Ricardo
Energy & Environment

Air Quality at Heathrow Airport 2016

Report for Heathrow Airport Ltd
ED59405

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Executive summary

This report provides details of air quality monitoring conducted around Heathrow Airport during 2016. The work, carried out by Ricardo Energy & Environment on behalf of Heathrow Airport Ltd (HAL), is a continuation of monitoring undertaken at Heathrow Airport since 1993. The aims of the programme are to monitor air pollution around the airport, to assess compliance with relevant national air quality objectives, and to investigate changes in air pollutant concentrations over time.

Automatic continuous monitoring was carried out at four locations on behalf of HAL, referred to as LHR2, London Harlington, Green Gates and Oaks Road. Data from these four continuous monitoring stations, as well as eight other continuous monitors operated by Hillingdon, Hounslow, Slough, Spelthorne, and Defra are shared and summarised on heathrowairwatch.org.uk. LHR2 is located on the northern apron, between the airport boundary and the northern runway (grid reference 508400 176750), London Harlington is located at the Imperial College Sports Ground (508299 177809), Green Gates is located near the north western airport perimeter (505630 176930) and Oaks Road, on a residential location to the south west (505740 174500).

All sites monitored oxides of nitrogen (nitric oxide and nitrogen dioxide) and Particulate Matter (PM_{10} and $PM_{2.5}$). PM_{10} and $PM_{2.5}$ data for all sites in 2016 was measured using FIDAS instruments.

Ozone measurements were undertaken at London Harlington and Black Carbon (BC) monitoring was undertaken at LHR2 and Oaks Road using aethalometer instruments.

The minimum applicable data capture target of 90% (from the European Commission Air Quality Directive[3]) was achieved for all instruments at all stations.

The UK AQS hourly mean objective for NO_2 is 200 µg m^{-3}, with no more than 18 exceedances allowed each year. LHR2 registered 8 exceedances of this value during the year, and Harlington, Green Gates and Oaks Road registered no exceedances. All HAL sites met this objective for 2016.

The annual mean AQS objective for NO_2 is 40 µg m^{-3}. This was met at Harlington, Green Gates and Oaks Road. At LHR2, an annual mean of 47 µg m^{-3} was registered for 2016. This value is slightly higher than those registered in 2015 and 2014 at 44 and 46 µg m^{-3} respectively, showing a small increase in concentrations for this pollutant, however, similar increases were picked up throughout the south-east and London. The AQS objectives and EU limit values do not apply for this site, since LHR2 is located within the airport perimeter fence, where members of the public do not have access.

PM_{10} may exceed the 24-hour mean limit of 50 µg m^{-3} no more than 35 times per year to meet the AQS objective. During 2016, only 2 to 5 exceedances to the limit value were registered at each site. This AQS objective was therefore met for all HAL sites. The annual mean AQS target for PM_{10} is 40 µg m^{-3}. This objective was met at all the monitoring stations.

The Harlington station met the AQS objective for ozone in 2016.

Table ES-1 shows an overall summary of the AQS objective and data capture statistics recorded in 2016 at the Heathrow network, green shaded cells demonstrate the objective or requirement has been met whilst red shaded cells show failure to meet requirements.

Table ES-1- Summary of AQS Objective Compliance and Data Capture

Site name	Data Capture (%)	Annual Mean (µg m^{-3})	Hourly (NO_2), Running 8 Hour (O_3), Daily (PM_{10}) Objective Exceedances
LHR2 NO_2	92.54	47	8
LHR2 PM_{10}	98.91	15	3
LHR2 $PM_{2.5}$	98.91	10	-
Harlington NO_2	90.54	34	0
Harlington PM_{10} (FIDAS)	99.77	15	5
Harlington $PM_{2.5}$ (FIDAS)	99.76	10	-
Harlington O_3	98.26	34	30 (6days)
Green Gates NO_2	98.78	34	0
Green Gates PM_{10}	98.78	14	3
Green Gates $PM_{2.5}$	98.78	10	-
Oaks Road NO_2	99.18	31	0
Oaks Road PM_{10}	99.20	15	2
Oaks Road $PM_{2.5}$	99.21	10	-

Average concentrations of NO, NO_2, PM_{10}, $PM_{2.5}$ and O_3 at the Heathrow sites were generally comparable to those measured at urban background air pollution monitoring sites in London.

BC data collected at LHR2 and Oaks Road continues to show good agreement with comparable stations in London.

The pattern of monthly averaged concentrations throughout the year showed that concentrations of the primary pollutant NO were typically highest in the winter months. NO_2, which has both primary and secondary components, showed a similar pattern. PM_{10} and $PM_{2.5}$ showed a much less pronounced seasonal pattern, which is quite common for particulates in urban areas. Ozone (measured at Harlington only) showed higher concentrations in the spring and summer. This is a typical seasonal pattern for ozone, which is formed from other pollutants in the presence of sunlight.

Wind speed direction data measured at the LHR2 location were used to investigate effects on pollutant concentrations and potential sources. Bivariate plots of pollutant concentration indicated that nearby sources, such as the perimeter road, were probably the main source of NO. There were also moderate NO concentrations at greater wind speeds from the south west. With regards to NO_2, there also appeared to be a contribution from the south south west at higher wind speeds, possibly indicating a major source further away, in this direction are; Terminal 5, the Central Terminal Area (CTA) and the M25. For both PM_{10} and $PM_{2.5}$, concentrations were high under calm conditions and, in contrast with previous years, no relevant PM concentrations seem to be prevalent at higher wind speeds (> $5ms^{-1}$), showing that local sources are the likely main drivers for the PM concentrations recorded at LHR2. Ozone measured at Harlington registers low levels near the site and high levels far away from the site,

for higher wind speeds. Bivariate plots of Black Carbon data indicate readings were higher under calmer conditions suggesting local emission sources were probably the main source.

Several high pollution episodes occurred during 2016. At all sites, particularly high concentrations of PM_{10} were recorded in March (10^{th} – 13^{th}), October (29^{th} – 30th) and December (1^{st} – 6^{th} and 27^{th}-30^{th}). Local emissions, combined with trans-boundary emissions from continental Europe, in conjunction with anti-cyclonic weather conditions are the origin of this high concentration episodes.

In the long term, annual mean concentrations of total oxides of nitrogen and NO appear to show a general decrease over the past decade at LHR (although there is considerable year-to-year fluctuation). The trend for NO_2 is less clear. The proportion of NO_x measured as NO_2 has increased over the last decade, but have stabilised since 2011, although with a slight decrease in 2016. The annual mean concentrations of PM_{10} have remained similar to last year. A slight decrease in long term trends can be seen in the PM data as a result of new analysers being installed in 2014. Annual means are generally consistent with those measured at other sites in London, excluding PM_{10} and $PM_{2.5}$ which recorded lower annual averages than the comparison sites located in London. While the annual average of ozone (monitored at Harlington only) has returned to similar levels seen in 2012 the long term profile is still one of a slow increase in concentrations, likely due to its relationship with nitrogen oxides.

There is a slight increase of ozone (monitored at Harlington only), following a trend started in 2012.

Although the airport is a material contributor to local air pollutant concentrations, there appears to be no relationship between air traffic movements and ambient pollutant concentrations, either on a seasonal or long-term basis. This indicates that variations in ambient concentration are mainly driven by other factors (such as variations in meteorological conditions and emissions from non-airport sources such as road transport and stationary combustion processes). Air quality in the wider region can also be significantly influenced by long-range trans-boundary air pollution.

Table of contents

Appendices

1 Introduction

1.1 Background

Heathrow Airport is the world's busiest 2 runway international airport, handling approximately 75.7 million passengers in 2016[15]. The airport is situated approximately 12 miles to the west of London, but within the general urbanised area of Greater London.

Airports are potentially significant sources of many air pollutants. Aircraft jet engines emit pollutants including oxides of nitrogen (NO_x), carbon monoxide (CO), oxides of sulphur (SO_x), particulate matter, hydrocarbons from partially combusted fuel, and other trace compounds. There are also pollutant emissions from the airside vehicles, and from the large number of road vehicles travelling to and from the airport each day. Also, Heathrow Airport is situated in an urban area, containing many domestic, commercial and industrial sources of pollution.

Heathrow Airport Ltd therefore carries out monitoring of ambient air quality at four sites around the airport: on the northern apron near the perimeter and northern runway (LHR2), and outside the airport boundary at Harlington, Green Gates and Oaks Road.

The following pollutants monitored at these sites:

- Oxides of nitrogen (nitric oxide (NO) and nitrogen dioxide (NO_2));
- Particulate matter (PM_{10} and $PM_{2.5}$ fractions);
- Ozone (O_3);
- Black Carbon (BC).

LHR2 also records meteorological data.

Ricardo Energy & Environment was contracted by Heathrow Airport Ltd (HAL) to carry out the required programme of air pollution measurements during 2016, the 24th continuous year of monitoring, and this report presents and summarises the fully validated and quality controlled dataset for the period 1st January to 31st December 2016.

In addition to this report, HAL has daily access to provisional data from its monitoring sites via their own Heathrow Airwatch website[1] and data from the UK's national air quality monitoring network, through the Defra UK Air Information Resource (UK-AIR) [2].

Data in the annual report have been processed according to the rigorous quality assurance and quality control procedures used by Ricardo Energy & Environment. These ensure the data are reliable, accurate and traceable to UK national measurement standards.

1.2 Aims and Objectives

The aim of this monitoring programme is to monitor concentrations of several important air pollutants around the airport. The results of the monitoring are used to assess whether applicable national air quality objectives have been met, and how pollutant concentrations in the area have changed over time. Additionally, meteorological data were used to investigate the importance of various sources of pollution.

It is important to note that the pollutants measured in this study will have originated from a wide variety of sources, both local and long range. Not all of these sources will be directly connected with the airport.

Monitoring data collected at Heathrow are compared in this report with:

• Relevant UK air quality limit values and objectives.

• Corresponding results from a selection of national air pollution monitoring sites.

• Statistics related to airport activity.

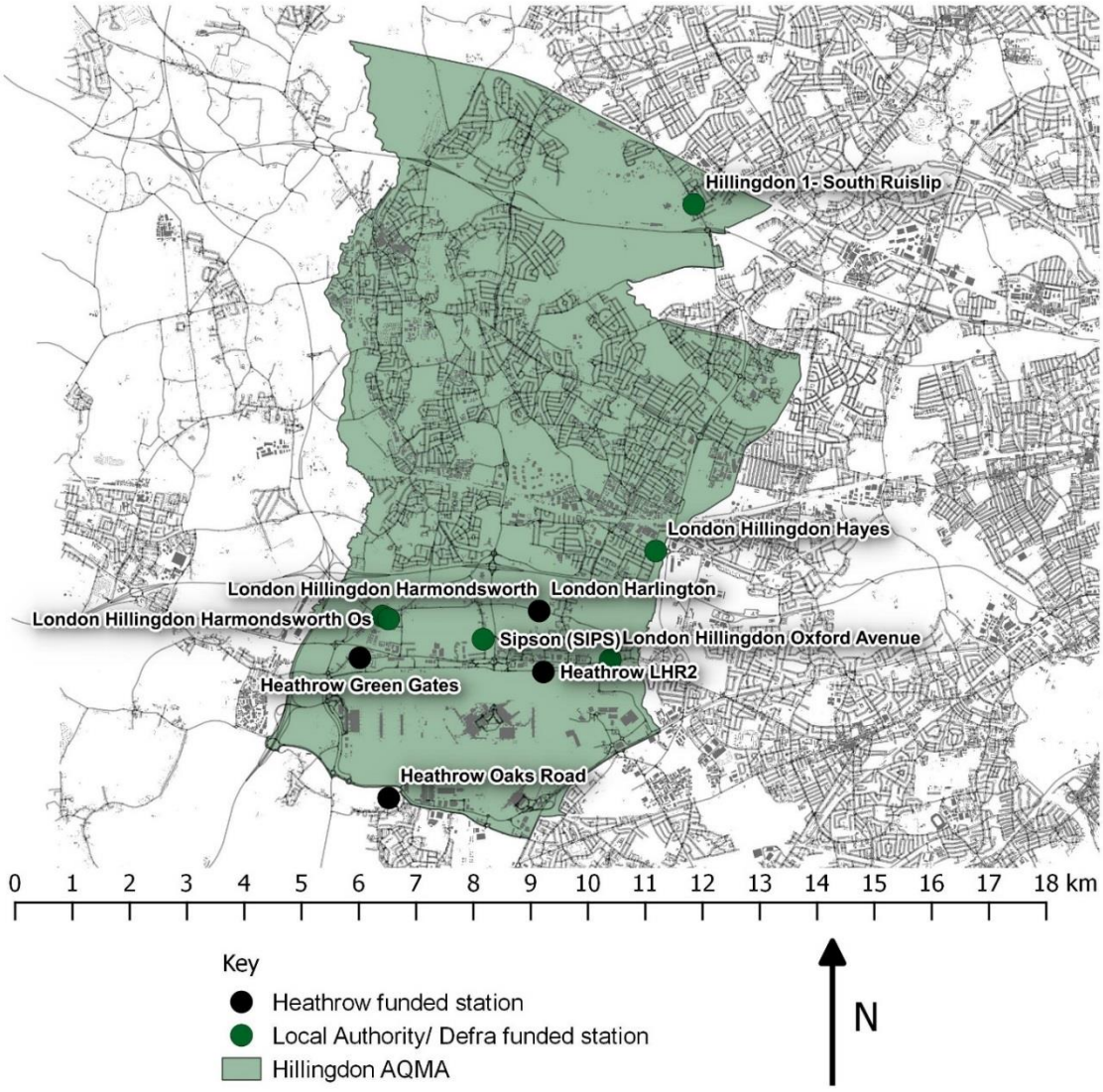
In addition, periods of relatively high pollutant concentrations are examined in more detail.

1.3 UK Air Quality Strategy

Within the European Union, controls on ambient air quality are covered by Directive 2008/50/EC[3], and its update EU2015/1480[11], known as the Air Quality Directive. This consolidated three previously existing Directives, which set limit values for a range of air pollutants with known health impacts. The original Directives were transposed into UK law through The Environment Act 1995 which placed a requirement on the Secretary of State for the Environment to produce a national Air Quality Strategy (AQS) containing standards, objectives and measures for improving ambient air quality.

The Environment Act 1995 also introduced the system of local air quality management (LAQM). This requires local authorities to review and assess air quality in their areas against the national air quality objectives. Where any objective is unlikely to be met by the relevant deadline, the local authority must designate an air quality management area (AQMA). Local authorities then have a duty to carry out further assessments within any AQMAs and draw up an action plan specifying the measures to be carried out, and the timescales, to achieve the air quality objectives. The legal framework given in the Environment Act has been adopted in the UK through the UK AQS. The most recent version of the AQS was published by Defra in 2007[4], and the currently applicable air quality objectives are summarised in Appendix 1 of this report. Figure 1.1 shows a map of Hillingdon AQMA.

Figure 1.1 – Map of Hillingdon AQMA



2 Air Quality Monitoring

2.1 Pollutants Monitored

2.1.1 Nitrogen Oxides (NO_x)

Combustion processes emit a mixture of oxides of nitrogen – NO and NO_2 - collectively termed NO_x.

i) NO is described as a primary pollutant (meaning it is directly emitted from source). NO is not known to have any harmful effects on human health at ambient concentrations. However, it undergoes oxidation in the atmosphere to form the secondary pollutant NO_2.

ii) NO_2 has a primary (directly emitted) component and a secondary component, formed by oxidation of NO. NO_2 is a respiratory irritant and is toxic at high concentrations. It is also involved in the formation of photochemical smog and acid rain and may cause damage to crops and vegetation.

Of the NO_x emissions (including NO_2) considered to be airport-related, over 50 % arise from aircraft during take-off and landing, with around two-thirds of all emissions occurring at some distance from airport ground-level. The Air Quality Expert Group (AQEG) [5] has stated that: "*Around a third of all NO_x emissions from the aircraft (including ground-level emissions from auxiliary power units, engine testing etc., as well as take-off and landing) occur below 100 m in height. The remaining two-thirds occur between 100 m and 1000 m and contribute little to ground-level concentrations. Receptor modelling studies show the impact of airport activities on ground-level NO_2 concentrations. Studies have shown that although emissions associated with road traffic are smaller than those associated with aircraft, their impact on population exposure at locations around the airport are larger*". Previous rounds of review and assessment within the LAQM process have not highlighted any cases where airports appear to have caused exceedances of air quality objectives for particulate matter measured as PM_{10}. Therefore, in the context of LAQM, the key pollutant of concern from airports is NO_2. Local authorities whose areas contain airports with over 10 million passengers per annum must take these into account in their annual review and assessment of air quality[5].

