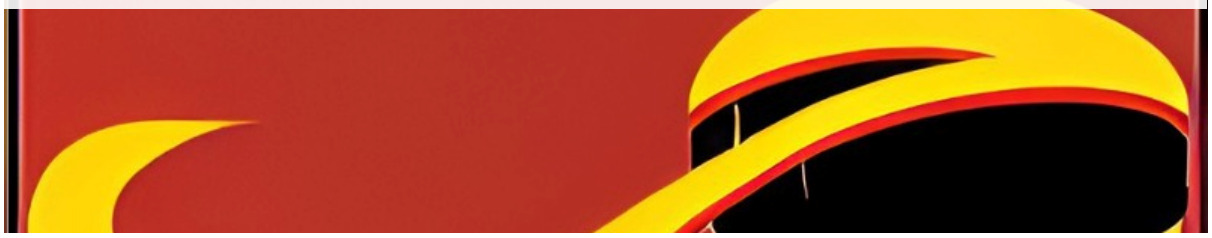
Air Quality in the 21st Century



9 December 2024 10:00-16:45, London, United Kingdom

Conference programme

10:00 Welcome and registrations (with tea, coffee & biscuits)
10:30 Introduction to the meeting

Session 1, The work of DEFRA's Air Quality Expert Group (Chair: Alastair Lewis)
10:35 James Allan (University of Manchester, NCAS): New opportunities for air pollution measurement: particulate matter
10:55 Alastair Lewis (University of York, NCAS): Air pollution arising from H_2 combustion
11:15 David Topping (University of Manchester): Integration and adoption of AI in air quality
11:35 Jo Barnes (University of the West of England): Differentials in UK air pollution emissions and concentrations
11:55 Sarah Moller (University of York, NCAS): Air Pollution horizon scanning
12:15 Open Discussion

12:40 Exhibitors flash talks
13:00 Lunch

Session 2, NO_x emissions and controls (Chair: Gary Fuller)
14:00 Lucy Webster (University of York): Evaluating the variability and consistency of NO_x emission regulation between sectors
14:15 David Carslaw (University of York, Ricardo): Review of the effectiveness of bus retrofit abatement strategy

Keynote Lecture
14:30 Anna Hansell (University of Leicester): Air quality and health in the 21st century

15:15 Poster Session and coffee

Session 3, Emerging sources and health effects (Chair: Valerio Ferracci)
15:45 Steven Turnock (Met Office): The Drivers of Change in the Historical Human Health Burden from Long-Term Exposure to Surface Ozone
16:00 Karn Vohra (University of Birmingham): Global health burden of ammonia emissions from fossil fuel derived synthetic nitrogen fertilizer use
16:15 Connor Barker (University College London): Air pollution and environmental impacts of megaconstellation satellite missions

16:30 Concluding Remarks
16:35 Close

Poster presentations

Amy McCarron (University of Stirling): *Forth Environmental Resilience Array (Forth-ERA): Developing an indoor-outdoor monitoring network for the Forth Valley Region*

Andrew Brown (National Physical Laboratory): *Implementation of a new value of the ozone absorption cross-section for measurements of ozone in ambient air (CCQM.O3.2019)*

Babak Jahanshahi (Queen's Business School): *Exposure to $PM_{2.5}$ and Mortality in Northern Ireland*

Beatriz Galindo-Prieto (Imperial College London): *Evaluating the impact of London's Ultra Low Emission Zone Policy on urban air quality*

Christina Vanderwel (University of Southampton): *Identifying regional air quality trends from sensor network data: An analysis of $PM_{2.5}$ measurements in Hampshire*

Congbo Song (University of Manchester): *Normet package— NORmalising METeorological Impacts on Air Quality*

Dan Stone (University of Leeds): *Development and initial deployment of a novel instrument for long-term measurements of OH reactivity*

Eleanor Gershenson-Smith (University College London): *Understanding urban nitrous oxide (HONO) in central London with vertically-resolved observations and a numerical model*

Eloïse Marais (University College London): *Disparities in health burdens from unequal exposure to traffic-related air pollution in UK cities*

Finja Löher (University of York): *About the spatio-temporal variability of VOCs in the city and their link to air quality*

Hazel Hunter: *Air Not Chocolate - artwork inspired by atmospheric research*

Henrik Hof (Palas GmbH): *Measurements of airborne fine dust and ultrafine particles at a seaport in southern Italy*

James Parkin (University of Southampton): *Brake-wear $PM_{2.5}$ affects alveolar homeostasis through a copper-dependent mechanism*

John S Ji (Tsinghua University): *Interaction between residential greenness and air pollution mortality in China*

Maryam Makanvand (University of Bristol): *Metabolomics signature of air pollution exposure across the life-course*

Maryam Makanvand (University of Bristol): *Long-term exposure to ambient air pollution and incidence of emergency cardiovascular, cerebrovascular, and respiratory hospital admissions in the West Midlands: a population-based cross-sectional study*

Matthew L. Thomas (University of Manchester): *A Data Integration Approach to Estimating Personal Exposures to Air Pollution*

Matthew L. Thomas (University of Manchester): *Data integration for high-resolution, continental-scale estimation of exposures to air pollution*

Nat Easton (University of Southampton): *Elemental Source Profiles, Spatial Distribution and Potential for Isotope Analysis in Assessing UK Port Emissions*

Nathan R Gray (University of York): *Disparities in air pollution emissions experienced by minoritised ethnic groups in England*

Prashant Kumar (University of Surrey): *Mitigating children exposure to air pollution in and around classrooms*

Richard Pope (University of Leeds): *Integration of Earth Observation into the UK Met Office Air Quality Forecasting System*

Ruth Winkless (University of York): *Laboratory studies on the photolysis of atmospherically important carbonyls*

The Clean Air Champions, The Met Office and The Institution of Environmental Sciences: *Community for Clean Air – a new forum to unify existing knowledge and stakeholders*

Ying Zhang (National Physical Laboratory): *Future Trends in Air Quality Measurement*

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Book of Abstracts
(in alphabetical order by first author's first name)

Forth Environmental Resilience Array (Forth-ERA): Developing an indoor-outdoor monitoring network for the Forth Valley Region

A.S. McCarron[1], M. Modlich[1], H.D. Price[1] and P. Hunter[1]

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Keywords: lower-cost sensor, air quality, exposure reduction, participatory research, network.
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The Forth Environmental Resilience Array (Forth-ERA) is a pioneering "living laboratory" dedicated to enhancing Scotland's environmental resilience by providing real-time environmental data and analytics. Forth-ERA is designed to support cutting-edge scientific research, optimise environmental management and regulation and stimulate business innovation to drive Scotland's transition toward a net-zero carbon society. This initiative addresses multiple interconnected environmental themes - air quality, flooding, water quality and biodiversity - through an accessible platform that enables diverse stakeholders to make data-informed decisions. Ultimately, Forth-ERA will create a "one-stop shop for environmental data," hosted on a web-based platform that consolidates and presents insights from all data collected. By doing so, Forth-ERA empowers scientists, policymakers, businesses and the public to make informed decisions that contribute to long-term environmental sustainability.

Within this broader context, air quality monitoring is a crucial focus of the Forth-ERA project, reflecting the urgent need to address air pollution's significant health and environmental impacts. Air pollution is estimated to contribute to around 49,000 premature deaths annually in the UK alone. Given these health impacts, the World Health Organization (WHO) has called for both emissions and exposure reductions, emphasising the role of data-driven policy and behavioural changes in achieving these goals. By including air quality in its monitoring framework, Forth-ERA aims to provide insights that can support meaningful reductions in exposure to pollutants and help inform policies that protect public health.

The air quality theme within Forth-ERA involves several key objectives: 1) Deploying a co-designed network of approximately 100 indoor and 20 outdoor air quality sensors across Stirlingshire and Clackmannanshire. This network is strategically positioned to capture detailed pollutant data, aiding in the identification of high-risk areas and supporting targeted emission reduction strategies. 2) Engaging communities to identify their specific air quality priorities through online participatory approaches, which allows for a focused response to local concerns. Based on this input, we deploy additional sensors (n = 10) in priority areas to address the specific needs of communities and gather relevant data on pollution impacts on vulnerable populations.

Additionally, Forth-ERA aims to establish an online digital repository for air quality data, making this information accessible and actionable for a wide array of stakeholders. This repository will present data in meaningful formats tailored to the needs of local authorities, the Scottish Environment Protection Agency (SEPA), community groups and the general public. By offering accessible data, the repository will help support policy formulation and raise public awareness of local air quality issues.

We will present an update on our progress, share initial findings, and reflect on lessons learned in aligning community engagement with advanced air quality research. Through this collaborative approach, Forth-ERA demonstrates how scientific research, when integrated with public and stakeholder priorities, can create a more informed and resilient society, contributing not only to Scotland's environmental goals but also to global efforts in combating air pollution and its health impacts.

Implementation of a new value of the ozone absorption cross-section for measurements of ozone in ambient air (CCQM.O3.2019)

Andrew S. Brown[1], Paul J. Brewer[1], Sangil Lee[2], Joele Viallon[3], Robert I. Wielgosz[3], Joseph J. Hodges[4], Jennifer Carney[4], James Norris[4], Louise Sorensen[5], Joann Rice[6], Melinda Beaver[6], Christoph Zellweger[7], Hiroshi Tanimoto[8], Bernhard Niederhauser[9] and Brian Stacey[10]

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Keywords: ozone, cross-section, ambient air, photometers, uncertainty.
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A new ozone absorption cross-section is being adopted globally. This new ozone cross-section value 'CCQM.O3.2019' at room temperature at the mercury-line wavelength (253.65 nm, air), is 1.1329 x 10^{-17} cm^2 with a standard uncertainty of 0.0035 x 10^{-17} cm^2 [1]. This is around 1.2 % lower than the conventionally accepted 'Hearn.1961' cross-section [2] and has an uncertainty approximately six times smaller. It was defined by a Task Group established by the Gas Analysis Working Group of the Consultative Committee for Amount of Substance: Metrology in Chemistry and Biology (CCQM-GAWG) from the analysis of absorption cross-section data from fourteen independent sets of measurements between 1959 and 2016.

