West Midlands Air Quality Report from Birmingham Air Quality Supersite (BAQS): *Summer 2024 (June 2024 – August 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 June to August 2024, as measured at the Birmingham Air Quality Supersite (BAQS):

- Compared with long-term mean for summer (2019-2023), low levels of $PM_{2.5}$ concentrations were observed, well below the (annual) air quality objectives. NO_2 levels were below the national annual mean objective but were 6% higher than the long-term average.
- Ozone (O_3) levels were 18% higher than the 2019-2023 average, with a maximum concentration of 136.8 µg m^{-3}. The 100 µg m^{-3}. 8-hour mean target was exceeded six times during this period.
- Due to instrument maintenance, only black carbon and inorganic aerosol components were measured, contributing 6% and 29% to $PM_{2.5}$, respectively. The remaining portion, primarily composed of organic carbon and inorganic elements, accounted for more than 65% of $PM_{2.5}$. This was the main factor driving the observed increase in $PM_{2.5}$ concentrations during this period.
- Black carbon was mainly formed from local sources, while inorganic aerosols, primarily from 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): 01/06/2024 to 31/08/2024

Parameter	Mean value	Peak value	Previous mean value (2019-2023)*	National (England) air quality objectives
Temperature (T)	16.2 °C	28.7 °C (25/06 13:00)	16.7 °C	
Wind speed (ws)	3.4 m s^{-1}	8.0 m s^{-1} (10/06 14:00)	3.4 m s^{-1}	
Nitrogen dioxide (NO_2)	8.4 µg m^{-3}	50.2 µg m^{-3} (29/07 21:00)	7.9 µg m^{-3}	40 µg m^{-3} (annual mean)
Ozone (O_3)	56.4 µg m^{-3}	136.8 µg m^{-3} (25/06 13:00)	47.7 µg m^{-3}	100 µg m^{-3} (8-hour mean)
Fine particulate matter ($PM_{2.5}$)	5.9 µg m^{-3}	29.9 µg m^{-3} (26/08 16:00)	6.4 µg m^{-3}	20 µg m^{-3} (annual mean)

**Previous mean calculated from measurements at BAQS in June, July and August in 2019-2023*

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

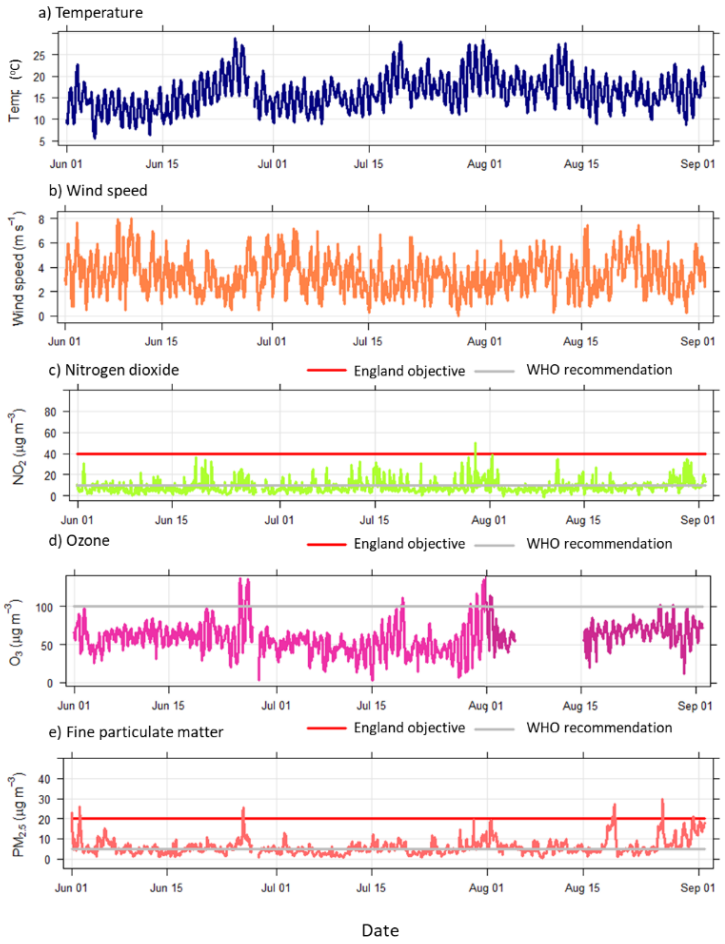

Figure B1: Time series of (a) Temperature, (b) wind speed, (c) provisional ozone concentrations, (d) provisional nitrogen dioxide and (e) provisional fine particulate matter ($PM_{2.5}$) recorded at BAQS from June to August 2024.

