governing ash accumulation in the DPF and, therefore, the achievable maintenance interval.

In this study, the influence of lubricating oil sulfated ash content on DPF performance, pressure drop evolution, and particle emission characteristics is investigated. Laboratory experiments were conducted using a Cambustion Diesel Particulate Generator to expose a marine-relevant DPF to particle-laden exhaust gas under controlled flow and thermal conditions. Three trunk piston engine oils with sulfated ash contents of 0.7 wt% (low-ash reference oil), 1.45 wt% (standard ash), and 0.5 wt% (ultra-low ash) were evaluated under identical conditions. Accelerated testing simulated approximately 6,000 equivalent operating hours within a reduced test duration.

The results reveal a clear ash-dependent trend in DPF behavior. Higher sulfated ash levels led to a faster increase in DPF pressure drop due to ash accumulation, pore blockage, and partial channel plugging. Field data from megawatt-scale engines equipped with DPF-SCR systems confirm sustained particle number (PN) and particle mass reduction efficiencies above 98 % over operating periods exceeding 6,000 h when using low-ash lubricating oils [3].

Compared to [3], the present work extends laboratory investigations by incorporating real-life PN emission data from a vessel with a medium-speed engine and a DPF-SCR system [2]. On-board measurements using a High Concentration – Nano Particle Emission Tester enable direct comparison between laboratory experiments and real-world emissions.

These findings demonstrate that lubrication oil formulation, particularly sulfated ash content, is a key factor governing DPF lifetime and long-term particle emission control in marine diesel applications.

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Nanoparticle and secondary aerosol emissions of EURO6d passenger cars fueled with gasoline, diesel and natural gas: The role of exhaust after-treatment byproducts

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The latest EURO6 emission classifications have led to significant reductions in primary particulate emissions from passenger cars. However, several studies report EURO6 passenger vehicles as important sources of secondary aerosol precursor emissions, potentially leading to several orders of magnitude higher secondary aerosol emissions in comparison to primary emissions (e.g. Hartikainen et al., 2023). Moreover, methane fuel, originating either as natural gas, biogas or e-methane, has been proposed as a method to improve air quality and decrease climate pollutants. However, ultrafine primary particle emissions and secondary aerosol formation potentials of methane-operated cars have not been extensively reported.

We measured the direct particle emissions and secondary aerosol (SA) formation potential of three Euro 6d-level passenger vehicles: one gasoline vehicle equipped with gasoline particulate filter (GPF), one diesel vehicle with diesel particulate filter (DPF), and one compressed natural gas (CNG) vehicle without particle filter. The vehicles were repeatedly driven 1-hour driving cycles on a wheel dynamometer. At least 29 cycles were run for each vehicle corresponding to more than 1500 km driving distance. The particle number emissions were measured with two condensation particle counters with cut-off sizes of 1.3 nm and 4 nm, and particle size distributions with instrumentation covering size range of 5 – 600 nm. The SA formation potential was measured using PEAR oxidation flow reactor. The formed secondary aerosol mass and composition was determined using Aerosol Mass Spectrometer (Aerodyne Research Inc.) and size distribution measurements. Volatile organics were monitored by a PTR mass spectrometer (PTR-ToF 4000, Ionicon) utilizing two different ionization modes. The overall gas phase composition was monitored using an FTIR analyzer (Gasmet DX4000).

The highest primary particulate number emissions were measured for the CNG vehicle in most driving conditions, whereas the diesel vehicle emissions were close to detection limit. However, the DPF regeneration events generated very high emissions during long distance operation, finally leading to the highest particle number emissions for the diesel vehicle. Comparable SA formation potentials in the range 1-2 mg/km were measured for each of the vehicle, which is roughly 1000 times more than the primary particle mass emission. The major identified secondary organic aerosol precursors were aromatic hydrocarbons for gasoline exhaust, but long-chain aliphatics for the diesel exhaust. Ammonium nitrate was a dominant SA component for gasoline and CNG emissions. This is due to the generation of ammonia emissions in the three-way catalyst of the vehicles, and subsequent reaction of ammonia and NOx during oxidative aging. Overall, this work highlights the role of emission after-treatment byproducts in both primary particle emissions and secondary aerosol formation potential of the emissions.

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Real-world particle number emission factors of heavy-duty vehicles: Contribution of sub-10 nm particles

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More evidence is emerging on the harmful brain impacts of human exposure to ultrafine particles (UFPs; <100 nm) [1-2]. The smallest UFPs (sub-10 nm) deposit efficiently in human extrathoracic airways [3], leading to a potential nose-to-brain pathway via the olfactory bulb [4]. Traffic is a major source of UFPs in urban environments [5], with heavy-duty vehicles contributing significantly [6]. Yet, even the stringent EU emission regulations do not address sub-10 nm particles in current and forthcoming legislations (Euro 7). In this study, we determined real-world particle number emission factors (EFs) for hundreds of passing heavy-duty vehicles, with a particular focus on the sub-10 nm size range.

Measurements were conducted on the causeway to Global Container Terminals Deltaport in Vancouver, Canada, using the UBC PLUME Van, a mobile laboratory, over seven days in October-November 2025. The causeway was dominated by goods-movement traffic, with minimal influence from other pollution sources due to its marine surroundings. The setup included a CO_2 analyser and two water-based condensation particle counters (CPCs) with different cut-off sizes (2 nm and 7 nm), enabling 1-s measurements of particle number concentrations for particles >2 nm and >7 nm. CO_2-based particle number EFs were derived using two approaches: individual CO_2 plume analysis to obtain EF distributions and fleet-averages, and correlation-based fleet-average EF estimation. Additional gaseous and particulate instruments of the broader campaign provided context on pollutant emissions, including non-exhaust particle emissions.

According to the preliminary results, the EFs showed very large variability, ranging from zero to 10^{17} #/(kg fuel). The fleet-average EF for particles >2 nm was approximately twice as large as the fleet-average EF for particles >7 nm, highlighting the significant contribution of sub-10 nm particles to total particle number emissions. Both EF calculation methods produced fleet-average EFs of similar magnitude, on the order of 10^{15} #/(kg fuel). These observations underline that heavy-duty vehicles can have a substantial impact on UFP concentrations in urban environments when operating on urban streets, even though cleaner vehicles also exist.

Measurements were part of the Urban Freight System Emissions program funded by Environment and Climate Change Canada’s (ECCC) Climate Action and Awareness Fund (CAAF). Lintusaari's research visit to UBC was supported by the KAUTE Foundation through the Researchers Abroad program. Both Salo and Lintusaari were supported by the GIANT project funded by Business Finland (grant number 5582/31/2023), Helsinki Region Environmental Agency HSY, and several Finnish municipalities and companies. This research was undertaken, in part, thanks to funding from the Canada Research Chairs Program.

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Ammonium Nitrate Nanoparticles from Ammonia Combustion in Engines and Burners

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Ammonia is generally assumed to emit no fuel-derived nanoparticles when combusted because it contains no carbon. This presentation debunks that assumption, revealing through a body of experimental investigations, the formation of particulate-phase ammonium nitrate (AN) from combustion in both flames and engines. Experimental research was conducted on an engine platform [1] and in turbulent [2] and laminar [3] flame setups. In all cases, gaseous emissions were measured using a Fourier Transform Infrared (FTIR) analyzer, while particle size distribution was assessed using a scanning mobility particle sizer (SMPS) following a dual-stage dilution system. The engine was operated on pure ammonia at 1200 and 1800 rpm, 50% load. Burner experiments were conducted over a range of equivalence ratios and thermal input levels. Size-separated particles were collected using a MOUDI impactor and characterized for chemical composition using attenuated total reflectance-FTIR, Raman spectroscopy, and X-ray photoelectron spectroscopy. Additionally, particle morphology was studied using transmission electron microscopy, while energy-dispersive X-ray spectroscopy mapping was performed to confirm elemental composition. In both engine and burner experiments, particle size distributions were monomodal lognormal, with diameters ranging from 6 nm to 224 nm as shown in Figure 1.

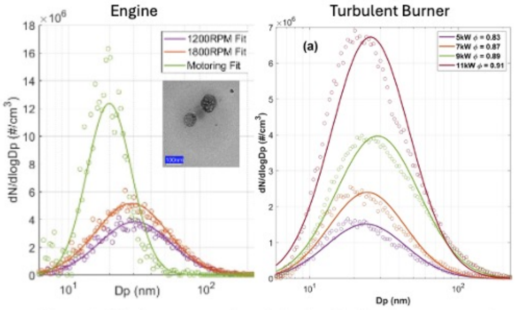

Figure 1. Dilution corrected particle size distributions measured using SMPS from engine experiments (left) and turbulent cyclone burner experiments (right). Raman image of ammonium nitrate particles (inset).

