MODELAIR – DELIVERABLE

D2.2 – REVIEW AND RESULTS OF ACTIVITIES IN TC1

This report is part of a project that has received funding from the European Union's Horizon Europe MSCA Doctoral Networks 2021 programme under **Grant Agreement No. 101072559**

Deliverable number:	D2.2
Due date:	31st December 2024
Type[1]:	R
Dissemination Level[1]:	PU
Work Package:	WP2
Lead Beneficiary:	Air Quality Consultants (AQC)
Contributing Beneficiaries:	UPM

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Type	R = Report ADM = Administrative PDE = diss./ex. O = Other DEC = Websites, patents filing, press & media actions, videos, etc.
Dissemination Level	PU = Public CO = Confidential, only for members of the consortium (including the Commission Services) CI = Classified SEN = Sensitive, limited under the conditions of the Grant Agreement

DOCUMENT HISTORY

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Version	Date	Description
0.1	29/11/24	Draft
1.0	18/12/2024	**Final version**

Abstract

This report describes the activities and results of MODELAIR Test Case 1, which focuses on Bristol in the UK. The report summarises the emissions sources which drive air quality in the city, and thus drive spatio-temporal variations in measured concentrations. This information is important if open air measurements are used to validate models. While emissions from local road transport are an important source of nitrogen oxides, $PM_{2.5}$ concentrations are typically dominated by emissions released tens or hundreds of km away. The main local source of primary $PM_{2.5}$ is domestic combustion.

A suite of activity data can be used to predict emissions and so formulate air quality models. This has been summarised. The locations of domestic combustion emissions are not known and so the report describes an analysis to predict the effects on concentrations of these sources with unknown locations.

Work to characterise the topography and topology across central Bristol is ongoing. This relates to Deliverable D3.3 and so is not described here.

The University of Bristol boundary layer wind tunnel facility is being used to understand urban flow patterns. This report summarises current activities.

The meteorological data collected for Bristol are summarised. All of the meteorological monitors are outside of the city centre and away from large buildings. They are intended to capture wider-scale meteorological patterns rather than those at specific locations within the city. Only one meteorological monitor provides good data capture over multiple years, but it is a well-sited instrument with respect to wider-scale patterns.

Open air measurements of a range of pollutants are made at more than 200 monitoring sites across the city. Eight of these measure on a 1-hour or shorter time step. These eight sites are all 'reference quality' instruments. The remaining 193 sites use Palmes diffusion tubes. Recent measurements from the reference quality stations are summarised.

Ongoing work to better understand these data is described in a separate deliverable (D4.1).

The information will allow work to continue toward improving predictive air quality modelling capabilities and testing those models against open air measurements. This, in turn, will allow the effect of local-scale urban topology on pollutant dispersion to be better understood, thus allowing future building and urban designs to help in reducing exposure to poor air quality.

Keywords: air quality, industry, pollution, transport, urban topology

Acronyms

AP: Associated Partner

AQMA: Air Quality Management Area

BCC: Bristol City Council

BEN: Beneficiary

CAZ: Clean Air Zone

CFD: Computational fluid dynamics

COO: Coordinator

DC: Doctoral candidate

NO: Nitric Oxide

NO_2: Nitrogen Dioxide

NOx: Nitrogen Oxides (NO_2 + NO)

$PM_{2.5}$: Airborne Particulate Matter with an aerodynamic diameter <2.5 μm

PM_{10}: Airborne Particulate Matter with an aerodynamic diameter <2.5 μm

SIA: Secondary Inorganic Aerosol

SOA: Secondary Organic Aerosol

VOC: Volatile Organic Compounds

WP: Work package

DOCUMENT HISTORY

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1. Introduction

This report fulfils Requirement D2.2 of MODELAIR, which is a review and results of activities in Test Case 1 (TC1). TC1 seeks to understand the influence of the urban topology in air pollution, with specific application in Bristol city centre and outskirts, UK.

The main activities in TC1 are related to WP1: high-fidelity simulations (DC3, DC5), open-air and wind tunnel experiments modelling different complex urban topologies (DC6) and WP2-3: remote-sensing ROMs using deep learning architectures (DC2, DC5).

2. Background

Bristol is a city, unitary authority area and ceremonial county in Southwest England, 105 miles (169 km) west of London, and 44 miles (71 km) east of Cardiff. It has an estimated population of 472,4005 for the unitary authority at present. Within England and Wales, it is the 8th largest city and the 11th largest local authority.

Long-term exposure to air pollution can cause chronic conditions such as cardiovascular and respiratory diseases as well as lung cancer, leading to reduced life expectancy. Short-term exposure (over hours or days) to elevated levels of air pollution can also cause a range of health effects related to lung function, exacerbation of asthma, increases in respiratory and cardiovascular hospital admissions, and mortality. There are a number of other emerging links for air pollution and health, including dementia, a variety of mental health conditions, and adverse pregnancy outcomes.

Exposure to nitrogen dioxide (NO_2) and fine particulate matter (PM_{10} and $PM_{2.5}$) causes around 300 deaths each year of Bristol residents[1]. This represents about 8.5% of all deaths in the City of Bristol being attributable to air pollution. Air quality varies considerably across the city; this is principally linked to spatial variability in emissions, but it also relates to topography and urban topology. The proportions of deaths attributable to air pollution therefore vary across the City, from around 7% in some wards to around 10% in others. Concentrations are highest in the centre of the city and therefore so are deaths attributable to air pollution[1].

Bristol City Council (BCC) has put in place an Air Quality Management Area (AQMA), which covers the city centre and parts of the main radial road network. The AQMA was originally declared in 2001 for exceedances of the UK domestic objectives for annual mean NO_2 and 24-hour mean PM_{10}. It was subsequently updated

[1] https://www.bristol.gov.uk/files/documents/599-health-impacts-of-air-pollution-in-bristol-february-2017/file

in 2003, 2008 and 2011. BCC has put in place a wide range of local measures and policies to improve air quality in the city.

In 2022, BCC introduced a Clean Air Zone (CAZ) with the intention of achieving the EU limit value (now transposed into domestic UK legislation) for annual mean nitrogen dioxide concentrations in the shortest possible time. The CAZ focuses on reducing nitrogen oxides (NOx) emissions from road traffic by restricting vehicular access to vehicles which conform with older European type approval emissions standards. The CAZ is managed using a network of Automatic Numberplate Recognition cameras; owners of non-compliant vehicles entering the CAZ either pay a daily fee or face a punitive fine.

3. Understanding Air Quality in Bristol

To allow model predictions to be made, and in particular to allow them to be reliably compared with the results from open air measurements, it is first necessary to understand local emissions and the relative importance of these local sources to total ambient concentrations; spatial or temporal correlation of model predictions against measurement is only valuable if the variation in measurements is caused by features which are included in the models.

Figure 1 shows, at a spatially coarse resolution, predicted annual mean NO_2 concentrations across Bristol in 2024. The highest concentrations are in the centre of the city, with some elevated concentrations to the north of the city where the M5 Motorway passes and where there is heavy industry around Avonmouth.

Figure 2 shows the relative contributions that different emissions sources make to 1 km^2 average NOx concentrations (it is more convenient to describe the source-apportionment of NOx than NO_2 because of the curvilinear relationship between them). This shows a relatively small contribution from long-range sources, which varies little across the city. The single largest component is road transport, which varies substantially by area. Emissions from industry and domestic combustion are smaller but still significant.

These annual mean concentrations have been averaged over a 1 km^2 grid and so do not capture the additional increments driven by local emissions sources and their interaction with the local topography and topology. Close to roads or other combustion sources, experience shows that NO_2 concentrations can be several tens of $\mu g/m^3$ above these 1 km^2 averages.

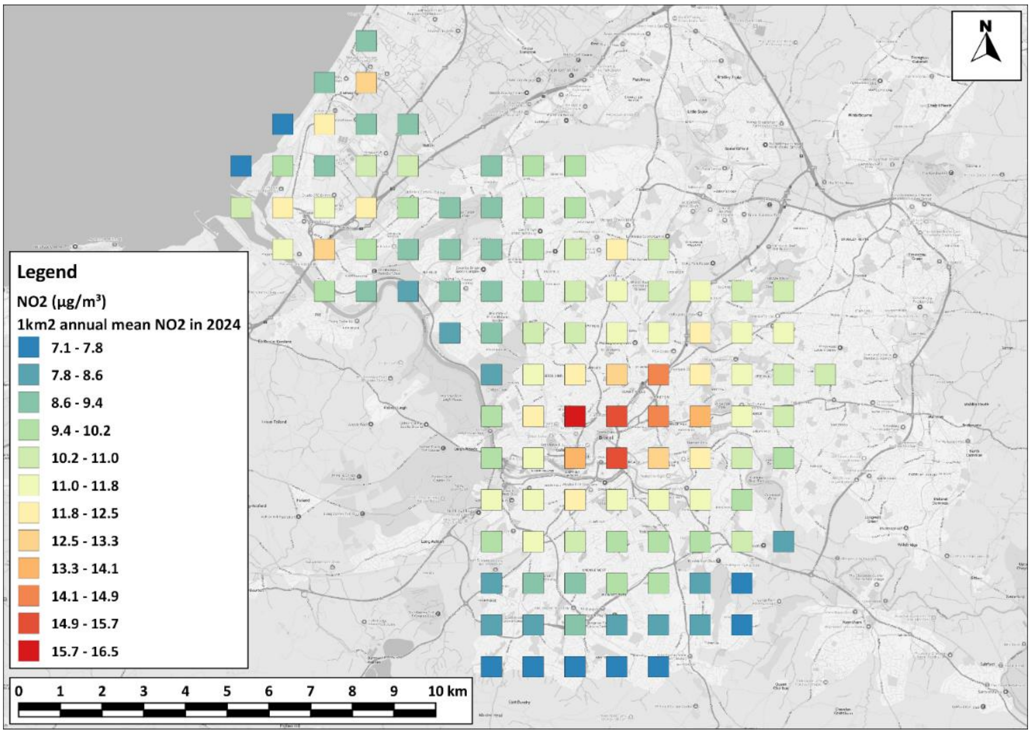


Figure 1: 1km^2 Average Annual Mean NO_2 Concentrations Across Bristol in 2024[2].

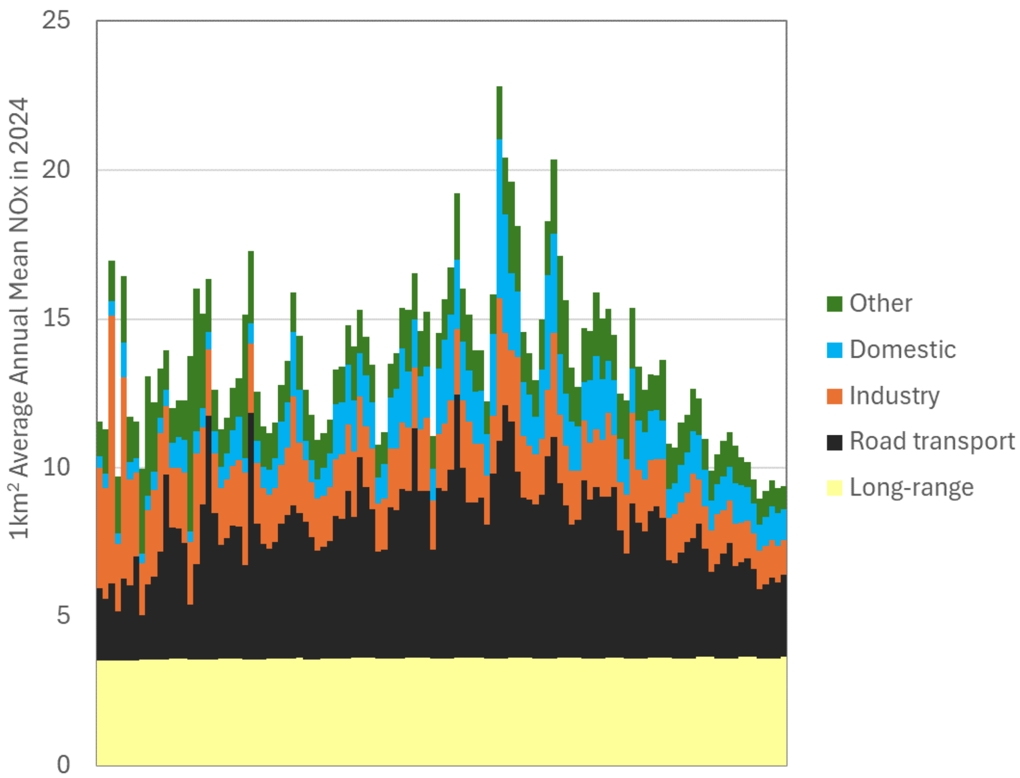


Figure 2: Apportionment of 1km^2 Average Annual Mean NO_2 Concentrations Across Bristol in 2024[2].

