West Midlands Air Quality Report from Birmingham Air Quality Supersite (BAQS): *Summer 2024 (September 2024 – November 2024)*

A report from the WM-Air project for WMCA

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A) High-level Summary

Background Air Quality across the West Midlands from September to November 2024, as measured at the Birmingham Air Quality Supersite (BAQS):

- Compared to the long-term autumn mean (2019-2023), nitrogen dioxide (NO_2) concentrations remained low, well below the annual air quality objectives, showing no significant changes from the long-term average.
- Fine particulate matter ($PM_{2.5}$) and ozone (O_3) levels were 22% and 12% higher than the 2019-2023 average, respectively, but both remained below the national annual mean objective level. Notably, O_3 concentrations did not exceed the 100 µg m^{-3} 8-hour mean target
- Black carbon and inorganic aerosol components contributed 5.5% and 21% to $PM_{2.5}$, respectively. The remaining portion, primarily composed of organic carbon and trace elements, accounted for more than 73% of $PM_{2.5}$. Using data from November, the proportion of trace elements was approximately 14%, with organic carbon contributing over 58%, making it the main driver of the observed increase in $PM_{2.5}$ concentrations during this period.
- Black carbon concentrations were predominantly derived from local sources, while inorganic aerosols, mainly formed through secondary gas-particle interactions, were influenced by long-range transport from outside the region, as indicated by back trajectories and wind polar plots.

Summary of provisional air quality at Birmingham air quality supersite (BAQS): 01/09/2024 to 30/11/2024

Parameter	Mean value	Peak value	Previous mean value (2019-2023)*	National (England) air quality objectives
Temperature (T)	10.7 °C	25.6 °C (06/09 13:00)	11.3 °C	
Wind speed (ws)	3.4 m s^{-1}	9.8 m s^{-1} (24/11 4:00)	3.4 m s^{-1}	
Nitrogen dioxide (NO_2)	15.2 µg m^{-3}	71.9 µg m^{-3} (21/11 12:00)	15.2 µg m^{-3}	40 µg m^{-3} (annual mean)
Ozone (O_3)	43.1 µg m^{-3}	141.8 µg m^{-3} (18/09 13:00)	38.3 µg m^{-3}	100 µg m^{-3} (8-hour mean)
Fine particulate matter ($PM_{2.5}$)	9.2 µg m^{-3}	46.3 µg m^{-3} (09/11 19:00)	7.5 µg m^{-3}	20 µg m^{-3} (annual mean)

**Previous mean calculated from measurements at BAQS in September, October and November in 2019-202*

B) Full Report

1. introduction

The Birmingham air quality supersite (BAQS), located on the University of Birmingham campus (52.46 N, 1.93 W), serves as a typical urban background station. In contrast to other automated high-resolution stations, it not only monitors conventional pollutants such as nitrogen dioxide (NO_2), sulphur dioxide (SO_2), carbon monoxide (CO), ozone (O_3), inhalable particulate matter (PM_{10}) and fine particulate matter ($PM_{2.5}$) but also records additional pollutants including ammonia (NH_3), methane (CH_4), Volatile organic compounds (VOCs), and Black Carbon, as well as particle number concentration, size distribution, and chemical composition. Based on these comprehensive data, a thorough assessment of atmospheric pollution can be conducted, whilst combining these data with model analysis enables the extraction of source information for different components, providing essential data support for the air quality situation in Birmingham and the wider West Midlands region. For more information about BAQS, including a detailed list of instruments installed at the site, definitions of term used, and break down of the analysis, please refer to the Appendix and Supplementary Information.

This air quality report provides a quarterly overview of the meteorological parameters (temperature and wind speed) and key pollutants (O_3, NO_2, $PM_{2.5}$) observed at BAQS over the past three months. It also offers a brief summary of the changes observed during this period. Additionally, the report includes a preliminary discussion on the potential sources of $PM_{2.5}$ based on its temporal and spatial distribution, along with air mass movement trajectory modelling.