Figure B1 illustrates the changes in temperature, wind speed, concentrations of ozone, nitrogen dioxide, and $PM_{2.5}$ from June to August 2024. The average temperature was 16.2 °C, with the maximum and minimum 28.7 °C and 5.6 °C, respectively. This is 0.1 °C lower on average compared to the same period from 2019 to 2023. The diurnal variation was similar to previous years, but night-time temperatures were around 1°C lower (shown in Figure S1 in Supplementary materials). The highest temperature occurred at the end of June, with no days exceeding 30°C. The average wind speed was 3.4 m s^{-1}, consistent with past records, with a maximum wind speed of 8.0 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 8.4 µg m^{-3}, 56.4 µg m^{-3}, and 5.9 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 lower by 0.5 µg m^{-3} (21%), while the concentration of NO_2 has increase 0.5 µg m^{-3}. For O_3, the target is for an 8-hour mean of 100 µg m^{-3} not to be exceeded more than 10 times a year. The maximum concentration recorded at BAQS from June to August was 136.8 µg m^{-3}.

O_3 concentrations typically rise during the summer due to higher temperatures and stronger sunlight. It's important to note that our site’s O_3 monitor underwent maintenance in August, so we don't have complete data for that month. However, by comparing with observations from the Ladywood (an urban background site, detailed comparison below), there was only one instance in August where the 8-hour average O_3 concentration exceeded 100 µg m^{-3}. From June to August, there were 6 exceedances of the 100 µg m^{-3} 8-hour average, accounting for 2% of the total data. Combined with the 8 exceedances recorded in spring (March to May), the total number of exceedances for just these two seasons already surpasses the national objective (10 times). Additionally, the average O_3 concentration was 8.7 µg m^{-3} higher compared to the same period in previous years. This increase could be attributed to several factors, including not only temperature, sunlight, and wind speed, but also elevated concentrations of VOCs and NOx, which promote ozone accumulation. It also implies an increased health risk for residents, as prolonged exposure to elevated ozone levels can impact public health. In summary, 14 exceedances within six months indicate a potential ozone pollution issue, highlighting the need for emission reduction measures or restrictions on high-pollution activities to improve air quality.

Analysis of the daily variation of NO_2, O_3 and $PM_{2.5}$ (see Supplementary Material Figure S2) shows that higher levels of NO_2 and PM2.5 during morning and evening traffic peaks, indicating that traffic is the primary source. NO_2 concentrations have remained almost unchanged compared to the long-term data from 2019-2023, with only a slight midday increase of about 1 µg m^{-3}, which aligns with the diurnal pattern of O_3. Ozone concentrations in this summer were nearly 10 µg m^{-3} higher than in 2019-2023. As discussed above, this may indicate intense midday chemical reactions contributing to ozone accumulation. A similar trend can be observed in the diurnal variation of $PM_{2.5}$, where instead of a smooth curve, a small midday peak appears, suggesting the possible formation and accumulation of $PM_{2.5}$ during this period.