[2] Calculated from modelling carried out on behalf of the UK Government: https://uk-air.defra.gov.uk/data/laqm-background-maps?year=2021

Figure 3 shows the distribution of 1km^2 average annual mean $PM_{2.5}$ concentrations across Bristol. The spatial distribution is very different from that of NO_2, with the highest concentrations away from the centre of the city and around the residential areas to the east of the city centre.

Figure 4 shows how different sources contribute to these 1km^2 averages. The single largest component to annual mean $PM_{2.5}$ is secondary aerosol; itself broken down into Secondary Organic Aerosol (SOA) and Secondary Inorganic Aerosol (SIA). SOA and SIA are both formed through chemical reaction of precursor gases (including NOx and, to a lesser extend NH_3 and VOCs from road traffic, domestic combustion and industry). Owing to the reaction speeds, SOA and SIA can form significant distances from where the emissions were released. This means that most SOA and SIA in Bristol's air will originate from outside the City.

The next largest source of anthropogenic $PM_{2.5}$ in Bristol is domestic emissions, with domestic solid fuel burning being particularly important (primary $PM_{2.5}$ emissions from gas combustion are relatively trivial). This explains the different spatial distribution of $PM_{2.5}$ when compared with NO_2. Road transport is a relatively minor source of primary $PM_{2.5}$ (although NOx and NH_3 emissions from transport contribute to SIA over longer scales).

As with NO_2, location-specific $PM_{2.5}$ concentrations close to primary $PM_{2.5}$ emissions sources are elevated above these spatially averaged values. However, the local increments to $PM_{2.5}$ tend to be much smaller (both relatively and by mass) than for NO_2.

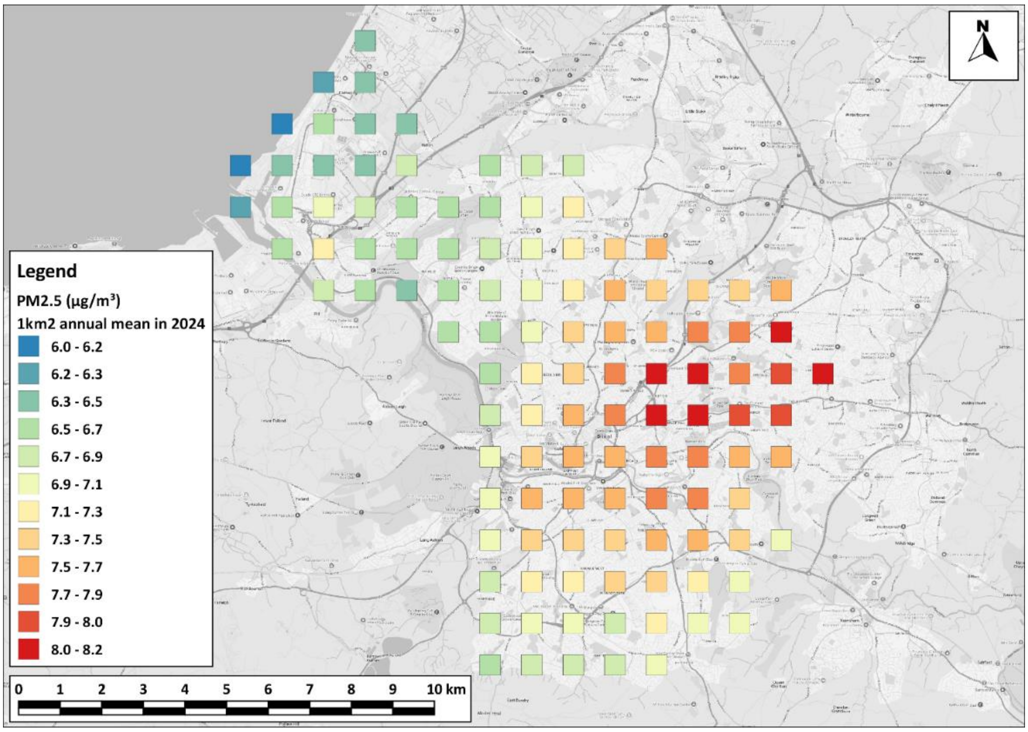


Figure 3: 1km^2 Average Annual Mean $PM_{2.5}$ Concentrations Across Bristol in 2024[2].

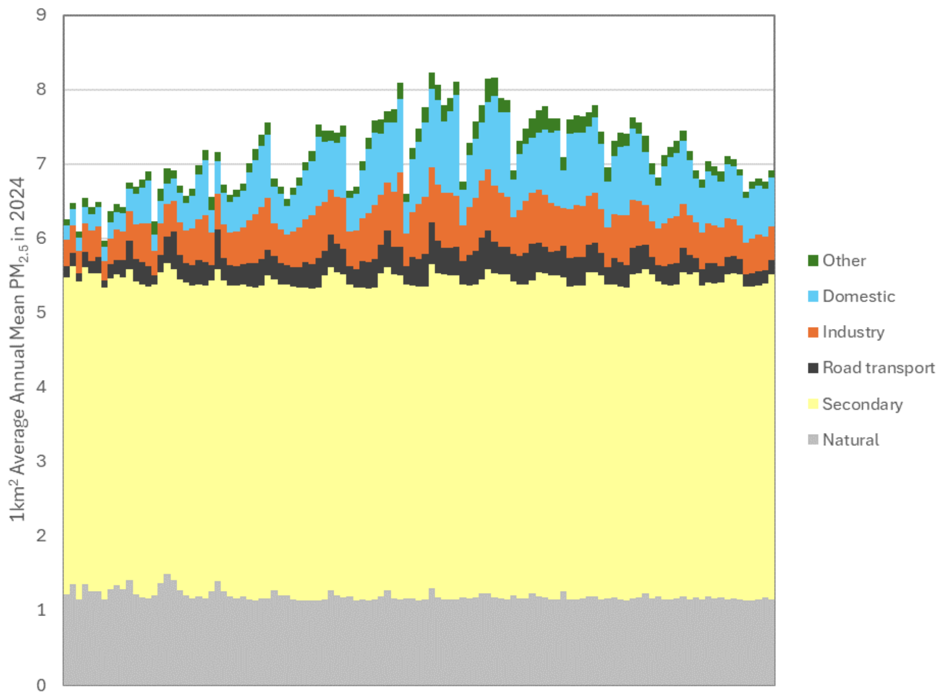


Figure 4: Apportionment of 1km^2 Average Annual Mean $PM_{2.5}$ Concentrations Across Bristol in 2024[2].

4. Activity Data for Air Quality Modelling

Figure 5 shows the locations of traffic surveys, while Figure 6 shows an example of the speed limits which apply across the city. These can be used to characterise street-scale road traffic emissions. Figure 7 shows the locations of significant industrial emissions sources in the central part of the city.

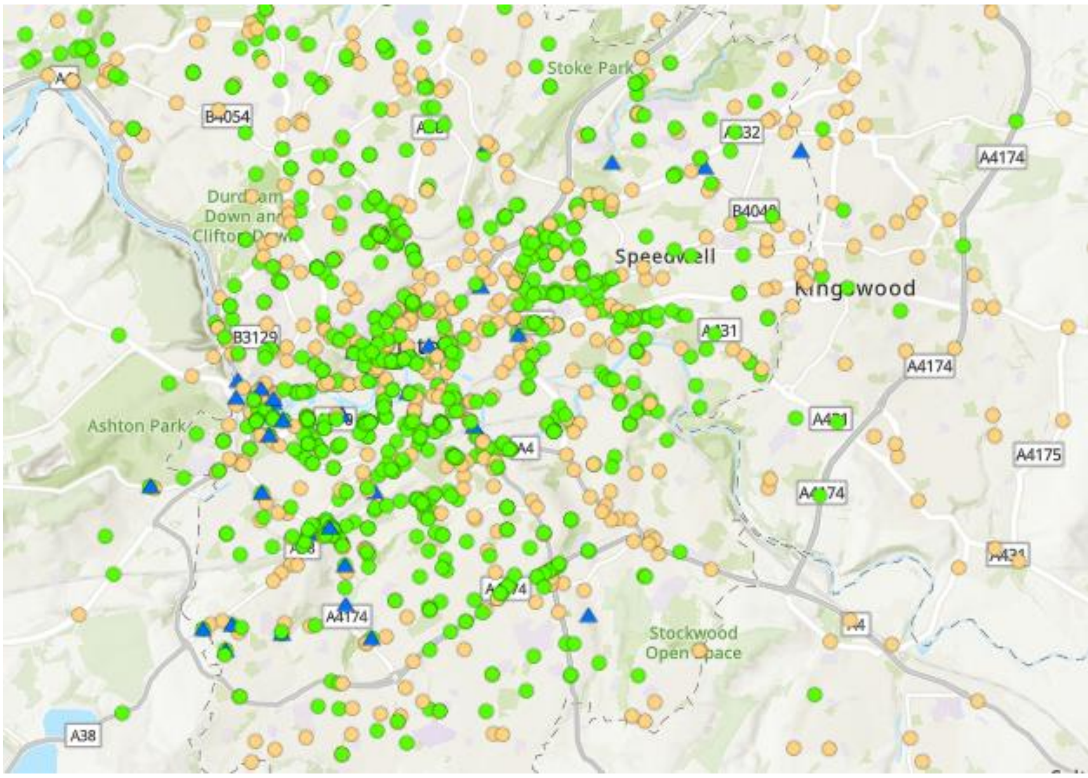


Figure 5: Traffic Survey Locations in Bristol (orange sites are historic, green sites are newer, and blue sites are permanent real-time counters).

Figure 6: Traffic Speed Limits in Bristol (miles per hour).