2.1.2 Particulate Matter (PM_{10} and $PM_{2.5}$)

Airborne particulate matter varies widely in its physical and chemical composition, source and particle size. The terms PM_{10} and $PM_{2.5}$ are used to describe particles with an effective size less than 10 and 2.5 µm respectively. These are of greatest concern with regard to human health, as they are small enough to penetrate deep into the lungs. They can cause inflammation and a worsening of the condition of people with heart and lung diseases. In addition, they may carry surface absorbed carcinogenic compounds into the lungs. Larger particles, meanwhile, are not readily inhaled, and are removed relatively efficiently from the air by sedimentation.

The main sources of airborne particulate matter in the UK are combustion (industrial, commercial and residential fuel use). The next most significant source is road vehicle emissions. Based on 2015 NAEI data, less than 0.1% of UK total PM_{10} emissions are believed to originate from civil aircraft taking off and landing [6].

Previous rounds of review and assessment within the LAQM process have not highlighted any cases where airports appear to have caused exceedances of air quality objectives for particulate matter measured as PM_{10}.

2.1.3 Ozone (O_3)

Ozone (O_3) is not emitted directly into the atmosphere in significant quantities, but is a secondary pollutant produced by reaction between nitrogen dioxide (NO_2) and hydrocarbons, in the presence of sunlight. Whereas nitrogen dioxide (NO_2) contributes to ozone formation, nitrogen oxide (NO) destroys ozone and therefore acts as a local sink. For this reason, ozone levels are not as high in urban areas (where NO is emitted from vehicles) as in rural areas. Ozone levels are usually highest in rural areas, particularly in hot, still, sunny weather conditions giving rise to "summer smog".

2.1.4 Black Carbon (BC)

Black Carbon (BC) is the strongest light-absorbing component of particulate matter. It is a primary aerosol, emitted directly at the source, as a result of incomplete combustion of fossil fuels (automobile

exhaust, industrial and power plant exhaust, aircraft emissions, etc.) and biomass burning (burning of agricultural wastes, forest fires). Therefore, much of atmospheric BC is of anthropogenic origin. Exposure to BC is of great concern with regard to human health due to its small size, typically finer that $PM_{2.5}$. It has been linked to health impacts such as cardiopulmonary morbidity and mortality, cancer and respiratory diseases. Reductions in exposure to particles containing BC will consequently reduce such adverse health impacts.

2.2 Monitoring sites and Methods

Automatic monitoring was carried out at four sites during 2016. These are referred to as LHR2, London Harlington, Green Gates and Oaks Road. The location descriptions of the sites fall into the category "other" as defined by the Defra Technical Guidance on air quality monitoring LAQM.TG(09)[7], (i.e. "*any special source-oriented or location category covering monitoring undertaken in relation to specific emission sources such as power stations, car-parks, airports or tunnels*").

The pollutants that were monitored at each monitoring site are shown in Table 2.1. The LHR2 site has been in operation since 1993; the Harlington site commenced in 2003. The Green Gates and Oaks Road sites were originally set up for monitoring in connection with the Terminal 5 Construction Impact Assessment in 2001, but were retained at the conclusion of this project, as part of the ongoing monitoring programme from 2007 onwards. Figure 2.1 shows a map of the locations of all monitoring sites used in this study.

Table 2.1 - Description of air quality monitoring sites at Heathrow

Site name	Description	Grid Reference	Pollutant	Date pollutant started
LHR2	Old northern apron	508400 176750	NO_x	01/01/1993
			PM_{10}	16/11/1994
			$PM_{2.5}$	09/12/2009
			BC	01/01/2014
			MET (WS and WD)	01/01/1993
Harlington	Imperial College Sports Ground, 1 km North of LHR2	508299 177809	NO_x	01/01/2004
			O_3	01/01/2004
			PM_{10}	01/01/2004
			$PM_{2.5}$	16/09/2008
Heathrow Green Gates	Bath Road, close to north west of airport	505630 176930	NO_x	01/07/2001
			PM_{10}	04/05/2001
			$PM_{2.5}$	19/04/2002
Heathrow Oaks Road	Residential area to South West of airport	505740 174500	NO_x	01/07/2001
			PM_{10}	04/05/2001
			$PM_{2.5}$	19/04/2002
			BC	01/01/2014

Figure 2.1 - Map of air quality monitoring sites at Heathrow

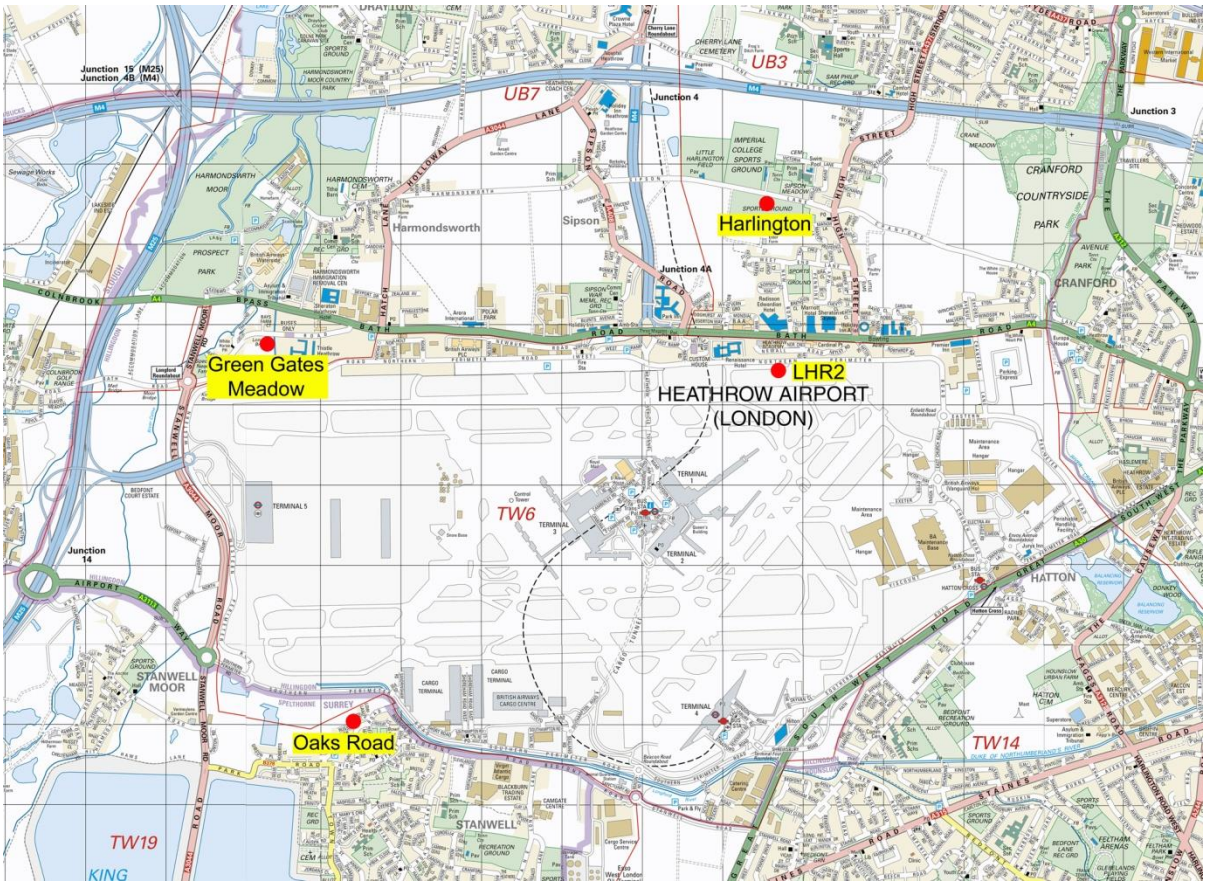


Figure 2.2 shows the LHR2 monitoring site. This is located on an area of the old apron between the northern runway and the northern perimeter road, 14.5 m from the kerb and 179 m from the runway centre. The prevailing wind direction is from the south west and hence this site, situated to the north east of the airport, was selected to monitor air pollutants arising from the airport area. The EU limit values and AQS objectives only apply to locations where public exposure may occur. As LHR2 is located within the airport perimeter, where members of the public do not have access, these limits do not apply.

Figure 2.3 shows the Harlington site. This was established to measure air pollution concentrations in residential areas close to the airport. The site is located in the grounds of the Imperial College Sports Ground, approximately 1 km north of LHR2 and 300 m from the western edge of Harlington. Since 1st January 2004, the site has been part of the Defra Automatic Urban and Rural Network (AURN), and meets the Air Quality Directive siting criteria. Because the site is part of the national network, it is classified according to the site types defined in the Air Quality Directive: its classification of “Urban Industrial” reflects the presence of the airport.

Figure 2.4 shows the Green Gates site. This site is close to Bath Road, which runs along the northern perimeter of the airport.

Figure 2.5 shows the Heathrow Oaks Road site. This site is located in a residential area near to the south western boundary of the airport and is classified as an urban industrial site. Both Green Gates and Oaks Road meet the Directive criteria for urban industrial sites.

Figure 2.2 – Heathrow LHR2 air quality monitoring site

Figure 2.3 – London Harlington air quality monitoring site

Figure 2.4 - Green Gates air quality monitoring site

Figure 2.5 - Oaks Road air quality monitoring site

2.2.1 Automatic monitoring

The following techniques were used for the automatic monitoring of NO_x (i.e. NO and NO_2), PM, O_3 and Black Carbon (BC):

• PM_{10} and $PM_{2.5}$ - Fine Dust Analysis Systems (FIDAS);

• NO, NO_2 – Chemiluminescence;

• O_3 – UV absorption analyser;

• BC – Aethalometer.

Further information on these techniques is provided in Appendix 2 of this report. These analysers provide a continuous output, proportional to the pollutant concentration. This output is recorded and stored every 10 seconds, and averaged to 15-minute mean values by internal data loggers. The analysers are connected to a modem and interrogated through a GPRS internet device to download the data to Ricardo Energy & Environment. Data are downloaded hourly. The data are converted to concentration units at Ricardo Energy & Environment then averaged to hourly mean concentrations.

3 Quality assurance and data capture

3.1 Quality assurance and Quality control

In line with current operational procedures within the Defra Automatic Urban and Rural Network (AURN)[8], full intercalibration audits of the HAL air quality monitoring sites take place at six-monthly intervals. Full details of these UKAS-accredited calibrations, together with data validation and ratification procedures, are given in Appendix 3 of this report. In addition to instrument and calibration standard checking, the air intake sampling systems were cleaned and all other aspects of site infrastructure were checked.

Following the instrument and calibration gas checking, and the subsequent scaling and ratification of the data, the overall accuracy and precision figures for the pollutants monitored at Heathrow are summarised in Table 3.1.

Table 3.1 – Estimated precision and accuracy of the data presented

Pollutant	Precision (µg m-3)	Accuracy
NO	± 2.5	± 15 %
NO_2	± 6.9	± 15 %
O_3	± 3.0	± 15 %
PM_{10}, $PM_{2.5}$	± 4	FIDAS : ± 25 % (estimated)

3.2 Data capture

Data capture statistics for the four monitoring sites are given in Table 3.2. A data capture target of 90% is recommended in the European Commission Air Quality Directive[3] and Defra Technical Guidance is 85% LAQM.TG (16)[7].This is particularly important at Harlington, as data from this site feeds into the Automatic Urban and Rural Network (AURN), the UK's main network used for compliance reporting against the Ambient Air Quality Directives.

In 2016, data capture for all pollutants at all sites was above the 90% data capture requirement.

Table 3.2 – Data capture statistics (%) for Heathrow, 2016

Sites	NO_x	NO_2	PM_{10}	$PM_{2.5}$	BC	O_3
LHR2	92.49	92.49	98.91	98.91	95.39	-
Harlington	90.54	90.54	99.77	99.76	-	98.26
Heathrow Green Gates	98.78	98.78	98.78	98.78	-	-
Heathrow Oaks Road	99.81	99.81	99.20	99.21	97.09	-

Table 3.3 – Significant data gaps (Periods > 24h) occurred at Heathrow during 2016

Site	Pollutant	Start date	End date	No. of days	Reason	Comments
Harlington	NO_x	04/02/16	26/02/16	22	Analyser issue	
	NO_x	14/10/16	17/10/16	3	Analyser Issue	Pump problem
	NO_x	16/11/16	23/11/16	7	Analyser removed for repair	Moly problem
	Ozone	14/10/16	17/10/16	3	Analyser issue	Pump Problem
	Ozone	19/10/16	20/10/16	1	Analyser Issue	Pump problem
Green Gates	$PM_{10/2.5}$	01/11/16	02/11/16	1	Power cut followed by coms issue for FIDAS	NOx saw a 12 hour gap
LHR2	NO_x	24/02/16	01/03/16	5	Analyser left out of service	
	NO_x	14/12/16	18/12/16	4	No data	Transfer between collection systems
	BC	24/06/16	30/06/16	6	Analyser issue	
	BC	01/12/16	2/12/16	1	Analyser issue	

4 Results and discussion

4.1 Automatic monitoring data

The summary statistics for 2016 are presented in Tables 4.1, 4.2, 4.3 and 4.4. The time series of data for the full year, as measured by the automatic monitoring sites, are shown in Figure 4.1, 4.2, 4.3 and 4.4.

Figure 4.5 shows the hourly averages for BC at LHR2 and Oaks road sites.

Table 4.1 – Air pollution statistics for LHR2, from 1st January to 31st December 2016

LHR2	NO (µg m^{-3})	NO_2 (µg m^{-3})	NO_x (µg m^{-3})	$PM_{2.5}$ (µg m^{-3})	PM_{10} (µg m^{-3})	BC (µg m^{-3})
Maximum hourly mean	785	216	1368	256	294	25
Maximum running 8 hour mean	500	167	887	133	148	21
Maximum running 24 hour mean	419	135	760	72	83	13
Maximum daily mean	482	139	878	64	71	14
Average	45.86	47.75	117.69	9.93	14.57	2.38
Data capture	92.49	92.54	92.54	98.92	98.92	95.39

Table 4.2 – Air pollution statistics for Harlington, from 1st January to 31st December 2016

Harlington	NO (µg m-3)	NO_2 (µg m-3)	NO_x (µg m-3)	$PM_{2.5}$ (µg m-3)	PM_{10} (µg m-3)	O3 (µg m-3)
Maximum hourly mean	603	189	1100	205	224	131
Maximum running 8 hour mean	494	164	919	130	141	125
Maximum running 24 hour mean	361	129	682	71	84	87
Maximum daily mean	325	115	599	63	68	77
Average	22.50	34.45	68.78	10.22	15.36	33.72
Data capture	90.54	90.54	90.54	99.76	99.77	98.26

Table 4.3 – Air pollution statistics for Green Gates, from 1st January to 31st December 2016

Heathrow Green Gates	NO (µg m^{-3})	NO_2 (µg m^{-3})	NO_x (µg m^{-3})	$PM_{2.5}$ (µg m^{-3})	PM_{10} (µg m^{-3})
Maximum hourly mean	640	199	1156	134	143
Maximum running 8 hour mean	475	149	875	92	98
Maximum running 24 hour mean	357	115	660	72	77
Maximum daily mean	294	103	553	69	75
Average	23.84	34.17	70.45	10.02	14.25
Data capture	98.78	98.78	98.78	98.74	98.78

Table 4.4 – Air pollution statistics for Oaks Road, from 1st January to 31st December 2016

Heathrow Oaks Road	NO ($\mu g\ m^{-3}$)	NO_2 ($\mu g\ m^{-3}$)	NO_x ($\mu g\ m^{-3}$)	$PM_{2.5}$ ($\mu g\ m^{-3}$)	PM_{10} ($\mu g\ m^{-3}$)	BC ($\mu g\ m^{-3}$)
Maximum hourly mean	428	160	772	147	158	16
Maximum running 8 hour mean	370	120	662	89	96	-
Maximum running 24 hour mean	286	98	533	62	66	-
Maximum daily mean	236	95	456	59	63	8
Average	19.07	31.34	60.33	10.02	14.53	1.44
Data capture	99.18	99.18	99.18	99.20	99.21	97.09

Figure 4.1 – Time series of hourly averaged concentrations of NO_x and PM for LHR2 site, 2016