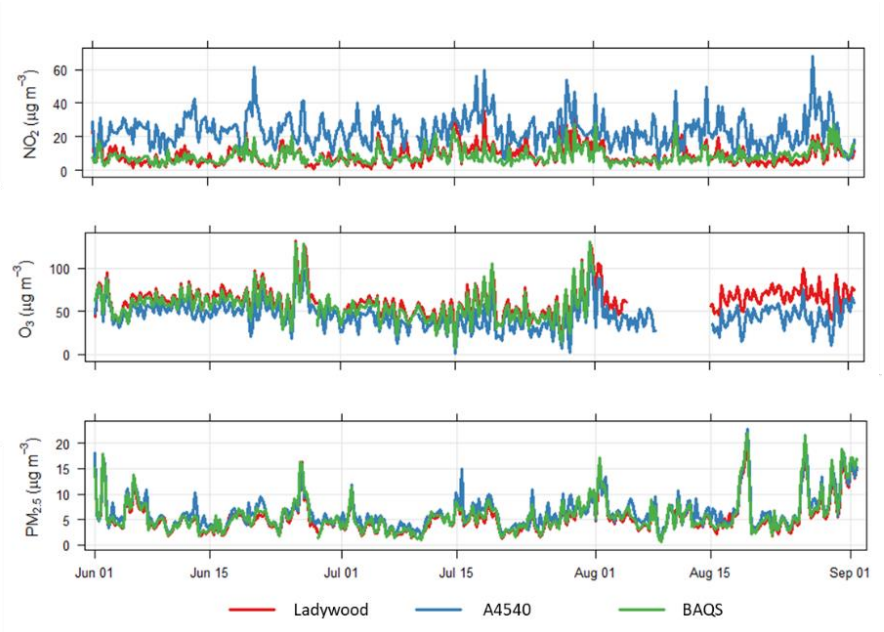

Figure B2: time series of (a) Nitrogen dioxides, (b) Ozone and (c) fine particulate matter ($PM_{2.5}$) from March to May 2024, the red, blue and green line refer to data measured at A4540 site, Ladywood site and BAQS site, respectively. For detailed information of A4540 site and Ladywood site please 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 NO_2, O_3 and $PM_{2.5}$ range between 8 % and 10 %. "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 % in 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	23.5±11.4	2.2-84.9
	lady wood	9.1±7.6	-0.1-68.0
	BAQS	8.4±5.7	0.1-51.2
O_3	A4540	45.1±18.5	-0.3-121.5
	lady wood	62.2±19.1	1.7-140.2
	BAQS	56.4±20.2	2.8-136.8
$PM_{2.5}$	A4540	6.4±3.7	0.4-31.0
	lady wood	5.5±3.6	0.3-26.8
	BAQS	5.9±3.9	0.4-29.9

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

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

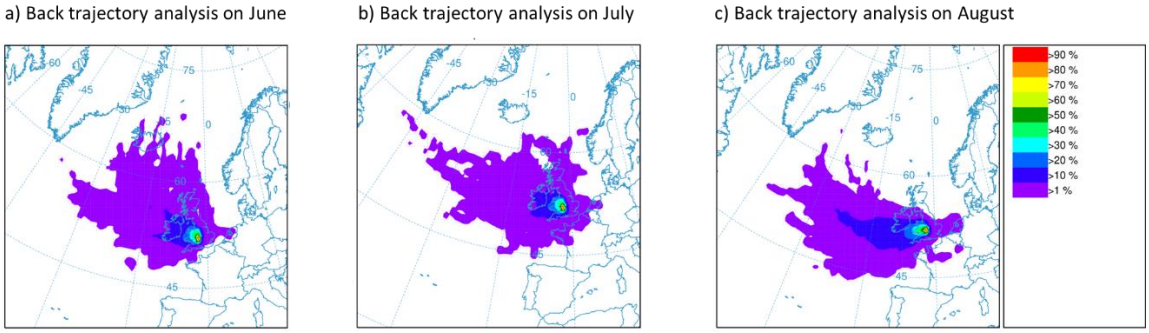

Figure B3: 48h back trajectory frequency analysis on (a) June, (b) July, and (c) August in 2024

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 B3 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 June to August have travelled in the 48 hours prior to arriving in the WM, predominantly originating from the northwest and the west. 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, it is unable to analyse inorganic elements and organic carbon in $PM_{2.5}$ in this report, limiting the discussion to changes in inorganic aerosols and black carbon only. As shown in Figure B4, the average proportion of inorganic aerosols in $PM_{2.5}$ was 29%, with black carbon accounting for 6%. The remaining 65% mainly consisted of inorganic elements and organic carbon components. Inorganic aerosols experienced three distinct periods of growth, with their proportion in $PM_{2.5}$ increasing accordingly. This coincided with temperature spikes, suggesting that higher temperatures and stable meteorological conditions are more conducive to the formation and accumulation of inorganic salts, such as nitrates and ammonium salts, which in turn promoted the increase in $PM_{2.5}$ concentrations.