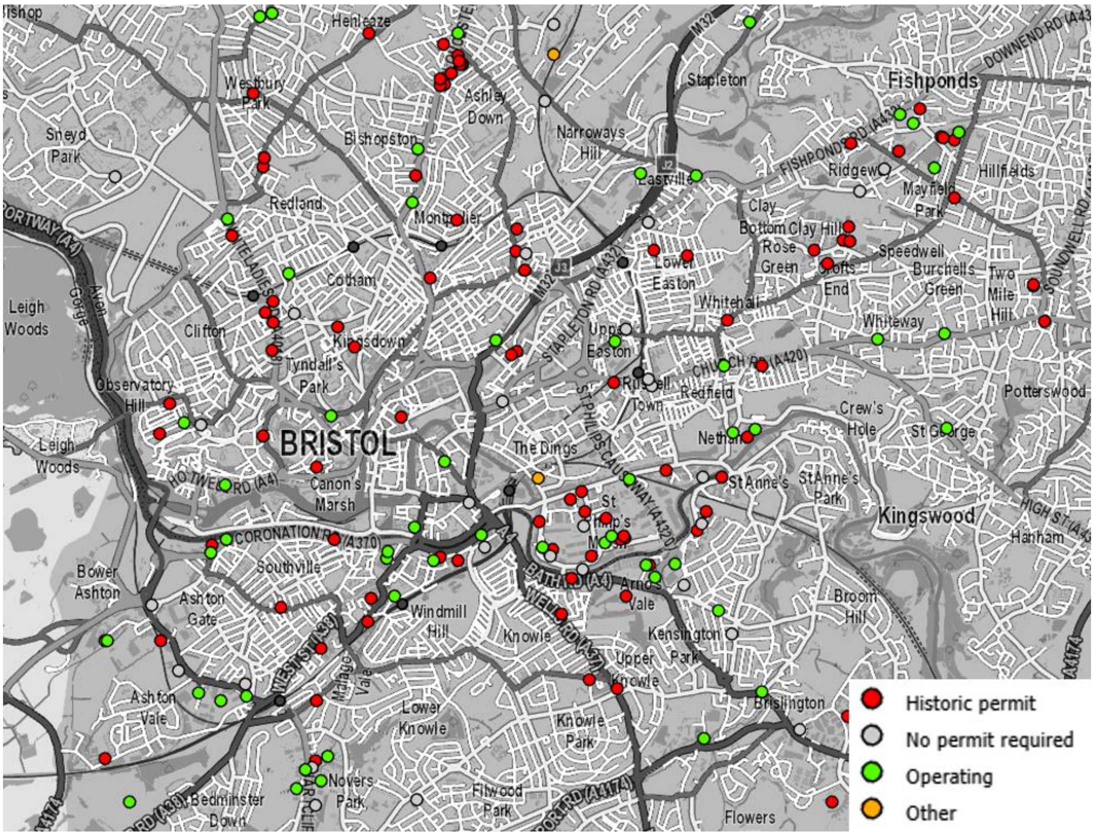


Figure 7: Significant Industrial Processes in Bristol.

It is more difficult to characterise domestic emissions of $PM_{2.5}$. Total domestic emissions of primary $PM_{2.5}$ are released by a relatively small proportion of the Bristol population, but there are no accurate records on which residents burn solid fuels, where, or how often. We have therefore carried out work to better understand this source and how its distribution is likely to affect concentrations across the city. We have first estimated the number, and very approximate spatial distribution, of domestic properties which regularly burn solid fuels (Figure 8).

Next, we generated preliminary dispersion footprints associated with each individual release. At present, this is based on simplistic Gaussian plume modelling, but work is ongoing which will allow these assumptions to be refined (Figure 9).

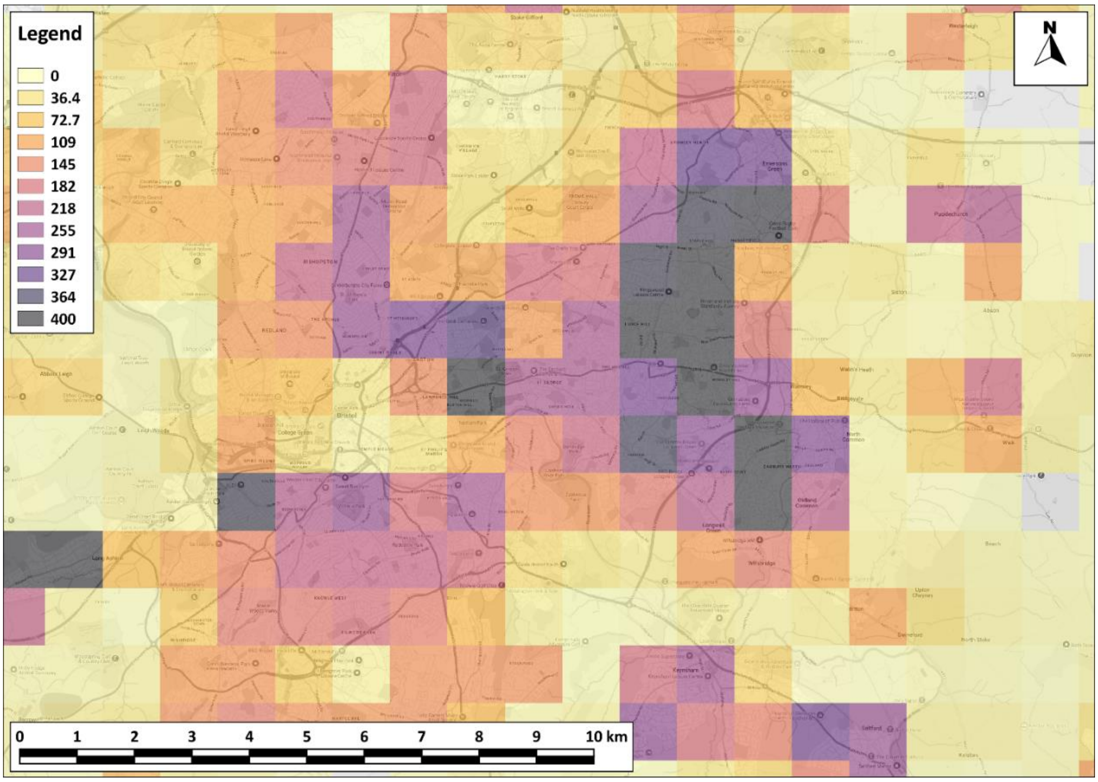
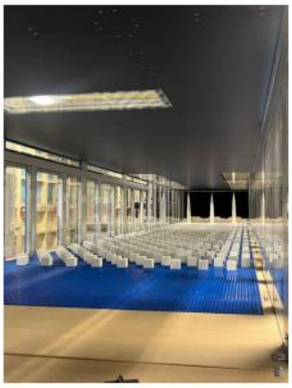
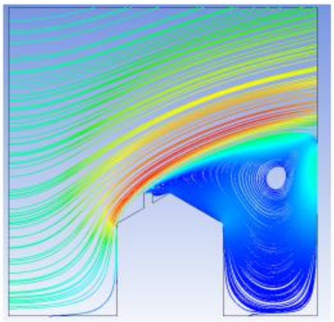


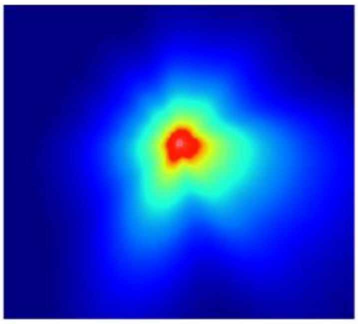
Figure 8: Approximate Number of Houses per km^2 Who Regularly Burn Solid Fuels in Bristol[3].



Wind tunnel from University of Bristol



Streamlines from CFD simulation



ADMS software pollutant distribution

Figure 9: Generating local dispersion footprints from domestic $PM_{2.5}$ releases.

[3] Calculated from emissions data and a-priory assumptions published by UK Government.

Working alongside Imperial College London, we have tested the effects of large numbers of random spatial distributions for the domestic emissions within each of the grid square depicted in Figure 8. Figure 10 shows an example of how the contribution of domestic burning to annual mean $PM_{2.5}$ concentrations varies along a transect for a single random distribution of 800 homes burning solid fuel, while Figure 11 shows, based on the current Gaussian dispersion estimates, the relationship between the maximum ambient $PM_{2.5}$ concentration and the number of houses burning solid fuels.

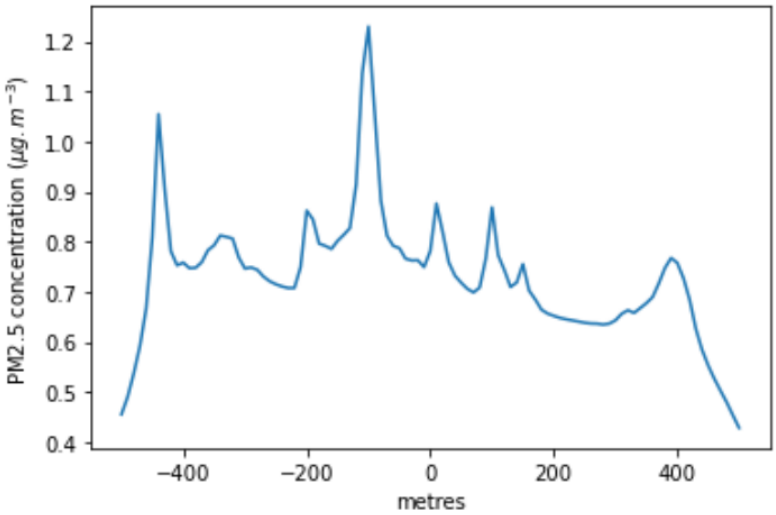


Figure 10: Initial[4] Transect of $PM_{2.5}$ Concentrations from Domestic Woodburning for a Single Random Distribution of 800 Emissions Sources[5].

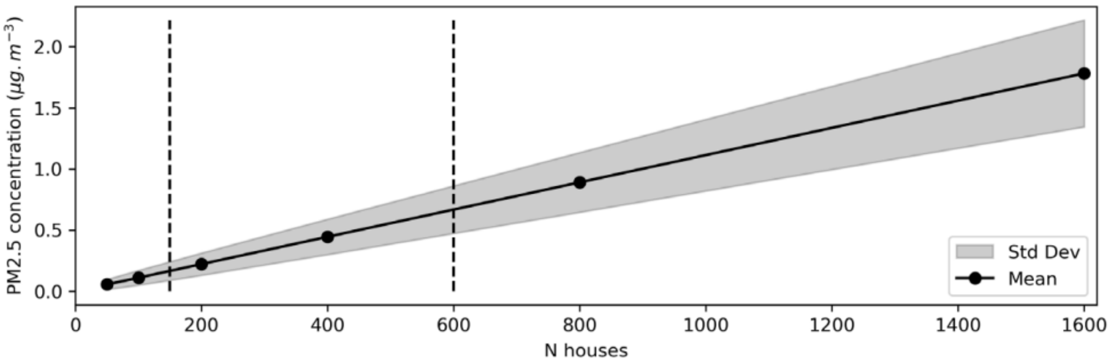


Figure 11: Initial[4] Relationshp Between Number of Houses with Domestic Solid Fuel Emissions and the Maximum Increment to Annual Mean $PM_{2.5}$ Concentrations[5].

[4] Prior to subsequent refinements.
[5] Almeida and Woodward, 2024 (https://aprilresearchlondon.wordpress.com/2024/06/18/april-meeting-on-air-pollution-from-domestic-wood-burning-monday-29th-july/)

5. Characterising the Topography and Topology

Work undertaken to characterise the topography and topology of Bristol is ongoing and is addressed separately in Deliverable D3.3.

6. Understanding Urban Flow Patterns

The study of fluid dynamics and pollutant dispersion in the atmospheric boundary layer often requires modelling complex phenomena that occur in real-world environments, which in this deliverable we will call “full-scale” environments. In the wind tunnel environment, the controlled environment can be achieved once the variables that determine the type of atmospheric boundary layer are set. These include velocity, roughness element height or arrangement, boundary layer thickness, etc. This process involves selecting appropriate scaling laws and ensuring that key dimensionless numbers governing the flow, buoyancy and dispersion remain consistent with the full-scale systems.

For our study, three very important dimensionless numbers are used for the scaling process which are the Reynolds number, Richardson number and Jensen number. The Reynolds is represented by the following equation:

$$Re_h = \frac{\rho U_h h}{\mu}$$

where ρ, U_h, h and μ are the density of the fluid, the velocity at the building’s height h and the dynamic viscosity, respectively. This dimensionless number represents the ratio of inertial to viscous forces in the flow, where flow independency can be reached for $Re_h > 10^4$.