Implementation of the new CCQM.O3.2019 ozone cross-section across air quality networks will commence on 1 January 2025 and be completed 12 months later. In preparation for this change, the CCQM-GAWG Task Group on Ozone Absorption Cross-Section Change Management are overseeing the revision of international and national documentary standards (including the European standard EN 14625 [3]), actively communicating the change, and producing implementation documents for ozone calibration laboratories, instrument manufacturers, end-users and groups maintaining historical datasets of ozone concentrations.

We present the rationale for this change in the ozone-cross section, describe how it will be rolled out across Europe (including in United Kingdom through the Automatic Urban and Rural air quality monitoring Network (AURN)) and describe the effect the change will have on measured ozone concentrations. We also signpost the freely available resources available to ozone calibration laboratories, operators of air quality monitoring networks, and instrument manufacturers to support the change in cross-section.

References

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[2] A.G. Hearn, *Proc. Phys. Soc*., 78, 932-940 (1961).
[3] European Standard EN 14625:2012, Ambient air - Standard method for the measurement of the concentration of ozone by ultraviolet photometry.

Exposure to $PM_{2.5}$ and Mortality in Northern Ireland

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[2]Rutgers School of Public Health

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Keywords: Mortality, $PM_{2.5}$, Northern Ireland

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This paper assesses the relationship between $PM_{2.5}$ exposure and mortality in Northern Ireland, a setting where pollution is low compared with most other countries. The study used data from a new linkage between the Northern Ireland Longitudinal Study (NILS), matched to pollution data at the 1km grid-square level and death events. The NILS is a longitudinal study that tracks a 28% representative sample of the Northern Ireland population drawn from the NI Health Card Registration System, which contains address histories updated biannually. The NILS is linked to several other administrative datasets including Census records for 2001 and 2011, which provided rich information on socioeconomic and demographic characteristics and contexts for sample members. The pollution data, matched at the residential property level to NILS participants, provided annual 1km grid-square modelled pollution data from 2002-2019 for some pollutants including $PM_{2.5}$. These data were produced by Ricardo Energy & Environment for the UK Government's air quality assessments.

We apply two analytical methods to this data to better understand the relationship of interest: Cox proportional hazards models, and propensity score matching. Cox proportional hazards models reveal associations between mortality risk and $PM_{2.5}$ exposure, though the magnitude of the effects depend on the specification. Without adjustment for measured characteristics, an interquartile range increase in the five-year moving average of exposure is associated with a relatively large increase in the hazard of mortality. This effect decreases after adjusting for prior individual-level demographic, socioeconomic and health-related factors and household-level factors; however, the hazard ratio remains above one and comparable with estimates from other studies. In further analysis, propensity score matching is used to assess whether, among those with similar levels of pre-move exposure, those who go on to move to areas with different pollution levels face different subsequent mortality risks. This analysis suggests that mortality risk is higher (lower) for those who move to a more (less) polluted area.

This study offers evidence of mortality effects of $PM_{2.5}$ from a setting where annual mean $PM_{2.5}$ concentrations averaged roughly 8 micrograms per cubic metre over the study period. Therefore, we conclude that, consistent with similar studies in England, Canada, and European countries, Individuals with higher long-term exposure face additional mortality risk even in the context of exposure to low pollution.

Evaluating the impact of London's Ultra Low Emission Zone Policy on urban air quality

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Keywords: ULEZ, air policy, air pollution, particulate matter, nitrogen dioxide.
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Air pollution, primarily from traffic emissions, is a major global health concern contributing to premature mortality and a range of non-communicable diseases. To mitigate these risks, various interventions, particularly targeting diesel vehicle emissions, have been implemented at national and local levels. This study assesses the impact of the phased introduction of London's Ultra-Low Emission Zone (ULEZ) policy on air quality in London, with the scheme introduced in April 2019, and extended to London's North and South circular in October 2021. We did not consider the extension across the whole of Greater London in August 2024.

A comparative analysis was conducted on time series data of nitrogen dioxide (NO_2) and fine particulate matter ($PM_{2.5}$) concentrations from 88 monitoring sites in London, and 66 sites outside London (excluding areas with, or considering the adoption of Clean Air Zones), covering the period from January 1, 2015, to December 31, 2022. Data were sourced from three national monitoring networks: AURN, AQE, and LAQN. Both roadside and urban background sites were included, while low-cost sensor sites were excluded. We considered an extended period prior to the implementation of the scheme to account for potential pre-compliance.

The analysis employed a combination of statistical techniques, including Theil-Sen visualizations, forest plots, principal component analysis (PCA), and CUSUM charts. These methods were used to evaluate the impact of the ULEZ policy and events like COVID-19 lockdowns on air quality trends in different regions of London, using the sites outside of London as controls for national level trends over this period.

The findings revealed a statistically significant decrease in NO_2 and $PM_{2.5}$ concentrations in London's air. Notably, the annual rate of change for aggregated roadside NO_2 concentrations within the original ULEZ area (central) was -7.48 μg/m³, compared to -4.77 μg/m³ and -2.57 μg/m³ for inner and outer London, respectively. $PM_{2.5}$ concentrations also decreased, particularly in the central zone, with reductions of -1.13 μg/m³, -0.93 μg/m³, and -0.54 μg/m³ per year for central, inner, and outer London, respectively. Attributing these changes specifically to the ULEZ is complex, as the policy was enacted in parallel to multiple parallel policies at both local and national level, however the impacts on NO_2 (particularly at roadside locations) were greatest in the original ULEZ area and across the period of initial implementation, as confirmed by the CUSUM analysis, with all changes across London Central, to Outer being greater than the national downward NO_2 trend. For $PM_{2.5}$, the changes in London appeared broadly indicative of the national trend.

These results provide valuable insights into the effectiveness of air quality improvement policies. The study underscores the importance of targeted interventions, particularly those aimed at reducing traffic emissions, in mitigating the adverse health impacts of air pollution. This ULEZ study serves as a positive example of how such interventions can significantly improve urban air quality, and as example of a robust methodology for evaluating their impacts.

Identifying regional air quality trends from sensor network data: An analysis of PM2.5 measurements in Hampshire

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Keywords: air quality monitoring, particulate matter, sensor networks
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Poor air quality is the UK's greatest environmental health hazard and a particular concern in major cities across the country. It contributes to poor health, such as heart and lung disease, and increased mortality, disproportionately effecting the young, the elderly, and vulnerable populations [1].

In Hampshire, major sources of air pollution include road traffic, shipping and port activities, the airport, and local industry. There are over 30 air quality management areas (AQMAs) in the region where national Air Quality Objectives are locally not being met. The improvement of outdoor air quality is therefore a priority for local authorities who are engaged with local monitoring and have developed air quality action plans [2-5].

This investigation by the University of Southampton aimed to analyse air quality sensor measurements from across Hampshire to:

1. Investigate the extent and severity of air pollution in the region.
2. Identify trends that could lead to targeted interventions and an improvement in quality of the air we breathe.

Our analysis focused on a dataset of measurements of particulate matter smaller than 2.5 µm (PM2.5), the major cause of the negative health effects of poor air quality. The data was collected from a network of 17 EarthSense Zephyr [6] ambient air quality monitors spread across the region (Figure 1), measured every 15-minutes over the period of January 2023 – March 2024, supplemented with data from DEFRA's Automatic Urban and Rural Network [7] and weather data from the Met Office [8]. We applied statistical and machine learning techniques to identify trends in the data.

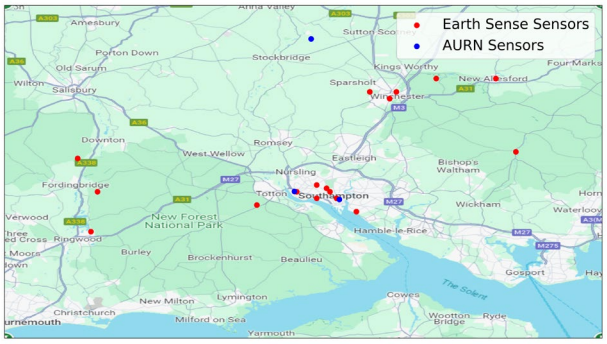

Figure 1: Map of the sensor locations

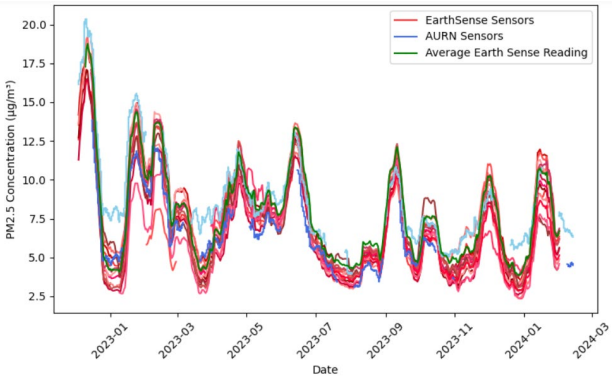

Figure 2: Measurements from all the sensors follow the same trends in time with little regional variation. Peak episodes, such as the one resulting from a large fire in June 2023, were often felt across the region. The annual average PM2.5 level was 7.5 µg/m³.

We gratefully acknowledge Southampton City Council, Winchester City Council, Eastleigh Borough Council, and the New Forest District Council who provided access to the air quality data measured in their communities funded by DEFRA's Burn Better Campaign. Funding for this research was provided by the University of Southampton's Low Carbon Comfort Centre of Excellence and the Public Policy|Southampton New Things Fund.