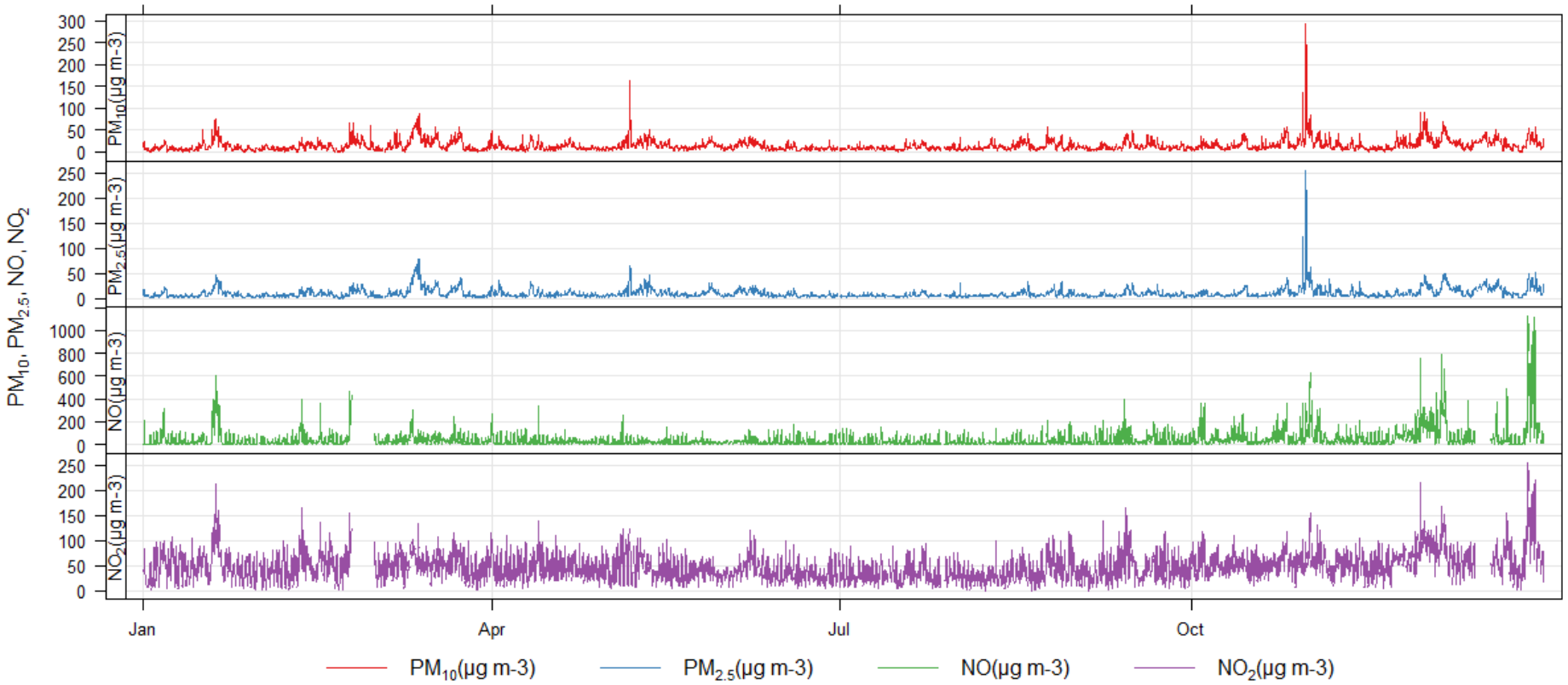


Figure 4.2 – Time series of hourly averaged concentrations of NO_x, PM and O_3 for Harlington site, 2016

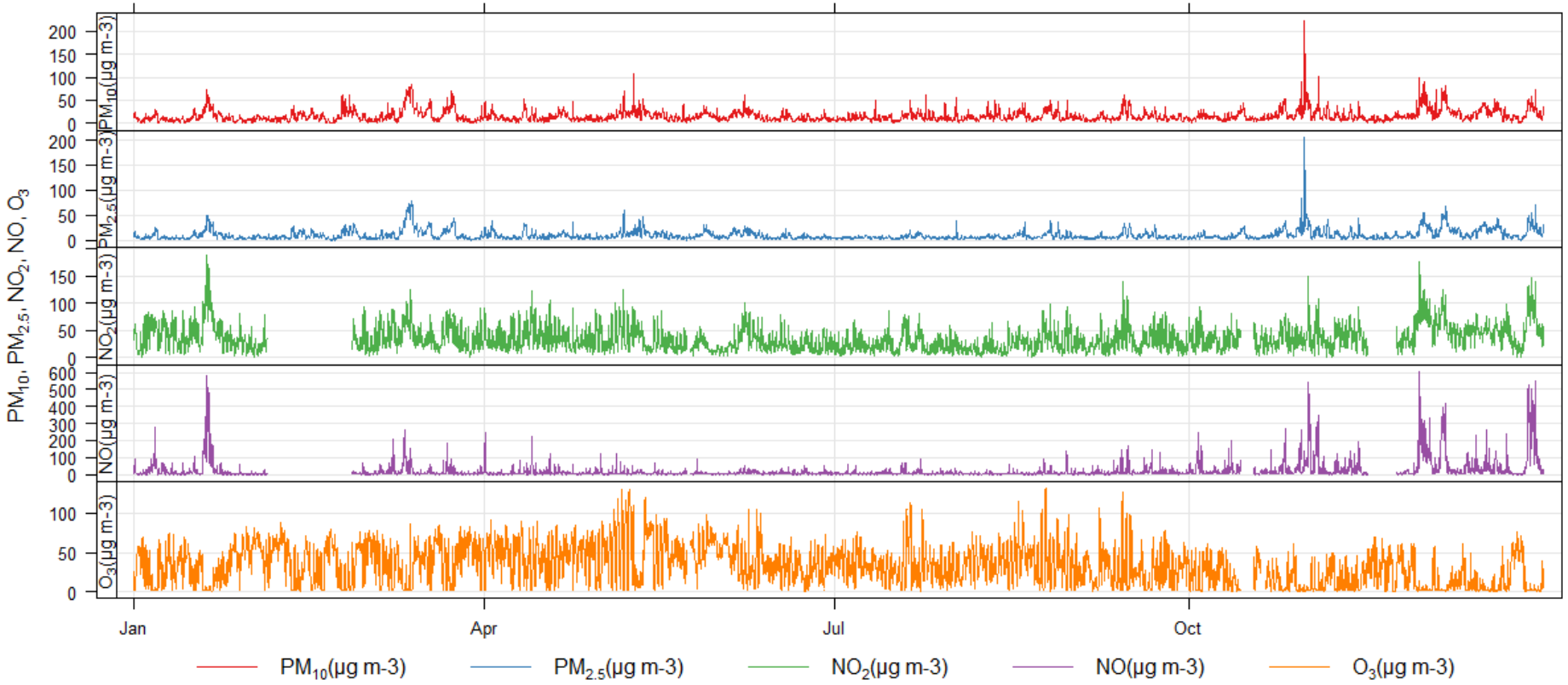


Figure 4.3 - Time series of hourly averaged concentrations of NO_x and PM for Green Gates site, 2016

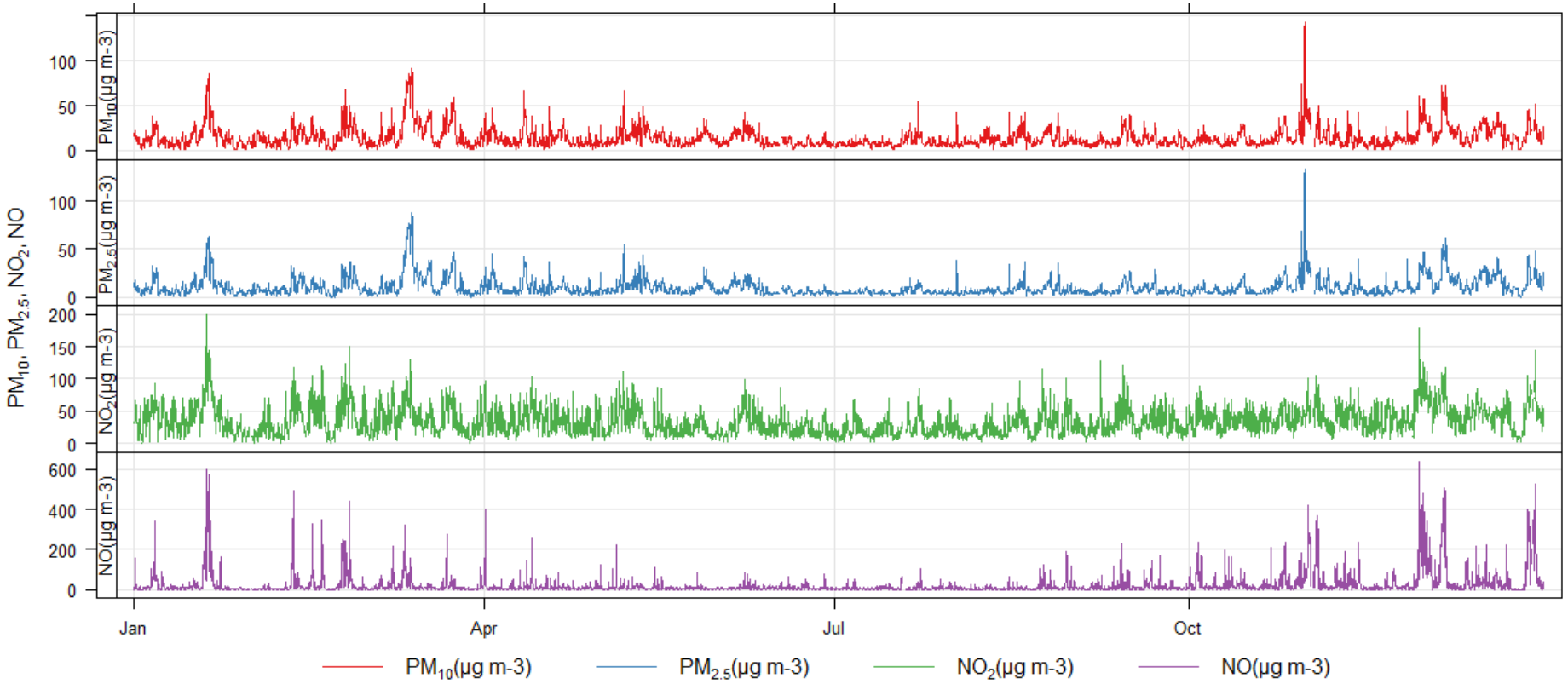


Figure 4.4: Time series of hourly averaged concentrations of NO_x and PM for Oaks Road site, 2016

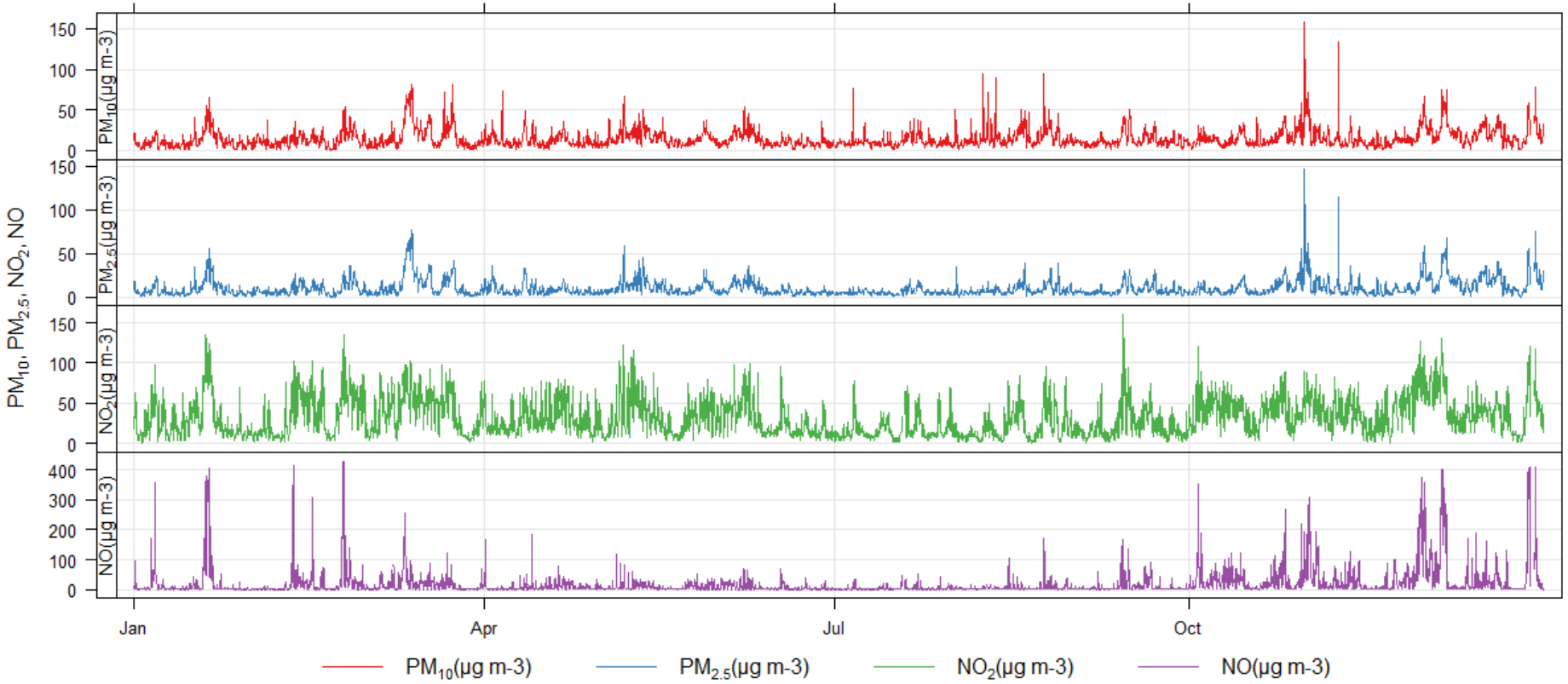
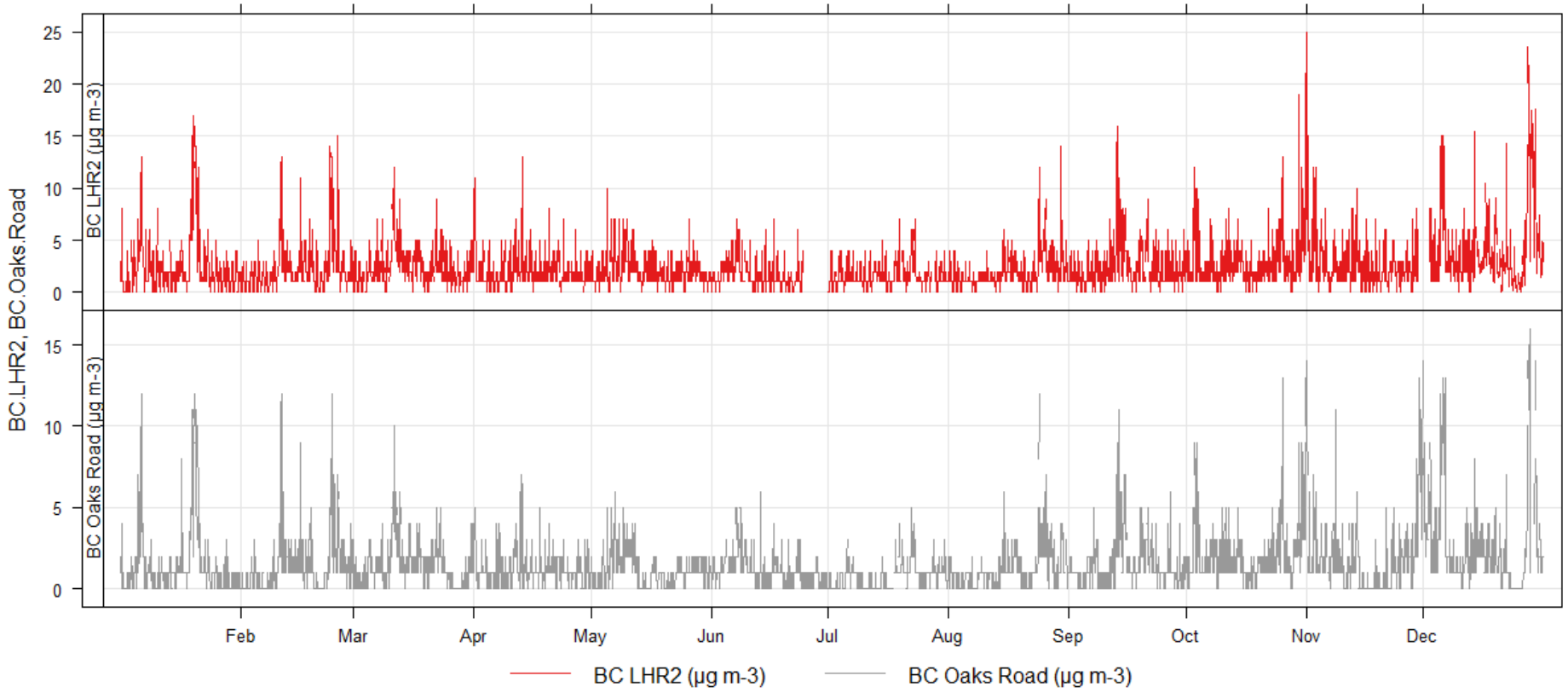


Figure 4.5-Time series of hourly averaged concentrations of Black Carbon (BC) for Heathrow LHR2 and Oaks Road sites, 2016



All sites show similar peaks of PM_{10} and $PM_{2.5}$ during March and November. The origin of such elevated concentrations of PM are investigated later in the report. The elevated peaks of NO_x/NO_2 and BC appear, to some extent, during the same periods mentioned for PM, and also during winter months following a typical seasonal pattern.

4.2 Comparison with air quality objectives

None of the annual, hourly or daily mean limits specified by Defra for all the measured pollutants were exceeded at HAL monitoring locations in 2016.The Details of UK air quality standards and objectives specified by Defra are provided in Appendix 1.