2. Meteorological parameters and key air pollutants

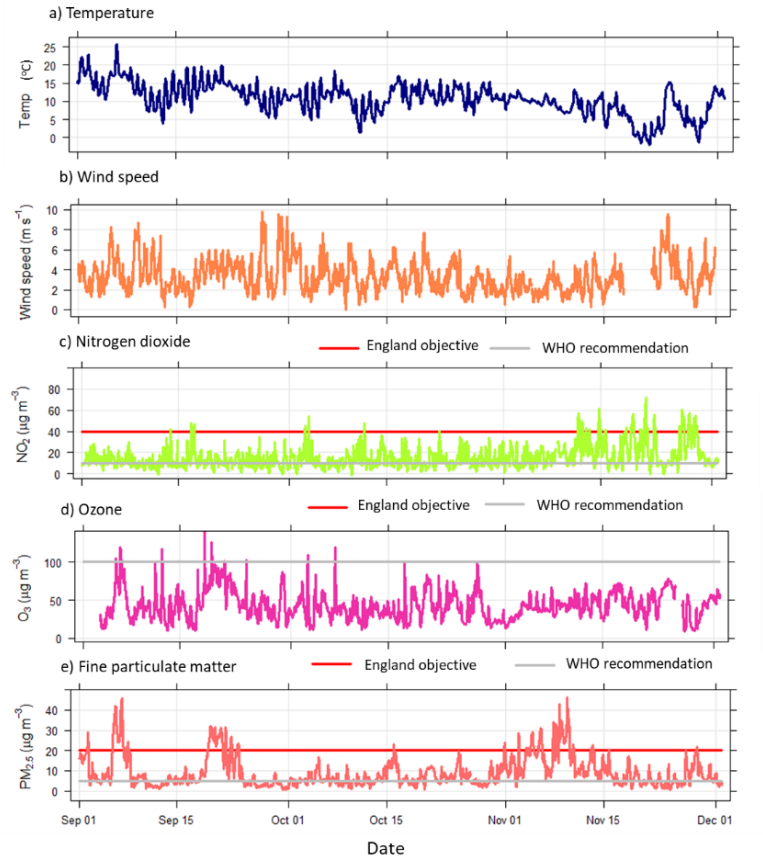

Figure B1: Time series of (a) Temperature, (b) wind speed, (c) provisional ozone concentrations, (d) provisional nitrogen dioxide and (e) provisional fine particulate matter ($PM_{2.5}$) recorded at BAQS from September to November 2024.

Figure B1 illustrates the changes in temperature, wind speed, concentrations of ozone, nitrogen dioxide, and $PM_{2.5}$ from September to November 2024. The average temperature was 10.7 °C, with the maximum and minimum 25.6 °C and -2.0 °C, respectively. This is 0.4 °C lower on average compared to the same period from 2019 to 2023. 1.4% of the temperature records were below 0°C, which is 8.5 times more than the average from 2019 to 2023. The average wind speed was 3.4 m s^{-1}, consistent with past records, with a maximum wind speed of 9.8 m s^{-1}. The average wind speed corresponds to a level 2 "Light breeze" on the Beaufort scale (https://www.metoffice.gov.uk/weather/guides/coast-and-sea/beaufort-scale), and it remains relatively unchanged compared to the same period from 2019 to 2023.

The observed average concentrations of NO_2, O_3, and $PM_{2.5}$ were 15.2 µg m^{-3}, 43.1 µg m^{-3}, and 9.2 µg m^{-3}, respectively. For context the national (England) air quality objectives for NO_2 and $PM_{2.5}$ are annual means of 40 µg m^{-3} and 20 µg m^{-3} respectively. Comparing these values with the Daily Air Quality Index (DAQI) defined by DEFRA, the observed values of NO_2 and $PM_{2.5}$ from BAQS fall within the "low" level (Please refer to the appendix for detailed information on the classification of DAQI levels). Additionally, when compared to the same period from 2019 to 2023, the concentration of $PM_{2.5}$ is higher by 1.7 µg m^{-3} (23%), while the concentration of NO_2 has no changed. For O_3, the maximum concentration recorded at BAQS from September to November was 141.8 µg m^{-3}, the target is for an 8-hour mean of 100 µg m^{-3} not to be exceeded more than 10 times a year. From September to November, there were 0 exceedances of the 100 µg m^{-3} 8-hour average. Additionally, the average O_3 concentration was 4.8 µg m^{-3} higher compared to the same period in previous years.