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Normet package— NORmalising METeorological Impacts on Air Quality

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Keywords: air quality, machine learning, weather normalisation, time series
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Assessing the effectiveness of air quality intervention policies is a crucial task in air quality management. However, this assessment is challenging because air quality is influenced by both emissions and meteorological factors. Machine learning-based weather normalization has been developed to decouple emission-related changes in air quality from observed data. In this study, we enhance existing weather normalization models and introduce a new model, 'normet', by incorporating Automated Machine Learning (AutoML) on both R and Python platforms. AutoML helps to select the optimal model and hyperparameters, improving the accuracy of meteorologically normalized concentrations. Additionally, we implement time series decomposition and an ML-based synthetic control method within 'normet' to better interpret air quality time series data and support air quality intervention studies. This open-source package on both R and Python platforms advances analytical capabilities in air quality management.

Air pollution and environmental impacts of megaconstellation satellite missions

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Keywords: atmospheric chemistry, climate, space, stratospheric ozone, emission inventory
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Three-quarters of satellites in low-Earth orbit (LEO) are now from satellite megaconstellations (SMCs) such as Starlink and OneWeb. These SMCs are a major contributor to increasing space activity, representing one fifth of rocket launches and one quarter of re-entries annually. Both activities release harmful emissions throughout all layers of the atmosphere, including above the tropopause where longer lifetimes lead to significant ozone depletion and radiative forcing. In addition to the over 7,000 satellites operational in LEO, a further 60,000 are expected in the next decade, yet the environmental impacts of SMCs remain under investigated and under regulated. These uncertainties need to be addressed too in anticipation of the UK entering the space race with seven planned spaceports.

Here we develop a 3D, hourly, global inventory of air pollutant and CO_2 emissions for rocket launches and re-entries of end-of-life satellites and discarded rocket bodies and other components. Pollutants include black carbon (BC), nitrogen oxides ($NO_x \equiv NO+NO_2$), water vapour (H_2O), carbon monoxide (CO), alumina aerosol (Al_2O_3) and chlorine species ($Cl_y \equiv HCl+Cl_2+Cl$) from rocket launches and NO_x and alumina aerosol (Al_2O_3) from re-entries. We calculate the emissions to cover the introduction and rapid rise of SMCs (2020-2022), and project the emissions to 2029 based on the current growth rates in annual propellant consumption and object re-entries. We embed the emissions of air pollutants in the atmospheric chemical transport model GEOS-Chem coupled to a radiative transfer model, to simulate the impact of a scenario of a decade of SMC mission growth on atmospheric composition, ozone depletion, and climate.

We find that by 2029, SMC missions result in minimal global stratospheric ozone depletion (0.003%), representing 12% of the ozone depletion by all mission types. Ozone depletion is concentrated in the northern midlatitude upper stratosphere. Limited SMC impact on the ozone layer is attributed to the dominance of kerosene fuel for SMC missions (98% of fuel mass), that exclude solid propellants that emit ozone-depleting Al_2O_3 and Cl_y. Conversely, SMC missions contribute to large increases in stratospheric BC emissions (>1500% increase). SMC missions are responsible for over half of the increase in BC, even though these missions account for only a fifth of all mission launches.

We calculate a net instantaneous radiative forcing of 16.9 mWm^{-2} at the top of the atmosphere at the end of 2029, with SMC missions contributing over half of this increase (9.1 mWm^{-2}). At the tropopause, we find that the stratospherically adjusted radiative forcing is negative (-5.9 mWm^{-2}), with SMC missions again contributing over half of this change (-3.4 mWm^{-2}). All radiative forcing changes are driven by the absorption of shortwave radiation by BC.

As these are no independent observations to validate our results, current work includes testing the effect of uncertainties on our findings.

Development and initial deployment of a novel instrument for long-term measurements of OH reactivity

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Keywords: OH reactivity, ozone production, air quality.
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Emissions of trace species into the atmosphere lead to reaction cascades that can result in the generation of secondary pollutants such as ozone (O_3) and secondary organic aerosol (SOA), which are harmful to human health. However, the chemistry involved is complex and, in the case of ozone production, highly non-linear, creating a challenge for the accurate prediction of atmospheric composition, and thus of air quality. The difficulties associated with predicting the outcomes of such complex non-linear processes is further aggravated by the overwhelming array of VOCs present in ambient air, which originate from a wide variety of sources including vehicle exhausts, industry, agriculture and plants. While much has been achieved in terms of sensitive and selective VOC measurements, estimates have indicated the presence of over 10,000 different VOCs in ambient air. Despite the challenges associated with the detection and identification of such a vast array of species, it is possible to quantify the impact of unmeasured trace species on the production of ozone and SOA through measurements of the total OH loss rate in the atmosphere since the vast majority of trace species emitted into the atmosphere react with OH radicals.

Measurements of the total OH loss rate in the atmosphere can be used to define the OH reactivity (kOH), which is the pseudo-first-order rate coefficient describing the loss of OH and the inverse of the chemical lifetime of OH (τ_{OH} = 1/kOH), enabling quantification of the total extent of reactive compounds present in an air sample. When coupled with NO_x measurements, knowledge of kOH has the potential for use in the identification of the chemical regime responsible for formation of secondary pollutants, and thus the design of appropriate pollution abatement strategies. Knowledge of kOH has much to offer in terms of ensuring the evaluation of the accuracy and extent to which the reactivity and impacts of pollutants are considered in atmospheric models, atmospheric chemical mechanisms, and the chemical regimes in operation in the atmosphere.

Observations of kOH in environments ranging from polluted urban regions to pristine rainforests have revealed that the total OH reactivity is typically underestimated from calculations based on measurements of composition and relevant reaction kinetics alone, with 'missing reactivity' demonstrating the presence and the impacts of unmeasured species. Seasonal differences in kOH have been observed to such an extent that enabled identification of a shift in position from NO_x-limited chemistry in winter to VOC-limited in summer, requiring that successful policies to manage air quality consider the potential seasonal differences in outcomes.

In this work we report the development and characterisation of a new instrument designed to make long-term measurements of OH reactivity in a wide range of environments, and initial results from field measurements. The potential for improvements to assessments and predictions of air quality through improved understanding of the total reactive pollutant loading in the air will be discussed.

Review of the effectiveness of bus retrofit abatement strategy

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Keywords: NO_x, Air Quality,
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In September this year the Transport Secretary announced a permanent end to further government funding for Selective Catalytic Reduction (SCR) retrofit technology on buses and the closure of the Clean Vehicle Retrofit Accreditation Scheme (CVRAS) for accreditations of new retrofit technologies. Retrofitting older buses with SCR technology aimed to reduce NO_x emissions and lead to improvements in ambient concentrations of NO_2. However, evidence from real-world vehicle emission remote sensing measurements suggested that that the expected reduction in NO_x emissions was not being realised. Evidence on the effectiveness of the technology on buses and the factors causing underperformance was published in a report. This presentation will provide an overview of the evidence from an emissions perspective with respect to NO_x and directly emitted NO_2 and highlight some of the challenges associated from a technology and a certification perspective.

Understanding urban nitrous oxide (HONO) in central London with vertically-resolved observations and a numerical model

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Keywords: Nitrous acid, London, Remote sensing, Chemical transport modelling.

In polluted cities with large sources of NO_x, rapid photolysis of nitrous acid (HONO) may be a major daytime source of the main atmospheric oxidant, OH. Current understanding of urban HONO is problematic, as indicated by severe underestimates in HONO by state-of-science models.

We use daytime vertically resolved measurements of HONO throughout the lower troposphere from a Multi-Axis Differential Optical Absorption Spectroscopy (MAX-DOAS) instrument installed on a 60 m rooftop on the Bloomsbury University College London (UCL) campus and the GEOS-Chem chemical transport model to determine potential sources of urban HONO in Central London.

We find that the MAX-DOAS instruments only detects HONO in winter on cold (< 4°C), clear, calm (wind speeds < 4 m s^{-1}) days when model reanalysis meteorology suggests the boundary layer is very shallow (< 100 m) and when coincident surface network observations have anomalously low surface ozone depletion (< 24 ppb), and there is a relatively large contribution of NO to total NO_x ($NO/NO_x \geq 0.3$).

Peak HONO concentrations are detected by the instrument in the early morning and decrease to a minimum at approximately 2:00 pm. In contrast, HONO concentrations in GEOS-Chem deplete much earlier (11:00 am) than the observations and are 2 orders of magnitude less than is observed, as the model is missing direct emissions of HONO from vehicles and heterogeneous conversion of NO_2 to HONO on urban surfaces (Fig. 1).

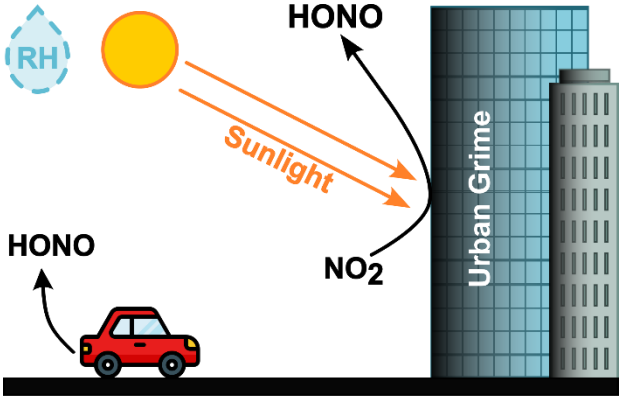

Figure 1: Urban sources of HONO: direct emissions and heterogeneous conversion of NO_2 on urban surfaces.

We find that direct emission of HONO, represented as 0.85 % of NO_x emissions, and heterogeneous conversion of NO_2 on urban grime with dependence on relative humidity (RH), light intensity and NO_2 concentration, doubles modelled HONO, but the model is still biased low. Currently under investigation is the potential for other urban surfaces, like soil and vegetation, to enhance heterogeneous formation of HONO.