The Richardson number quantifies the relative importance of buoyance to shear forces and can be written as:

$$R_i = \frac{g\Delta\theta h}{\theta_0 U^2}$$

where $g, \Delta\theta, \theta_0$ and U is the gravitational acceleration, difference between two reference points, a reference temperature and reference velocity, respectively. Basically, three different types of atmospheric boundary layer can be classified according to the Ri number. When $Ri < 0$, we have an instable boundary layer where strong turbulence and mixing level are achieved and a rapid dispersion of pollutant can be observed, $Ri = 0$ is the neutral boundary layer where turbulence is primarily driven by shear forces and usually occurs when $\Delta\theta \approx 0$, in other words, when heating and cooling effects are minimal. When $Ri > 0$ we have a stable boundary layer where colder, denser air below resists vertical motion.

The Jensen number is a dimensionless number which correlates the ratio between the building height and the boundary layer thickness $\left(\frac{h}{\delta}\right)$, which is the first dimensionless number used to scale a real building height into the wind tunnel scales.

The benchmark chose to be reproduced into the wind tunnel was selected from the paper titled "*Effect of turbulence and its scales on the pressure field on the surface of a three-dimensional square prism*" where three different boundary layer thicknesses were used with a rectangle of 0.25m height and 0.1m length and width to simulate a full-scale building of 125m height.

Taking account of the experiments in this paper, and scaling to the wind tunnel characteristics in the University of Bristol, the rectangular building has 0.146m height and 0.058m length and width, respecting the same Jensen number from the baseline paper. For rectangle building shapes, two different types of vortex formation can be observed, dipole and quadrupole vortex where it depends on the aspect ratio of the building $\left(\frac{h}{w}\right)$, where w is the building's width. This baseline is 2.52 aspect ratio which is basically the lower limit of the transition between the two-vortex regimes. Therefore, a RANS simulation was performed using OpenFOAM to verify what should be expected from the flow behaviour. Figure 12 shows that horseshoes can be expected in the bottom region, but also a high recirculation zone with two more vortex tips in the top region of the building, which can be used to say that we might expect a behaviour closer to the quadrupole vortex regime than two-vortex regime.

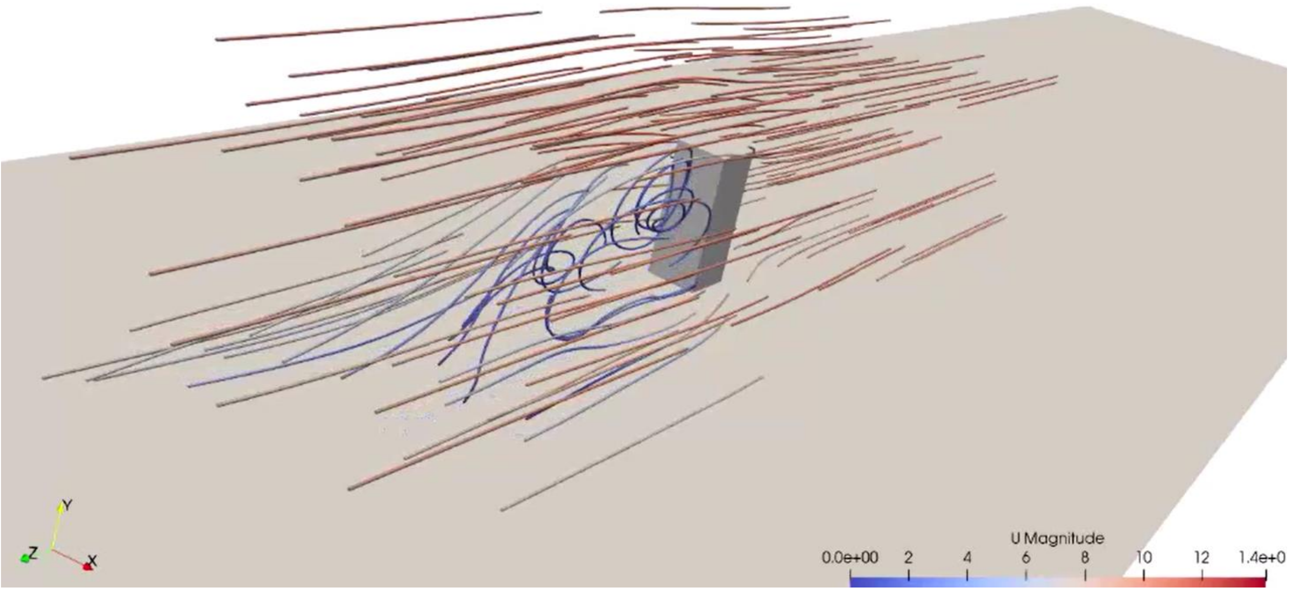


Figure 12: Velocity streamlines for a building of 2.52 aspect ratio.

A sketch of this building is shown in Figure 13, where the holes are following a logarithmic distribution where the lower and upper regions of the building have a higher density of holes to measure pressure, following the qualitative insight provided by the OpenFOAM simulation.

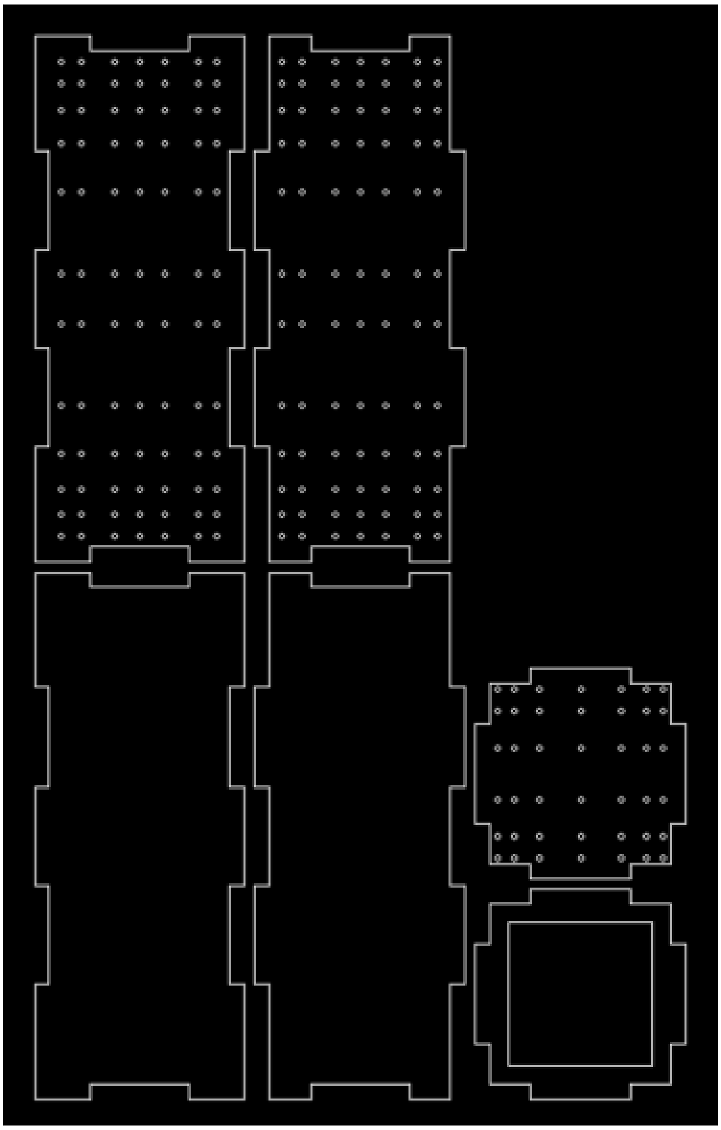


Figure 13: Sketch of the baseline building for University of Bristol experiment.

The material used was an acrylic of 4mm thickness which gave a certain stability to the sketch when it is attached in the wind tunnel. Once the sketch is laser cut, each hole can be filled with brass tube of 1.6mm OD (outer diameter) to measure the pressure distribution on the walls of each side of the building, including the top region. Figure 14 shows some brass tubes used in one side wall of the laser cut sketch. Despite that this process seems very simple, it took about 2 weeks to be finalised once we have done different types of sketches. Also, the process of brass tube cutting is very manual and takes a very long time. 126 tubes were used and a technique was needed to cut it without damaging the tubes throughout the process. Once the brass tubes were cut, sanding was necessary on each side to make sure that inlet and outlet regions were well smoothed and flat enough to not damage the hose that is then coupled on it as shown in Figure 15.

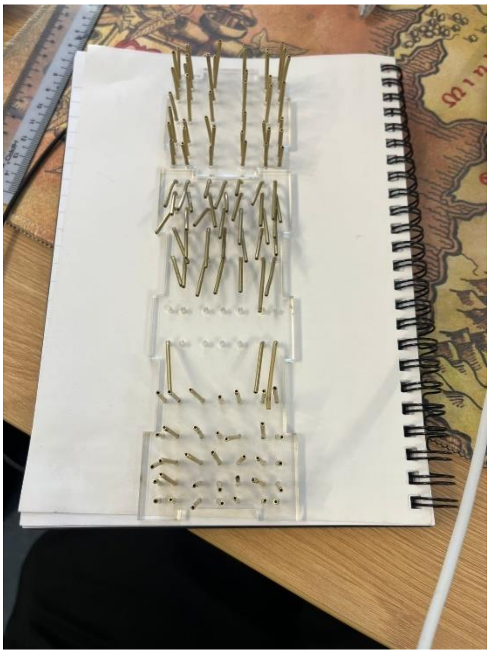


Figure 14: brass tubes filling the holes of one side of the building.

Figure 15 shows a coupled silicone hose on the brass tube and pressure sensor that we have ordered to run the future experiments. Previously, different types of hose were used for testing, but none were able to couple both brass tubes and the barbs on the pressure sensor once they have different outer diameters.

Throughout this process of planning the baseline experiments, there have been weekly meetings with supervisors and staff from the University of Bristol. These have discussed the research questions of this project and technical elements of the wind tunnel experiments; for instance, the traverse system and arm design.

Measurement of concentration profiles in different regions implies that we do need a 3D traverse system which would be able to measure in both concentration and velocity profiles in X, Y and Z direction inside the wind tunnel. As it is a big process, two MODELAIR DCs (Matheus -DC6 and Nada -DC8) have been in charge of the discussion with the responsible technical team in the University of Bristol to discuss the design. They have also been developing and discussing a new arm system, which is the support where the hot-wire probe and FID suction needle, the former to measure velocities and the later to measure concentrations. Specifically for analyses downstream of a building, the arm design must be robust enough to be stable and support the aerodynamic forces from the flow itself and the vibration caused by the vortex formation. In this case, an angled arm has been discussed to be manufactured. Throughout this whole process, the partnership between

(MODELAIR DCs) Matheus and Nada has been such that Nada has been supporting and helping Matheus to better understand the calibration process for single hot-wire measurement, laser cut and 3D printing, etc, while Matheus has been helping Nada with her experiments to obtain velocity profiles.

Figure 15: Brass tube coupled to a hose in the pressure Sensor.

7. Bristol Meteorology

Meteorology is measured in Bristol by the UK Meteorological Office and Civil Aviation Authority. There are four stations around the city (Figure 16), but only one (Bristol Lulsgate) has operated during every recent year. The Bristol Lulsgate monitor is located at Bristol Airport, approximately 376m above sea level and to the southwest of the city. The monitor is located on an approximately 10m tall mast in open ground away from the immediate influence of buildings. Figure 13 summarises the recent measurements from this station.

Figure 16: Meteorological Monitoring Sites Around Bristol.