The AQS objective for hourly mean NO_2 concentration is 200 µg m^{-3} which may be exceeded up to 18 times per calendar year.

During 2016 there were eight hourly mean NO_2 measurements exceeding 200 µg m^{-3}. The first occurred on the 19th of January while the remaining seven of these measurements occurred between the 27th and 29th of December. All of these were recorded at the LHR2 site. These were the only NO_2 concentrations measured at the Heathrow sites that exceeded the hourly limit value. The threshold of the Defra "Moderate" air quality band is from 201 to 400 µg m^{-3} for hourly means. NO_2 levels at all sites remained within the Defra "Low" band for the whole year a part from the previously mentioned NO_2 measurements at LHR2. This AQS objective was achieved for 2016.

The annual mean AQS objective for NO_2 is 40 µg m^{-3}. This was met at Harlington, Green Gates and Oaks Road, but not at the LHR2 site, where the calculated annual mean was of 47 µg m^{-3}. Although this value exceeds the AQS objective for NO_2, for this particular case, because. LHR2 falls into the category "other" as defined by the Defra Technical Guidance on air quality monitoring LAQM.TG (16)[7] : "*Any special source-orientated or location category covering monitoring undertaken in relation to specific emission sources such as power stations, car-parks, airports or tunnels*." The EU limit values and AQS objectives only apply to locations where public exposure may occur. As LHR2 is located within the airport perimeter, where members of the public do not have access, these limits do not apply.

The AQS objective for PM_{10} is a maximum of 50 µg m^{-3} for 24h mean periods, not to be exceeded more than 35 times a year. Results show that some exceedances to the 50 µg m^{-3} 24h mean periods value were registered at all sites. At LHR2, Harlington, Green Gates and Oaks Road, three, five, three and two exceedances respectively were recorded. The maximum value of exceedances of each site varies between 66 to 84 µgm^{-3}. All sites are well within the yearly maximum permitted number of exceedances of 35, thus all meeting the AQS objective for 24-hour mean PM_{10}.

The annual mean AQS objective for PM_{10} is 40 µg m^{-3}. All sites registered average annual values ranging between 14 and 15 µg m^{-3}, this objective was therefore met.

While no AQS objective exists for $PM_{2.5}$, there is an annual mean objective of 25 µg m^{-3}, although this is a non-mandatory compliance target to be met by 2020. The annual mean for this pollutant for all monitoring locations was 10 µg m^{-3}. This is less than half of the average concentration target limit for 2020.

O_3 was measured at Harlington only. The AQS objective for daily maximum on an 8 hour running mean is of 100 µg m^{-3} (not to be exceeded more than 10 days a year). Harlington exceeded the AQS objective for ozone over 6 days during 2016. The maximum hourly concentration of ozone was registered on the 24th of August, recorded at 131 µg m^{-3}. The site met the AQS objectives for this pollutant in 2015.

Black Carbon was measured at LHR2 and Oaks Road. The highest hourly mean registered was at 25 µgm^{-3} and 16 µgm^{-3} for LHR2 and Oaks Road respectively. This values are similar to the ones obtained in the previous year for the same sites (19 and 18 µgm^{-3}). The UK Government does not have specific policies to address black carbon and other short lived climate forcers, and therefore, no comparison to a limit can be made. As a proportion of particulate matter is black carbon, action to reduce particle emissions will reduce this pollutant.

4.3 Temporal variation in pollutant concentrations

Figure 4.7, 4.8, 4.9 and 4.10 show the variation of monthly, weekly, daily and hourly NO_x and PM concentrations during 2016 at LHR2, Harlington, Green Gates and Oaks Road respectively. Figure 4.8, the Harlington site, also includes O_3. Figure 4.11 shows the same results for BC at LHR2 and Oaks Road.

Figure 4.7 - Time series of seasonal and diurnal variations of NO_x and PM for the LHR2 site, 2016

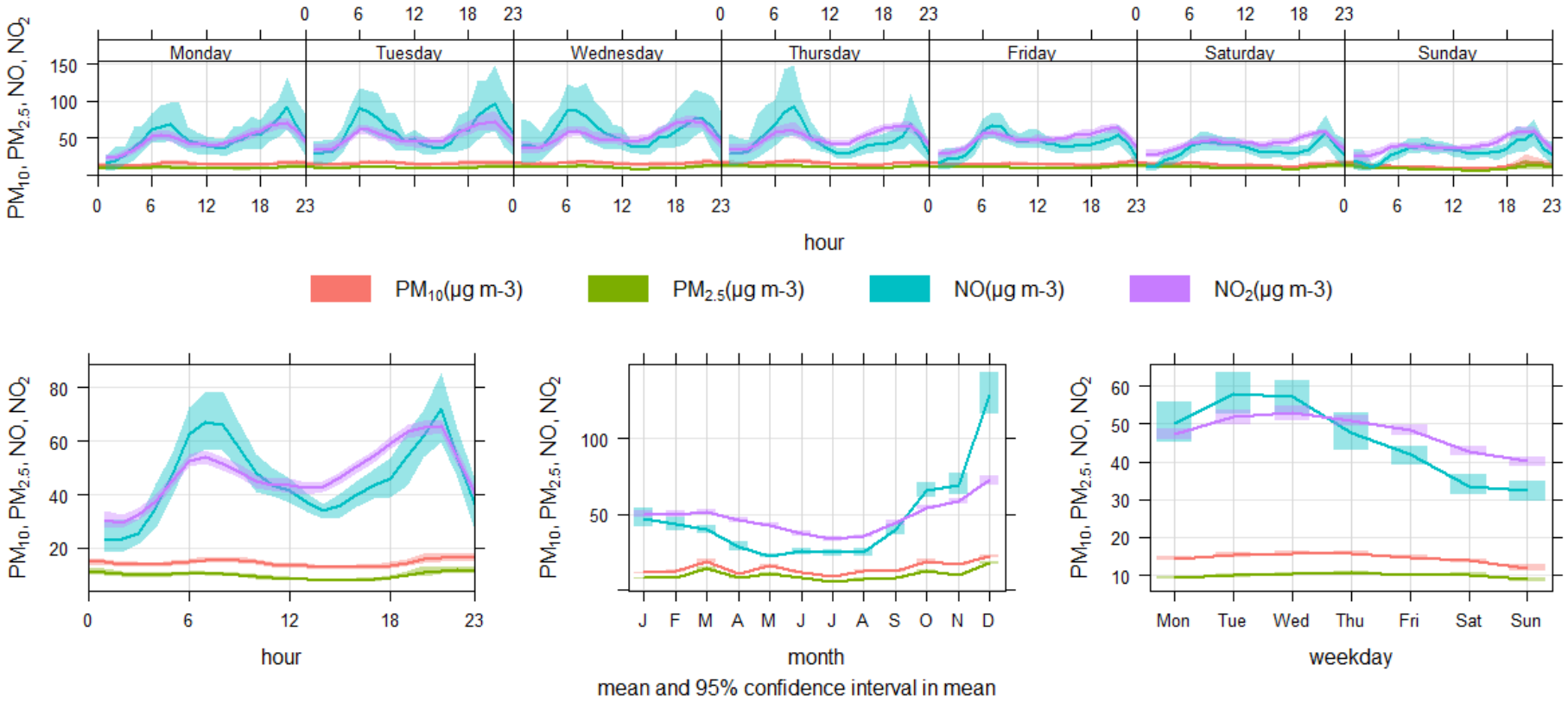


Figure 4.8 – Time series of seasonal and diurnal variations of NO_x, PM and O_3 for the Harlington site, 2016

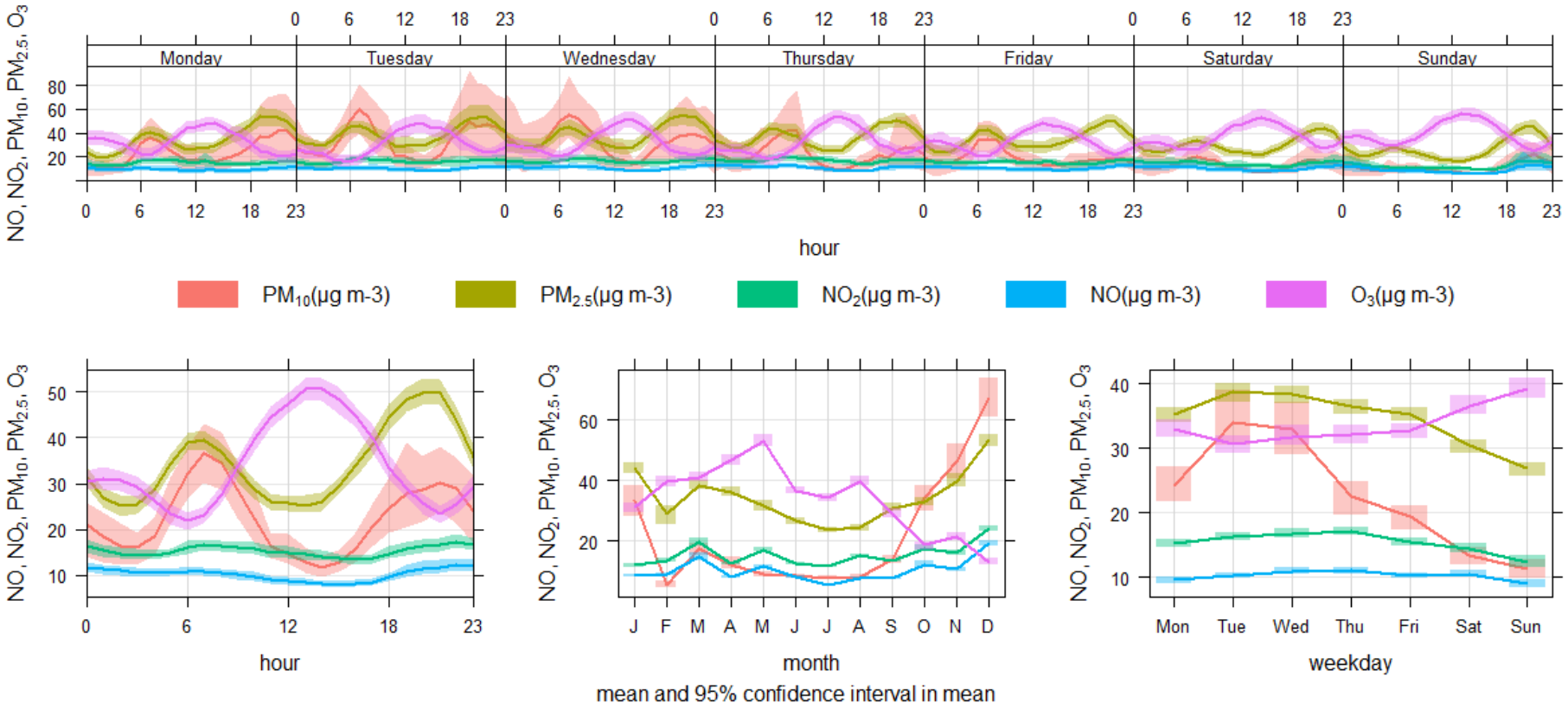


Figure 4.9 – Time series of seasonal and diurnal variations of NO_x and PM for the Green Gates site, 2016

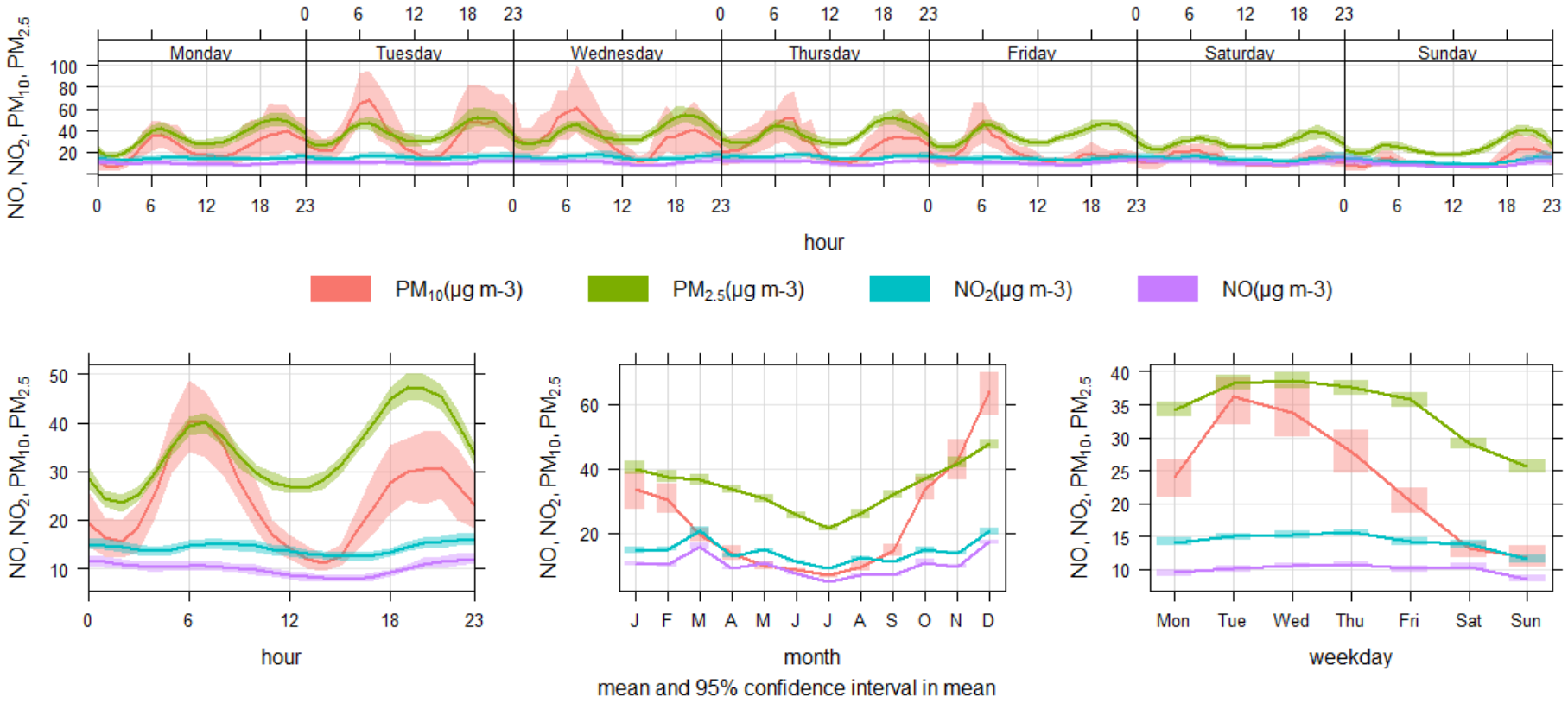


Figure 4.10 – Time series of seasonal and diurnal variations of NO_x and PM for the Oaks Road site, 2016