Disparities in health burdens from unequal exposure to traffic-related air pollution in UK cities

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Keywords: urban traffic, NO_2, disparate exposure, health burden.
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Traffic-related nitrogen dioxide (NO_2) pollution in urban environments is associated with adult premature mortality and with childhood onset asthma. The impact is most severe for communities dominated by ethnic minority populations and low-income households. The lack of availability of contemporary, high spatial resolution NO_2 surface concentrations limits the ability to quantify the severity of disparate exposures and health outcomes to prioritise the most affected communities to address inequities in exposure to traffic-related air pollution.

Here we apply advanced inversion and gridding techniques to integrated tropospheric column densities of NO_2 from the space-based TROPOspheric Monitoring Instrument (TROPOMI) to derive contemporary (2018-2023) annual climatological mean surface concentrations of NO_2 for specific UK cities at much finer spatial resolution (~400 m) than the native resolution of the instrument (3.5 km × 5 km for nadir pixels). The observationally derived values are quality checked against the regulatory network of observations of NO_2. We target UK cities most affected by traffic emissions, as diagnosed with the UK National Atmospheric Emission Inventory (NAEI): London, Birmingham, Manchester, Leeds, and Glasgow. The recent (2021) UK census demographic and baseline mortality data and Global Burden of Disease (GBD) study data on childhood-onset asthma incidences are used with epidemiologically-informed health-risk assessment models to quantify disparities in exposure and health burdens in these cities.

The satellite-derived surface concentrations of NO_2 in London (Figure 1) are within 10-20% of 24 of the 30 collocated *in situ* regulatory network site measurements analysed so far and biased low by 26-33% for the other 6, suggestive of conservative exposure estimates. Population-weighted traffic-related NO_2 for the cities quantified so far all exceed the World Health Organization (WHO) 10 μg m^{-3} threshold for risk of harm to health. Values are 17.7 μg m^{-3} for London, 12.5 μg m^{-3} for Birmingham, and 11.3 μg m^{-3} for Leeds.

Disparities in exposure are determined relative to the city-wide population-weighted mean. The most severe relative exposures in our initial analysis disparities are amongst communities that identify as Black and Others in London (0.81 μg m^{-3} more than the city mean), Asian and Black in Birmingham (1.1 μg m^{-3} more), and Black in Leeds (0.84 μg m^{-3} more).

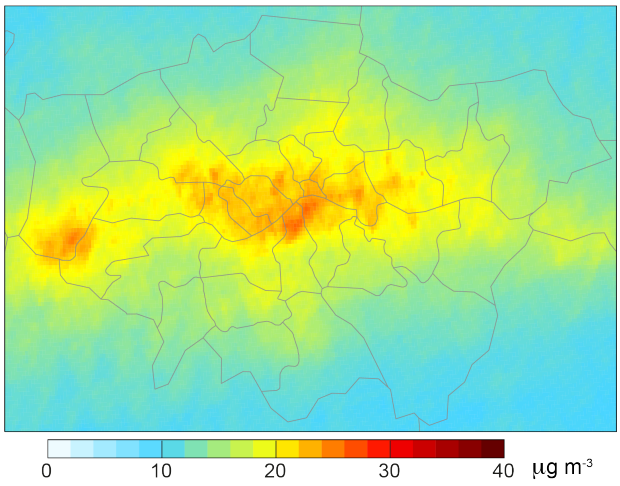

Figure 1. London multiyear mean surface concentrations of NO_2 at ~400 m resolution derived from TROPOMI showing hotspots in Central London and at Heathrow airport.

About the spatio-temporal variability of VOCs in the city and their link to air quality

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Keywords: Urban Air Quality, Mobile Measurements, VOC, PTR-ToF-MS, Photochemistry.
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Urban air quality is influenced by the interplay of multiple physical and chemical factors and processes. Identifying the key dynamics that determine whether and which pollutants form and accumulate in the air is therefore essential for evaluating the potential risk to the environment and human health. While the major known air pollutants, such as ozone (O_3), nitrogen oxides (NO and NO_2), and particulate matter (PM10 or PM2.5), are monitored extensively, the composition and spatio-temporal variation of volatile organic compounds (VOCs) in urban air remains poorly constrained, even though VOCs drive the ambient chemistry.

Especially in confined urban street canyons, the comprehensive characterization of VOCs can be a powerful tool to reveal relevant sources, the potential of the ambient air mixture for photochemical production of secondary pollutants, and the effect of mixing and stagnation as determined by micrometeorological conditions. However, due to multiple methodological and logistical challenges, street-scale VOC observations in urban environments are still rare.

In this study, we investigated the spatio-temporal variation of VOCs in a densely populated and heavily trafficked street canyon in the city of Munich (Germany). For this purpose, we assembled a mobile laboratory in an air-conditioned trailer. This mobile laboratory contained a Proton-Transfer-Reaction – Time-of-Flight – Mass Spectrometer (PTR-ToF-MS) for the analysis of VOCs, NO_x and O_3 analysers, a GPS tracker, an ultrasonic anemometer, and an open-path infrared gas analyser for carbon dioxide (CO_2) and water (H_2O) measurements.

In September 2023, we first conducted a comprehensive mobile field campaign recording data along the main street and the side roads of the neighbourhood. Here, we show how the mobile VOC dataset can help classifying distinct chemical regimes within the study area, and how statistical tools can be used to detect and delineate small-scale spatial differences. Further, we discuss the implications of spatial variations in VOC mixing ratios for the oxidant chemistry and ambient air quality.

Following the mobile campaign, we performed stationary measurements on the sidewalk along the main street for one consecutive week. During this time frame, we switched between H_3O^+ ionisation and NH_4^+ ionisation (Müller et al., 2020) to assess VOC oxidation products with better sensitivity and selectivity. Using multiple photochemical indicators, we demonstrate how micrometeorological conditions and advection drive the ambient oxidation capacity and thereby influence the accumulation of atmospheric constituents, resulting in dramatic differences in ambient mixing ratios.

Jointly, these two data sets provide insight into typical urban composition and mixing ratios of VOCs. The analysis of the temporal and spatial variability of VOCs and the co-measured atmospheric constituents allows us to explore the underlying physical and chemical processes leading to the formation of secondary pollutants in a unique way.

This work was financed by the Bavarian Ministry of the Environment and Consumer Protection and the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) – 495692966.

Müller, M., Piel, F., Gutmann, R., Sulzer, P., Hartungen, E., and Wisthaler, A. (2020): A novel method for producing NH_4^+ reagent ions in the hollow cathode glow discharge ion source of PTR-MS instruments, Int. J. Mass Spectrom., 447, 116254.

Measurements of airborne fine dust and ultrafine particles at a seaport in southern Italy

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Keywords: Ultrafine, Source apportionment, Nanoparticles
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Airborne particles adversely affect human health, depending on their size. While mass-related limits for PM_{10} and $PM_{2.5}$ fine dust fractions are in place, and dust levels monitored, the potentially more harmful PM_1 fraction and the number concentration of nanoparticles are not under regulation today.

Measurements using a single particle counting aerosol spectrometer (AQ Guard 1100, Palas GmbH) and a diffusion charger based (DC) UFP analyzer (AQGuard Smart 2000, Palas GmbH) were taken in two locations, a marina and an airport, both in the surrounds of Brindisi, Italy.

Particle number concentration (C_n) of nanoparticles in the range 10nm to 1 µm and it's mean diameter (X_{50}) were measured, along with wind speed and direction in both locations.

Correlation with local predicted emittents such as ships, flight activity, traffic and natural events were analyzed.

Brake-wear PM2.5 affects alveolar homeostasis through a copper-dependent mechanism

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Keywords: $PM_{2.5}$, non-exhaust emissions, brake-wear PM, diesel PM.
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Background: While associations between $PM_{2.5}$ exposure and respiratory health effects are well-established, the underlying cellular mechanisms involved, and the effects of particle composition remain poorly understood. Vehicles are a major source of ambient $PM_{2.5}$, but car exhaust-derived $PM_{2.5}$ has decreased over time following technological advances and changes in legislation. However, the main vehicular source of $PM_{2.5}$ is unregulated, poorly characterised "non-exhaust" PM, a large constituent of which is brake-wear PM (BWPM).

Objectives: We aimed to study the differential effects of PM from 4 brake pad types, compared to diesel exhaust PM (DEP), on a model of the alveolar epithelium, a key $PM_{2.5}$ deposition site. Moreover, we aimed to identify the compositional and mechanistic drivers of these differential responses.

Methods: We exposed type-II alveolar epithelial cells (ATII) to 4-32 $\mu g/cm^2$ of PM2.5 from 4 brake pad types (low-metallic, semi-metallic, non-asbestos organic [NAO], ceramic), or DEP for 2-24 hours. Gene expression (qPCR, RNA-Seq), protein expression (Western blotting), transcription factor activity (reporter assays), and ATP production (Seahorse ATP-rate assay) were assessed to determine the effects on alveolar cellular homeostasis. Inductively coupled plasma mass spectrometry (ICP-MS) was used to determine the elemental composition of the different PM types, as well as to assess intracellular metal concentrations following PM exposure. Lastly, we used metal chelators with different selectivity for different metals to elucidate the compositional drivers of observed differential effects.