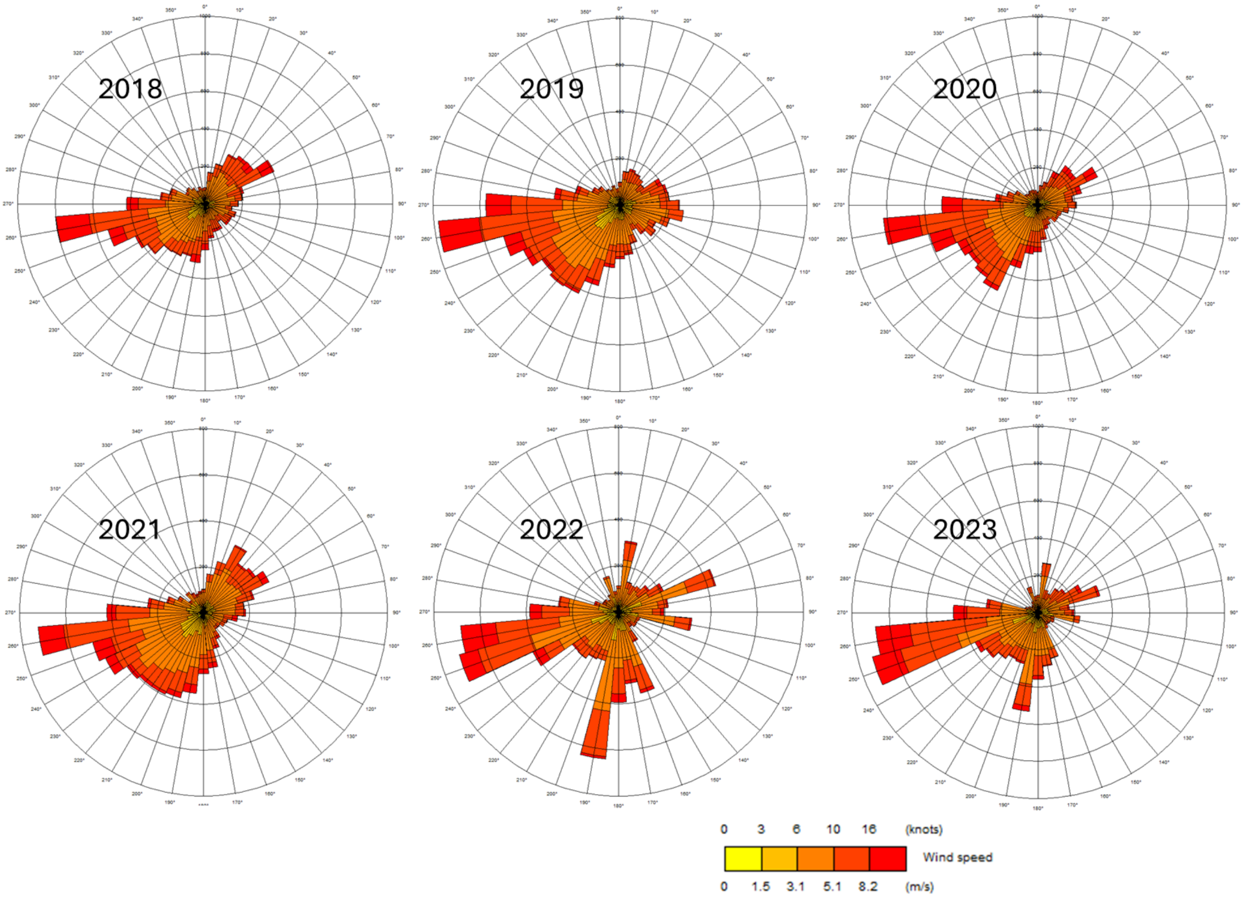


Figure 17: Summary of Six Years' Meteorological Measuremets at Bristol Lulsgate.

8. Open Air Measurements

Accurately measuring $PM_{2.5}$ in ambient air is extremely challenging. $PM_{2.5}$ is a measurement-defined metric; Standard EN12341 describes capturing particulate matter on filters and weighing them by means of a balance. It is not possible to collect time-resolved data in this way. Time-resolved monitors (e.g. those which measure on a 1-hour or less time-step) apply a range of techniques to approximate equivalence with the gravimetric approach[6]. This typically involves either complex or simple post-processing. Because the chemistry and volatility of $PM_{2.5}$ varies both spatially and temporally, so does the ability of any instrument to accurately replicate gravimetric filter measurements. A given chemical mix of $PM_{2.5}$ might cause measurement bias in one location which does not occur in another location even for the same instrument type.

This is a particular problem given the relatively narrow range in which $PM_{2.5}$ concentrations exist in any local environment. Figure 17 shows that 1 km^2 average annual mean $PM_{2.5}$ concentrations vary by less than 1

[6] https://uk-air.defra.gov.uk/assets/documents/reports/cat05/2411120859_PM_measurement_AQEG_submitted_19jun2023_update20241111.pdf

μg/m^3 across much of the city. The local increment of concentrations above these spatial averages is often less than 1 μg/m^3 even close to emissions sources[7]. It is, therefore, very often the case that differences between $PM_{2.5}$ concentrations measured in two contrasting locations are smaller than the potential error margins of those measurements.

While comparisons of temporal changes at a single site are less sensitive to these issues (particularly over a short time period), similar artefacts do still exist. For these reasons, the preferred instruments for time-resolved ambient $PM_{2.5}$ monitoring are termed 'reference equivalent' instruments. These have a demonstrated compliance with EN12341 as defined in EN 16450.

Measuring NOx and NO_2 is more straightforward. In particular, the near-source increments of NOx and NO_2 are relatively much greater than for $PM_{2.5}$, making between-site comparisons and short-term temporal patterns much less sensitive to measurement uncertainty. Most sources of primary $PM_{2.5}$ also emit NOx, and so NOx and NO_2 measurements can be very helpful to understanding the distribution of $PM_{2.5}$. Notwithstanding this, time-resolved data from reference equivalent instruments (in this case relying on chemiluminescence) are the most reliable basis of analysing concentrations.

This study relies on time-resolved measurements made around Bristol using reference equivalent instruments owned by BCC (and in one case, by central Government). Additional, indicative, monitoring of NO_2 is also used, but it is only appropriate to consider these measurements as annual averages which limits their value for model validation.

We have eight reference equivalent monitoring stations as described in Table 1 and shown in Figure 18. There are a further 193 indicative NO_2 monitoring sites using Palmes type tubes[8], most of which are shown in Figure 19.

[7] e.g. https://uk-air.defra.gov.uk/assets/documents/reports/cat09/1907101151_20190709_Non_Exhaust_Emissions_typeset_Final.pdf
[8] https://www.mdpi.com/2073-4433/10/7/357

Table 1: Description of Time-resolved Open Air Monitoring Sites in Bristol.

Site Name	Setting [a]	Pollutants measured	Monitoring Technique	Distance to kerb of nearest road (m)	Inlet Height (m)
Brislington Depot	UB	NOx NO_2 NO	Chemiluminescent	18	3.5
Parson Street School	R	NOx NO_2 NO $PM_{2.5}$	Chemiluminescent (NOx) and Beta Attenuation (PM)	4	1.5
Wells Road	R	NOx NO_2 NO	Chemiluminescent	1	1.5
AURN St Pauls	UB	NOx NO_2 NO $PM_{2.5}$ PM_{10} O_3	Chemiluminescent (NOx) and Beta Attenuation (PM)	n/a	4
Fishponds Road	R	NOx NO_2 NO	Chemiluminescent	3	1.5
Temple Way	R	NOx NO_2 NO PM_{10}	Chemiluminescent (NOx) and Beta Attenuation (PM)	5	1.5
Colston Avenue	R	NOx NO_2 NO	Chemiluminescent	2	1.5
Marlborough Street	R	NOx NO_2 NO	Chemiluminescent	3	1.5

[a] R= Roadside, UB = Urban Background.

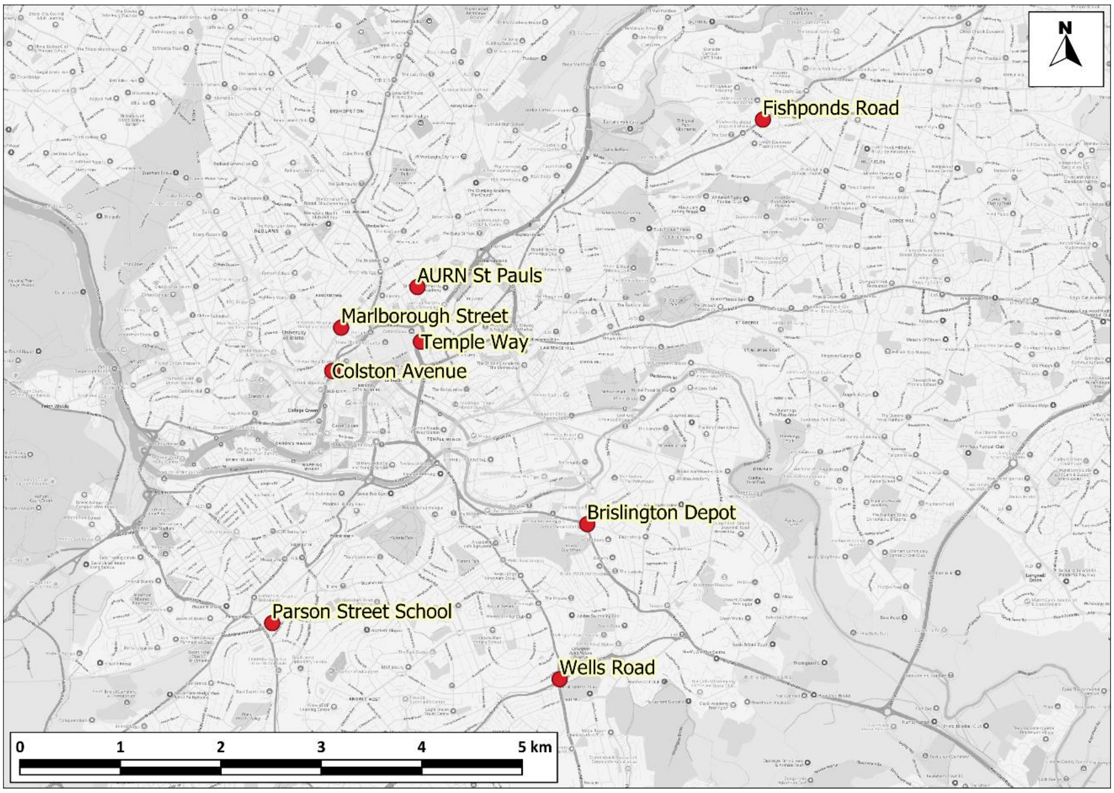


Figure 18: Locations of Reference Equivalent Open Air Monitoring Sites in Bristol.

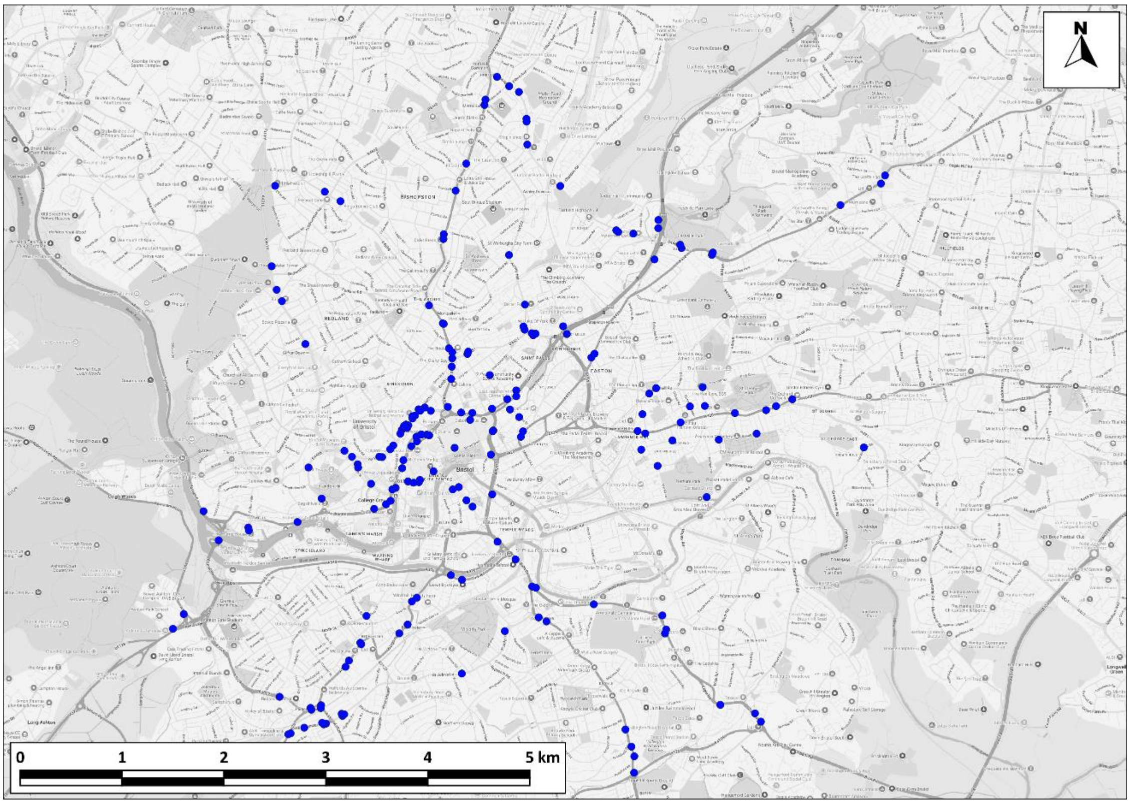


Figure 19: Locations of Indicative NO_2 Samplers in Bristol.