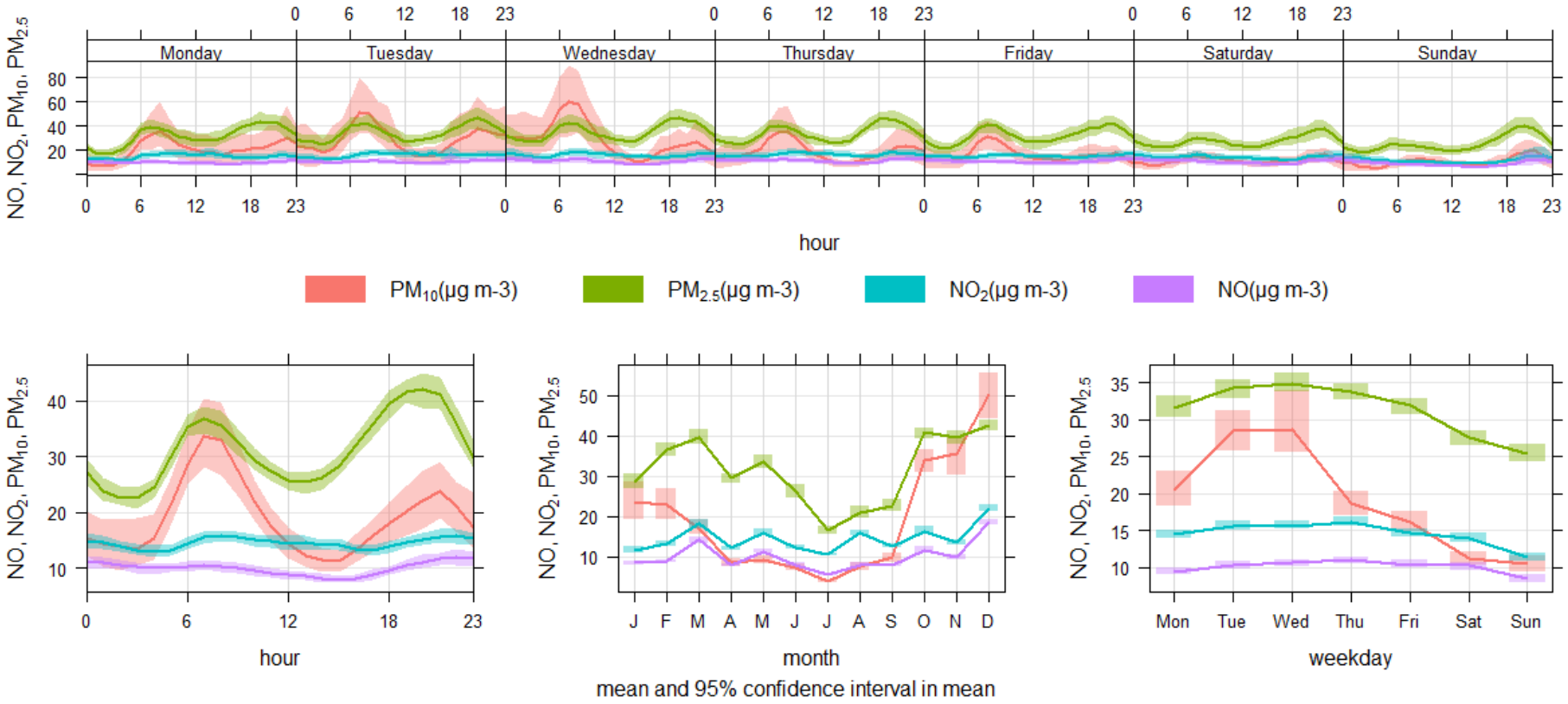
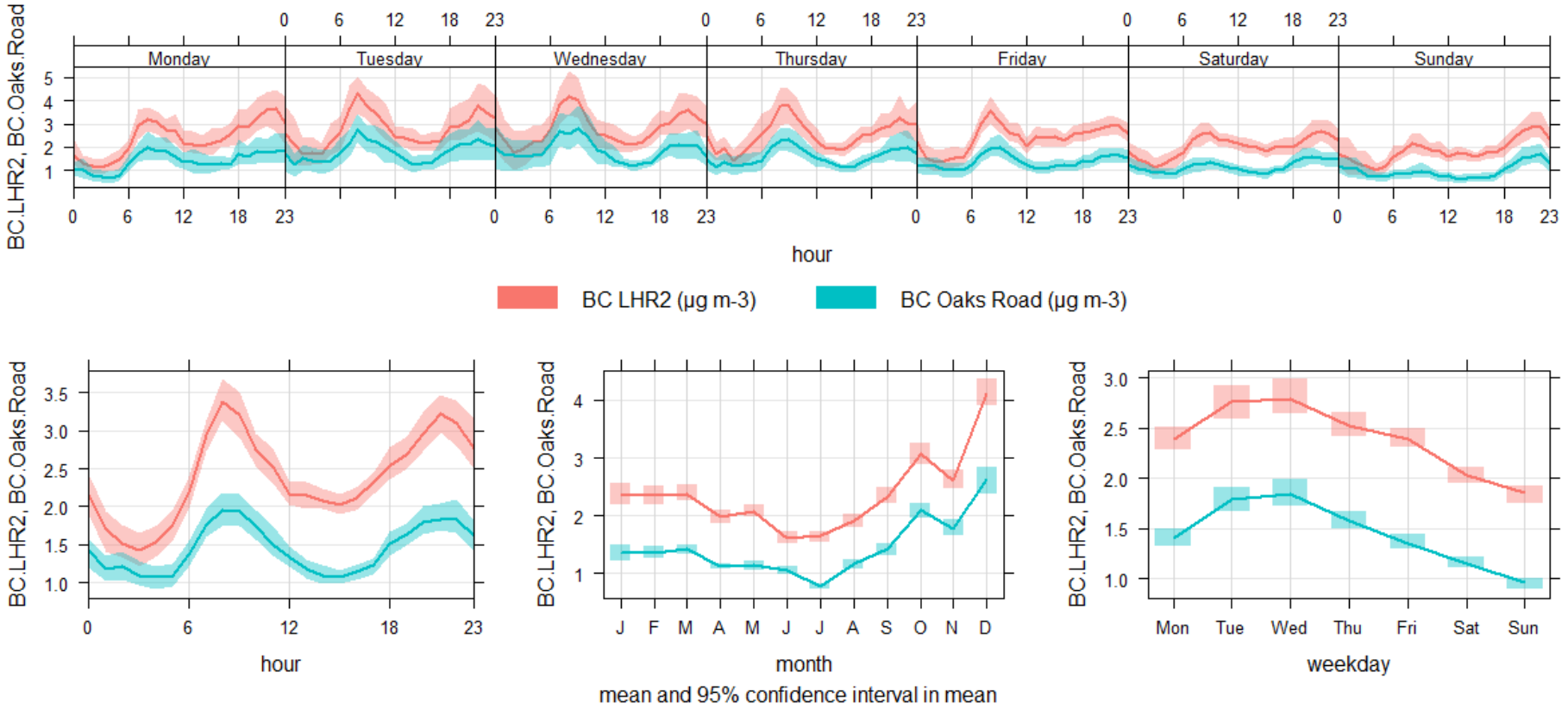


Figure 4.11 – Time series of seasonal variations of BC for the LHR2 and Oaks Road, 2016



4.3.1 Seasonal variation

Seasonal variations seem to follow similar trends for NO_x, PM and BC (when measured) at all sites during 2016, as it can be observed in the 'month' plots of figures 4.7 to 4.11. Elevated concentration peaks were registered for PM, and to a lesser degree NO and NO_2, at all sites (except LHR2 in the case of NO_x) in March, May and August. These peaks are not representative of a typical seasonal variation, and are the result of specific pollution episodes, that are to be explained further on this report (sub chapter 4.5).

As in previous years, PM_{10} and $PM_{2.5}$ concentrations showed much less seasonal variation than oxides of nitrogen. NO and NO_2 concentrations at all the sites generally follow a typical seasonal variation for urban areas with the highest concentrations occurring during the winter months. This pattern was also observed in previous years and is typical of urban monitoring sites. The highest levels of primary pollutants tend to occur in the winter months, when emissions may be higher, and periods of cold, still weather reduce pollutant dispersion.

O_3 concentrations registered at Harlington continue to follow a typical seasonal variation for this pollutant, with higher concentrations being registered in April, May, and August. At low/mid latitudes, high O_3 concentrations are generally observed during late spring and/or summer months. This is partly due to predominant anti cyclonic conditions (characterized by warm and dry weather systems) which increase the number of photochemical reactions in the atmosphere, responsible for the increase of ground level ozone production. In addition, the convective fluxes created during hot summer days can also be responsible for an increase of O_3 (stratospheric intrusion). The hot air generated at ground level due to high temperatures is lighter and tends to ascend, being replaced by colder stratospheric air masses coming from above, dragging stratospheric O_3 to ground level as a consequence.

BC data was recorded at LHR2 and Oaks Road sites. The seasonal variation of this pollutant shows in general elevated levels of BC during the winter months. BC is directly related with the incomplete combustion of fossil fuels, it's likely that during winter and colder periods fuel emissions associated with heating and reduced pollutant dispersion might be the main causes of elevated concentrations of this pollutant. Similar peaks as the ones registered for PM can be seen in May and October for this BC, and are comparable to regional episodes recorded at other UK stations.

4.3.2 Diurnal variation

The diurnal variation analyses viewed in the 'hour' plots in figures between 4.7 and 4.10 showed typical urban area daily patterns for NO and NO_2 in all sites. Pronounced peaks can be seen for these pollutants during the mornings, corresponding to rush hour traffic at around 07:00. Concentrations tend to decrease during the middle of the day, with a much broader evening road traffic rush-hour peak building up from early afternoon. NO also showed a much smaller peak than NO_2 in the afternoons at all sites. This is likely to be because concentrations of oxidising agents in the atmosphere (particularly ozone) tend to increase in the afternoon, leading to enhanced oxidation of NO to NO_2. A good example of this atmospheric reaction can be seen at the Harlington site. The NO concentrations decrease significantly in the early afternoon, while the concentration of O_3 increases in the same proportion. The diurnal concentration of O_3 in Harlington also follows a typical diurnal pattern seen at other sites in the UK.

O_3 concentrations always increase during daylight hours due to the photochemical reactions of NO_2 and photo oxidation of a range of VOC's and CO. In the evening and overnight, O_3 gets consumed by a fast reaction with NO (NO titration). The absence of sunlight prevents the photolysis of the O_3 precursors and formation of ozone.

The diurnal patterns for PM_{10} and $PM_{2.5}$ are determined by two main factors. The first is emissions of primary particulate matter, from sources such as vehicles. The second factor is the reaction that occurs between sulphur dioxide, NO_x and other chemical species, forming secondary sulphate, nitrate and other particles. Morning and afternoon road traffic rush-hour peaks for PM_{10} and $PM_{2.5}$ could be seen at all four sites, but these were less pronounced than those for oxides of nitrogen.

BC diurnal variation viewed in the 'hour' plots in figure 4.11 appears to follow the same trend pattern of NO_x and PM, with two peaks measured at the same periods (07:00 AM and 20:00 PM).

4.3.3 Weekly variation

The analyses of each pollutants weekly variation showed that the same type of diurnal patterns occur for all the days of the week. NO early morning and late afternoon rush hour peaks are in general much more pronounced during the first half of the working week, in particular Tuesday, than latter half and the weekend. PM shows similar trend, this probably indicates that the origin comes from some construction work in the vicinity of the site, mixed with some vehicle emissions from roads.

BC data slightly decreases during the week in both sites from Tuesday to Friday. The highest peak occurs on a Tuesday, and is consistent to PM and NO_x observations for the same day at all sites. The lowest values tend to be measured on Sundays.

4.4 Source investigation

In order to investigate the possible sources of air pollution being monitored around Heathrow Airport, meteorological data measured at LHR2 was used to add a directional component to the air pollutant concentrations.

Figure 4.12 shows the wind speed and direction data, measured at LHR2. The lengths of the "spokes" against the concentric circles indicate the percentage of time during the year that the wind was measured from that direction. Each "spoke" is divided into coloured sections representing wind speed intervals of 2 ms^{-1} as shown by the scale bar in the plot. The prevailing wind, from the south west, had a mean speed of 3.39 ms^{-1}. The maximum measured wind speed was 14.5 ms^{-1} and the 10 highest wind speeds were recorded in February and March.

Figure 4.12 - Wind rose showing the wind speeds and directions at LHR2 in 2016.

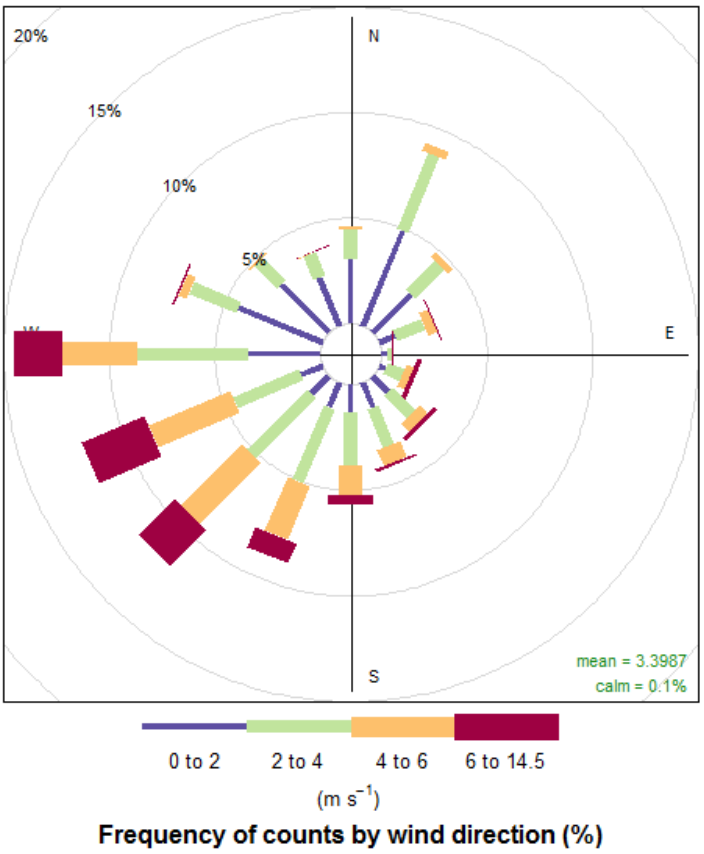


Figure 4.13 to Figure 4.18 show bivariate plots of hourly mean concentrations of NO, NO_2, PM_{10}, $PM_{2.5}$ and BC at LHR2 against wind speed and wind direction. Figure 4.19 shows a bivariate plot of ozone concentration at Harlington, plotted using wind speed and direction data measured at LHR2. These plots should be interpreted as follows:

- The wind speed is indicated by the distance from the centre of the plot; the grey circles indicate wind speeds in 2 ms^{-1} intervals.
- The pollutant concentration is indicated by the colour (as indicated by the scale).

These plots therefore show how pollutant concentrations varied with wind direction and wind speed.

The plots do not show distance of pollutant emission sources from the monitoring site. However, in the case of primary pollutants such as NO, the concentrations at very low wind speeds are dominated by emission sources close by, while at higher wind speeds, effects are seen from sources further away.

Figure 4.13 – Pollution rose for NO at LHR2

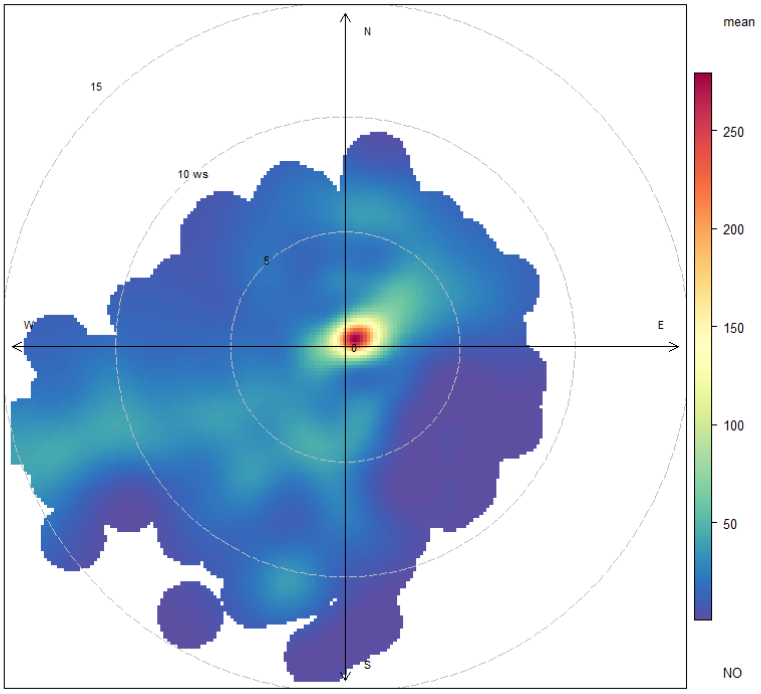


Figure 4.13 shows, as in previous years, that the highest concentrations of NO occurred under calm conditions. Such conditions will have allowed NO emitted from nearby sources (vehicles on the northern perimeter road, Bath Road, and within the hotel car parks beside it) to build up, reaching high concentrations.

Figure 4.14 – Pollution rose for NO_2 at LHR2

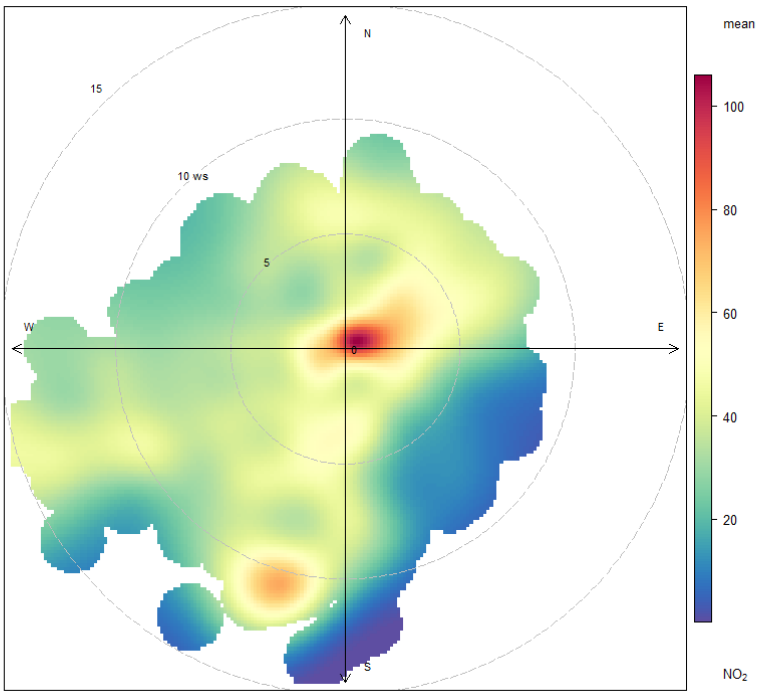


Figure 4.14 shows higher concentrations of NO_2 were associated with two sets of conditions, winds from the north west quadrant and from the south west quadrant. This can then be broken down into; several sections. Calm conditions and light winds (<5 ms^{-1}) from the east brought pollutants from the nearest roads and the built-up area of Harlington. Part of this NO_2 was also created by the fast reaction of local emission NO with ozone. As in previous years, other high NO_2 concentrations are associated with a wind direction of south west for high wind speeds, (>10 ms^{-1}), possibly indicating a major source further away. In this direction the airports departures and arrivals area along with the Central Terminal Area (CTA) can be found.