Results: Exposure to non-cytotoxic concentrations of $PM_{2.5}$ from NAO and ceramic brake pads induced the most oxidative stress (DCF: ~2-fold increase, $p<0.01$) and pro-inflammatory mediator release (IL-6: ~40-fold increase, $p<0.001$; IL-8 ~3-fold increase, $p<0.001$). Moreover, NAO BWPM led to a ~40% increase in the proportion of ATP generated through glycolysis ($p<0.05$), and disruption of metal ion homeostasis, as evidenced by increased expression of genes in the metallothionein family (*MT1G*: ~170-fold increase, $p<0.001$; *MT2A*: ~4-fold increase, $p<0.001$). Elemental analysis revealed that NAO and ceramic BWPM had the highest copper content. Furthermore, using ICP-MS we determined that copper accumulates intracellularly following NAO BWPM exposure. Selective chelation of copper reduced the expression of oxidative stress and pro-inflammatory markers ($p<0.05$). Furthermore, copper-enriched BWPM triggered oxygen-independent (pseudohypoxic) activation of the lung fibrosis- and cancer-associated hypoxia-inducible factor (HIF) pathway, through oxidative stress- and copper-dependent manners ($p<0.05$).

Conclusions: Our findings demonstrate that BWPM exerts greater effects on lung cell function compared to DEP, across a broad range of disease-relevant cellular endpoints, including oxidative stress, inflammation, metabolic reprogramming, and pseudohypoxic HIF pathway activation. The source- and copper-dependence of these effects emphasise the need for targeted regulatory measures to mitigate the potential health effects of non-exhaust emissions.

Interaction between residential greenness and air pollution mortality in China

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Keywords: residential greenness, air pollution, all-cause mortality, older adults, cohort study
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Introduction:

Previous research suggests that greenness may mitigate health impacts from air pollutants, but findings are inconsistent. This study analyses a longitudinal cohort to clarify these interactions in China, focusing on how residential greenness affects health outcomes in older adults exposed to air pollution. Understanding this relationship can inform urban planning and public health policies to enhance community well-being and reduce mortality risks.

Methods:

We utilized data from the 2008 wave of the China Longitudinal Healthy Longevity Survey (CLHLS), a prospective cohort study aimed at understanding healthy longevity determinants. Participants aged 65 years and older were recruited from 22 provinces in China, with a sample representing approximately 85% of the population. We excluded individuals lost to follow-up, those with missing data on mortality or air quality, and younger participants.

Remote sensing was employed to calculate the Normalized Difference Vegetation Index (NDVI) within a 500 m radius of participants' residences. NDVI values, indicative of residential greenness, were derived from the Moderate-Resolution Imaging Spectro-Radiometer (MODIS). We also calculated ground-level PM2.5 concentrations using satellite data and chemical transport models, applying a 3-year average prior to mortality events.

Cox proportional hazards models were employed to analyse all-cause mortality, adjusting for various demographic, socioeconomic, and lifestyle factors. We examined the independent effects of NDVI and PM2.5, including their interaction. Sensitivity analyses were performed to validate results, including stratified analyses by sex, residence type, and financial status. Statistical analyses were conducted using STATA version 14.0.

Results:

Out of 16,954 participants interviewed in the 2008 CLHLS, our final sample comprised 12,873 individuals after excluding those lost to follow-up, those with missing data, and younger participants. The mean age was 87.01 years (SD 11.34), with 72.7% aged 80 and older. The cohort had a higher proportion of female participants (57.4%) and rural residents (84.6%). Participants in greener areas tended to be ethnic minorities, financially dependent, and less formally educated. The mean contemporaneous NDVI was 0.42 (SD 0.21), while the mean 3-year PM2.5 was 49.63 μg/m³ (SD 13.72).

In the fully adjusted model, each 0.1-unit decrease in NDVI corresponded to a hazard ratio (HR) of 1.08 (95% CI 1.03–1.13), and each 10 μg/m³ increase in PM2.5 had an HR of 1.13 (95% CI 1.09–1.18). The interaction term was 1.01 (95% CI 1.00–1.02, p=0.027). Sensitivity analyses confirmed these findings, with urban participants showing more significant benefits from greenness and rural participants experiencing more adverse effects from air pollution. No effect modification was observed by sex.

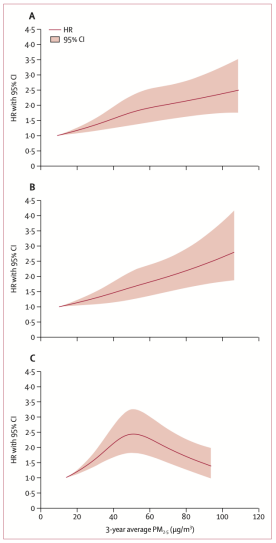

Figure 1: Association curve for 3-year average $PM_{2.5}$ and mortality under different tertiles of contemporaneous NDVI
(A) Tertile 1 of contemporaneous NDVI. (B) Tertile 2 of contemporaneous NDVI. (C) Tertile 3 of contemporaneous NDVI. HR=hazard ratio. NDVI=normalised difference vegetation index. $PM_{2.5}$=fine particulate matter.

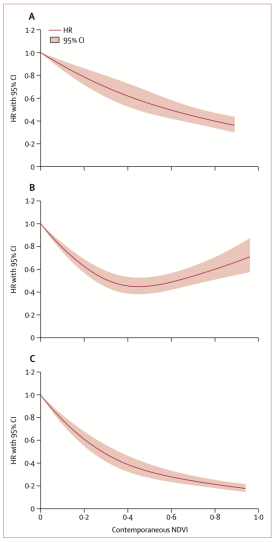

Figure 2: Association curves for contemporaneous NDVI and mortality under different tertiles of 3-year average $PM_{2.5}$
(A) Tertile 1 of 3-year average $PM_{2.5}$. (B) Tertile 2 of 3-year average $PM_{2.5}$. (C) Tertile 3 of 3-year average $PM_{2.5}$. HR=hazard ratio. NDVI=normalised difference vegetation index. $PM_{2.5}$=fine particulate matter.

Conclusion:

This study highlights a significant interaction between residential greenness and air pollution on mortality among older adults in China. Greenness offers protective effects against air pollution, although the interaction effect is relatively small. Findings suggest that urban planners should consider increasing green spaces to mitigate health risks from air pollution, particularly in densely populated areas. Further research is needed to explore whether there is possible air pollution and green space collider bias. Air pollution components and etiology warrant further investigation.

Global health burden of ammonia emissions from fossil fuel derived synthetic nitrogen fertilizer use

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Keywords: ammonia, fine particle pollution, nitrogen fertilizer, health impacts, nitrogen deposition
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Almost all (>95%) global synthetic nitrogen fertilizer is produced using natural gas and coal, but this end-use activity is not considered in global fossil fuel end-use health burden assessments. This type of fertilizer is used extensively in agriculture to enhance crop yields, though efficiencies of use are low, leading to release of a large portion of this nitrogen as gas-phase ammonia (NH_3). NH_3 readily partitions to aerosols to form fine particulate matter ($PM_{2.5}$) pollution that is linked to a range of adverse health outcomes leading to premature mortality. Emissions data specific to synthetic fertilizer use NH_3 emissions are severely limited, necessitating we derive a relationship between $PM_{2.5}$ formation from synthetic nitrogen fertilizer use NH_3 emissions and acidic aerosol abundances using data from countries with reasonably well-constrained emissions.

Here, we use high-resolution ($0.25^o \times 0.3125^o$ or ~28 km latitude × ~27 km longitude) GEOS-Chem chemical transport model simulations nested over the US and the UK that have undergone extensive validation against independent surface observations of total and components of $PM_{2.5}$ and satellite column measurements of NH_3. These countries are selected due to availability of or ability to calculate gridded, time-resolved NH_3 emissions from synthetic nitrogen fertilizer use. We use the model output to parameterize the relationship between acidic sulfate (pSO_4) and nitrate (pNO_3) aerosol abundances and the $PM_{2.5}$ formed from synthetic nitrogen fertilizer use NH_3 emissions.

We then apply this parameterization to global distributions of acidic pSO_4 and pNO_3 aerosol abundances, also modelled using GEOS-Chem, to estimate global $PM_{2.5}$ exposure linked to synthetic nitrogen fertilizer use. This is then used with a contemporary health risk assessment model to yield a plausible range of global attributable mortality of 45,600 to 124,100. China and India together are 35-60% of this burden. Our estimate is a potentially significant (up to 12%) contribution to the global burden of air pollution from fossil fuel end-use.

Policies targeting precursor emissions of pSO_4 and pNO_3 mitigate $PM_{2.5}$ and attributable health burden, but not the risk to sensitive habitats. The amount of nitrogen deposited to sensitive habitats will be unchanged and more gas-phase NH_3 will be liberated to harm ammonia-sensitive plants. More effective to target NH_3 emissions from fertilizer directly. Refinements of our estimates on global scales requires national inventories report gridded, time-resolved fertilizer usage emissions of NH_3.

Evaluating the variability and consistency of NOx emission regulation between sectors

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Keywords: NO_x, Air Quality, Regulatory Consistency
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The emissions of nitrogen oxides (NO_x) from combustion have been regulated for several decades with substantial reductions in national totals being reported in high-income counties since the 1990s.

Most technical regulation on emissions is sectoral, appliance specific, and uses metrics aligned to activity data, for example grams per kilometre driven or grams per kilonewton thrust. It is not straightforward therefore to compare the relative stringency of emission regulation between sectors. As Figure 1 demonstrates, NO_x emissions are not proportionally distributed to the activity level of each sector.

We have undertaken a regulatory assessment; standardising the NO_x emission limits from all the key polluting sectors onto a common grams of NO_x per kilowatt hour ($g_{[NOx]}\,kWh^{-1}$) baseline, covering appliances as small as 1 kW to greater than 2 GW.

When viewed on a per kWh output basis, we find little regulatory consistency between sectors, with non-road mobile machinery (NRMM), medium combustion plants (MCPs) and aviation having more permissive regulatory limits than when compared to emissions from passenger cars and domestic boilers. This difference can be large for appliances with the same nominal power rating (for example, in the case of a backhoe loader versus a car, the permitted NOx emission limit is 12.5 times greater for the loader than the car).

There are also significant differences in the transparency of pollutant emissions between sectors, with data from MCPs and the Industrial Emissions Directive (IED) being less accessible due commercially sensitivities and the use of less well described principles of 'Best Available Techniques'.