Characterization results indicate that measured nanoparticle emissions primarily consist of AN, but do not conclusively prove where in the exhaust system AN is formed. From the engine data, elemental maps show nitrogen and oxygen, indicating the presence of nitrates, along with sulfur, magnesium, potassium, and calcium, likely originating from lubricant oil additives. One formation mechanism is believed to involve heterogeneous nucleation, during which particles adsorb onto lubricant oil-derived ash particles. Burner nanoparticles contain no ash nuclei, suggesting that AN can also form via homogeneous chemical nucleation, with ammonia driving particle concentration, NO_2 contributing to cluster formation, and water vapor promoting particle growth via heterogeneous condensation. This presentation will clearly review these comprehensive results and provide an outlook for AN mitigation in future ammonia combustion systems.

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Effects of Extreme Cold Climate on Particulate Emissions of Light-Duty Gasoline Vehicles

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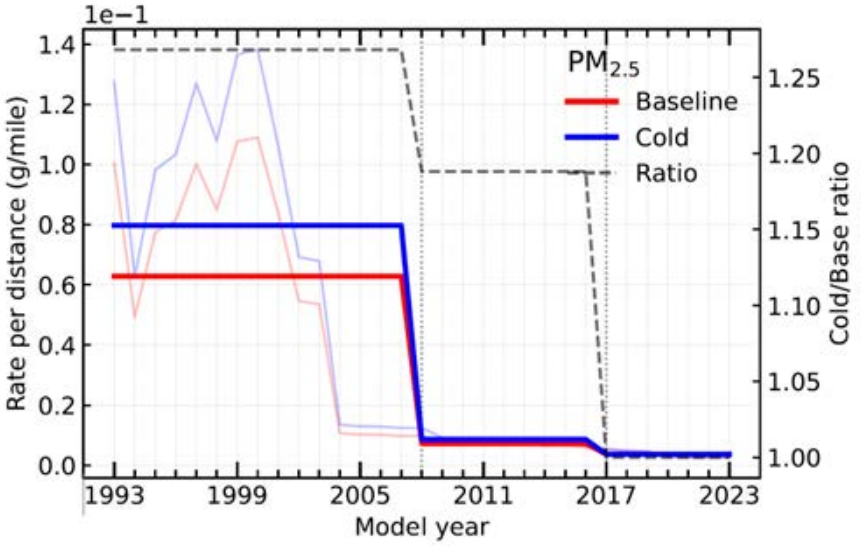
Extreme cold weather affects traffic activity and vehicle emission characteristics, yet the impacts are not represented in urban on-road emission inventories. The efficiency of catalytic converters depends on temperature, and achieving optimal operating temperatures in cold weather is challenging [1]. US EPA Tier 4 standards have recently introduced a PM limit of 0.5 mg/mi that requires a cold temperature test at -7°C [2]. However, in many parts of the world, extremely cold weather temperatures go below this limit value. This study quantifies the effect of cold weather on exhaust air emissions with a focus on light-duty vehicles for urban passenger transport. Using the City of Edmonton, Canada, as a case study, link-level traffic activity data, meteorological observations, and temperature-dependent emission factors were combined in a bottom-up emission inventory model based on U.S. EPA's MOVES. Technology- and model-year-specific emission rate multipliers were applied to account for differences between gasoline port fuel injection (PFI) and gasoline direct injection (GDI) vehicles and for changes associated with emission control standards.

Results show that cold-weather conditions increase running-exhaust emissions for vehicles prior to the Tier 3 regulatory era, with the magnitude of increase varying by pollutant and model-year. For PM2.5, average cold-to-baseline emission rate ratios are highest for pre-2008 vehicles (1.27) and remain elevated for cars produced between 2008 and 2016 (1.19). These results demonstrate that advances in emission control technologies have reduced both absolute emission rates and their sensitivity to cold ambient conditions for particulate matter, while older vehicles remain affected by winter operation.



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Direct radiative properties of modern European woodstove emissions: effect of photochemical aging and an electrostatic precipitator

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Residential wood combustion (RWC) is a major source of carbonaceous aerosols in Europe, yet large uncertainties remain in assessing the climate impacts of emissions from modern wood stoves. We investigated the physical, chemical, and optical properties of aerosols emitted from combustion of beech woodlogs in an air-staged chimney stove. Each experiment lasted for 4 hours and consisted of the burning of 6 batches of logwood. Fresh emissions were characterized with and without an electrostatic precipitator (ESP, Oekotube). In addition, emitted aerosols were photochemically aged using an oxidation flow reactor (PEAR) under two different OH exposures corresponding to equivalent aging upto ~1.4 (short aging) and ~3 (medium aging) atmospheric days.

Emissions of CO_2, CO and major non-methane VOCs were monitored using an online Fourier-Transform Infra-Red spectrophotometer (FTIR). The temporal evolution of CO_2 and CO was used to calculate time series of modified combustion efficiency, as well as to define distinct combustion phases, namely ignition, flaming and residual char burning [1].Light absorption (β_{abs}) and scattering coefficients (β_{sca}) of fresh and aged aerosols were measured using a multi-wavelength aethalometer (AE33) and integrating nephelometer, respectively. Equivalent black carbon (eBC) concentration and fraction of total light absorption by brown carbon (BrC) were also estimated from AE33. Chemical composition of organic (OA) and inorganic aerosol were estimated by an aerosol mass spectrometer. Timeseries of aerosol particle size distributions were measured by a scanning mobility particle sizer (SMPS), as well as an electrical low-pressure impactor (ELPI). Finally, Simple forcing efficiency (SFE, W g^{-1}) of fresh and aged aerosols over both average global terrain and fresh snow surface were estimated as per previous literature [2] using albedo values of 0.19 and 0.8 respectively.

Fresh emissions were dominated by soot-rich particles with low single scattering albedo (SSA) and high mass absorption coefficients (MAC), particularly during flaming combustion phases. We also observed presence of dark BrC (or strongly absorptive BrC) in emissions from flaming combustions. The ESP reduced overall OA and eBC emissions respectively by approximately 80% and 69%, but altered particle size distributions and increased mean volume diameter (VMD) of fresh emissions due to size and particle composition dependent collection efficiency. As a result, fresh RWC emission was more soot-rich yet relatively more scattering (with 44% higher SSA_{550}) in presence of ESP. Photochemical aging led to substantial secondary organic aerosol (SOA) formation, increasing OA/eBC ratios as well as VMD, due to condensation of SOA. As a result, we observed enhanced β_{sca} and reduced β_{abs} in aged emissions compared to fresh emissions. Consequently, short and medium aging decreased SFE estimated over average global terrain by 39% and 43% respectively, compared to that of fresh RWC emission (96.3±88.3 W g^{-1}). However, estimated SFE values were still positive even after aging, suggesting significant warming potential of RWC emitted particles from modern woodstoves.

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Session 5: Ambient air, biomass burning and wildfires, environmental impacts, Talk

Spatiotemporal modelling of ambient concentration of ultrafine particles in Switzerland

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Keywords: Ultrafine particles, air pollution, spatiotemporal modelling, particle number concentration, random forest

Introduction

Despite mechanistic evidence from toxicological studies, large-scale epidemiological evidence for health effects of ultrafine particles (UFP) remains limited due to sparse monitoring. UFP exhibit large spatial and temporal contrasts, and while several spatial models have been published, few so far incorporate temporal variability. Within the framework of the MARKOPOLO ("Markers of Pollution") project , we aimed to develop a national, three-season, high-resolution (daily, 25x25m) spatiotemporal model which can be harnessed to estimate exposure for cohorts across Switzerland.

Methods

The project is conducting UFP measurements in Switzerland with national coverage between June 2025 and April 2026 using a mobile platform, visiting all major cities, many smaller towns and a selection of minor villages, balancing population coverage and capturing the full range of concentration contrasts. Ultrafine particle number concentration (PNC) was measured using an EPC 3787 at 1-second intervals , alongside co-pollutants (PM2.5, NO□, black carbon), GPS position, temperature and relative humidity. Random forest models were developed to predict logged PNC using spatial and temporal environmental predictors such as altitude, meteorology, land-use and road type data.