Although we lack data on the concentration changes of inorganic elements and organic carbon components, the changing proportions of these components (represented as "the rest" in the pie chart) suggest that they remain the primary contributors to $PM_{2.5}$. As $PM_{2.5}$ concentrations rise, their contribution increases as well. For example, in Figure B5, when $PM_{2.5}$ concentrations ranged from 0 to 5 µg/m³, the contribution of these components was 54%. However, when $PM_{2.5}$ concentrations reached 16-20 µg/m³, their contribution increased to 87.5%, indicating that the accumulation of inorganic elements and organic carbon components was the primary driver of the observed $PM_{2.5}$ increase.

This finding aligns with previous reports from winter 2023 and spring 2024, which also highlighted that organic carbon and inorganic elements contributed up to 60% of $PM_{2.5}$, while black carbon and inorganic aerosols contributed 6-7% and 22-30%, respectively. These results are consistent with the current report's findings.

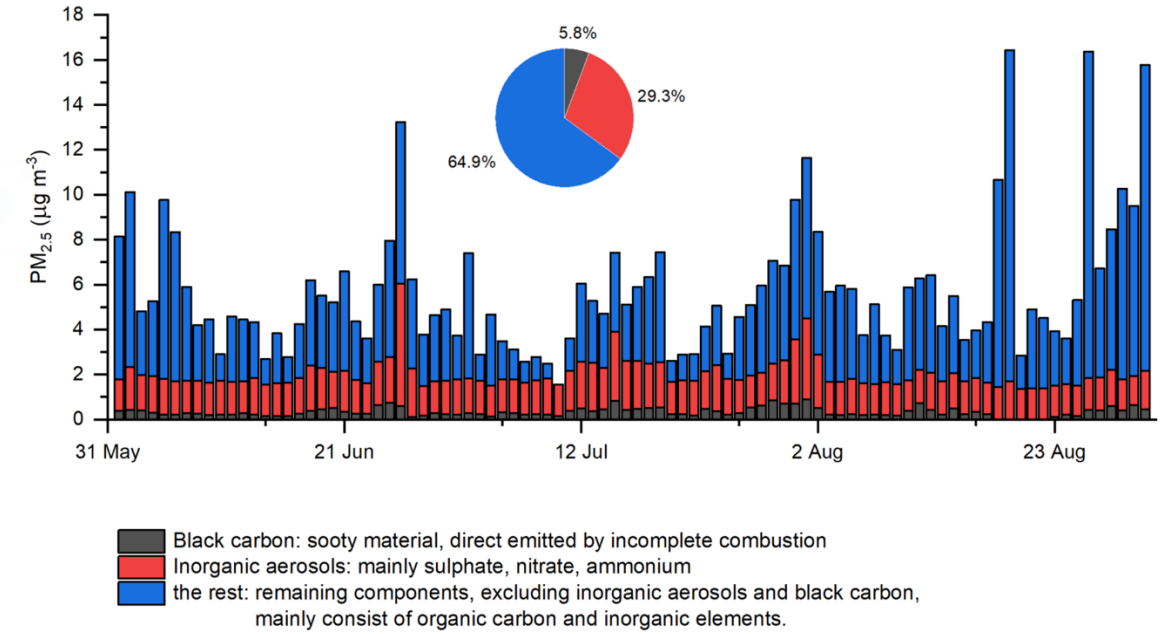

Figure B4: Daily variations in the composition of $PM_{2.5}$ resolved from December 2023 to February 2024. The pie chart shows the mean proportions of each composition (Please note that this data is very preliminary and should be used with caution for reference purposes only).