Compiling this regulatory data is useful for informing future policy and emission legislation decisions. Whilst electrification is likely in the long-term to eliminate some NO_x sources, it is notable that this will be in sectors that currently have the lowest regulatory limits (e.g. road transport, domestic heating). More permissively regulated sectors such as NRMM, MCPs and aviation may instead retain combustion and the associated NO_x emissions.

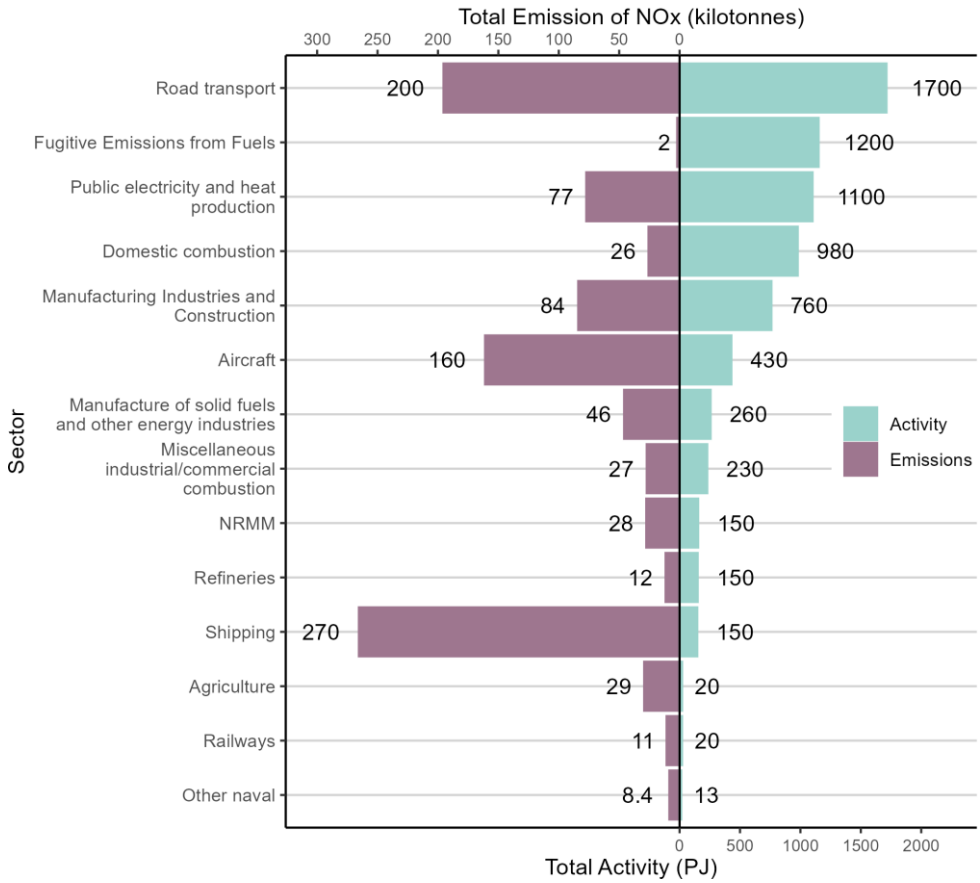

Figure 1 2022 annualised totals of the total activity (PJ) compared to the total emissions of NOx (kilotonnes). All data is taken from the National Atmospheric Emissions Inventory

Metabolomics signature of air pollution exposure across the life-course

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Keywords: Metabolomics, Air pollution, $PM_{2.5}$, Lipid Profile, Inflammation
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Long-term exposures to air pollution have been linked to higher inflammation, oxidative stress and poor cardiometabolic health. However, the underlying metabolic mechanisms across the life course remain poorly understood, especially when assessed using metabolomics which assess small molecules substrate, intermediates and products of cell metabolism.

We aimed to determine the changes in the blood metabolome associated with long-term exposure to air pollution at different ages from childhood to early adulthood.

We quantified 148 blood metabolites using nuclear magnetic resonance (NMR) spectrometry on samples collected in the Avon Longitudinal Study of Parents and Children (ALSPAC) at ages 7, 15, 18 and 24 years. Modelled annual average concentrations of fine particulate matter ($PM_{2.5}$) and black carbon (BC) were obtained from the ELAPSE project. We assessed the association between long-term exposure to $PM_{2.5}$ and each metabolite using multivariate linear regression at each age, adjusted for possible confounders. We also evaluated the association between the proportion of BC to $PM_{2.5}$ and the metabolites to understand the effects of components of $PM_{2.5}$.

Overall, $PM_{2.5}$ was positively associated with metabolites related to a poorer lipid profile such as total cholesterol in, very small VLDL and small LDL with 6.1% (95% CI: 10.4 – 20) and 8.3% (95% CI: 1.3 – 15.7) increase, respectively. Risk estimates of these associations weakened with age, becoming negative at ages 15 and 18 and are positive again at age 24. Larger risk estimates were found for the ratio BC/$PM_{2.5}$ than for $PM_{2.5}$ at younger ages.

Air pollution was associated with metabolites often reflecting a poorer lipid profile, and overall associations weakened with age. Associations in earlier ages were stronger for the ratio BC/$PM_{2.5}$ than for $PM_{2.5}$, suggesting a stronger effect of primary combustion sources. The findings suggest that early-life exposure to primary combustion sources plays a critical role in shaping metabolic health, particularly in early life.

Long-term exposure to ambient air pollution and incidence of emergency cardiovascular, cerebrovascular, and respiratory hospital admissions in the West Midlands: a population-based cross-sectional study

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Keywords: Air Pollution, Emergency Hospital Admissions, $PM_{2.5}$, Ischaemic Heart Disease (IHD), Respiratory Disease

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Long-term exposure to ambient air pollution has been linked to an increased risk of cardiovascular and respiratory diseases. However, its impact on emergency hospital admissions remains underexplored, especially in regions like the West Midlands, UK.

This study aimed to assess the association between long-term exposure to ambient air pollution and emergency hospital admissions for cerebrovascular disease, ischaemic heart disease (IHD), and respiratory disease in the West Midlands.

A population-based cross-sectional study was conducted in the West Midlands Combined Authority area, covering 2.85 million adult residents from April 2016 to March 2017. Modelled annual average pollutant concentrations for NO_2, NOx, O_3 , PM_{10} , and $PM_{2.5}$ were obtained from the WM-Air ADMS Urban model at a 10 m^2 resolution. Emergency hospital admissions were extracted from Hospital Episode Statistics, and mixed log-linear regression models were used to estimate age and sex standardised risks per 1 $\mu g\ m^{-3}$ increase in pollutant exposure, adjusting for socio-demographic and lifestyle factors. Restricted threshold analysis was used to determine health risks at each 1 $\mu g\ m^{-3}$ increment.

Mean annual standardised admission rates for cerebrovascular disease, IHD, and respiratory disease were 2.1, 3.6, and 22.9 per 1,000, respectively. Each $\mu g\ m^{-3}$ increase in $PM_{2.5}$ and PM_{10} was associated with a 4.74% (95% CI: 0.39 to 9.28, p=0.032) and 2.22% (95% CI: -0.18 to 4.6, p=0.069) increase in respiratory disease admissions, respectively, and a 10.74% (95% CI: 3.85 to 18.08. p=0.002) and 5.24% (95% CI: 1.51 to 9.1, p= 0.006) rise in IHD admissions, respectively. There was little evidence for associations with cerebrovascular disease and for the other air pollutants. Restricted threshold analysis showed evidence of health risks below existing UK regulatory standards, particularly for NO_2.

This study provides evidence that long-term air pollution exposure, particularly $PM_{2.5}$ and PM_{10}, is associated with increased emergency hospital admissions for respiratory disease and IHD in the West Midlands. Health risks exist below regulatory standards, with significant implications for air quality management.

A Data Integration Approach to Estimating Personal Exposures to Air Pollution

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Keywords: air pollution, data integration, micro-simulation, health effects, personal exposures, agent-based model

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Globally, air pollution is the largest environmental risk to public health. In order to inform policy and target mitigation strategies there is a need to increase our understanding of the (personal) exposures experienced by different population groups. The Data Integration Model for Exposures (DIMEX) integrates data on daily travel patterns and activities with measurements and models of air pollution using agent-based modelling to simulate the daily exposures of different population groups. Here we present the results of a case study using DIMEX to model personal exposures to PM2.5 in Greater Manchester, UK, and demonstrate its ability to explore differences in time activities and exposures for different population groups. DIMEX can also be used to assess the effects of reductions in ambient air pollution and when run with concentrations reduced to 5 μg/m3 (new WHO guidelines) lead to an estimated (mean) reduction in personal exposures between 2.7 and 3.1 μg/m3 across population (gender-age) groups.

Data integration for high-resolution, continental-scale estimation of exposures to air pollution

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Keywords: air pollution, data integration, health effects, population exposures, spatio-temporal statistics, Bayesian statistics

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Air pollution constitutes the highest environmental risk factor in relation to heath. In order to provide the evidence required for health impact analyses, to inform policy and to develop potential mitigation strategies comprehensive information is required on the state of air pollution. Information on air pollution traditionally comes from ground monitoring (GM) networks but these may not be able to provide sufficient coverage and may need to be supplemented with information from other sources (e.g. chemical transport models; CTMs). However, these may only be available on grids and may not capture micro-scale features that may be important in assessing air quality in areas of high population. We develop a model that allows calibration between multiple data sources available at different levels of support by allowing the coefficients of calibration equations to vary over space and time, enabling downscaling where the data is sufficient to support it. The model is used to produce high-resolution (1km × 1km) estimates of NO2 and PM2.5 across Western Europe from 2010. Concentrations of both pollutants are decreasing during this period, however there remain large populations exposed to levels exceeding the WHO Air Quality Guidelines and thus air pollution remains a serious threat to health.