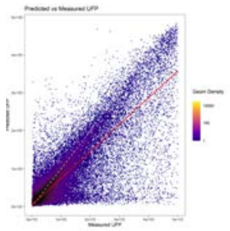

Figure 1

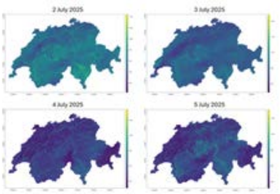

Figure 2

Figure 1: Measured versus predicted UFP number concentration. The dashed line indicates the 1:1 ratio. The red line indicates a slight typical underestimation of the model as compared to measured concentrations. This is due to scatter on the lower right end of the graph, which results from high-exposure outliers on roads. These are challenging to predict due to highly specific local or temporary emissions or conditions, which are not captured by any of the predictors.

Figure 2: Swiss-wide prediction of UFP number concentration across Switzerland on 4 consecutive days in July 2025. Concentrations are shown as the log(ultrafine paricle number concentration [#particles/cm3]). Predicted concentrations range roughly between e8 ≈ 2980 particles/m3 and e12 ≈ 163000 particles/m3.

Results

During the summer measurement period (16 June – 4 August 2025), 50 days and 5115km of data captured on Swiss roads yielded a median level of 7700 particles/m3 [interquartile range 5800-8500 particles/m3]. We measured within 100m of the homes of 4.5% of the Swiss population. The performance of our preliminary Swisswide model yielded an overall R2 of 0.90 (Figure 1). Road length of motorways and traffic intensity in buffers of 100-500m and weather-related variables (temperature, humidity) were the most important predictors. Example predictions for four consecutive summer days are shown in Figure 2.

Conclusion

We provide some of the first spatiotemporal national concentration models for ultrafine PNC, allowing timevarying exposure assessment for health studies.

Session 5: Ambient air, biomass burning and wildfires, environmental impacts, Talk

How coating pathway controls light absorption by black carbon

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class="MsoNormal" style="text-align: justify;">Black carbon (BC) aerosols are among the most important climate-forcing agents in the Earth's atmosphere, yet the interaction of light with individual BC cores and their coating remains actively debated [1]. After emission, BC particles rapidly mix with non- or weakly-absorbing material through condensation and coagulation, altering their morphology, radiative properties, and atmospheric lifetime [2]. However, the impact of these distinct coating pathways is difficult to disentangle in ambient observations.

Here, we independently investigate condensation- and coagulation-driven coating mechanisms using controlled laboratory experiments combined with numerical optical modeling. Two custom-built aerosol chambers are used to generate mixed BC particles by coating soot with an atmospheric liquid surrogate via either evaporation–condensation or coagulation with oppositely charged droplets. The resulting particles are characterized in real time in terms of size, mass, and wavelength-dependent optical absorption. In parallel, single-particle optical properties are simulated using the discrete dipole approximation and multi-sphere T-matrix methods.

We find that the coating pathway governs particle morphology and, consequently, optical absorption. Condensation leads to encapsulated, near-spherical BC particles, whereas coagulation produces irregularly-shaped aggregates. The mass absorption cross-section (MAC) of condensed BC increases systematically with coating mass at 405, 532, and 781 nm, with stronger enhancement at shorter wavelengths (e.g., $\mathrm{MAC_{405\,nm}} = 13.9\ \mathrm{m^2g^{-1}}$ at a mass ratio of 4). In contrast, the MAC of coagulated BC remains largely insensitive to coating amount and only slightly exceeds that of fresh BC (e.g., $\mathrm{MAC_{405\,nm}} = 12.1\ \mathrm{m^2g^{-1}}$ at a mass ratio of 4). Consequently, even lightly condensed BC exhibits higher absorption than coagulated BC, a trend consistently reproduced in optical simulations.

These results demonstrate that coating morphology, rather than coating mass alone, controls BC absorption enhancement. Accounting for coating-dependent shape and mixing state can help reconcile discrepancies in field-derived absorption enhancements and reduce uncertainties in BC representation in regional and global climate models.

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Transient formation of organic gaseous emissions in residential wood combustion with and without an electrostatic precipitator

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Residential wood combustion can be a major source of atmospheric organic aerosols emitted in both gaseous and particle phases. In this work, we aimed to resolve the temporal behavior of the gaseous organic emissions and determine the impacts of an electrostatic precipitator (ESP) on their release. Batches of beech logs were combusted in an air-staged chimney stove (6 batches per 4 h experiment). For half of the experiments, an OekoTube (Oekosolve) ‘electrostatic precipitator inside’ -unit was installed in the flue gas stack (n=4 with ESP off, n=4 with ESP on). Volatile organics were monitored by a proton transfer reactor - time of flight - mass spectrometer (PTR-ToF 8000, Ionicon) alongside extensive particle phase measurements.

The organic gaseous emissions were at their highest during batch ignition. As the combustion progressed to flaming conditions and the combustion temperature increased, organic gases were effectively oxidized in the flame, leading to pyrosynthesis of the organics and increase in the particulate emissions [1]. Slower ignition in the cold stove during the first batch led to a distinctly different emission profile compared to the later batches. The total organic gaseous emissions increased again for the later (fourth to sixth) batches, likely due to the faster combustion rate driven by the increased temperature.

Five distinct factors were resolved from the mass spectra time series by non-negative matrix factorization (NMF). Ignition phases were linked to two factors: one prominent for the cold ignition of first batch (dominated by acetic acid), one for the high temperature ignition of later batches (dominated by benzene). A factor comprised dominantly of nitromethane was linked with the flaming phase and correlated best with the particulate brown carbon emissions. The fourth factor may be linked to direct cellulose depolymerization products, as it contained the furan emissions. The fifth factor contained both polycyclic aromatic hydrocarbons (PAHs) and oxidized aromatics. In contrast to the other factors, its concentration grew towards the end of each batch.

The overall emission profile was similar with or without the ESP. However, the emission factors of PAHs and oxygenated polycyclic compounds (o-PAHs) were statistically significantly higher with the ESP on for all the combustion phases, with batchwise enhancement ratios of 1.8 and 1.5 for PAHs and o-PAHs, respectively. The increase was most prominent towards the end of combustion (‘ember phase’), when the ESP reduced particulate emissions especially efficiently [1], and likely caused by the decreased adsorption of polycyclic compounds onto particle phase when particle emissions were reduced.

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Session 5: Ambient air, biomass burning and wildfires, environmental impacts, Talk

Dynamics of urban particle number size distributions in Stockholm, Sweden

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Air pollution has a strong impact on human health [1]. Although growing scientific evidence shows that the smallest particles — so-called ultrafine particles (UFP)—are especially harmful to human health, it is mainly the coarse particle fractions (PM_{10} and $PM_{2.5}$) that are regularly measured against standards and reported in cities worldwide. As a consequence, data about UFP in urban environments is still very limited.

The Environment and Health Administration of the City of Stockholm has measured UFP in the urban background and in street canyons since 2002, and the time-series of particle number concentration (PNC) for Stockholm can now be considered one of the longest in Europe. Complementary measurements of the particle number size distributions (PNSD) have been conducted using a Differential Mobility Particle Sizer (DMPS) over certain periods and in different environments, in collaboration with Stockholm University. The dynamics observed in the urban PNSD is subject to continued analysis efforts [2].

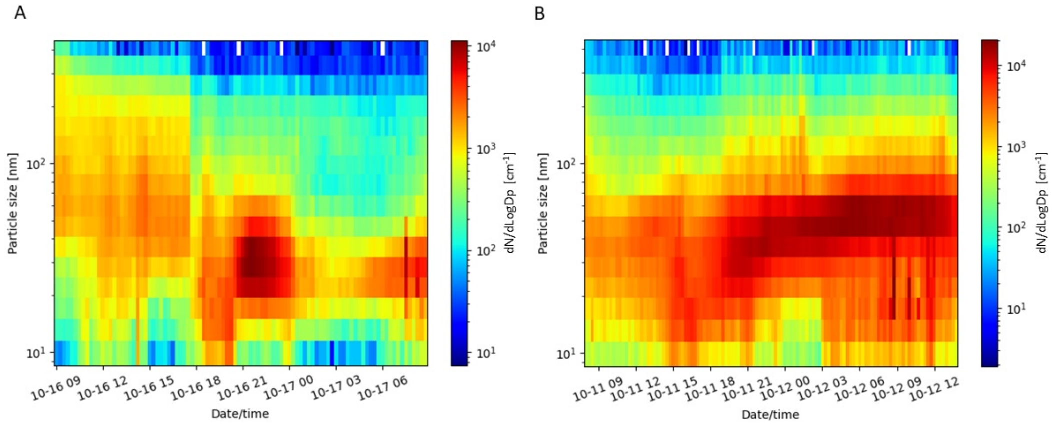

Figure: Scavenging (A) and particle growth (B) events in the urban background of Stockholm, Sweden.