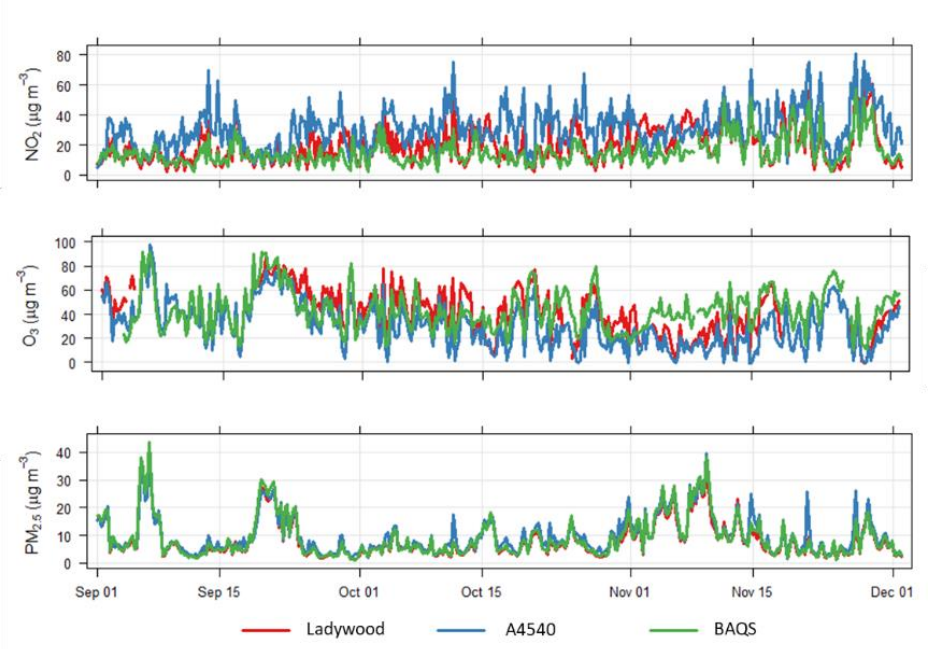

Figure B2: time series of (a) Nitrogen dioxides, (b) Ozone and (c) fine particulate matter ($PM_{2.5}$) from September to November, the red, blue and green line refer to data measured at A4540 site, Ladywood site and BAQS site, respectively. For detailed information of A4540 site and Ladywood site please see the appendix. Data at A4540 and Ladywood site were download from https://uk-air.defra.gov.uk/data/ .

BAQS represents a typical urban background site, making it a representative of air quality across the Birmingham urban area. Air quality at BAQS showed similar levels and trends to those at the Ladywood site (both are urban background sites in Birmingham. The concentration differences of O_3 and $PM_{2.5}$ range with 4%, the differences of NO_2 is higher, approximately 40%. "A4540" is an air quality monitoring

site situated on the A4540 ring road around Birmingham city centre, it is an urban traffic site and hence records higher NO_2 and thus lower O_3. Nonetheless, the differences observed in $PM_{2.5}$ concentrations between BAQS and those at A4540 are not significant (8 % on average).

Table B1: summary of concentrations measured at a4540 site, Ladywood site and BAQS site, respectively

Air pollutant	Site	Mean value ± SD (μg m^{-3})	Range (μg m^{-3})
NO_2	A4540	31.1±15.9	0.7-100.1
	lady wood	19.6±13.8	1.1-82.4
	BAQS	15.2±10.4	-1.6-71.9
O_3	A4540	30.8±20.7	-1.1-106.2
	lady wood	41.1±21.3	-0.7-93.6
	BAQS	43.1±18.9	0.1-141.8
$PM_{2.5}$	A4540	9.9±7.3	0.6-63.4
	lady wood	8.6±6.9	0.5-41.7
	BAQS	9.2±7.7	0.6-46.3

SD: standard deviation
Data at a4540 and Ladywood site were download from https://uk-air.defra.gov.uk/data/ .