Figures 20 to 24 summarise recent measurements of NOx, NO_2 and NO on a 1-hour time-step at Fishponds Road, Marlborough Street, Parson Street, Wells Road, and Brislington. The concentrations follow well-understood temporal patterns, driven principally by meteorology and the height of the atmospheric boundary layer.

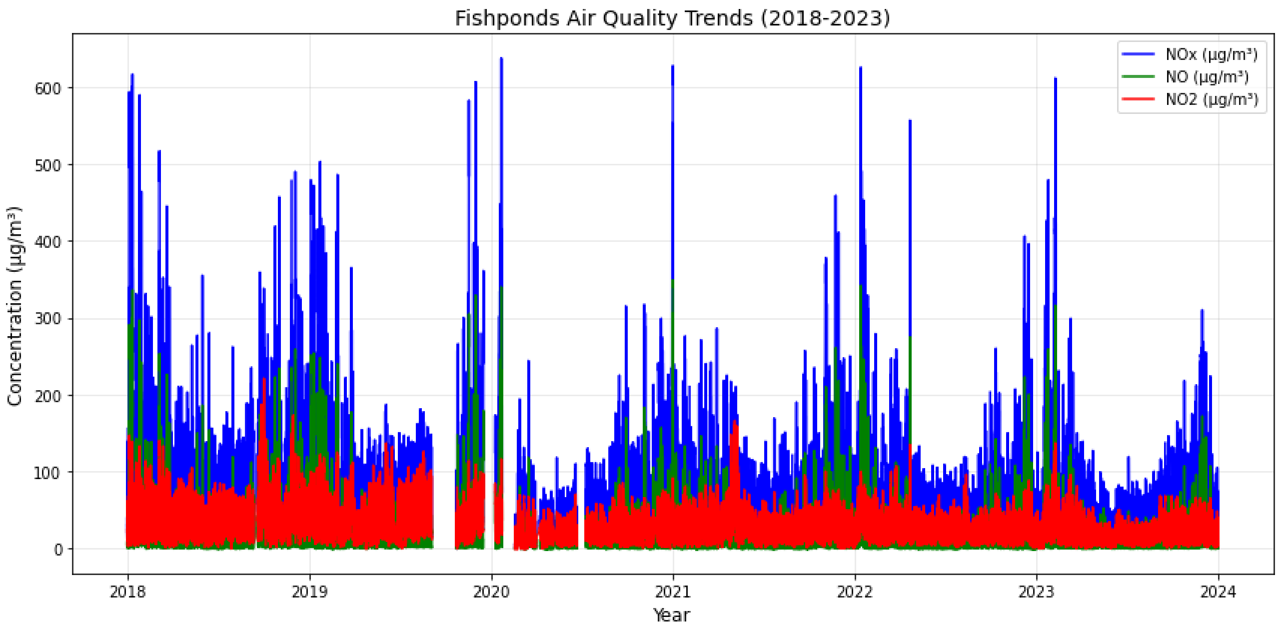


Figure 20: Concentration of NOx, NO and NO_2 from 2018 to 2023 in Fishponds.

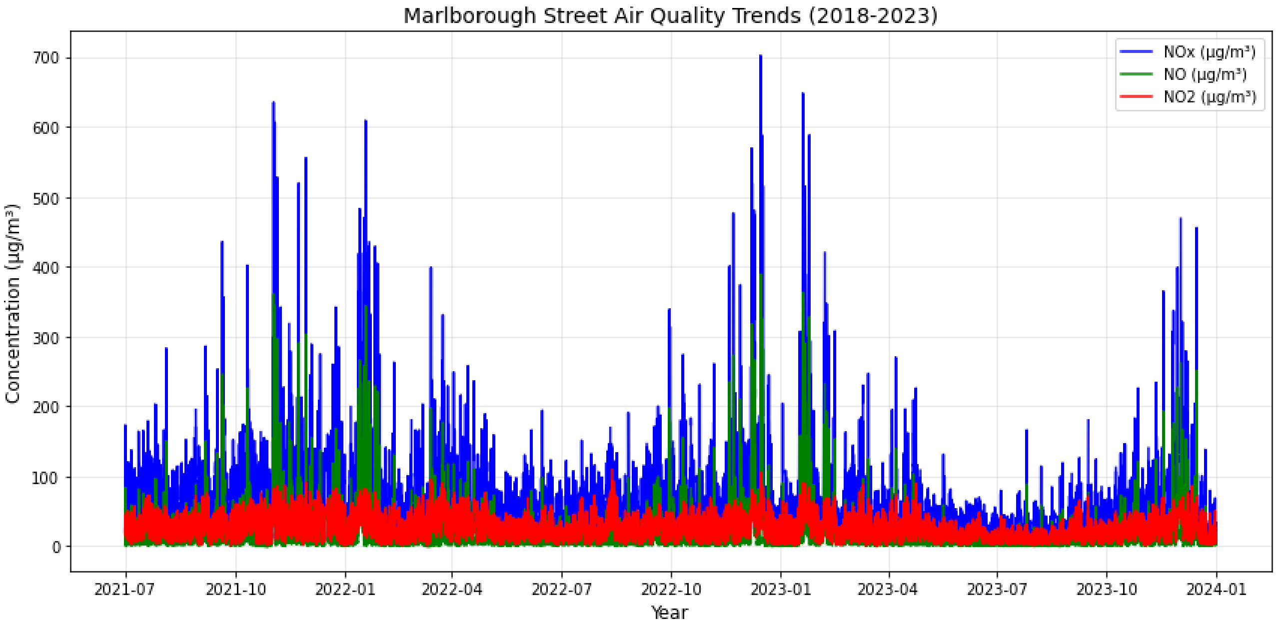


Figure 21: Concentration of NOx, NO and NO_2 from 2018 to 2023 in Marlborough Street.

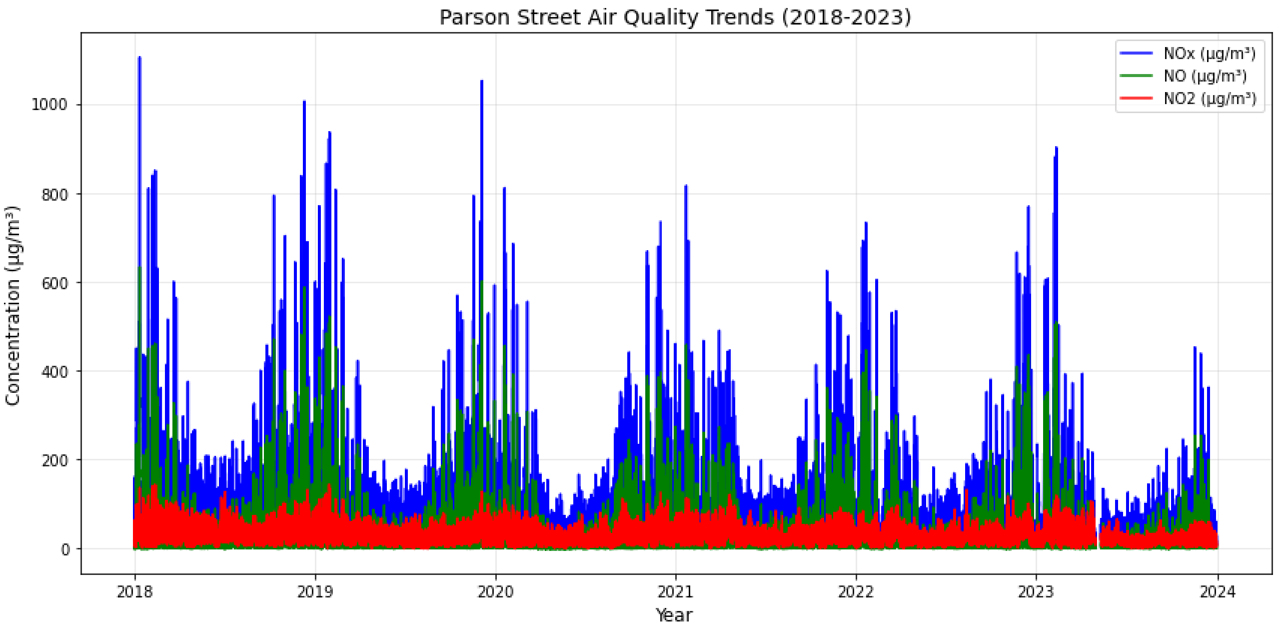


Figure 22: Concentration of NOx, NO and NO_2 from 2018 to 2023 in Parson Street.

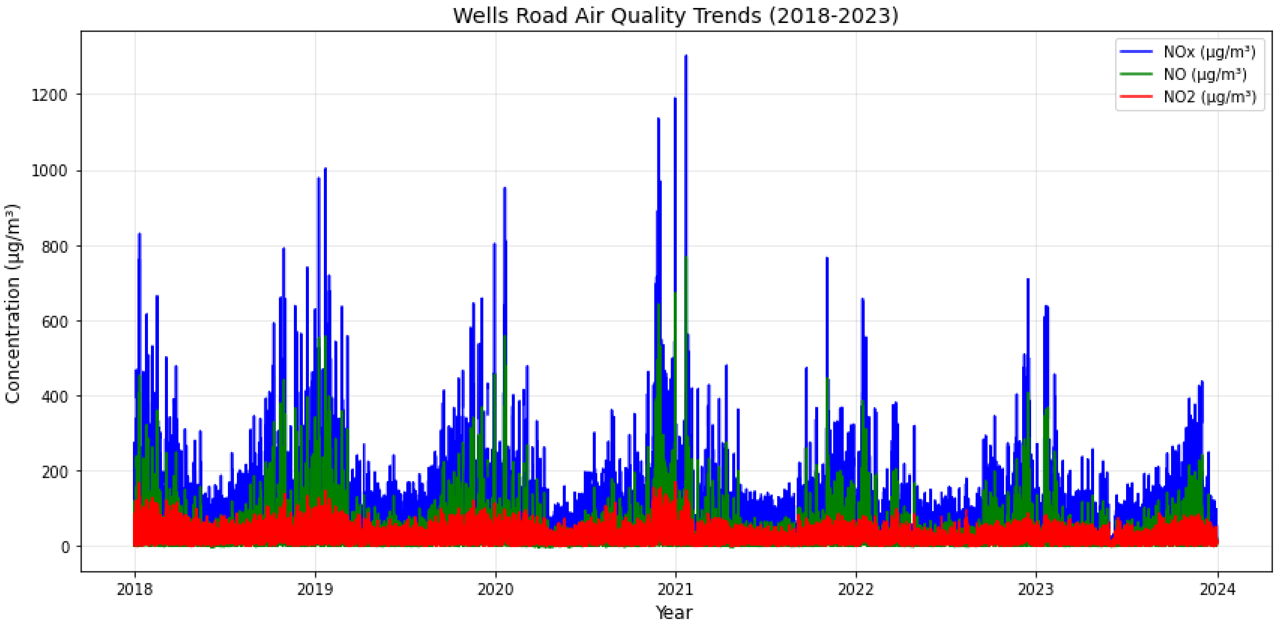


Figure 23: Concentration of NOx, NO and NO_2 from 2018 to 2023 in Wells Road.