Figure 4.15 – Pollution rose for PM_{10} at LHR2

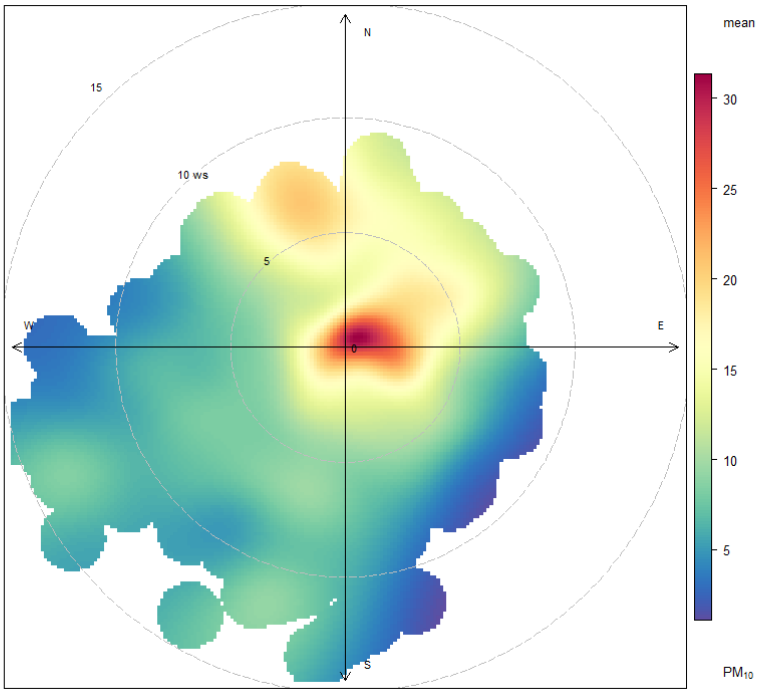


Figure 4.15 (for PM_{10}) shows high concentrations occurred under calm conditions very close to the monitoring station (north east and east). There was also a moderate source shown from north west for wind speeds between 5 and 10 ms^{-1}.

Figure 4.16 – Pollution rose for $PM_{2.5}$ at LHR2

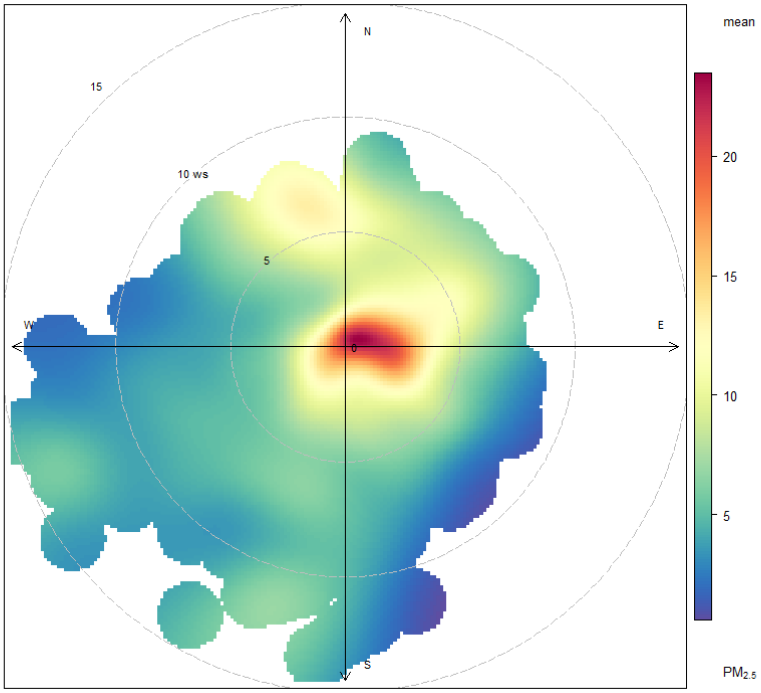


Figure 4.16 shows a similar directional pattern for $PM_{2.5}$ to the one seen for PM_{10}. Elevated concentrations are again associated with low wind speeds, suggesting the same sources were involved for both particulate size fractions. The signatures at moderate to high wind speeds were also similar, although $PM_{2.5}$ showed a lower contribution than the ones seen for PM_{10} (note the different scales between Figures 4.15 and 4.16).

Figure 4.17 – Pollution rose for BC at LHR2

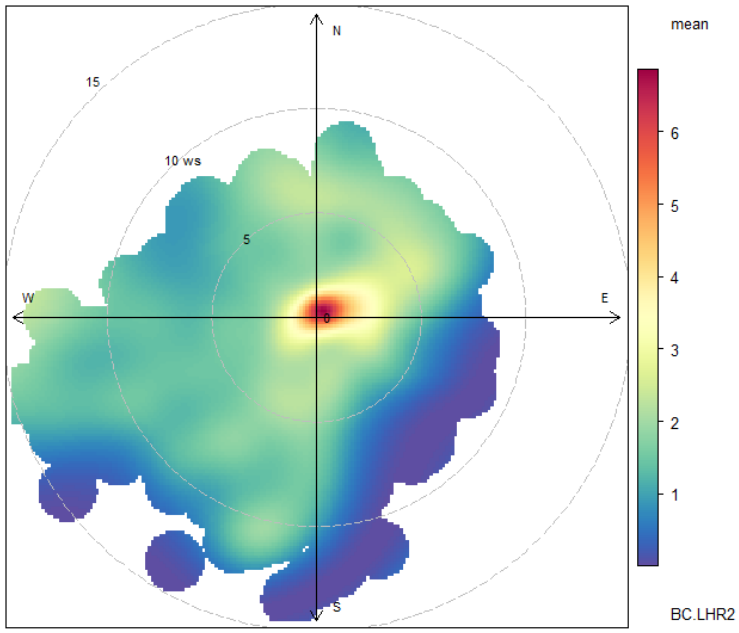
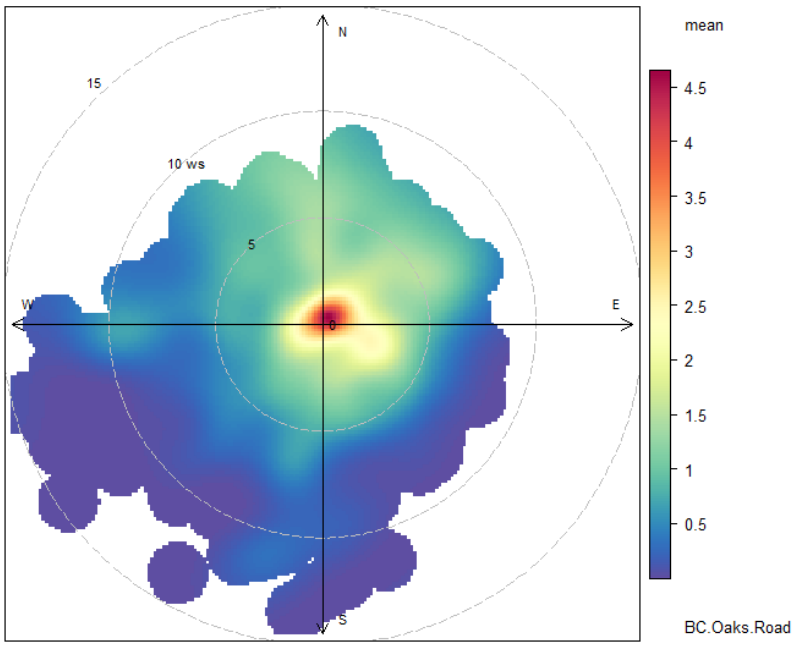
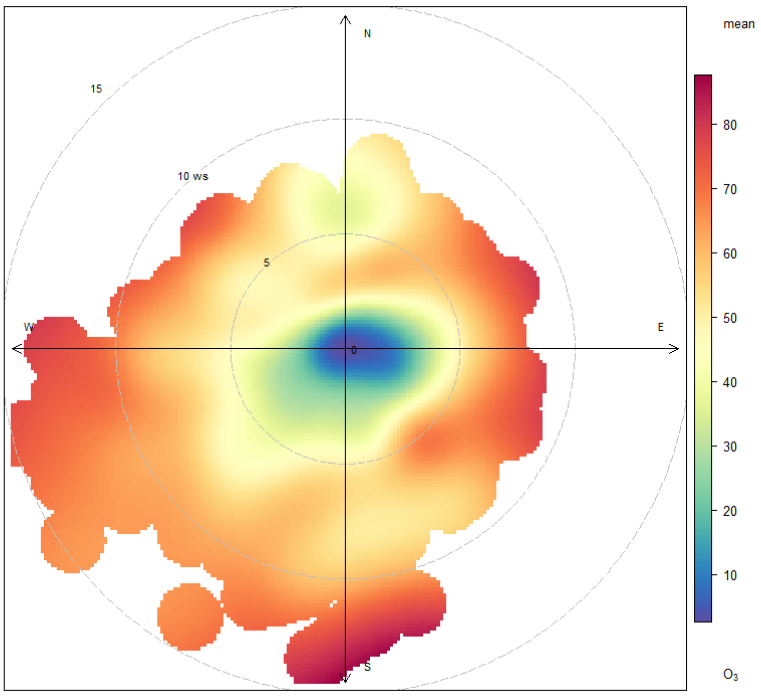


Figure 4.18 – Pollution rose for BC at Oaks Road



Figures 4.17 and 4.18 show the BC pollution roses for LHR2 and Oaks Road. These plots show that both sites have registered the highest BC concentrations when wind speed was low, which suggests that the major sources of BC are local. At LHR2, some elevated levels of BC seem to come also from the north east and to some extent from the south east which suggests that BC is not a significant emission from the airport.

Figure 4.19 – Pollution rose for O_3 at Harlington



The pollution rose for ozone (Figure 4.19) is based on ozone concentration data from Harlington, combined with wind speed and direction data measured at LHR2. The pattern for ozone was similar to the one of 2015. Lower ozone levels seem to appear at low wind speeds, which shows that ozone was being scavenged by local emissions. High levels of NO caused by the combustion of fossil fuels tend to react rapidly with O_3 to produce NO_2 (destruction of ozone by titration with NO). O_3 levels tend to be higher at high wind speeds, where the effect of local NO emissions is not so well pronounced. The highest ozone concentrations seem to come from the south, for wind speeds above 10 ms^{-1}.

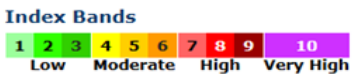
4.5 Periods of elevated pollutant concentration

This section reviews the most significant periods of high air pollution concentrations for the whole year. It is important to stress that, despite there being some periods when pollutant concentrations exceeded the applicable air quality objectives, these were attributable to specific external sources.

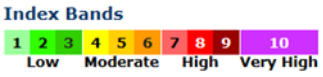
Several high pollution episodes occurred during 2016. LHR2 experienced eight exceedances of NO_2 limits, these occurred in three groups; 19th January, 29th November and December 27th to the 29th. All four sites had exceedances, with the highest hourly averages of PM_{10} being recorded in March (10th – 13th), May (6th), October (29th – 30th) and December (1st – 6th and 27th-30th).

The historic Air Quality Index data presented at the Department of Environment, Food & Rural Affairs (Defra) UK-AIR website[9] shows that when elevated pollution levels were recorded at Heathrow, similar elevated periods were also recorded for other areas of the UK. These events were largely due to localised emissions being trapped by weather conditions and trans-boundary emissions from continental Europe. The following days are looked at specifically: 20th January, 12th March, 31st October and 5th December. Investigation of these pollution events follow below:

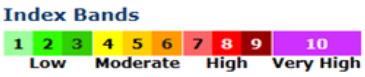
- The pollution event of the 20th of January was mainly confined to the south east and midlands areas. Wind speed data recorded at LHR2 shows calm conditions which would have allowed the build-up of local emissions.



- The period between Thursday 10th and Sunday 13th of March saw elevated, 'High' and 'Very High' PM levels over almost all of eastern England and stretching into the west midlands and south west. This pattern is often associated with the importing of pollution from the near continent.



- On the weekend of 29th October 'Moderate' PM_{10} and $PM_{2.5}$ were recorded. This can be put down to a combination of the Hindu festival of Diwali on Sunday 30th October and the proximity to Guy Fawkes night.



- Towards the end of the year London saw a prolonged period of elevated pollution levels. These elevated levels were seen at various time elsewhere within the country. The 5th and 6th of December were seen as the worst days and wind speed measured at LHR2 was low.

Other pollution episodes during 2016 that help explain elevated measures at the Heathrow sites include:

- Tuesday 22nd and Wednesday 23rd March 2016 with calm conditions allowing the build-up of local emissions.
- Between the 27th and 30th of December 2016 with calm conditions allowing the build-up of local emissions.
- Several Ozone episodes over the summer period, in particular early May and late August caused by warm sunny conditions.

4.6 Comparison with other UK sites

Annual mean pollutant concentrations at the four HAL sites are compared with those measured at other air quality monitoring sites in and around London and the south of England in Table 4.5 below.

The sites selected are all part of the UK's national Automatic Urban and Rural Network (AURN) and are as follows:

- London Bexley: a suburban site in a residential area to the south east of London.
- London North Kensington: an urban background site at a school in Kensington, to the west of central London.
- London Bloomsbury: an urban background site in Russell Square, central London
- London Marylebone Road: a kerbside city centre site close to a busy major road: this site measures some of the highest pollutant concentrations in London
- Chilbolton: a rural site in Hampshire, included for comparative purposes.

Table 4.5- Annual mean (NO_x, PM, O_3, BC) and Hourly Max (BC) pollutant concentrations at Heathrow compared with other sites, 2016

Site	Type	NO_2 ($\mu g\ m^{-3}$)	PM_{10} ($\mu g\ m^{-3}$)	$PM_{2.5}$ ($\mu g\ m^{-3}$)	O_3 ($\mu g\ m^{-3}$)	BC ($\mu g\ m^{-3}$)	BC (Hourly max) ($\mu g\ m^{-3}$)
LHR2	Other	47	15	10	-	2.4	25
Harlington	Urban	34	15	10	34	-	-
Green Gates	Urban	34	14	10	-	-	-
Oaks Road	Urban	31	15	10	-	1.4	16
London Bexley	Suburban	25	-	11	-	-	-
London North Kensington	Urban	35	22	12	37	1.8*	29.9*
London Bloomsbury	Urban	42	20	12	25	-	-
London Marylebone Road	Urban	89	26	16	15	5.1	21.3
Chilbolton	Rural	14	15	9	49	-	-

– means the pollutant was not measured at that location.
*less than 75% data capture and so only indicative.

The annual mean NO_2 concentrations at LHR2 and Harlington were comparable to those at the urban background sites, London Bloomsbury and London North Kensington respectively. None of the Heathrow Airport sites had NO_2 concentrations as high as those at London Marylebone, a city centre site beside a congested major road.

The annual mean PM_{10} concentrations at all four Heathrow sites are very similar and were lower than the annual means of all the other urban sites in London (Marylebone, N. Kensington, Bloomsbury) and comparable with the measurements obtained at Harwell (a rural background site). The same trend was observed for $PM_{2.5}$.

Concentrations of ozone tend to be higher in rural areas because of the chemistry of its formation. This is demonstrated by the annual mean recorded at Chilbolton, which was higher than those at the other sites. The annual mean concentration at Harlington is comparable with that measured at London N. Kensington. As expected, the ozone's annual mean at London Marylebone Road, an urban traffic site (highly influenced by intense local emission sources), is the lowest of them all.

BC data at LHR2 and Oaks Road is comparable with BC data from North Kensington. The highest BC annual values were found at Marylebone, which was expected, due to the nature and location of the site (close to a major busy road), in London.

4.7 Long term changes in pollutant concentrations

LHR2 has been in operation for 23 years (following installation in 1993). The other three sites have all been in operation since 2003 or earlier. There is now a considerable amount of data which can be used to assess how pollutant concentrations have changed over this period. Annual mean concentrations of NO_x, NO, NO_2, PM_{10}, $PM_{2.5}$ and O_3 are illustrated below in Figures 4.21 to 4.26. BC measurements only started in 2014. The amount of data is still considered not to be enough for this type of analyses, and therefore the BC time series for black carbon annual mean is not presented on this report. Annual means are only shown for years in which data capture was at least 75%. Also shown is the mean result from an average of up to six urban non-roadside monitoring sites in London. These are: London Bexley,

London Bloomsbury, London Eltham, London North Kensington, London Teddington and London Westminster.