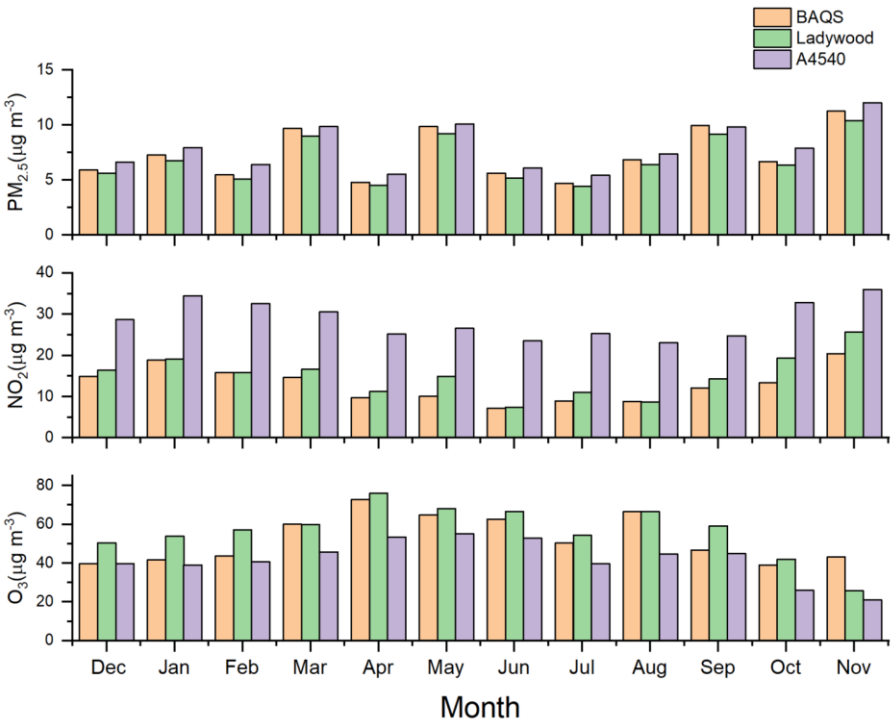

Figure B3: Monthly average bar charts showing a) fine particulate matter ($PM_{2.5}$), b) Nitrogen dioxide (NO_2) and c) Ozone from last November. The orange, green, and lavender bars represent data measured at the BAQS site, Ladywood site, and A4540 site, respectively.

Figure B3 presents the monthly average concentrations of $PM_{2.5}$, NO_2 and O_3 across BAQS, Ladywood, and A4540 sites. $PM_{2.5}$ concentrations exhibit no clear seasonal pattern but show relatively high levels in March, May, September, and November across all three sites. The highest $PM_{2.5}$ concentrations are observed at A4540, likely due to its location in a traffic-dense area. BAQS and Ladywood show similar $PM_{2.5}$ levels, are highest at A4540, as it is located in a traffic-heavy area. BAQS and Ladywood show similar levels, with slightly lower concentrations at BAQS, indicating relatively better air quality.

NO_2 concentrations are higher in winter and lower in summer, potentially due to increased traffic activity in winter and unfavourable dispersion conditions (e.g., temperature inversions). A4540 exhibits significantly higher NO_2 levels compared to the other two sites, especially in winter, highlighting the impact of traffic emissions. BAQS reports the lowest NO_2, suggesting it is farther from major pollution sources. O_3 concentrations peak during spring and summer (April to August) and decrease in winter, reflecting its photochemical formation mechanism, which depends on sunlight and precursor reactions. The highest O_3 concentrations are observed at BAQS, likely because it is farther from traffic sources, allowing precursors to generate O_3 without being consumed by NO. In contrast, O_3 levels are lower at A4540 and Ladywood, particularly at A4540, likely due to rapid reactions between NO and O_3 forming NO_2.

In summary, NO_2 and O_3 demonstrate notable seasonal trends, influenced by meteorological factors (e.g., temperature, humidity, and wind speed) and human activities. As a traffic-dominated site, A4540 records higher levels of NO_2 and $PM_{2.5}$ but lower O_3 concentrations. In contrast, the urban background sites of Ladywood and BAQS report lower levels of $PM_{2.5}$ and NO_2 but higher O_3 concentrations, indicating reduced traffic influence.