In the present work, we focus on the impact of different meteorological parameters from co-located measurements, particularly precipitation, on the PNSD in the urban background in Stockholm, Sweden to better understand its dynamics. These results will help to disentangle factors impacting the PNSD variability.

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Session 5: Ambient air, biomass burning and wildfires, environmental impacts, Talk

An equation describing the wavelength-dependence of brown-carbon light absorption at all wavelengths

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Natural carbonaceous particles from combustion can possess a range of light-absorbing properties, ranging from black soot to brown organics (the “brown-black continuum”). This light absorption is often described in terms of the absorption Angstrom exponent (AAE) power law: the negative slope of a log-log plot of light absorption versus wavelength. Black carbon has a fixed AAE of ≈1.0 at all wavelengths. However, different values of AAE for brown carbon are observed at different wavelengths (Moosmuller et al., 2011). This wavelength-dependent AAE is predicted by the Tauc model (Sun et al., 2007), which employs two theoretical parameters first derived for semiconductor materials. Here, we reformulate this Tauc model using easily measured aerosol properties: mass-specific light absorption (MAC) and AAE. An equation is provided to extrapolate the MAC and AAE at any arbitrary wavelength, given these properties at a reference wavelength in the visible. Notably, using the black-carbon MAC and AAE as reference accurately describes the available literature data, including soot, pyrolyzed carbon, char, and biomass-burning tarballs. Future work might apply this framework to quantify the spectrally integrated light absorption of brown carbon from unknown atmospheric samples.

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Characterization of a novel, mid-cost device for ambient monitoring of ultrafine particles

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Despite the potentially significant health impacts of ultrafine particles (UFP), they are not routinely measured at air quality monitoring stations. One barrier to routine monitoring of UFP is the relatively high cost and complexity of measuring solid and total particle number (sPN & tPN) down to 10 nm as is required by the new European Air Quality directive. Furthermore, ambient monitoring of the same metrics used for tailpipe emissions would allow stakeholders to better assess the effectiveness of emissions regulations and health impacts of such particles. To address this, a novel, mid-cost device for measuring UFPs down to 10 nm is characterized here.

The AirPN10 from nanoDUST GmbH measures particle number (PN) with a diffusion charging (DC) based particle counter, already approved for measuring particle number (PN) in diesel exhaust, adapted for ambient monitoring. The sample aerosol passes through a series of preconditioning steps before reaching the detector. This includes a stage with a high temperature zone to remove volatiles such that the sPN can be measured. A switch is used to by-pass the high temperature zone periodically such that sPN and tPN are monitored providing some information on particle composition. In addition, the two-stage DC sensor allows for the geometric mean mobility diameter (GMD_{mob}) of the particles to be estimated. The device was tested with polydisperse soot particles from a 5201 Type BC miniCAST soot generator. This generator produces particles with a very low volatile content, therefore, sPN and tPN were equal within the measurement variability. Various size distributions were used with GMD_{mob} of 10, 15, 23, 50, 80, 120 and 200 nm to span the operating range of the devices (10 to 200 nm). The counting efficiency (CE) of the AirPN10 was assessed by comparing the sPN and tPN values to that measured by a Condensation Particle Counter (CPC; TSI 3752). The results were in excellent agreement for aerosols with GMD_{mob} from 15 – 120 nm at concentrations above approximately 5000 cm^{-3}, with higher variability at very low concentrations (ca. 1000 cm^{-3}). At 10 and 200 nm, the CE was slightly reduced but the device was still able to detect these particles at CE of approximately 0.5 and 0.7, respectively. The GMD_{mob} was in excellent agreement with that measured by a Scanning Mobility Particle Spectrometer (SMPS; TSI 3752 and 3082) except at 200 nm where the size was slightly overestimated (ca. 10% overestimation).

Ensuring the comparability of nanoparticle measurements by the international metrology community

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The international comparability of measurements is underpinned by the Mutual Recognition Arrangement of the International Committee for Weights and Measures (the CIPM MRA). This is the framework through which National Metrology Institutes (NMIs) demonstrate the global equivalence of their measurement standards at the highest metrological level. A crucial activity in supporting the CPIM MRA is the delivery of formal comparison exercises between NMIs and, where appropriate, Designated Institutes (DIs) and other reference laboratories.

In November 2024, ten laboratories participated in the experimental campaign for the CCQM-K185/P237 comparison at PTB-Braunschweig, Germany. The laboratories (which cannot all be named here to a limit on the number of co-authors) were: NPL (UK), PTB (Germany), KRISS (Korea), METAS (Switzerland), NIM (China), A*STAR (Singapore), NMIJ (Japan), NRC (Canada), UBA (Germany) and TROPOS (Germany). The comparison, which was coordinated by NPL, required the participating laboratories to measure all or some of:

- Particle number concentration of 30 and 50 nm monodisperse soot at six number concentrations from 1 000 to 100 000 cm^{-3} using condensation particle counters (CPCs).
- Particle charge concentration of 30 and 50 nm monodisperse soot at six charge concentrations between 0.16 and 16.0 fC cm^{-3} using aerosol electrometers.
- Particle number concentration of 80 nm polydisperse soot at four number concentrations from 1 000 to 100 000 cm^{-3} using CPCs.

Here, we briefly outline the role of the CIPM MRA in ensuring international comparability before presenting the results from the CCQM-K185/P237 comparison, which covered a much wider range of concentrations than previous such comparisons (most recently [1]). By comparing the results from CCQM-K185/P237 against those from these earlier comparisons, we highlight the strides that the NMI community has made in advancing nanoparticle measurements since the first nanoparticles comparison nearly 20 years ago. We also identify some key remaining challenges revealed by the results of the comparison, including the need to improve and harmonise the use of dilution devices, which if addressed will further improve comparability in the future.

Finally, we describe the ongoing activities of an international Aerosol Metrology Task Group, which was established in 2024 to bring the NMI/DI nanoparticle community closer together and deliver improved and coordinated engagement with the global aerosol science stakeholder community. In addition to delivering comparisons, the Task Group is harmonising the terminology and nomenclature used in aerosol metrology, undertaking stakeholder engagement activities and developing a research roadmap for aerosol metrology.

[1] A. Brown *et al.*, NPL Report ENV 46, International Comparison CCQM-K150, Particle number concentration (100 to 20 000 cm^{-3}) and particle charge concentration (0.15 to 3 fC cm^{-3}).

Dynamic chemical evolution of incipient soot. An FT-IRC MS-based investigation

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In flame combustion, the inception of carbon nanoparticles is believed to be primarily driven by kinetics. However, experimental data on the concentration of species in the gas phase seem to challenge this view. While accurate knowledge of the chemical composition of incipient soot is essential for resolving this ongoing debate, measuring the properties of transient species in a reactive medium at high temperature remains extremely challenging.

The accurate determination of structure and concentration of transient species with minimum interference of the sampling process is possible by means of inline molecular beam synchrotron-based diagnostics. However, the complexity of this approach makes it feasible only for a few selected species. To capture the ensemble of the species generated during the nanoparticle inception process, ex situ mass spectrometry-based diagnostics are often employed. In this work, the chemical composition of incipient soot is investigated on a laminar premixed ethylene/air flame with unprecedented detail by means of a Solarix XR Fourier Transform Ion Cyclotron Resonance Mass Spectrometer having > 10 M nominal resolving power.

The advanced methodology proposed in this work reveals at least three distinct types of hydrocarbons in incipient nanoparticles, providing new molecular-level insights into the inception process. The findings indicate that, as the incipient nanoparticles evolve, dynamic interactions establish among oxygenated hydrocarbons, closed-shell polycyclic aromatic hydrocarbons, and hydrocarbons capable of undergoing easy dehydrogenation that may generate species such as resonance stabilized radicals. These findings will contribute to elucidate the fundamental mechanisms of carbon nanoparticles inception, and assist in the development of more accurate prediction models.

Session 6: Nanoparticles: instrumentation, metrology, fundamentals, Talk

Laboratory Intercomparison in Germany: Calibration of particle counters for the national periodical technical inspection

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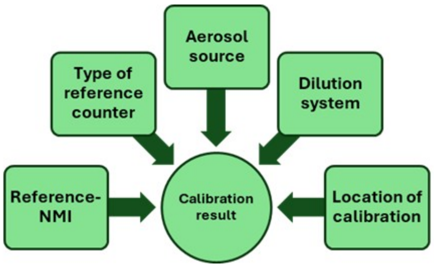
The measuring of the particle number concentration has been mandatory in Germany since 2023 for all diesel vehicles from emission class 6/VI as part of the national periodical technical inspection (PTI). The metrologically traceable calibration of these particle counters is a fundamental requirement for the comparability of PTI measurements on diesel vehicles and thus for the evaluation of the function of the installed diesel particulate filter.