Figure 4.21- Time series for annual mean NO

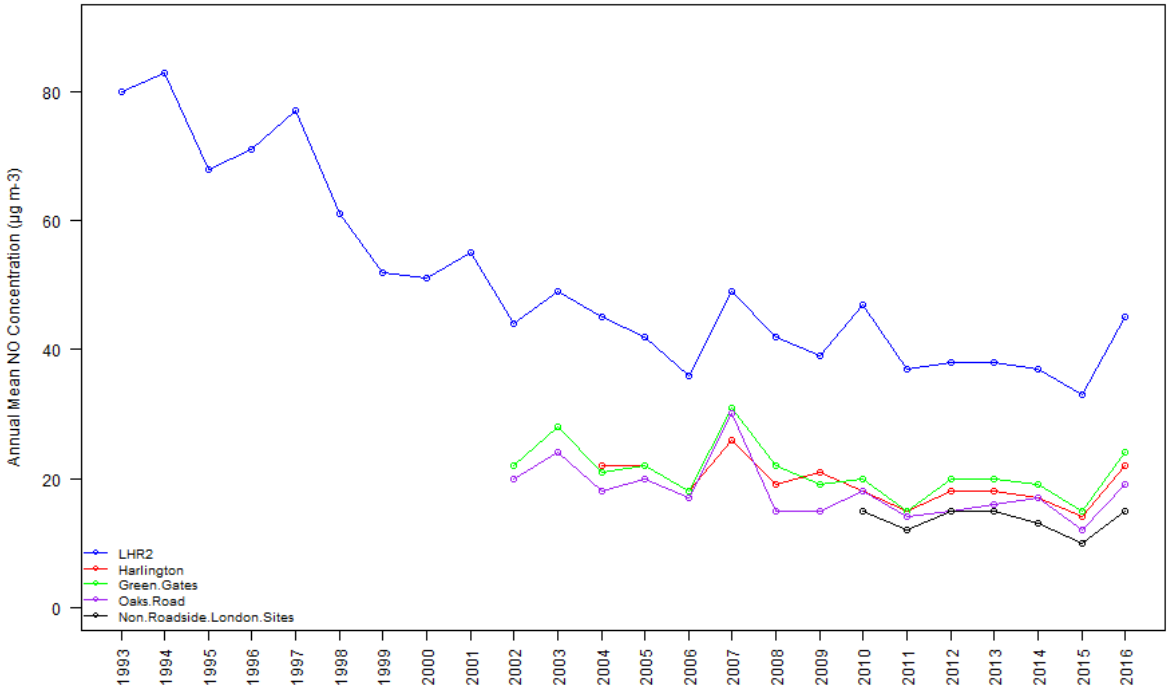
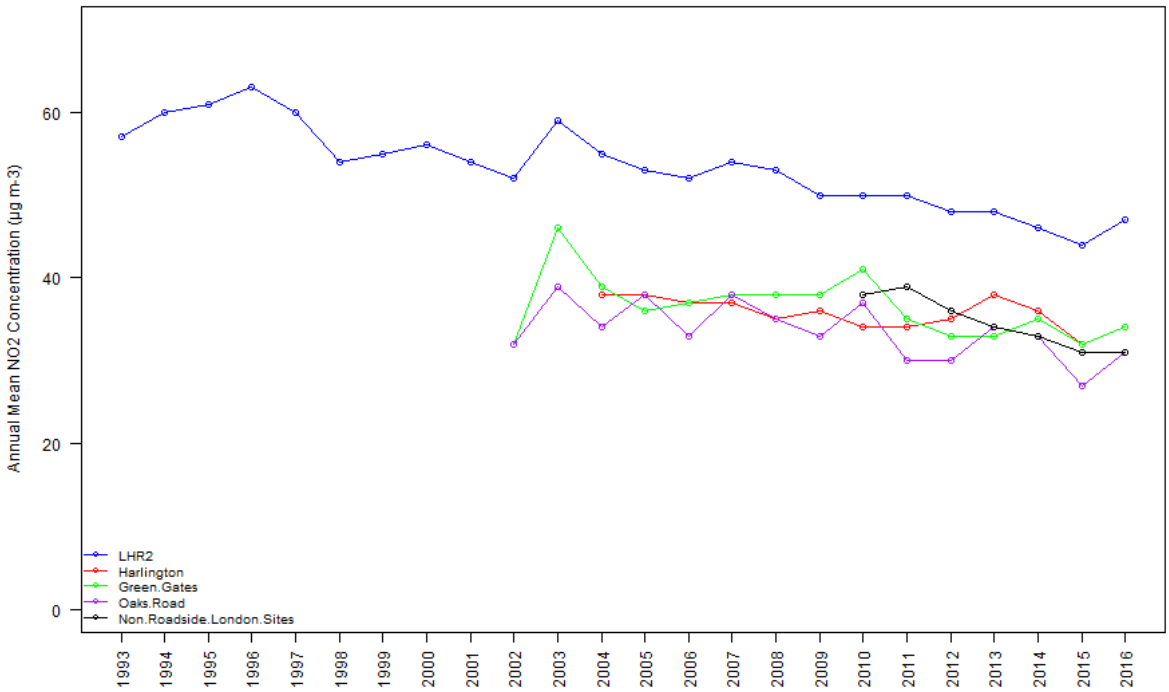


Figure 4.21 shows how annual mean concentrations of total NO have generally decreased at the four sites since the first site (LHR2) came into operation. There was a clear decrease throughout the 1990s at the LHR2 site. Since the turn of the millennium the decreasing trend is less obvious with the annual mean fluctuating between approximately 33 µg m^{-3} and 50 µg m^{-3}. At the other three sites, a slight decrease in annual mean NO_x has occurred during the period 2007-2011, although considerable variations have occurred from one year to the next. NO concentrations seemed to be decreasing at all sites over the last few years, however, 2016 shows a significant increase to record the highest annual mean of this decade at all sites. This pattern over the last six years, and last year's increase, is reflected in the other London sites average.

Figure 4.22- Time series for annual mean NO_2



In the case of NO_2 (illustrated in Figure 4.22), there is a stable downward trend at LHR2, although this is less marked than those seen for NO in the previous figure. The annual mean concentrations at Harlington, Green Gates and Oaks Road have also followed a general downward trend since installation. 2016 saw a slight increase in annual means at all sites, which is not reflected in the average of the other London sites, which remained steady.

Figure 4.23- Time series for NO_2 as a percentage of total NO_x

Figure 4.23 shows the annual mean concentration of NO_2 as a percentage of the total NO_x. From the early 1990s to about 2006 NO_2 accounted for an increasing percentage of total NO_x at LHR2. Since then, it has fluctuated between 40% and 50%. The proportion of NO_x measured as NO_2 at the other three sites has been consistently higher, but has followed broadly similar yearly variations to those seen at LHR2. This percentage seems to have stabilised in all sites since 2012 with a small general increase in 2015 followed by a sharp decrease in 2016, which is also seen in the average of the other London sites.

An increasing trend in the proportion of NO_2 relative to NO_x has been observed in the UK as a whole. The Air Quality Expert Group[5] considered this may be due to an increase in the proportion of total NO_x emitted as NO_2 resulting from an increased proportion of diesel cars and more prevalent use of catalytically regenerative particulate traps on buses.

Figure 4.24- Time series for annual mean PM_{10}

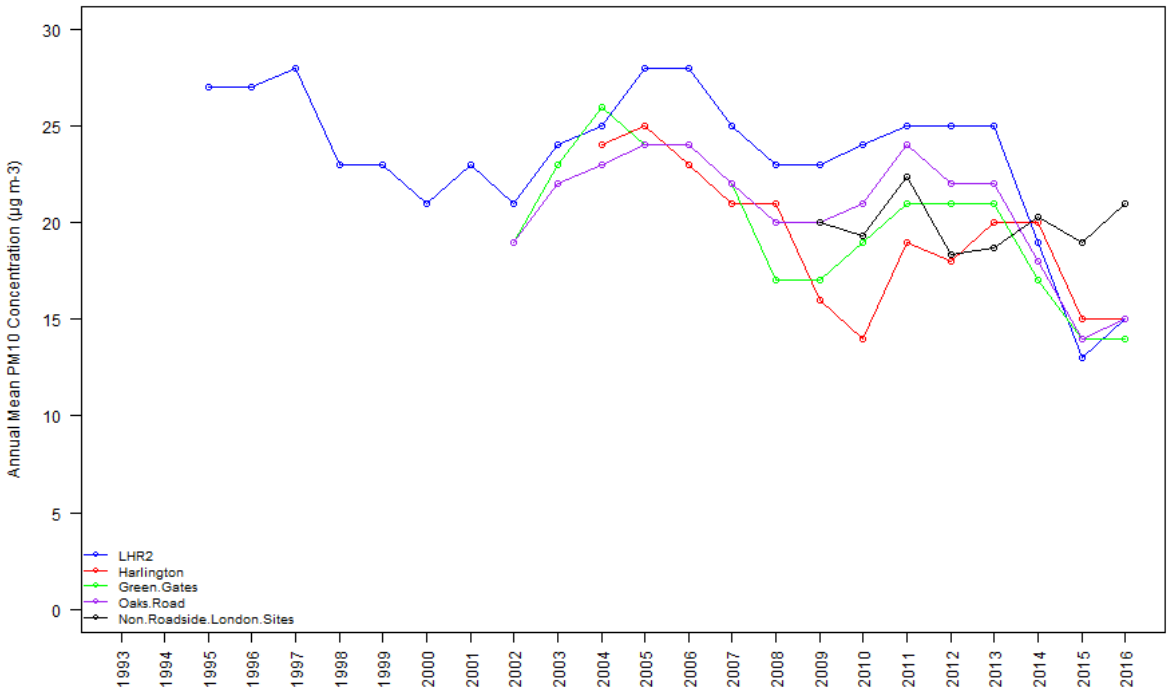


Figure 4.24 shows the annual averages of PM_{10} collected for LHR2 since 1995 and for all sites since 2002. Data was measured with a TEOM up until 2013 (2009 for Harlington). From then up until 2014 the data was VCM corrected. From 2014 onwards all data is from FIDAS instruments and therefore requires no correction factor for PM_{10}.

The annual means of PM_{10} recorded in 2016 are similar to those recorded in 2015. However, a step change in the trend can be seen at all sites, which appears to coincide with the installation of the new FIDAS analysers. Further to this the annual means of the four sites now all site well below the other averaged London sites. There are a number of possible reasons to explain this, but a study of PM concentrations using FDMS and FIDAS analysers was undertaken at Harlington, where over 30 months of co-located data is available for review. These studies concluded that annual mean FIDAS and FDMS PM concentrations agree to within 1ug/m^3 of each other.

Figure 4.25 - Trends in annual mean $PM_{2.5}$

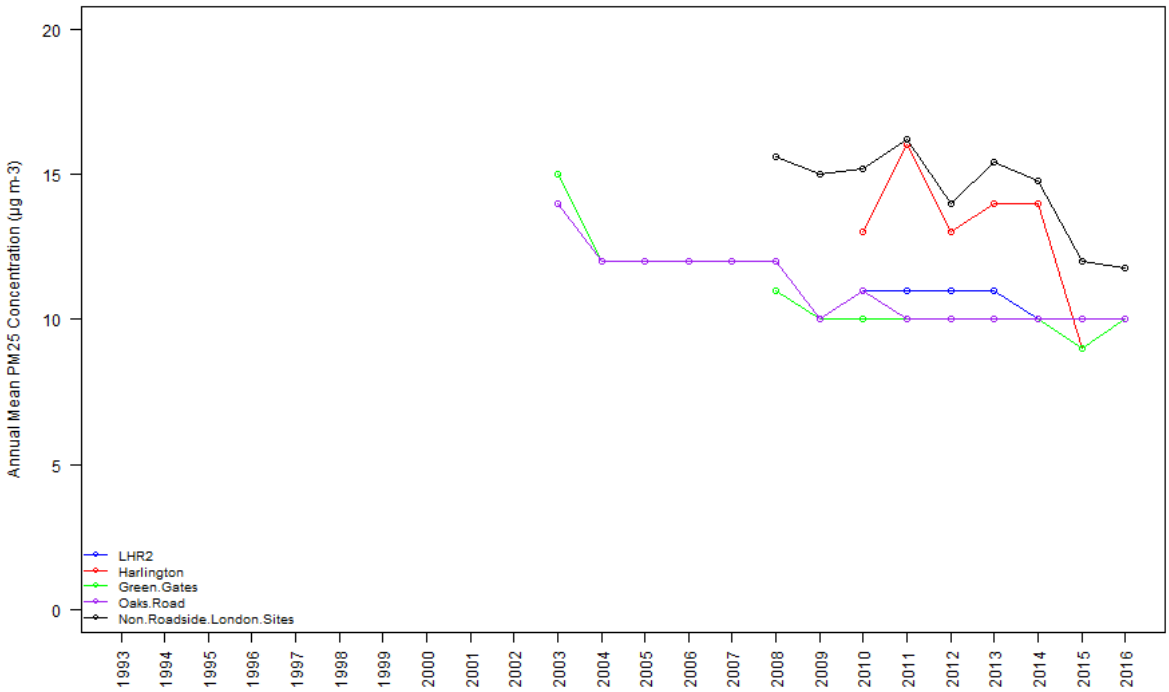
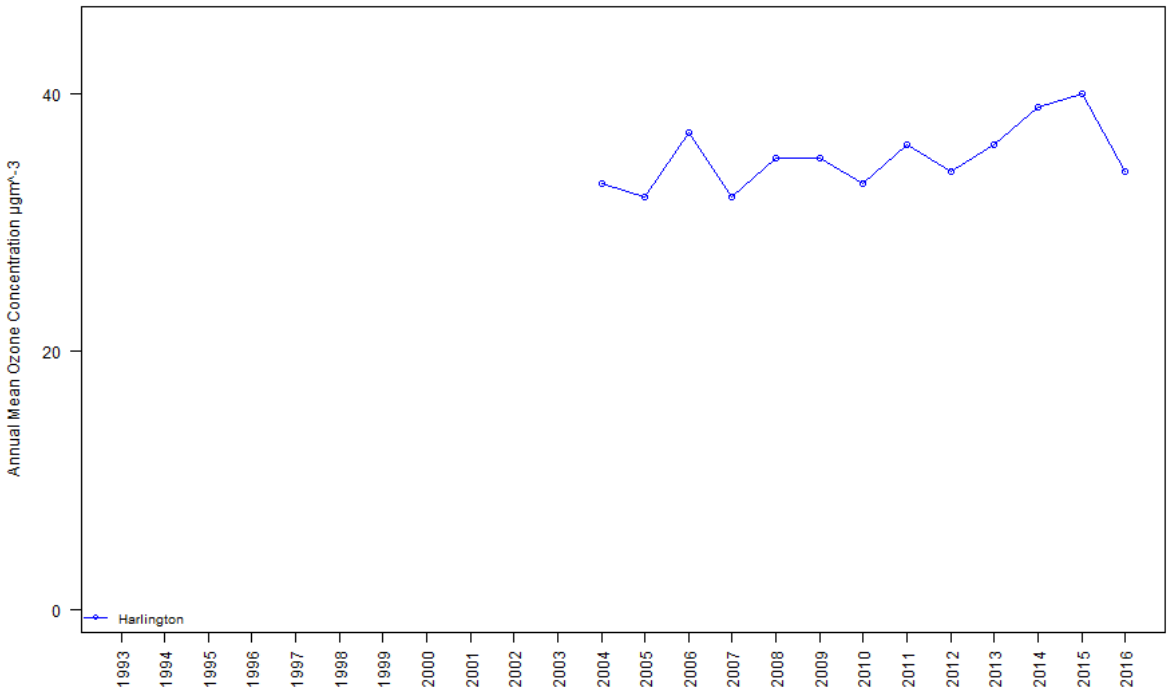


Figure 4.25 shows how annual mean concentrations of $PM_{2.5}$ have changed over time. For Green Gates and Oaks Road, where trends can be observed over several years, concentrations have decreased and remained stable, with the exception of Harlington until present.

Figure 4.26 - Trends in annual mean ozone at Harlington



Ozone was only measured at Harlington, as illustrated in Figure 4.26. A slight upward trend can be detected since measurements began. Annual means of NO and NO_2 have been slightly decreasing since 2013, which can probably indicate that ozone increase is caused by the reduction of concentration of combustion sources in the area, mainly NO - responsible for the fast consumption of O_3 to form NO_2. The balance of production and loss reactions combined with atmospheric air motion determines the global distribution of ozone on timescales of days to many months. A further possibility for the gradual increasing trend is a change in formation rate constants due to climate changes influence on factors such as temperature.

4.8 Relationship with airport activity

In this section, the potential for correlation between airport activity and pollutant concentrations is investigated by comparing pollutant concentrations with Aircraft Transport Movements (ATM) at Heathrow from the Heathrow website[10].