2. Where did the air come from? Back trajectory analysis

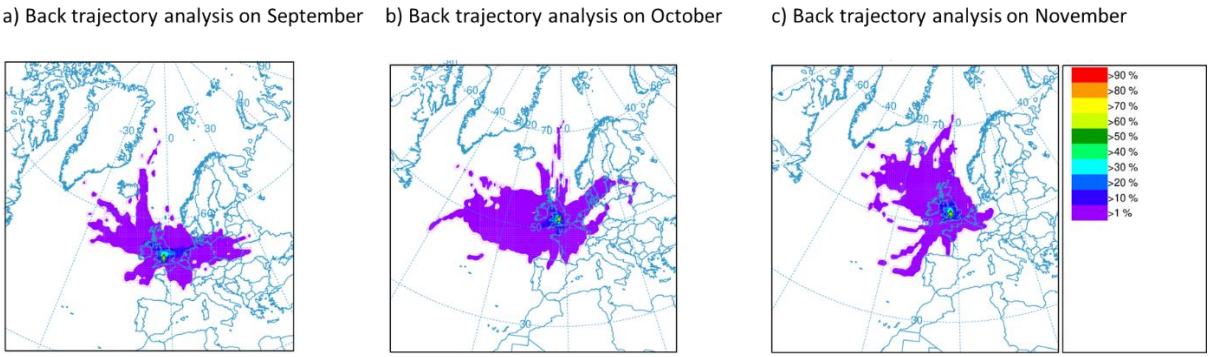

Figure B4: 48h back trajectory frequency analysis on (a) September, (b) October, and (c) November in 2024

Back trajectory modelling is an approach used to trace the movement of air "masses", the volumes of air which move around the atmosphere together. For a detailed explanation of the model, please refer to the appendix. Figure B4 shows the trajectory frequencies of air masses movements ending at BAQS simulated by the HYSPLIT Trajectory Model (https://www.arl.noaa.gov/hysplit/) over a period of 48 hours prior to their arrival in the West Midlands (at BAQS). As shown in the figure, the light blue areas represent the trajectory frequencies where more than 30% of air masses during September to November have travelled in the 48 hours prior to arriving in the WM, predominantly originating from the northeast and the southwest. This provides insight into the sources and pathways of air pollutants impacting the West Midlands and the influence of regional transport patterns on local air quality.

3. What is in the air – composition of fine particles ($PM_{2.5}$)

Due to instrument maintenance, the analysis of organic carbon in $PM_{2.5}$ was not possible, and measurements of trace elements were only available starting in November. This limitation restricts the discussion to changes in inorganic aerosols and black carbon. As shown in Figure B5, inorganic aerosols accounted for an average of 21.2% of $PM_{2.5}$, while black carbon contributed 5.5%. The remaining 73.3% was primarily composed of organic carbon and inorganic elements.

Although data on the concentration changes of organic carbon and trace elements are unavailable, the changing proportions of these components (grouped as "other" in the pie chart) suggest they remain the dominant contributors to $PM_{2.5}$. Notably, as $PM_{2.5}$ concentrations increase, their contribution also rises. For instance, Figure B6 shows that when $PM_{2.5}$ concentrations were between 0 and 5 μg m^{-3}, these components contributed 52.5%. However, at concentrations above 20 μg m^{-3}, their contribution rose to 76.3%, indicating that the accumulation of organic carbon and inorganic elements was the primary driver of the observed increase in $PM_{2.5}$. This finding aligns with previous reports from winter 2023 and spring and summer 2024, which demonstrated that organic carbon and trace elements contributed up to 60% of $PM_{2.5}$, while black carbon and inorganic aerosols contributed approximately 6-7% and 22-30%, respectively. These results are consistent with the current findings. In past analyses, trace elements were utilized as tracers to identify specific sources of $PM_{2.5}$ and discuss their potential origins. However, due to instrument maintenance, the measurement of trace elements has only been available since November. As shown in Figure B7, trace elements currently contribute about 13.6% to $PM_{2.5}$, while organic carbon accounts for approximately 58%.