The annual calibration of PTI particle counters is legally required in Germany and is carried out by independent calibration laboratories. The laboratories require accreditation from the German Accreditation Body (DAkkS) in accordance with ISO 17025 [1]. They must fulfil the German calibration guideline [2], which forms the framework and basic requirements for standardized calibration. More than 35 000 calibrations of particle counters are carried out in Germany per year.

Nevertheless, laboratories have freedom in the design of the calibration, such as in the selection of the calibration aerosol, the reference devices or the traceability chain. They may carry out calibrations both in the permanent or mobile laboratory and in the workshops on site. Some calibration laboratories form a further internal traceability level by calibrating other working standards with an externally calibrated reference standard (e.g. from an NMI). Depending on the procedure and traceability, the calibration laboratories calculate individual measurement uncertainties for their calibrations according to the Guide to the expression of uncertainty in measurement, GUM [3]. As part of the accreditation assessments, the achievable measurement uncertainties are confirmed by independent assessors.

The organization and responsibility for verification of particle counters in the field in Germany differs from that provided in the EU Recommendation [4]. It is mainly due to the large number of calibrations and is based on the established system of accreditation.

With the aim of evaluating the comparability of the different calibration procedures of AU particle counters, PTB has been carrying out a laboratory intercomparison in cooperation with the ASA Association (German Association of Manufacturers and Importers of Automotive Service Equipment) since October 2025. Twelve calibration laboratories and PTB as the pilot laboratory are taking part in the comparison measurement. Each laboratory calibrates a total of 5 measuring instruments of different manufacturers and types, according to their respective calibration procedures and with the individual accredited measurement uncertainty. The measurements will run from October 2025 to March 2026.



Ideally, the aim of the intercomparison is to confirm that the calibration results of the individual laboratories agree within the scope of their accredited measurement uncertainty. Potential systematic deviations will be identified from the results and recommendations for the further development of calibration procedures will be developed.

The first results of the intercomparison are expected in April / May 2026. They will be published in anonymized form.

The comparative measurement will contribute to the harmonization of calibrations and to improving the traceability of the particle number concentration for the periodic emissions test on diesel vehicles in the second and third traceability stage.

[1] DIN EN ISO/IEC 17025:2018-03 General requirements for the competence of testing and calibration laboratories

[2] Richtlinie zur Kalibrierung von Abgasmessgeräten, die für die Untersuchung der Abgase von Kraftfahrzeugen nach Nummer 6.8.2 der Anlage Vllla STVZO eingesetzt werden („AU-Geräte Kalibrierrichtlinie"), Verkehrsblatt 2021 Heft 11, Nr. 133, geändert durch Verkehrsblatt 2024 Heft 17, Nr. 118

[3] JCGM GUM-1:2023, Guide to the expression of uncertainty in measurement

[4] Commission Recommendation (EU) 2023/688 of 20 March 2023 on particle number measurement for the periodic technical inspection of vehicles equipped with compression ignition engines, (OJ L 90, 28.3.2023, p. 46)

NO-Triggered RO-Mediated Propagation in the OH Oxidation of a Saturated Cyclic Alkane

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Highly oxygenated organic molecules (HOMs) formed during gas-phase oxidation of volatile organic compounds play a key role in secondary organic aerosol (SOA) formation and particle growth. While HOM formation is commonly attributed to rapid unimolecular autoxidation of peroxy radicals (RO_2), this mechanism is often kinetically constrained in saturated hydrocarbons, particularly on short atmospheric timescales. In this work, we investigate the early-stage OH-initiated oxidation of cis-decalin, a representative bicyclic anthropogenic alkane, under controlled laboratory conditions to elucidate how radical propagation proceeds when unimolecular RO_2 isomerization is slow.

Experiments were conducted in a quartz flow-tube reactor at ambient temperature and pressure with residence times between 0.9 and 2.9 seconds. Oxidation products were characterized using a high-resolution Orbitrap mass spectrometer coupled to a multi-scheme chemical ionization inlet employing bromide and nitrate reagent ions. This dual-ionization approach enabled simultaneous detection of early-generation oxidation products and highly oxygenated species, including accretion products.

In the absence of NO, cis-decalin oxidation produced only minimal levels of oxygenated products within the studied timescale, indicating that OH initiation alone is insufficient to sustain multigenerational oxidation. In contrast, the introduction of NO led to a pronounced enhancement in oxidation, marked by the rapid appearance of highly oxygenated monomers containing up to ten oxygen atoms as well as C_{20} accretion products at longer residence times. Product distributions exhibited a strong, non-linear dependence on NO concentration, with maximum oxidation observed at moderate NO levels and suppression under high-NO conditions.

These observations demonstrate that NO promotes oxidation not merely through termination but by converting RO_2 to alkoxy radicals (RO), thereby enabling RO-mediated structural rearrangement, ring opening, and subsequent O□ addition. This bimolecular radical cycling bypasses kinetic limitations associated with slow RO_2 H-shifts and allows efficient propagation of oxidation on second timescales. The results reveal that saturated cyclic alkanes can rapidly form low-volatility, multifunctional products under polluted conditions when RO-mediated propagation is active.

Overall, this study highlights the critical role of bimolecular radical chemistry in controlling HOM formation from anthropogenic hydrocarbons and provides new mechanistic insight into SOA formation pathways in combustion-influenced and urban atmospheres.

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DfT Brake & Tyre Programme Phase 2: Impact of Regenerative Braking and Vehicle Mass on Brake Particle Emissions Across ICE, PHEV & EV Platforms

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Brake and tyre wear are now major contributors to non-exhaust particulate emissions, including PM10, PM2.5, and PN10, which are increasingly relevant for air quality and Euro 7 regulations. This study, part of the UK Department for Transport's Brake and Tyre Programme Phase 2, investigates the influence of regenerative braking and vehicle mass on brake particle emissions from internal combustion engine (ICE), plug-in hybrid (PHEV), and battery electric vehicles (EV). Using a controlled chassis dynamometer environment and common brake hardware across vehicles, emissions were measured under representative drive cycles (PG42 and RDE) at test masses ranging from 1500 kg to 1900 kg. Results show that regenerative braking significantly reduces PM2.5 and PM10 emissions compared to friction-only braking, with EV and PHEV outperforming ICE vehicles even at lighter masses. Conversely, PN10 emissions exhibited minimal sensitivity to either regenerative braking or mass changes, indicating dominance of non-volatile particle sources. The findings suggest that regenerative braking delivers a greater benefit for PM reduction than a ~20% reduction in vehicle mass, primarily through lower brake temperatures and reduced volatile material loss. These insights support the development of effective mitigation strategies and emissions factors for future brake emissions controls.

Non-Exhaust Emissions from Brakes: Comparative Assessment of Physico-Chemical Properties in Nanometric and Micrometric Particulates

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Results from literature review show that specific studies on nanometric particles generated by automotive brakes are extremely limited. Therefore, this contribution focuses on: i) the generation and the physico-chemical properties of nanometric brakes emissions; ii) the correlation of their composition with the materials composing the origin friction pair; and iii) the assessment on eventual compositional differences between nanoparticulates and corresponding coarser particulates. Five different automotive brakes friction pairs are tested following standard procedures for emission assessment of disc brake systems. Nano-particulates are collected and weighed to determine corresponding concentration ranges of 0.0005 and 0.0026 mg m^{-3} at a flow rate of 400 m^3/h. Several analytical techniques are deployed to investigate the physico-chemical characteristics of the collected particulates, including scanning electron microscopy, energy dispersive spectroscopy, mass spectroscopy gas chromatography and X-ray absorption spectroscopy. Main results of this study highlight significant differences in the physico-chemical composition of nanometric particulates compared to coarser ones. Clear increase in carbon content is identified when decreasing particle size distribution. Conversely, the amount of iron decreases in finer particulates, while its oxidation level increases. In addition, several Cr, Cu and Zn compounds are identified in investigated particulates, such as chromite, tenorite and zincite. Finally, for nanoparticulate emissions the polycyclic aromatic hydrocarbons (PAHs) concentrations vary largely ranging from 74 - 1460 µg g^{-1} and the oxygenated polycyclic aromatic hydrocarbons (OPAH) concentrations ranges from 8 to 110 µg g^{-1}. Comparatively, lower PAHs and OPAHs values are measured in particulates from coarser fractions.