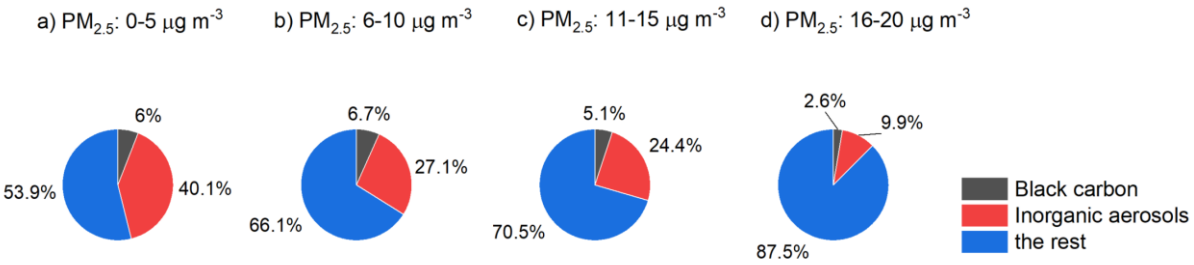

Figure B5: Pie charts of $PM_{2.5}$ composition under 4 different levels: a) $PM_{2.5}$ in range of 0-5 µg m^{-3}, b) $PM_{2.5}$ in range of 6-10 µg m^{-3}, c) $PM_{2.5}$ in range of 11-15 µg m^{-3}, d) $PM_{2.5}$ in range of 16-20 µg m^{-3}.

In previous reports, we utilized observed inorganic elements as tracers for specific sources of $PM_{2.5}$ to discuss potential origins. However, due to instrument maintenance, this report contains detailed data only on black carbon and inorganic aerosols, resulting in limited discussion. By plotting the concentration variations of the components against wind direction and speed, we obtained wind polar plots (see Figure B6). The polar plots for $PM_{2.5}$ and the remaining components (excluding black carbon and inorganic aerosols) were nearly identical, showing higher concentrations when the wind was coming from the east at lower speeds, 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 rather than external transport.

The polar plot for inorganic aerosols fells between the two patterns, suggesting that their sources included both local generation and contribution from eastern external sources. Notably, back trajectory modelling indicated that from June to August, the air masses over Birmingham primarily originated from the north and west, with fewer contributions from the east. This combination suggests that although the predominant air masses were from the north and west, they 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.

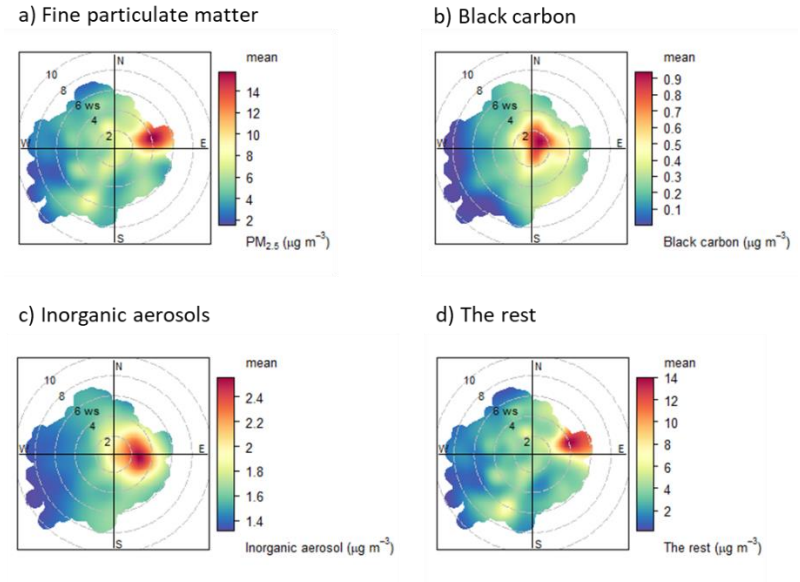

Figure B6: Wind polar plots depicting the distribution of various components of air pollutants measured at BAQS in January 2024. Panels (a) through (f) correspond to fine particulate matter, black carbon, inorganic elements, organic carbon, inorganic aerosols, and inorganic aerosols, respectively.

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).