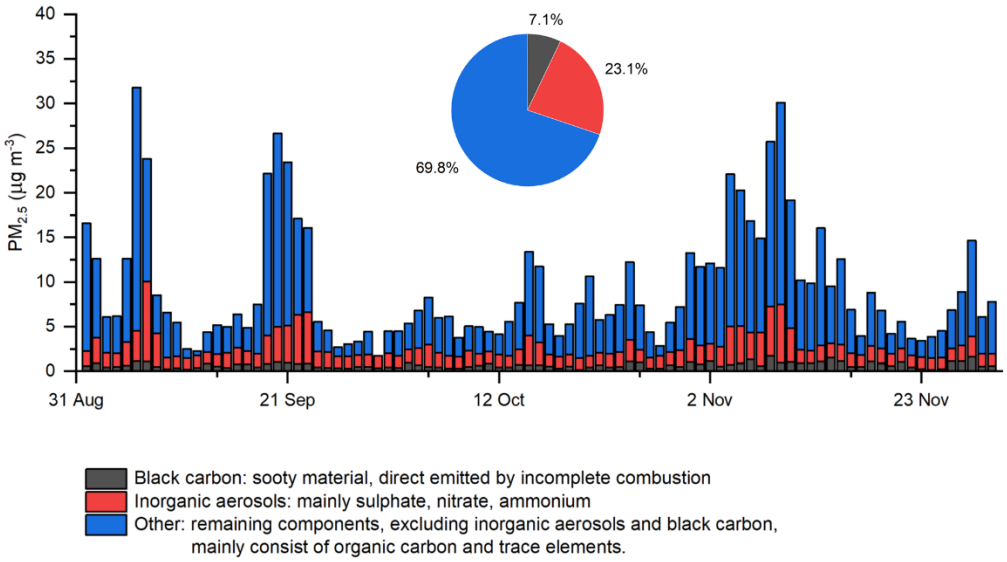

Figure B5: Daily variations in the composition of $PM_{2.5}$ resolved from September to November 2024. The pie chart shows the mean proportions of each composition (Please note that this data is very preliminary and should be used with caution for reference purposes only).

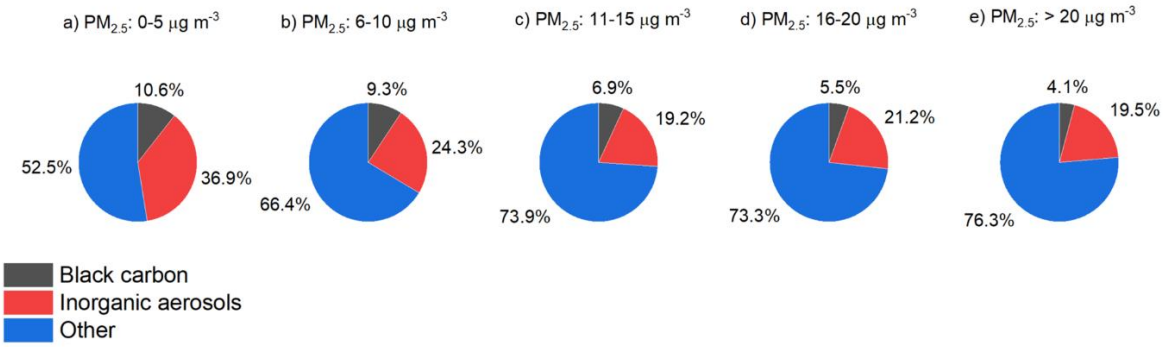

Figure B6: Pie charts of $PM_{2.5}$ composition under 5 different levels: a) $PM_{2.5}$ in range of 0-5 μg m^{-3}, b) $PM_{2.5}$ in range of 6-10 μg m^{-3}, c) $PM_{2.5}$ in range of 11-15 μg m^{-3}, d) $PM_{2.5}$ in range of 16-20 μg m^{-3} and e) higher than 20 μg m^{-3}.

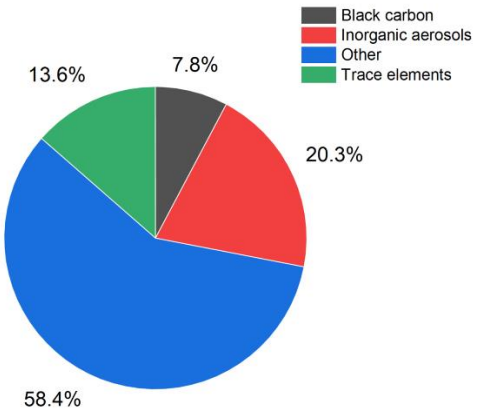

Figure B7: Pie charts of $PM_{2.5}$ composition since November 2024.