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Nanoparticle generation potential of summer and winter tyres at varying ambient temperatures

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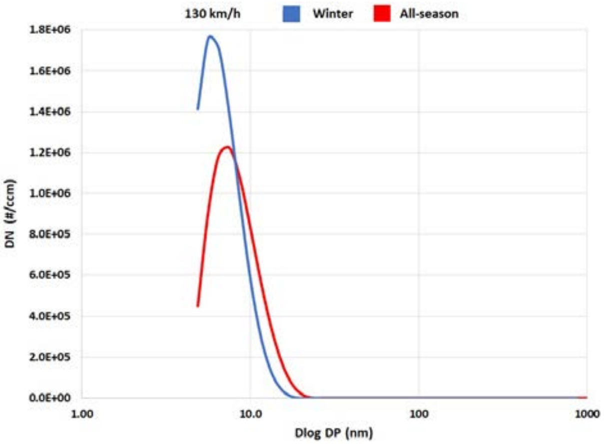
Automotive non-exhaust emissions, such as brake- and tyre wear are of rising interest, since they will be regulated for the first time with the EURO 7 regulation. While the majority of the particle mass of these abrasion derived particles is between 1 and 10 µm, a considerable percentage of the particle number is also generated in the nanoparticle range [1]. These particles can penetrate deep into the lungs, where they deposit in the alveoli and eventually reach the bloodstream via the blood-air barrier [2]. In this study particles generated from summer and winter and all-season tyres measured on a newly developed custom-built dynamometer, which is depicted in figure 1 were characterized.

All tyre types were measured at ambient dynamometer temperatures of 12°C and 23°C and a large change in emitted particle numbers (PN) was observed when changing to warmer temperatures. The large increase in PN was revealed to be in the nanometer size range, which was confirmed simultaneously by a DMS500 and a SMPS. Besides ambient temperatures, the tyres composition played a key role in the nanometer generation potential, with softer winter tyres emitting significantly more nanoparticles than summer tyres. The origin of the emitted nanoparticles was investigated to develop potential mitigation strategies for future policies. Average size distributions of the winter and all-season tyre at 23°C and a steady speed of 130 km/h as measured with the DMS500 are plotted in figure 2.



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[2] G. Bachler et al., Particle and Fibre Toxicology, 2015, 12(1), 18.

Chemical Origin of Tyre Nanoparticles in a Tube Furnace

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Since the 1970s, it has been hypothesised that airborne nanoparticles from tyre wear originate from heat-driven evaporation and condensation of an unidentified tyre component. Tyre extender oil has long been suspected as a source. Here, we revisit this hypothesis and provide a mechanistic characterisation of tyre nanoparticles generated from cryomilled tyre tread under controlled thermal conditions in a tube furnace. Removal of extractable components such as extender oil substantially reduced nanoparticle formation. These results suggest that volatile organic additives, rather than the rubber itself, are the primary source of the tyre nanoparticles in our study. Experiments with tyre extender oil confirmed its ability to emit ultrafine particles when heated to similar temperatures. Nanoparticles collected from both tyre tread and extender oil were chemically characterised using NMR spectroscopy and found to consist predominantly of saturated hydrocarbons, closely matching the pristine extender oil. These findings provide the first experimental confirmation linking tyre nanoparticle chemistry to tyre extender oil, offering a mechanistic basis to interpret tyre nanoparticle emissions and support risk assessments.

Session 8: Break wear and Tyre wear, Talk

Michelin's latest results on quantification of airborne Tire Road Wear Particules, from vehicule usage to micro

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[1]MICHELIN Research center

Michelin works since decades to reduce all the environmental impacts of its products, and Tire Road Wear Particles (TRWP) are one of the impacts of tires, intensively studied in our research center. Over almost a decade of research, we have delved ever deeper into this subject, from the nano and micro-scales of these particles to their transport.

This presentation explores the significance of TRWP emissions in the context of sustainable mobility and environmental impact, it will provide insights into the latest research methodologies of Michelin, aimed at accurately measuring TRWP airborne emissions.

Key discussions will include the factors influencing tire abrasion, such as driving style or tire design, highlighting how these elements interact to affect TRWP emission rates. Attendees will learn about cutting-edge analytical technologies being developed to improve the precision of airborne TRWP measurements, including advanced methodologies like Pyrolysis GC-MS. The presentation will also focus on the methodology developed by Michelin for TRWP analysis, the potential biases in this approach and the questions that remain open.

Conflict of interests : the authors declare that this research was funded by Manufacture Française des Pneumatiques Michelin, France

Airborne pathogen detection via MASC-On - Magnetic Antibody Sorting Coupled with flow Cytometry Online

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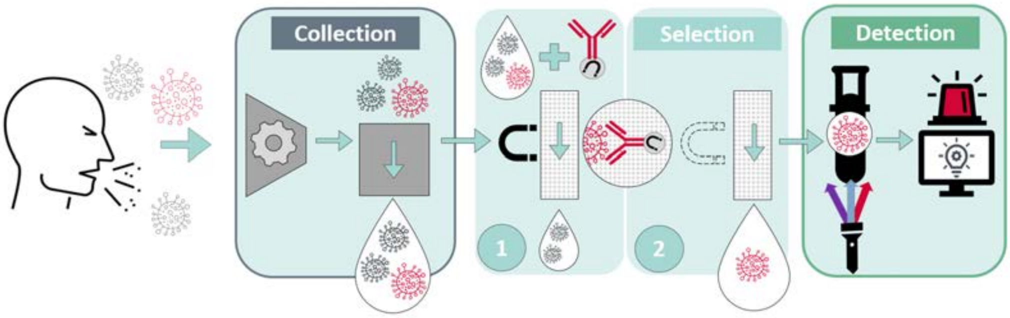
[1]University of Basel, Department of Environmental Science, Atmospheric Science Group



In light of the COVID-19 pandemic, airborne bioaerosol like bacteria and viruses are a major concern for human health. Therefore, monitoring of the concentrations of these bioaerosols plays a vital role in understanding disease transmission. Rapid, automated, quantitative and specific bioaerosol monitoring would allow for continuous assessment of airborne virus and bacteria at hospitals and similar locations.

In this proof-of-concept study, we develop and characterise a continuous pathogenic bioaerosol sampler and detector. The set-up consists of three main parts. In a first step (Collection phase), the bioaerosol is sampled continuously via a particle into liquid sampler. This bioaerosol liquid flow is mixed with an immunoassay (Selection phase) and then quantified in a flow cytometer (Detection phase).

We have already successfully connected all three phases into one continuous, automated, and autonomous prototype for pathogenic bioaerosol monitoring. With a time resolution of 60 minutes (of which 15 are spent on sample acquisition) our instrument collects 99.5% of nebulized E. coli bacteria continuously. Flow cytometry results were confirmed with agar plate analyses. Plating can only account for colony forming units, while flow cytometry can count all labelled cells.

While other instruments for automated pathogen detection exist, these techniques lack either specificity, quantification, automation or time-resolution. This novel mix of methods attempts to combine all factors mentioned. Our next step is to optimize further and apply this method to airborne virus.

Session 9: Indoor particles and occupational exposure, Talk

Physiologically Realistic Simulation of DEHP Penetration in the Human Airways

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Introduction: Di(2-ethylhexyl) phthalate (DEHP) is one of the most prevalent indoor phthalates, primarily due to its widespread use as a plasticizer in industrial and consumer products. During inhalation, airborne particles can act as carriers, transporting DEHP into the respiratory tract and facilitating its deposition within the airway lining fluid. This study presents a three-dimensional computational framework to investigate the penetration of nano-scaled DEHP, following its dissolution from particulate matter, into the airway surface liquid (ASL) of the human airways under physiologically realistic conditions, incorporating experimentally derived ciliary kinematics and mucus rheology. **Methods:** A hybrid immersed boundary–finite difference projection method is employed to discretize and solve the time-dependent governing equations for fluid flow, together with the convection–diffusion equation governing mass transfer within the tracheal ASL [1], accounting for the dissolution of particulate-bound DEHP into the ASL (Figure 1A). The immersed boundary framework enables accurate representation of cilia-driven fluid–structure interactions as well as DEHP–cilia interactions. Physiologically realistic ciliary properties are obtained from primary nasal epithelial cells derived from a healthy donor and cultured at the air-liquid-interface. Ciliary beat patterns are extracted from high-resolution microscopy images and incorporated into the computational model [2](Figure 1B). The mucus layer is modelled as a nonlinear viscoelastic fluid using a five-mode Giesekus constitutive model. Differential dynamic microscopy [3] is applied to quantify the frequency-dependent microrheological properties of mucus produced by epithelial cell cultures, providing experimentally derived inputs for the mucus rheology (Figure 1C and D). **Results:**The numerical simulations yield time-resolved, three-dimensional concentration fields of DEHP within the human ASL. This study presents, for the first time, a physiologically realistic numerical framework that simultaneously incorporates experimentally measured ciliary beat patterns obtained from high-resolution microscopy and mucus viscoelastic properties derived from differential dynamic microscopy. The results provide detailed insight into the spatiotemporal distribution of DEHP in healthy airways, accounting for the coupled effects of mucociliary clearance and particle–cilia interactions.