Elemental Source Profiles, Spatial Distribution and Potential for Isotope Analysis in Assessing UK Port Emissions

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Keywords: Particulate Matter, Shipping, Source Apportionment, Biomonitoring, Isotopes.
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Shipping emissions are an important source of Particulate Matter (PM) associated with an estimated 400,000 global deaths per year with negative effects on air quality disproportionately felt by port and coastal communities. Despite this, shipping remains one of the least regulated sources of emissions, with the main mitigation policies enacted through caps on sulfur content in maritime fuels. The physicochemical characterisation of port emissions and their contribution to local air quality in the UK remains understudied.

Aims:

i) Investigate the physicochemical characteristics of shipping- and port-related PM
ii) Identify and quantify the shipping contribution to PM load
iii) Investigate if isotope analysis offers further insight into the identification of shipping-related emissions
iv) Estimate how far these emissions are spreading

To understand the profiles from port- and ship-related activities, coarse ($PM_{10-2.5}$), fine ($PM_{2.5-0.1}$) and ultrafine ($PM_{0.1}$) PM was collected from different activities across the Port of Southampton, and elementally characterised using inductively coupled plasma mass spectrometry (ICP-MS). The resultant profiles were used to help identify factors in a Positive Matrix Factorisation (PMF) source apportionment model using coarse and fine PM samples collected between 2017 and 2020 at the Port of Southampton.

From the initial study the shipping profile was found to be rich in V and Ni, within the expected range for heavy fuel oil combustion-associated shipping. In addition, Co was identified as a novel tracer for this region. A strong seasonal difference was noted at the cruise terminal, however it was determined that shipping fuel combustion, in particular from summer cruise shipping is the dominant port source with ultrafine V concentrations 28 times greater than a non-port location 4 km downwind.

In the PMF investigations, five factors were identified: Sea Spray, Crustal, Non-Exhaust, Mixed Biomass/Exhaust Combustion and Shipping Fuel. The Shipping Fuel factor was found to contribute almost exclusively to fine PM with a mean contribution of 0.73 μgm^{-3} (0.041-3.89 μgm^{-3}), representing 19% of the measured components in fine PM.

As source apportionment requires large datasets and is resource intensive, we investigated whether Ni and V isotopes can be exploited to understand shipping contributions on smaller datasets. In our pilot data, Ni isotope analysis found a distinct compositional difference between PM collected near the cruise and container terminals, which aligned with the isotopic composition of oil, against PM collected adjacent to a metal-handling site. However, V isotopes appear more discerning with a different isotopic composition observed between cruise shipping and container shipping PM at the same port.

To estimate the spatial distribution of shipping emissions a methodology and pipeline to rapidly collect and analyse biomonitoring samples was established. Here, the outer layer of tree bark was removed using a handheld multitool and elementally analysed using ICP-MS. Due to preferential uptake by bark-surface lichens, V was unsuitable for use as a tracer in this analysis, but concentrations of Ni and Co in tree bark displayed an exponential decay with increasing distance from the port. Our data suggest a zone within 2 km may be exposed to elevated concentrations of shipping emissions.

Disparities in air pollution emissions experienced by minoritised ethnic groups in England

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Keywords: Environmental injustice, Emissions, Ethnic inequality, Socioeconomic inequality
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Environmental injustice is a global issue, one aspect is that emissions of pollutants that affect health are often distributed such that disadvantaged groups experience the highest emissions. This can lead to poor health outcomes, propagating inequality further.

Here, we evaluate the surface emissions of NO_x and primary $PM_{2.5}$ in England, how they intersect with ethnicity and socioeconomic deprivation, and how the relationship has changed in the past 20 years. Lower Layer Super Output Areas (LSOAs), geographic domains containing ~1600 people, were linked to emissions by overlaying their boundaries on a 1 × 1 km grid from the National Atmospheric Emissions Inventory with emissions grouped by source. The average emissions for each were calculated as the mean emissions within the space occupied.

Demographic data such as area deprivation and 2021 census data is available for LSOAs, allowing linking of emissions to demographic factors. A strong association between deprivation and emissions of NO_x from all major sources was observed, with the most deprived 10% of the population experiencing more than double the average emissions of the least deprived 10%.

Minoritised ethnic groups, including minoritised white ethnic groups were shown to experience higher emissions of NO_x and $PM_{2.5}$ than the majority "White: English, Scottish, Welsh or Northern Irish" group at all levels of deprivation. There was considerable variation in the average deprivation and emissions of the groups under umbrella categories e.g. Black, White, Asian, suggesting that these generalisations can obscure key information.

The observed disparities were shown to be affected by all major source sectors, and not solely road transport. Diagnosing these inequalities allows for better informed policy decisions to reduce them.

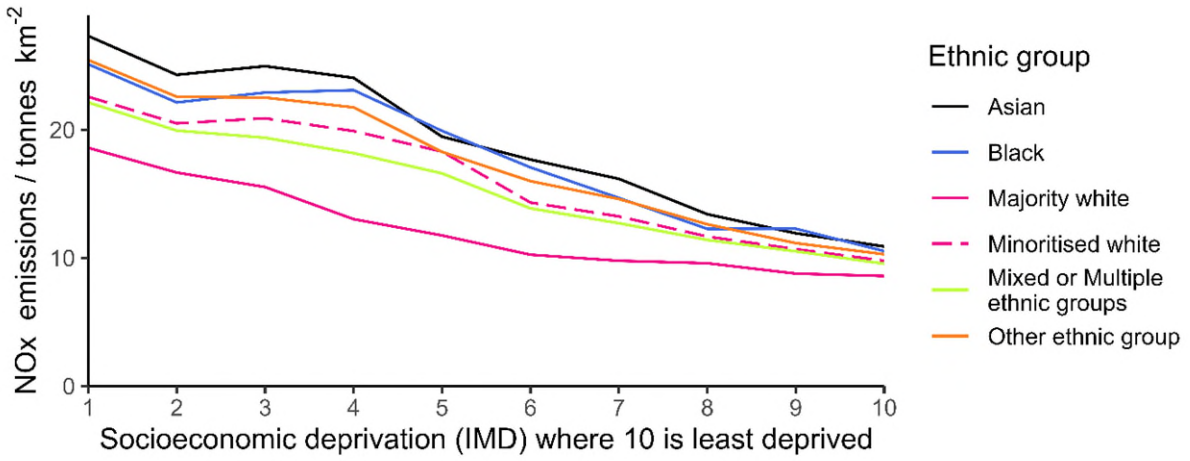

Fig. Graphical abstract. The link between residential emissions and socioeconomic deprivation for broadly classified ethnic groups in England

MITIGATING CHILDREN EXPSORE TO AIR POLLUTION IN AND AROUND CLASSROOMS

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Keywords: Classroom air quality, Thermal comfort, CO_2, PM_{10}, Ventilation rates, UK schools
Associated conference topics: 1.3, 3.10 and 4.9
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The health and academic performance of children are significantly impacted by air quality in classrooms. However, there is a lack of understanding of the relationship between classroom environmental pollutants and contextual factors such as physical characteristics of the classroom, ventilation and occupancy. As a part of EPSRC-funded COTRACE/SAMHE project, we monitored concentrations of particulate matter (PM), CO_2 and thermal comfort (relative humidity and temperature) across 60 classrooms in ten London schools. In another work, we implemented interventions to reduce children's exposure to air pollution in London schools (Abhijith et al., 2022): a green screen at school boundaries lowered outdoor particle levels by 44%, air purifiers reduced indoor particles by 57%, and "school streets" decreased outdoor concentrations by 36%. However, high occupancy levels raised PM_{10} and CO_2 in classrooms, showing the need for effective ventilation.

Results from the 60 classroom studies were compared between occupied and unoccupied hours to assess the impact of occupants and their activities, different floor coverings and the locations of the classrooms. In-classroom CO_2 concentrations varied between 500 and 1500 ppm during occupancy; average CO_2 (955±365 ppm) during occupancy was ~150% higher than non-occupancy. Average PM_{10} (23±15 µg m^{-3}), $PM_{2.5}$ (10±4 µg m^{-3}) and PM_1 (6±3 µg m^{-3}) during the occupancy were 230, 125 and 120% higher than non-occupancy. The average RH (29±6%) was below the 40–60% comfort range in all classrooms. Average temperature (24±2 °C) was >23 °C in 60% of classrooms. Reduction in PM_{10} concentration (50%) by dual ventilation (mechanical + natural) was higher than for $PM_{2.5}$ (40%) and PM_1 (33%) compared with natural ventilation (door + window). PM_{10} was higher in classrooms with wooden (33±19 µg m^{-3}) and vinyl (25±20 µg m^{-3}) floors compared with carpet (17±12 µg m^{-3}). The average CO_2 levels for smaller children (reception and year one) was ~190% higher than older children (year eight and nine) due to higher levels of activity. Air change rate (ACH) and CO_2 did not vary appreciably between floor levels and types. $PM_{2.5}/PM_{10}$ was influenced by different occupancy periods; the highest value (~0.87) was during non-occupancy compared with occupancy (~0.56). Classrooms located on the ground floor had $PM_{2.5}/PM_{10} > 0.5$, indicating an outdoor $PM_{2.5}$ ingress compared with those located on the first and third floors (<0.5). The large-volume (>300 m^3) classroom showed ~33% lower ACH compared with small-volume (100–200 m^3). Low PM_{10} events coincided with low CO_2 events in classrooms across all schools.

These findings provide guidance for taking appropriate measures to improve classroom air quality.