By plotting the concentration variations of the components against wind direction and speed, we obtained wind polar plots (see Figure B8). The polar plots for $PM_{2.5}$, inorganic aerosols and the remaining components (excluding black carbon and) were nearly identical, showing higher concentrations when the wind was coming from the northeast and southeast, indicating a trend of transport from eastern sources. In contrast, the polar plot for black carbon differed, with its highest concentrations occurring at the centre of the polar plot, indicating a strong local source; thus, the observed black carbon likely originates primarily from local emissions. Notably, back trajectory modelling indicated that from September to November, the air masses over Birmingham primarily originated from the east and west. This combination suggests that the predominant air masses from the west did not contribute to the formation and increase of $PM_{2.5}$ and secondary aerosols, indicating that these air masses were relatively clean. Conversely, the eastern air masses aligned with the city centre direction, likely influenced by urban pollution sources.

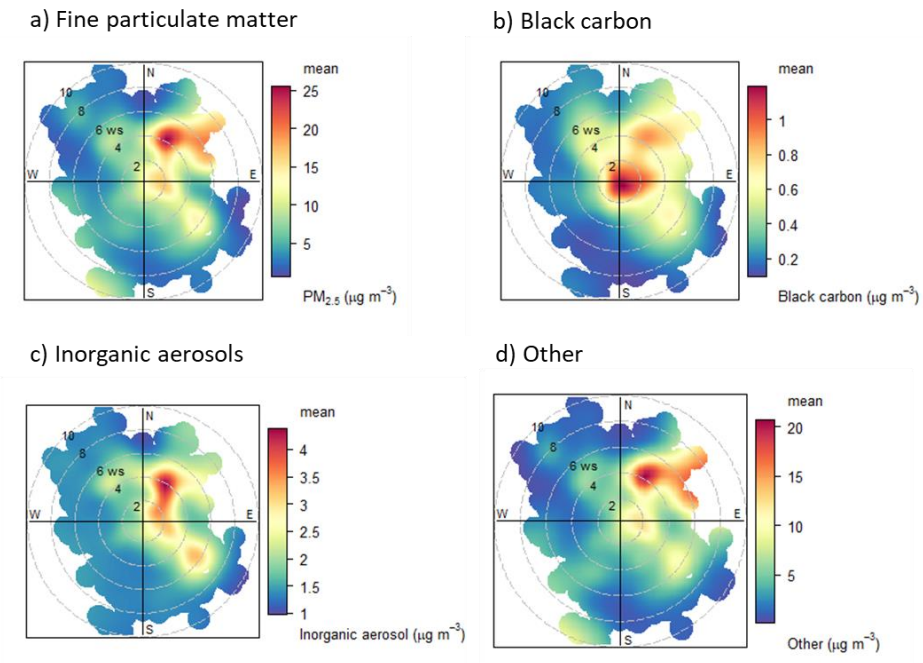

Figure B8: Wind polar plots depicting the distribution of various components of air pollutants measured at BAQS during September to November 2024. Panels (a) through (d) correspond to fine particulate matter, black carbon, inorganic aerosols, and other (mainly consisting of organic carbon, trace elements), respectively.

In addition, based on the diurnal variations, spatial distribution, and correlation analysis of the measured elements, four categories representing potential sources of $PM_{2.5}$ were identified in previous reports: biomass burning, sea salt, dust and traffic, and industrial emissions. However, due to the absence of SVOCs analysis, sources such as secondary aerosols, biogenic aerosols, and agricultural emissions cannot be accurately identified solely through elemental analysis.

In 2021, an alternative measurement approach—filter sampling—was implemented at the BAQS site, followed by source apportionment using a Positive Matrix Factorization (PMF) model. This analysis identified six sources of $PM_{2.5}$: biomass burning, resuspended dust and traffic-related emissions, fuel oil combustion, sea salt, secondary aerosols from power generation and agriculture, and biogenic aerosols. Their estimated contributions were 25%, 22%, 9%, 9%, 25%, and 10%, respectively (see Appendix for details).