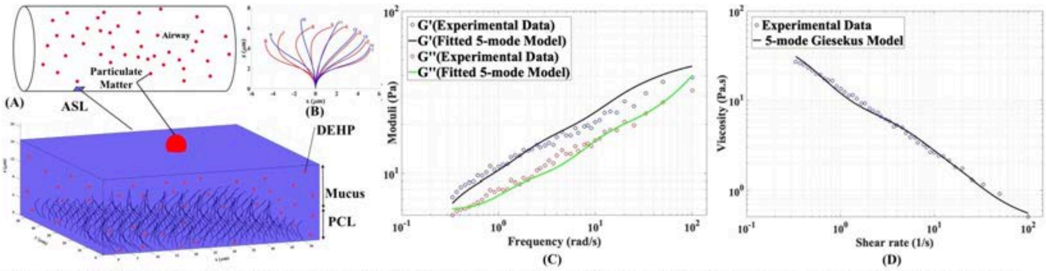

Figure 1. (A) Schematic of particulate matter transport in the airway, particle dissolution into DEHP, and subsequent penetration into the ASL.
(B) Computer-generated ciliary configurations at 14 time steps; blue and red indicate effective and recovery strokes, respectively.
(C) Experimental measurements and 5-mode model fits of the storage (G′) and loss (G″) moduli of mucus as functions of frequency.
(D) Mucus viscosity as a function of shear rate from experimental data (symbols) and the 5-mode Giesekus model (solid line).

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Lithium-ion battery thermal runaway particle emissions

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In recent years, the use of lithium-ion (Li-ion) batteries has seen significant growth, driven by their widespread application in electric vehicles and the broader energy transition. However, this increased use has brought to the forefront safety concerns, particularly regarding their susceptibility to thermal runaway. Thermal runaway is a violent chain reaction of exothermic chemical reactions resulting in an uncontrollable increase in system temperature, which can lead to a fire or explosion. Battery fires are known to pose significant environmental risks as they release aerosols and various toxic chemicals that can also adversely affect human health. Moreover, the methods used to extinguish these fires can alter the composition and nature of the emissions, further complicating the risks. For this study, Li-ion battery cells were triggered into thermal runaway via overcharging them. The battery cells were placed in a container and temperature and pressure were monitored throughout the experiment. The entire experiment was also monitored with cameras. Two experiments were performed where the battery fire was extinguished with water and with a chemical surfactant. Emission measurements were made for all experimental conditions, including fine particles collected onto filter media and real-time particle number and particle size distributions using a Dekati high-resolution ELPI+. PM chemical composition included the analysis of metals and trace elements with inductively coupled plasma mass spectrometry (ICP-MS), inorganic ions (lithium, ammonium, sodium, magnesium, potassium, calcium, fluoride, chloride, nitrate, sulfate, and phosphate) by ion chromatography, and polycyclic aromatic hydrocarbons (PAHs) by gas chromatography. Near-real-time metals were measured with a toxic metal aerosol analyzer (TARTA). The morphology and elemental composition of battery fire aerosols were analyzed by scanning electron microscopy (SEM) and energy-dispersive x-ray spectroscopy (EDS). The toxicological properties of PM were also measured by quantifying the oxidative stress, mutagenicity, and inflammatory markers.

Occupational diesel exhaust exposure assessment using miniaturized aerosol instruments – intercomparison of aerosol instruments in different workplace environments

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Occupational exposure to diesel exhaust is regulated by the European Union Directive 2004/37/EC due to its carcinogenic effects. Diesel exhaust exposure of underground mine workers has been reported in many recent studies, but it is not well quantified in other sectors. New miniaturized instruments, such as micro-aethalometers and ultrafine particle counters, are potentially useful for the assessment of occupational exposure to particles. In this study, occupational exposure of bus drivers, bus depot mechanics, street maintenance workers, construction workers and inspection station workers was measured. Diesel exhaust exposure of the workers was measured as elemental carbon (EC) according to NIOSH5040 method and as equivalent black carbon (eBC) using portable micro-aethalometers (MA200, Aethlabs), and the lung deposited surface area (LDSA) was measured using a nanoparticle detector (Partector 2 Pro, Naneos). Background air quality in workplace environments was measured, including measurements of eBC (aethalometers AE33 and AE36s, Magee Scientific) and LDSA (NSAM, TSI and ELPI, Dekati). In addition, an intercomparison of the instruments was conducted in a laboratory setting. The test aerosol was produced with a Combustion Aerosol Standard (CAST) soot generator (Matter Engineering AG) using propane as fuel. Data from the miniaturized instruments was compared to EC results, data from other above-mentioned instruments as well as a scanning mobility particle sizer (SMPS, TSI) that was used as a reference instrument for particle size, mass and number concentration. Diesel exhaust exposure was below the occupational exposure limits in all workplaces and was clearly lower than the exposure levels in underground mines measured by the same authors [1]. High momentary concentrations were observed particularly during bus maintenance works at the bus depot. LDSA and eBC measured in the ambient air of workplace environments correlated well, whereas the correlation in personal exposure measurements was less clear. Ångström exponent (AAE) values for most workers were below 1 which indicates that the primary source of the carbonaceous aerosol was vehicular exhaust. A few construction workers, street maintenance workers and mechanics had an AAE value 1.2 or higher, which might imply there are black carbon sources besides traffic or a higher coating of diesel soot particles by organic matter [2]. The eBC results obtained with microaethalometers and aethalometers agreed well, whereas the comparability of Partector to SMPS in terms of particle size, mass and number concentration and to ELPI in terms of LDSA wasn't as good. At low concentrations the EC/eBC correlation was weak, which should be considered when using aethalometers for assessing exposure to diesel soot. Overall, the diesel exhaust exposure levels of the workers were below the regulation limit, but high momentary exposure peaks related to specific work actitivities were identified. The correlation between LDSA and eBC indicates that black carbon plays an important role in exposure to fine particles in the studied workplaces. This work was supported by the Finnish Work Environment Fund (grant 240104), Mestar Kuopio Oy, Koiviston Auto Kuopio Oy and A-Katsastus Oy.

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Session 9: Indoor particles and occupational exposure, Talk

The MARKOPOLO Indoor/Outdoor project: Real-time assessment of residential ultrafine particle exposure indoors and outdoors

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Ultrafine particles (UFP, <100 nm) are of concern due to their ability to penetrate deep into the respiratory tract and translocate to other organs, leading to potential adverse health effects. As individuals spend much of their time indoors, accurate assessment of indoor UFP exposure is essential.

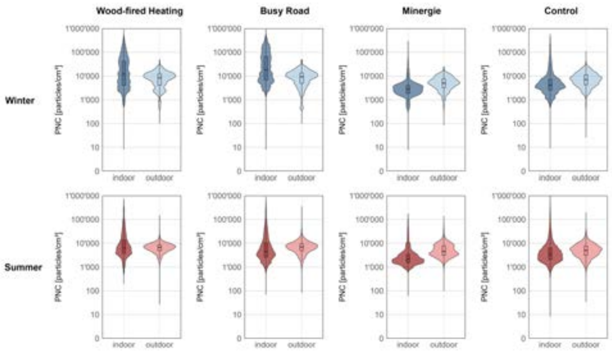
The MARKOPOLO ("Markers of Pollution") indoor/outdoor project investigates how outdoor concentrations, residential building characteristics and everyday occupant behaviour influence indoor UFP number concentrations (PNC) using real-time measurements. The study aims to include 60 Swiss households, each monitored during two one-week periods during the warm and cold seasons, capturing seasonal differences in behaviour, ventilation, and heating conditions. In each household, air quality sensors are installed both indoors and outdoors simultaneously, measuring PNC at a temporal resolution of 1 second, and $PM_{2.5}$, CO_2, temperature and relative humidity at 5-minute resolution. This captures short-term concentration peaks resulting from indoor behaviours and activities that would be obscured in daily or multi-hour averages. To link concentration dynamics with occupant activities, participating households complete a time-activity diary with 10-minute resolution, documenting activities known to influence indoor particle levels, such as cooking, candle burning, fireplace use, and window opening. So far, 35 households could be recruited in four categories: 11 residences with indoor fireplaces, 6 Minergie-certified buildings, 9 households located along heavily trafficked roads, and 13 control households, with 4 households belonging to two categories.