Acknowledgments

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Integration of Earth Observation into the UK Met Office Air Quality Forecasting System

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Keywords: air quality, Earth observation, modelling, satellite data
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Poor air quality (AQ) is one of the largest environmental stresses on human health. In the UK, poor AQ results in 28,000-36,000 premature deaths per year and annual socioeconomic costs of ~£20 billion. To help address this, the UK Met Office (UKMO) provides critical national daily AQ forecasts of key pollutants (e.g. ozone (O_3), nitrogen dioxide (NO_2) and aerosols) to provide the public and government bodies (e.g. Defra) with prior warning of hazardous AQ events.

To evaluate the skill of their forecast model (AQUM – Air Quality in the Unified Model), and to bias-correct the forecasts, the UKMO use AQ measurements from the UK Automated Urban and Rural Network (AURN) of surface sites. The AURN observations are used in the "Statistical Post Processing of Observations (SPPO)" step to correct the forecasts (known as "hybrid-forecasts") before release. However, sparse surface monitoring sites are often unrepresentative of widespread pollution.

Satellite AQ data provides a powerful resource to help address this issue with daily UK spatial coverage, detection of pollution hotspots and transboundary pollution gradients. Therefore, the new project described here (AIRSAT) aims to integrate key satellite AQ products (e.g. tropospheric NO_2 & O_3) into the UKMO's SPPO framework to improve these "hybrid-forecasts", thus benefiting the downstream users of this service.

Here, I will show the first results of the AIRSAT project, comparing AQUM hindcast simulations of key air pollutants with a range of satellite products to quantify the existing model biases and determine a suite of suitable satellite products for the SPPO approach.

Laboratory studies on the photolysis of atmospherically important carbonyls

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Keywords: Atmospheric chemical mechanisms, Photochemistry, Kinetics
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Carbonyls are an important class of volatile organic compounds (VOC) in the atmosphere, being both directly emitted and produced by the oxidation of other VOCs. UV-B photolysis is known to be an important loss process for several classes of carbonyls (ketones and aldehydes), and a source of radicals in the troposphere. Carbonyl photolysis is a driver of atmospheric radical propagation cycles that break down primary pollutants and form secondary pollutants such as ozone (Figure 1). Carbonyls are also broken down by UV-C light of the kind currently popular in air cleaning devices, and so the photolysis of indoor carbonyls emitted from activities like cooking has the potential to also affect indoor air quality.

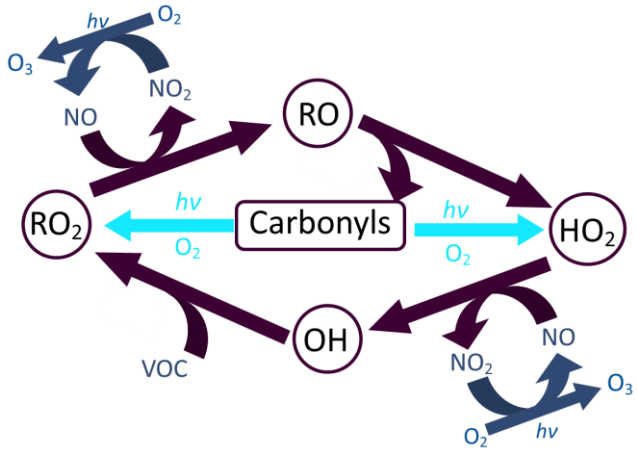

Figure 1: The role of carbonyl photolysis on the NOx catalysed free radical propagation cycles that play a central role in atmospheric chemistry.

However, photochemical data concerning atmospheric photolysis of carbonyl compounds is limited, and research tools such as the Master Chemical Mechanism (MCM; mcm.york.ac.uk) must rely on using parameters from a small number of surrogate compounds to estimate photolysis rates for a larger suite of photolysis-sensitive VOCs.

To address this, we have developed a new laboratory flow reactor that utilises UV-LED technology to study photolysis quantum yields. Currently this uses nitric oxide as a tracer for the peroxy radical photoproducts, assisted by a zero-dimensional chemical box model of the reactor. Preliminary results for acetaldehyde and butanone show reasonable agreement with literature values, and the technique is fast and easy to apply to a range of previously understudied compounds such as longer chain and branched ketones.

A wider understanding of carbonyl quantum yields will improve atmospheric modelling capabilities, particularly under ambient conditions where other sources of gas phase radicals are low. This in turn will allow a better understanding of the fates of pollutants and their effect on air quality both inside and out.

The Drivers of Change in the Historical Human Health Burden from Long-Term Exposure to Surface Ozone

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Keywords: Ozone, Air Quality, Health, Climate.

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Tropospheric ozone is the third most important greenhouse gas within the atmosphere and the growth in its concentrations over the industrial period have contributed to the increase in global mean surface temperatures. In addition, ozone at ground-level is a major air pollutant, with elevated concentrations having detrimental long-term effects on human health though increases risk to respiratory disease. In the troposphere the ozone budget is controlled by chemical production and loss, stratosphere-troposphere exchange of ozone and is removed by deposition at the surface. Ozone concentrations at the surface have increased throughout the 1850 to 2014 period, mainly due to increases in anthropogenic precursor emissions. This increase will have had a large impact on the health of the world population from long-term exposure to ozone concentrations.

Here we use results from chemistry-climate models to quantify the impact on surface ozone concentrations and human health over the period 1850 to 2014 in different scenarios that were conducted as part of the Aerosol and Chemistry Model Intercomparison Project (AerChemMIP), a sub-MIP of the 6th Coupled Model Intercomparison Project (CMIP6). Sensitivity scenarios were used to explore the impact from fixing different drivers of ozone formation at pre-industrial values. We estimate the change in the relative risk of the mortality burden from long-term exposure to ambient surface ozone concentrations in the different scenarios.

Our results show that the global peak season surface ozone concentrations have increased by 40 to 60% from 1850 to 2014 in three different models. Concurrently the percentage of the global population exposed to concentrations above the theoretical minimum risk exposure level (32.4 ppb) has increased from <20% in 1850 to >90% in 2010 (Fig 1a). This has increased the risk of mortality from respiratory disease due to the increase in the long-term exposure to surface ozone concentrations. The increase in surface ozone concentrations and mortality risk is largely driven by increases in anthropogenic NOx and global methane concentrations over the industrial period. If emissions of NOx are kept fixed at 1850 values then the fraction of the near present-day global population exposed to ozone concentrations above 32.4 ppb is reduced substantially to 34%, from >90% when emissions are allowed to increase (Fig 1b). Smaller influences on surface ozone concentrations occur from changes in other anthropogenic ozone precursor emissions, anthropogenic aerosols, transport from the stratosphere and historical climate change. These results show the importance of certain drivers in the human health risk from the long-term exposure to air pollution, which can be used to inform future policy directions.

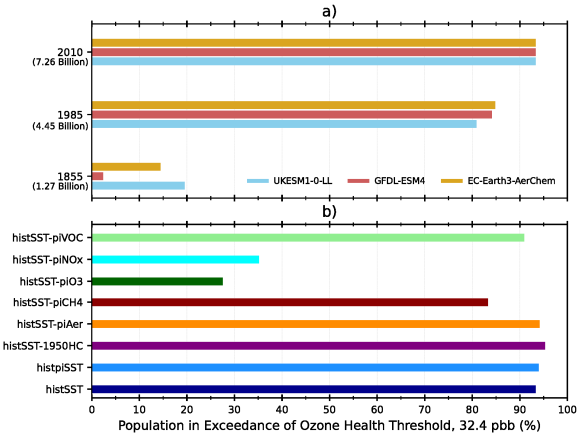

Figure 1 - Percentage of total global population in exceedance of the theoretical minimum risk exposure level (TMREL - 32.4 ppb) to ozone across 3 historical time periods from 3 different CMIP6 models a) and in the different present day (2010) for sensitivity scenarios with different drivers of ozone fixed b). Total global population for each time-period is shown in parenthesis on a).

Future Trends in Air Quality Measurement

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Keywords: Air Quality, Measurement, Metrology, Future Trend, measurement challenges
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Despite significant improvements in air quality, air pollution remains one of the biggest environmental risks to human health. UK government and world organisations continue to emphasize the importance of air quality, and the need to monitor and understand air pollution.

This study by the National Physical Laboratory (NPL) explores future trends in air quality measurement out to 2050, taking a holistic view across science and research, government priorities, societal changes, industrial progress and the international landscape. It drew from the literature, UK Air Quality experts' interviews and NPL knowledge and expertise.

Key challenges in air quality Measurement were identified and summarised across 7 themes:

1. An evolving emission landscape, with lowering concentrations of regulated pollutants and emerging new pollutants, requires agile responses to underpin measurements well in advance of legislation.
2. New technologies enabling dense hybrid air quality monitoring networks, resulting in higher spatial and temporal resolution, and the ability to monitor more measurands such as speciation and source apportionment. Improvement in accuracy of these novel and low-cost sensors will be required.
3. Increasing health consciousness and public awareness could lead to better personal exposure understanding and use of accurate and reliable wearable personal monitors. There needs to be more research into the links between air quality, genomics, and health implications.
4. Increased use of data science, modelling, machine learning and AI in forecasting and data processing will allow better planning and understanding of air quality at lower cost. Challenges will be to ensure transparency, method validation and resulting data confidence.
5. Climate change, increasing global temperatures and extreme weather events risk increasing air pollution. On the other hand, studies show air quality improves with reduced GHG emission from net zero policies.
6. For the biosphere, shortcomings in measurement methods for mould and pollen are concerns. Robust measurements of environmental DNA (eDNA) in air have the potential to revolutionise biodiversity monitoring.
7. Indoor air quality is a theme on the rise. More research is required. This could start with monitoring in public spaces (e.g., trains stations, schools, hospitals), and then progress on to regulations.

An overview of the biggest changes and most impactful future trends was captured in a roadmap. Included are direct measurement trends and future challenges that will require significant science and technology development and innovation.

This work serves as the start of the discussion on future trends in air quality measurement, and it will continue to evolve as political, economic, societal, technological, and environmental factors play out.