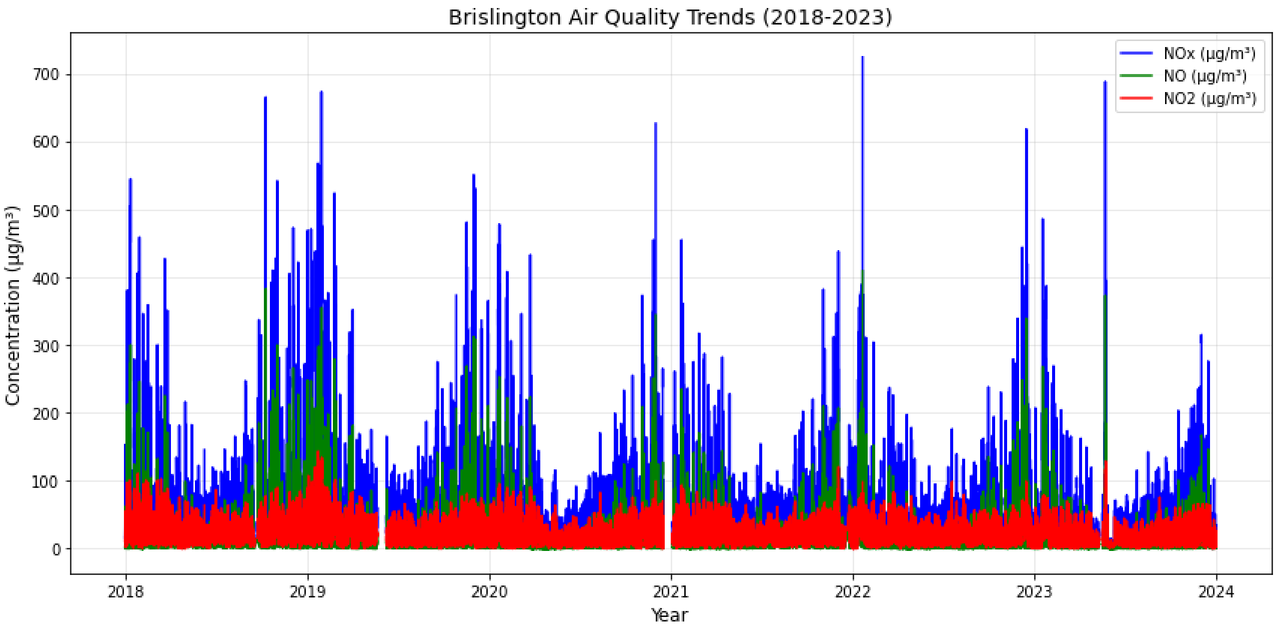


Figure 24: Concentration of NOx, NO and NO_2 from 2018 to 2023 in Brislington.

Figure 25 compares NO_x concentrations measured at different sites. Over this period, NOx concentrations have reduced, particularly at roadside sites within the CAZ.

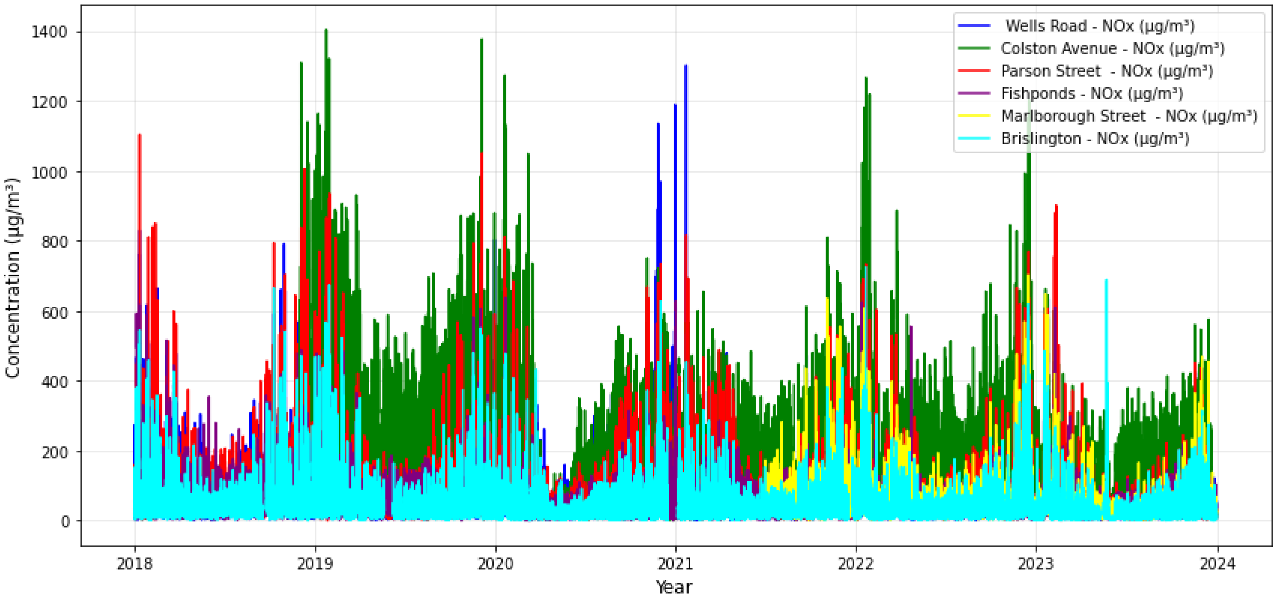


Figure 25: Concentration of NOx at different sites in Bristol City.

Figure 26 shows $PM_{2.5}$ concentrations on a 1-hour timestep measured at Parson Street from 2020 to 2023. It is common for $PM_{2.5}$ concentrations to experience isolated periods of atypically high concentrations, as is shown in this example. These can be caused by local fugitive emissions or regional episodes.

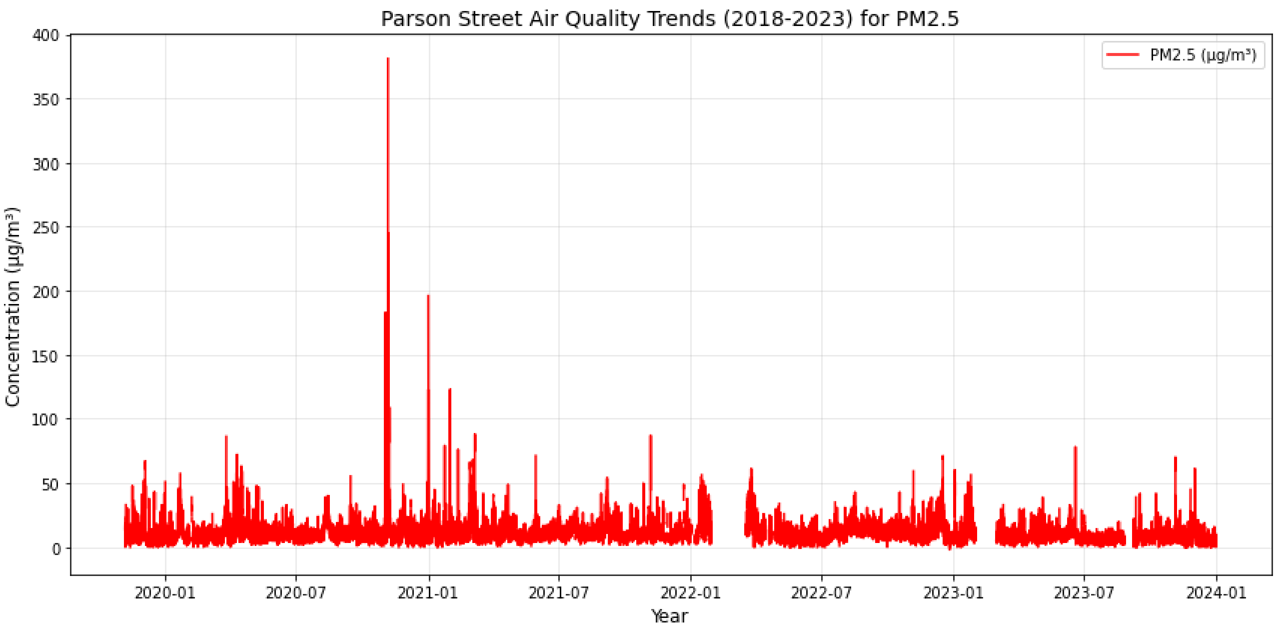


Figure 26: Concentration of $PM_{2.5}$ at Parson Street.

To see the whole dataset, please access: https://docs.google.com/spreadsheets/d/1a-_Qn6atcWIFsgp9IdzwLH0DR5yYe41u/edit?usp=drive_link&ouid=105073662840815718145&rtpof=true&sd=true

As an example of how building topology affects pollutant concentrations in Bristol, Figure 27 shows in more detail the location of the Temple Way monitor. One of the main traffic routes through the city is approximately 5 m to the west of the monitor, running in a northeast to southwest direction. Immediately to the northeast is a large building, while to the west is a semi-pedestrianised area with limited vehicular access.

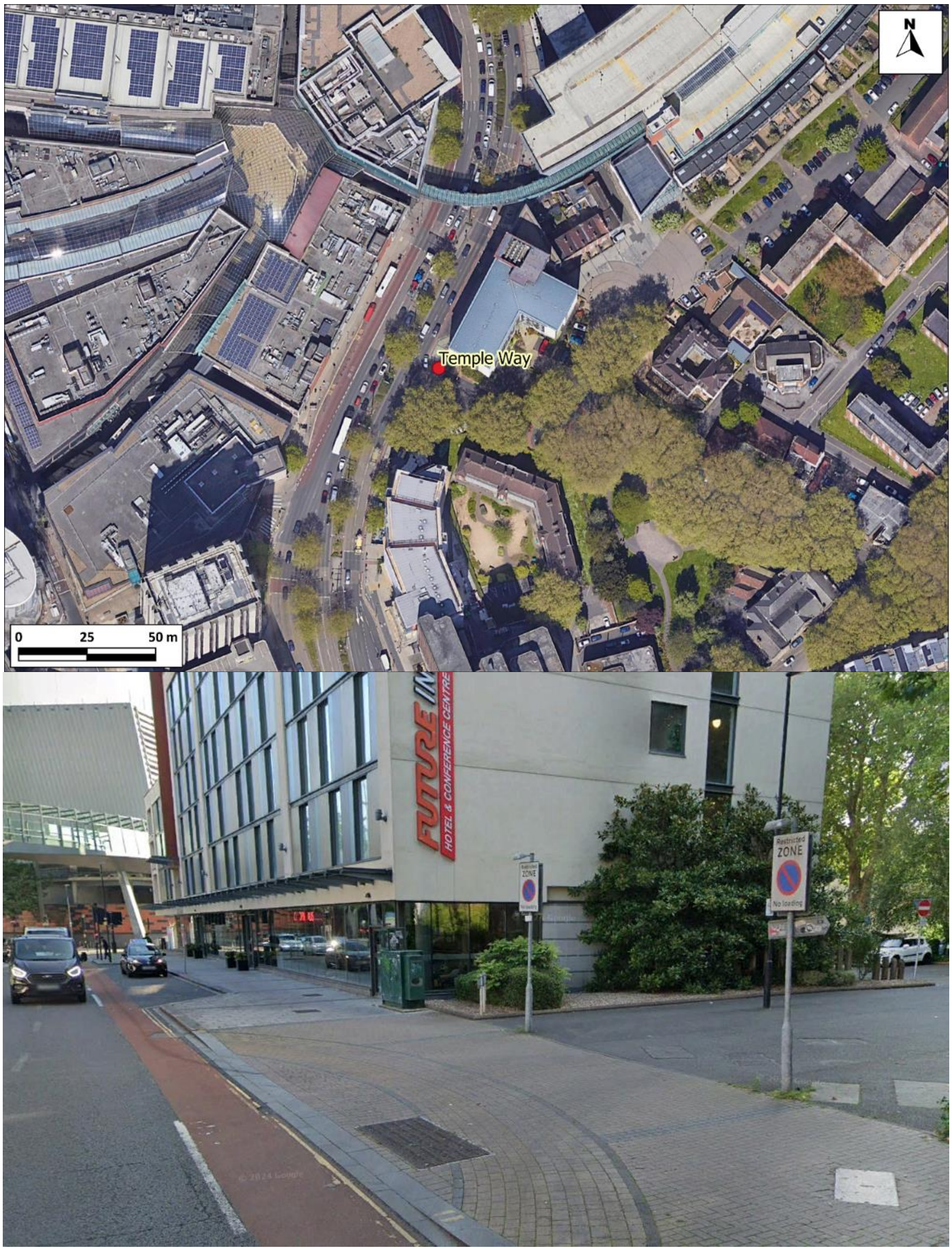


Figure 27: Setting of Temple Way Monitor (street-level photograph from the south).