Data collection is still ongoing. Initial observations show pronounced short-term increases in indoor UFP concentrations associated with combustion-related activities, particularly cooking and candle burning. Outdoor PNC was significantly associated with indoor PNC, but indoor combustion-related activities, particularly woodburning, cooking and candle burning are more strongly associated with short-term increases in indoor PNC.

The study highlights the value of real-time measurements for accurately characterizing residential UFP exposure and the effects of building properties and occupant behaviour.

Figure 1: Particle number concentrations over time during summer and winter, with household activities logged below.

Figure 2: Distribution of measured indoor and outdoor ultrafine particle number concentrations (PNC) across residential categories during the winter and summer campaign.



Session 9: Indoor particles and occupational exposure, Talk

Underground Rail Air Quality: Determination of UFP and BC Concentrations in a Train Station and its Adjacent Tunnel

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Introduction: Recognized as a more environmentally friendly alternative to cars and airplanes, rail transport plays a crucial role in connecting Germany with other European countries, serving daily millions of passengers over a railway system of over 33,470 km [1]. Nonetheless, the growing evidence that train emissions also contribute to air pollution [2, 3, 4] has not yet been matched by extensive research, leaving this sector relatively unexplored compared to road transport. This work seeks to contribute to a deeper understanding of rail-related emissions, specifically focusing on UFP and BC.

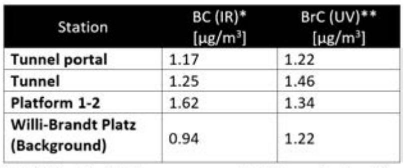
Methodology: From January to March 2024, air quality measurements were carried out at four strategic locations at the Berlin Airport Train Station: the platform, tunnel, tunnel portal, and an outdoor brackground site (shown in Figure 1). At each measurement station, the concentrations of PM10 and PM2.5 were determined gravimetrically via sequential samplers, the filters were later analyzed for Black Carbon and Brown Carbon (BC and BrC) using an non-destructive Optical Transmissometer. These time-averaged data were complemented by continuous monitoring of coarse/fine particles (light-scattering), UFP (diffusion charger), and BC (mini-aethalometers). Finally, meteorological data such as temperature, humidity, wind speed and direction was collected to assess how natural airflow and vehicle-induced turbulence governed pollutant dispersion within the tunnel.

Results: As shown in Table 1, BC levels near the railway tracks significantly exceeded ambient background concentrations. BrC levels, however, remained relatively stable across sites, confirming the absence of internal BrC sources and suggesting that indoor concentrations are primarily driven by external air exchange. The study period was further marked by two railway strikes and one airport strike, which allowed us to differentiate traffic-related emissions from regional background signals and filter out potential interference from neighboring air traffic. ***Evaluation of the continuous UFP and BC time-series is currently being finalized.***

Conclusions and Outlook: This study confirms that track-side BC levels significantly exceed background concentrations, driven by traffic and the piston effect. BrC stability suggests external infiltration rather than internal sources. Ongoing high-resolution analysis of UFP and BC time-series will further clarify these emission patterns and their impact on air quality.

Figure 1. Location of Measurement stations

Table 1. Average BC Concentration



Station	BC (IR)* [μg/m³]	BrC (UV)** [μg/m³]
Tunnel portal	1.17	1.22
Tunnel	1.25	1.46
Platform 1-2	1.62	1.34
Willi-Brandt Platz (Background)	0.94	1.22

* BC (IR) = Black Carbon measured at 880 nm (Infrared)
** BrC (UV) = Brown Carbon measured at 370 nm (Ultraviolet)

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Characteristics of Brake-Wear Particles and Chemical Speciation Profiles and Potential Health Effects of the Particles in California

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Brake-wear emissions have become the dominant source of directly emitted particles from motor vehicles, as tailpipe emissions have been substantially reduced in response to stringent tailpipe emissions standards in California. Understanding the characteristics of brake-wear particles, including particle number, size distributions, and mass, as well as their chemical speciation profiles, is a crucial step in understanding their potential adverse health effects. The presence of heavy metals in the particles is a concern for public health, particularly in communities near major urban arterials and highways.

The California Air Resources Board (CARB) has undertaken investigations to measure airborne brake-wear particles under brake-dynamometer testing conditions, characterize their chemical speciation profiles, and assess their potential health effects locally and regionally. Airborne brake-wear particles are generated during vehicle braking when shear forces increase between the friction material and the disk. CARB analysis revealed that the major inorganic contents of brake-wear particles from California light-duty and heavy-duty vehicles include iron (Fe), barium (Ba), copper (Cu), zinc (Zn), and titanium (Ti), while approximately half of the particles consisted of non-metallic components. The oxidative potentials of the particles collected near roadways were significantly greater than those collected in urban background areas, indicating that brake-wear particles may have a greater adverse health effect in near-road communities and populated urban areas.

Systematic review and meta-analysis on the health effects of long-term exposure to ultrafine particles

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BACKGROUND: Ultrafine particles (UFP; ≤100 nm diameter) may have a higher toxicity than larger particles but are still not regulated nor part of routine air pollution monitoring. So far, health effects of long-term exposure to ambient UFP are not well understood, due to a lack of exposure data and epidemiological studies.

METHOD: We conducted a systematic review and meta-analysis on the health effects of long-term exposure to UFP, including studies published until December 2024. Meta-analysis was conducted for outcomes with at least four available effect estimates. Confidence in the body of evidence was evaluated using the Office of Health Assessment and Translation (OHAT) method.

We identified 85 studies investigating various mortality, morbidity, and subclinical outcomes. In meta-analyses of single-pollutant models, we found positive associations with natural mortality (hazard ratio: 1.06 [95% confidence interval [CI]: 1.04; 1.08]) and C-reactive protein (10.14% increase [95% CI: -0.51; 21.99]), per 10,000 pt/cm^3 increase in long-term exposure to UFP, with low and inadequate levels of evidence, respectively. The remaining studies revealed overall limited evidence for adverse effects on a wide range of outcomes. Less than half of the studies adjusted for co-pollutants.

CONCLUSION: The evidence base on long-term health effects of UFP has increased substantially in the last decade, while the overall evidence for independent effects of long-term UFP exposure remains inadequate to low. More studies are needed to draw firm conclusions about the independent adverse effects of long-term UFP on various health endpoints, with a special focus on the influence of co-pollutant adjustment.

FUNDING: The project was financed by the German Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection and supervised by the German Environment Agency (FKZ 3721612020). The views in this article are those of the authors and do not necessarily reflect the views of the Health Effects Institute or its sponsors.

Non-Tailpipe Traffic Emissions and Airway Dysfunction: Evidence from a Real-World Crossover Study (IONA)

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Background: Non-exhaust traffic emissions from brake, tyre, and road wear are now major contributors to urban particulate matter (PM), yet remain unregulated and insufficiently characterised in terms of health effects. These mechanically generated particles are enriched in metals and contain fine and ultrafine fractions. We investigated whether source-resolved non-tailpipe particles induce airway dysfunction and immune activation in adults with asthma.

Methods:

In a randomised crossover study, 38 adults with mild-to-moderate asthma were exposed during intermittent exercise to three real-world London environments: a stop–go traffic site enriched in brake wear, a high-speed traffic site enriched in tyre/road wear, and an urban background control site. High-time-resolution aerosol chemical speciation (ACSM), X-ray fluorescence (Xact), and positive matrix factorisation were used to quantify $PM_{2.5}$ and PM_{10} mass and resolve source contributions, including brake wear, tyre/road wear, train wear, re-suspended dust, and long-range transport. Respiratory outcomes (FEV_1, FVC and Oscillometry indices), fractional exhaled nitric oxide (FeNO), and nasal lavage cytokines (IL-6 primary inflammatory endpoint) were measured pre-exposure, immediately post-exposure, and the day after the exposure. Nasal metals were quantified using ICP-MS as biomarkers of airway particle deposition.

Results:

Non-tailpipe–dominated exposures produced delayed impairments in lung function. Compared with the background site, FEV_1 declined by 140–220 mL at the day after the exposure ($p<0.05$), with parallel reductions in FVC. Tyre/road wear fractions were associated with next-day reductions in FEV_1 and FVC, while brake wear was associated with increased small airway resistance (R5–R20). PM_{10} and tyre/road wear were significantly associated with increased nasal IL-6.

Conclusions:

Short-term exposure to non-exhaust traffic particles leads to delayed airway dysfunction in adults with asthma. These findings highlight the emerging health relevance of nanoparticle-rich non-tailpipe emissions and the urgent need for regulatory frameworks addressing evolving urban PM sources.