Figure 28 shows polar plots of mean NOx concentrations by direction and wind speed during each of the last six years. While the direct effect of the main road is evident in higher concentrations (largely shown in yellow) to the southwest and northeast, the highest concentrations occur during slow wind speeds when the wind is from the northeast. This is most likely to reflect the effect of the adjacent building, entraining wind flows and causing emissions from the road to stagnate in the area of the monitoring site.

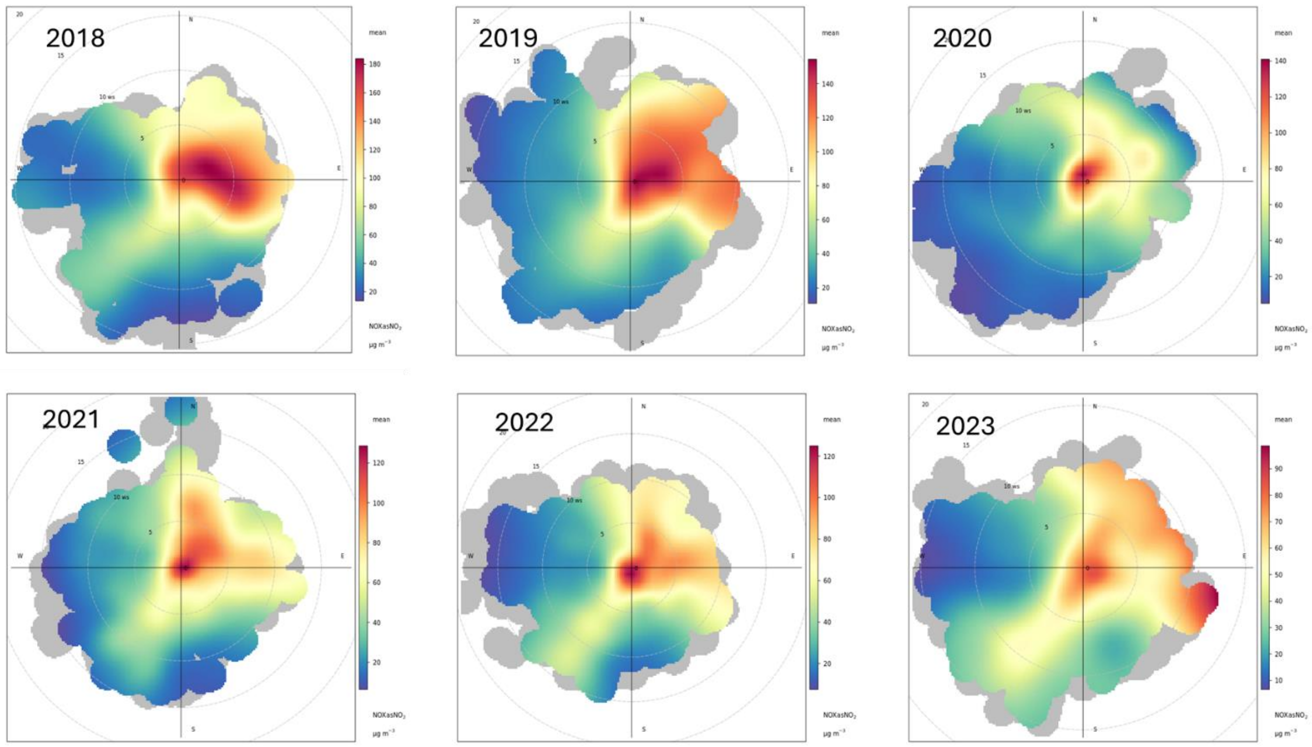


Figure 28: Polar Plots of Average NOx Concentration at Temple Way over Six Years.

Figure 29 shows the polar frequency and polar anulus for the same monitor, presented as the average over the six years to 2023. While (as shown in Figure 13), the most frequent winds are from the southwest, average NOx concentrations at the Temple Way monitor are driven by winds from the northeast. These concentrations show the diurnal pattern expected from a nearby emission of road traffic in the UK, with pronounced peaks at 8.00 AM and around 6.00 PM.

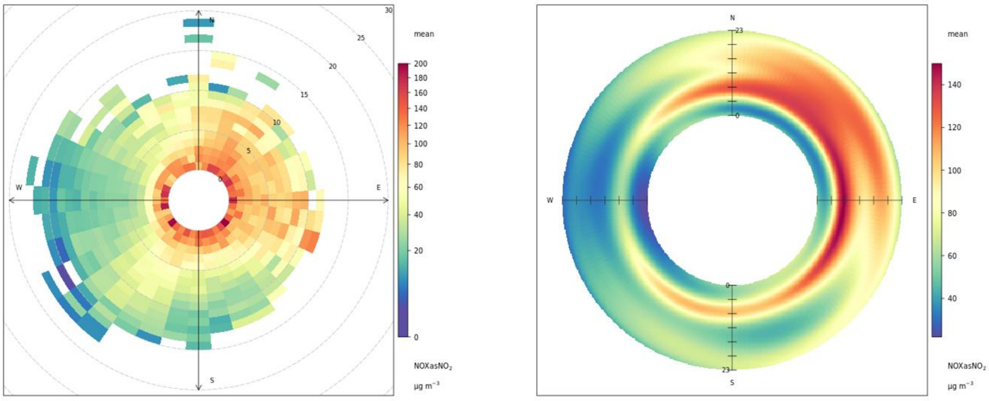


Figure 29: Polar Frequency and Polar Anulus Plots of Average NOx Concentration at Temple Way over Six Years.

While the spatial and diurnal patterns of measured NOx concentrations at Temple Way have remained broadly the same, total concentrations have fallen. This has happened at roadside monitoring sites across the UK and relates to changes to the vehicle fleet, driven by both natural fleet turnover and local interventions such as the Bristol CAZ. To understand changes in concentrations over time, it is helpful to look across multiple monitoring sites and to normalise for repeated and predictable effects of weather. Figure 30 shows the average monthly NO_2 concentrations measured at 99 roadside monitoring sites with good data capture which are spread across the UK. The effects of weather have been nominally removed using Boosted Regression Trees[9].

[9] Gellatly, R. and Marner, B. (2020) *Nitrogen Oxides Trends in the UK 2013 to 2019*; Gellatly, R., and Marner, B. (2020) *The Effect of COVID-19 Social and Travel Restrictions on UK Air Quality*; Gellatly, R., Marner, B., Liska, T. and Laxen, D. (2020) *The Effect of COVID-19 Social and Travel Restrictions on UK Air Quality – 06 April Update*; Liska, T., Gellatly, G., Laxen, D., and Marner, B. (2020) *The Effect of COVID-19 Social and Travel Restrictions on UK Air Quality – November Update*; Pearce, H., Marner, B., and Moorcroft S. (2022) *Trends in UK NOx and NO_2 Concentrations through the COVID-19 Pandemic: January 2022;* Pearce, H., Marner, B., and Moorcroft S. (2022) *Trends in UK NOx and NO_2 Concentrations through the COVID-19 Pandemic: May 2022 Update*. All reports available at: https://www.aqconsultants.co.uk/resources.

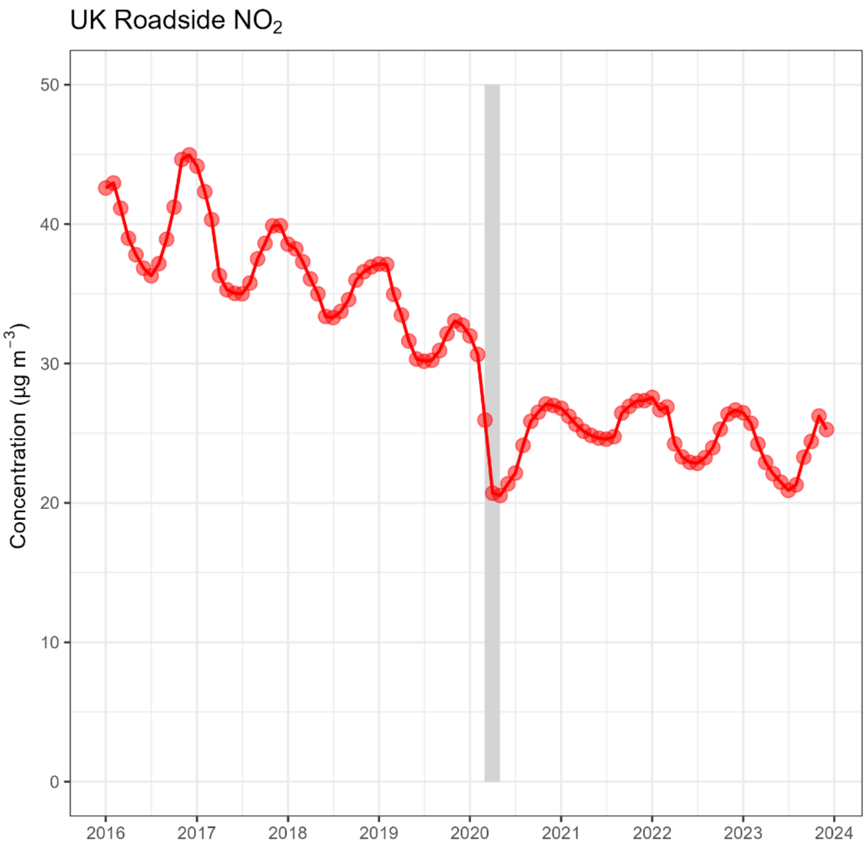


Figure 30: Mean Monthly Weather-normalised NO_2 Concentrations from 2016 to 2024 at 99 Roadside Monitoring sites with Sufficient Data Capture Across the UK (vertical grey bar shows the first Covid-19 lockdown).

Ongoing work to clean the monitoring data and provide enhanced understanding of the effects of meteorology on ambient concentrations is described in Deliverable D4.1.

9. Conclusion

The information described above will allow work to continue toward improving predictive air quality modelling capabilities and testing those models against open air measurements. This, in turn, will allow the effect of local-scale urban topology on pollutant dispersion to be better understood, thus allowing future building and urban designs to help in reducing exposure to poor air quality.