Figure 4.27 -Time series for annual ATM and annual mean NO_x concentrations

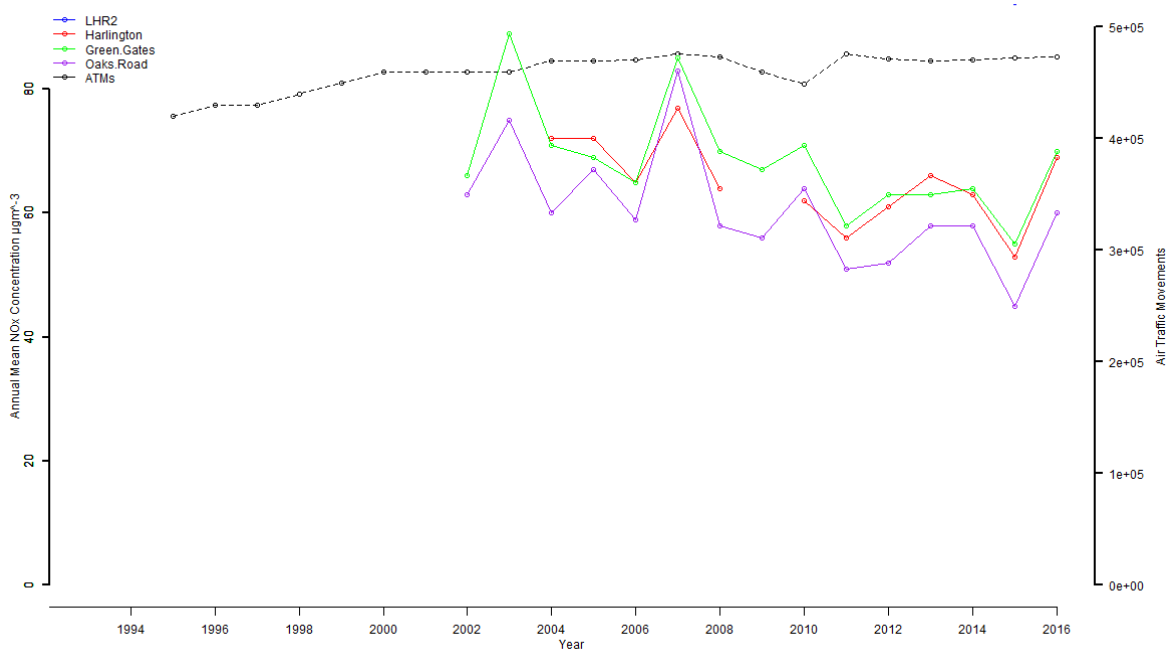


Figure 4.27 shows annual mean NO_x concentrations at the four monitoring sites, together with annual total ATMs. ATMs rose steadily at Heathrow from 1995 to 2007, after which there was a decline until 2011. Since then, ATMs have remained steady at around 470,000. Local ambient concentrations in NO_x have fluctuated over the same period, but there is no obvious relationship between NO_x concentrations and airport activity.

Figure 4.28 - Time series for annual ATM and annual mean PM_{10} concentrations

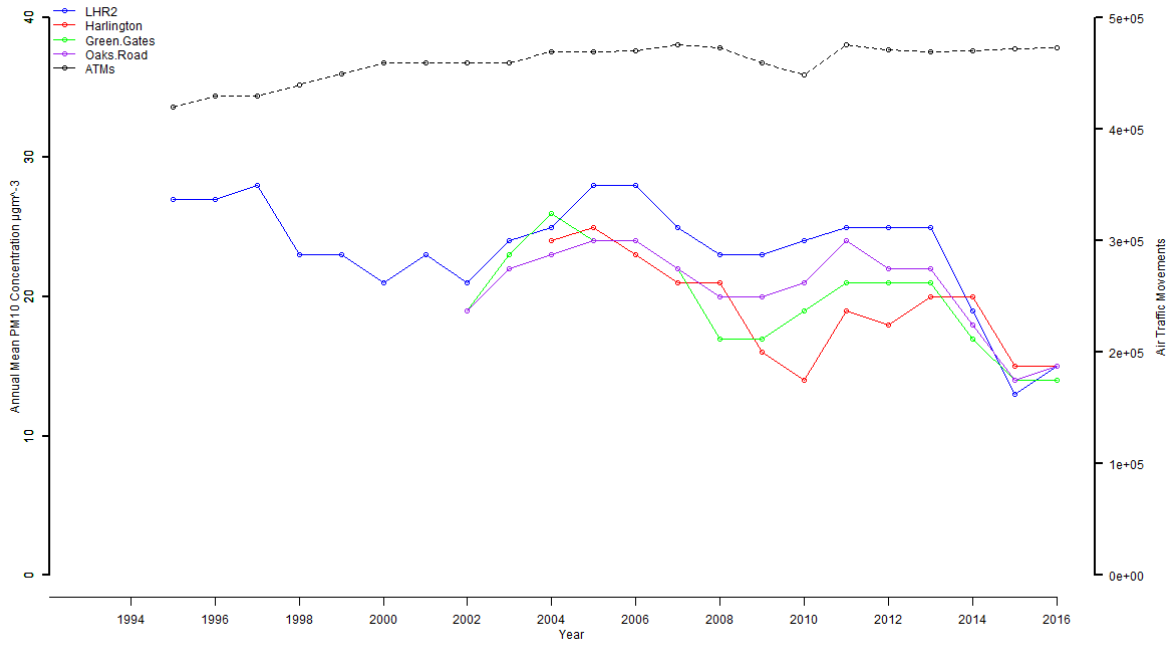


Figure 4.28 shows the same comparison for PM_{10}, with no clear relationship being apparent between annual mean PM_{10} and changes in air transport movements. This does not mean that the airport is not a major contributor to local ambient PM_{10}, but suggests that variations in ambient PM_{10} concentrations are also dependent on other factors. This simple analysis of air traffic movements indicates that annual variation in pollutant concentrations (i.e. the periods of high and low concentration) around Heathrow are influenced to a greater extent by general meteorological factors than by air traffic movement.

5 Conclusions

The following conclusions have been drawn from the results of air quality monitoring around Heathrow Airport during 2016.

Oxides of nitrogen and particulate matter (as PM_{10} and $PM_{2.5}$) were monitored throughout 2016 at four sites around Heathrow Airport (LHR2, London Harlington, Green Gates and Oaks Road). Ozone was measured at Harlington. BC was measured for the at LHR2 and Oaks Road. The conclusions of the 2016 monitoring programme are summarised below.

1. Data capture of at least 90% was achieved for all pollutants at all the monitoring sites.
2. Oxides of nitrogen were monitored at all four sites. No sites exceeded the AQS objective of 200 µg m^{-3} for hourly mean NO_2 more than the 18 permitted times per year during 2016.
3. One site, LHR2, exceeded the annual mean AQS objective of 40 µg m^{-3} for NO_2 in 2016, with an annual mean of 47 µg m^{-3}, although the EU limit values and AQS objectives do not apply at the LHR2 site, because it is within the airport boundary where there is no public exposure. The other three HAL sites did not exceed this objective.
4. All four sites met the AQS objective for 24-hour mean of 50 µg m^{-3} (not to be exceeded more than 35 times a year) and annual mean of 40 µgm^{-3} for PM_{10}. The particulate matter was measured using a FIDAS instrument with no VCM correction required for PM_{10}.
5. Ozone was measured at Harlington only, this site exceeded the AQS objective for ozone on 6 days during 2016, entering into the “Moderate” band for 30 times during that period. These results are less than the permitted maximum of 10 days per calendar year. The AQS objective was therefore met in 2016.
6. Seasonal variations in pollutant concentrations at all sites were similar to those observed in previous years and at other urban background sites. Both NO, NO_2 and BC exhibited higher concentrations during the winter months. PM_{10} and $PM_{2.5}$, which have both primary and secondary components, showed a much less pronounced seasonal pattern. Ozone levels were highest during the spring and summer, as is typical.
7. The diurnal patterns of concentrations of all pollutants were similar to those observed at other urban monitoring sites. Peak concentrations of NO, NO_2, particulate matter and BC coincided with the morning and evening rush hour periods, and levels of ozone peaked in the afternoons.
8. Several periods of elevated PM_{10} concentration (daily mean concentration in the Defra “High” and “Very High” bands) occurred during 2016. As in previous years, other urban background monitoring sites in London and the south east of England showed a similar pattern of elevated PM_{10} concentrations during the above periods. This indicates that the higher concentrations measured at Heathrow reflected regional variations in PM_{10} concentration, rather than any emission sources specific to the airport.
9. Meteorological measurements are made at LHR2, allowing the effect of wind direction and speed to be investigated. Bivariate plots of NO and BC concentration and wind data showed that concentrations of NO and BC at LHR2 were typically highest in calm conditions, indicating that the main sources of this pollutants were nearby. The pattern was slightly different for NO_2, with a strong signal also appearing from the south west at higher wind speeds. The patterns for PM_{10} and $PM_{2.5}$ were similar. In contrast with the last few years, no relevant PM concentrations seem to be associated with higher wind speeds (>5ms^{-1}), showing that local sources are the likely main drivers for the PM concentrations measured at LHR2.
10. Mean concentrations of pollutants at the four Heathrow sites in 2016 were comparable with those measured at other suburban and urban background monitoring sites in London.
11. Long-term annual mean concentration data from this monitoring program show a gradual downward trajectory in levels of NO with some yearly variation. It is not possible to state if the rise seen in 2016 is a change in this trend or not. A small increase is also observed in annual mean concentrations of NO_2 at all sites for 2016. PM_{10} measurements at all sites are similar to last year. The proportion of total NO_x measured as NO_2 has stabilized over the last 4 years, showing a slight decrease in 2016. O_3 concentrations continue to increase over time.
12. Neither seasonal patterns, nor long-term trends, in pollutant concentration at the Heathrow sites showed any obvious relationship to annual aircraft transport movements. Although the airport is likely to be a significant contributor to local air pollution, ambient concentrations are also influenced by meteorological and other factors.

6 Acknowledgements

Ricardo Energy & Environment would like to thank Andrew Chen, Christopher Butler, Rachel Thomas and Spencer Thomas of Heathrow Airport Ltd for their assistance with this work.

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Appendices

Appendix 1: Air Quality objectives and Index bands

Appendix 2: Monitoring apparatus and techniques

Appendix 3: Quality assurance and quality control

Appendix 1 – Air Quality objectives and Index bands

Table A1.1: UK air quality objectives for protection of human health, July 2007.

Pollutant	Air Quality objective		Date to be achieved by
	Concentration	Measured as	
Benzene All authorities	16.25 µg m^{-3}	Running annual mean	31/12/2003
England and Wales only	5.00 µg m^{-3}	Annual mean	31/12/2010
Scotland and Northern Ireland	3.25 µg m^{-3}	Running annual mean	31/12/2010
1,3-Butadiene	2.25 µg m^{-3}	Running annual mean	31/12/2003
Carbon monoxide England, Wales and Northern Ireland	10.0 mg m^{-3}	Maximum daily running 8-hour mean	31/12/2003
Scotland	10.0 mg m^{-3}	Running 8-hour mean	31/12/2003
Lead	0.5 µg m^{-3}	Annual mean	31/12/2004
	0.25 µg m^{-3}	Annual mean	31/12/2008
Nitrogen dioxide	200 µg m^{-3} not to be exceeded more than 18 times a year	1-hour mean	31/12/2005
	40 µg m^{-3}	Annual mean	31/12/2005
Particles (PM_{10}) (gravimetric) All authorities	50 µg m^{-3}, not to be exceeded more than 35 times a year	24-hour mean	31/12/2004
	40 µg m^{-3}	Annual mean	31/12/2004
Scotland	50 µg m^{-3}, not to be exceeded more than 7 times a year	24-hour mean	31/12/2010
	18 µg m^{-3}	Annual mean	31/12/2010
Particles ($PM_{2.5}$) (gravimetric)* All authorities	25 µg m^{-3} (target)	Annual mean	2020
	15% cut in urban background exposure	Annual mean	2010-2020
Scotland only	12 µg m^{-3} (limit)	Annual mean	2020
Sulphur dioxide	350 µg m^{-3}, not to be exceeded more than 24 times a year	1-hour mean	31/12/2004

	125 µg m^{-3}, not to be exceeded more than 3 times a year	24-hour mean	31/12/2004
	266 µg m^{-3}, not to be exceeded more than 35 times a year	15-minute mean	31/12/2005
PAH*	0.25 ng m^{-3}	Annual mean	31/12/2010
Ozone*	100 µg m^{-3} not to be exceeded over 10 days a year	8-hour mean	31/12/2005

** Not included in regulations.*

Table A1.2: UK air quality objectives for protection of vegetation and ecosystems, July 2007

Pollutant	Air Quality objective		Date to be achieved by
	Concentration	Measured as	
Nitrogen oxides measured as NO_2	30 µg m^{-3}	Annual mean	31st December 2000
Sulphur dioxide	20 µg m^{-3}	Annual mean	31st December 2000
	20 µg m^{-3}	Winter average (October to March)	31st December 2000
Ozone	18 µg m^{-3}	AOT40+, calculated from 1-hour values May to July. Mean of 5 years, starting 2010	1st January 2010

+ AOT40 is the sum of the differences between hourly concentrations greater than 80 µg m^{-3} (= 40 ppb) and 80 µg m^{-3} over a given period using only 1-hour averages measured between 08:00 and 20:00.

Defra Air Pollution bands and index values

Table A1.3: Air pollution bandings and descriptions.

Banding	*Index*	*Accompanying health messages for at-risk individuals**	*Accompanying health messages for the general population*
Low	1	**Enjoy** your usual outdoor activities.	**Enjoy** your usual outdoor activities.
	2		
	3		
Moderate	4	Adults and children with lung problems, and adults with heart problems, **who experience symptoms**, should **consider reducing** strenuous physical activity, particularly outdoors.	**Enjoy** your usual outdoor activities.
	5		
	6		
High	7	Adults and children with lung problems, and adults with heart problems, should **reduce** strenuous physical exertion, particularly outdoors, and particularly if they experience symptoms. People with asthma may find they need to use their reliever inhaler more often. Older people should also **reduce** physical exertion.	Anyone experiencing discomfort such as sore eyes, cough or sore throat should **consider reducing** activity, particularly outdoors.
	8		
	9		
Very high	10	Adults and children with lung problems, adults with heart problems, and older people, should **avoid** strenuous physical activity. People with asthma may find they need to use their reliever inhaler more often.	**Reduce** physical exertion, particularly outdoors, especially if you experience symptoms such as cough or sore throat.

Table A1.4: Boundaries between index points for each pollutant

Band	Index	Ozone	Nitrogen Dioxide	Sulphur Dioxide	$PM_{2.5}$ Particles (EU Reference Equivalent)	PM_{10} Particles (EU Reference Equivalent)
		Running 8 hourly mean	**hourly mean**	**15 minute mean**	**24 hour mean**	**24 hour mean**
		μgm^{-3}	**μgm^{-3}**	**μgm^{-3}**	**μgm^{-3}**	**μgm^{-3}**
Low	1	0-33	0-67	0-88	0-11	0-16
	2	34-66	68-134	89-177	12-23	17-33
	3	67-100	135-200	178-266	24-35	34-50
Moderate	4	101-120	201-267	267-354	36-41	51-58
	5	121-140	268-334	355-443	42-47	59-66
	6	141-160	335-400	444-532	48-53	67-75
High	7	161-187	401-467	533-710	54-58	76-83
	8	188-213	468-534	711-887	59-64	84-91
	9	214-240	535-600	888-1064	65-70	92-100
Very High	10	241 or more	601 or more	1065 or more	71 or more	101 or more

Appendix 2 – Monitoring apparatus and techniques

Monitoring Equipment

The following continuous monitoring methods were used at the Heathrow air quality monitoring stations:

- NO, NO_2: chemiluminescence with ozone.
- PM_{10} and $PM_{2.5}$: Fine Dust Analysis Systems (FIDAS).
- O_3: UV absorption analyser, Harlington only.
- Black Carbon (BC): Aethalometer, LHR2 and Oaks Road only.

These methods were selected in order to provide real-time data. The chemiluminescence and the UV absorption analysers are the European reference method for ambient NO_2 and O_3 monitoring.

Each analyser provides a continuous output, proportional to the pollutant concentration. This output is recorded and stored every 10 seconds, and averaged to 15 minute average values by the on-site data logger. This logger is connected to a modem and interrogated twice daily, by telephone, to download the data to Ricardo Energy & Environment. The data are then converted to concentration units and averaged to hourly mean concentrations.

The analysers for NO_x and O_3 are equipped with an automatic calibration system, which is triggered daily under the control of the data logger. Fully certificated calibration gas cylinders are also used at each site for manual calibration.

Aethalometers quantify black carbon on filter samples based on the transmission of light through a sample. The sample is collected on a quartz tape, and the change in absorption coefficient of the sample is measured by a single pass transmission of light through the sample measured relative to a clean piece of filter. The aethalometers operate most commonly at two wavelengths, 880 nm and 370 nm. The 880 nm wavelength is used to measure the black carbon (BC) concentration of the aerosol, while the 370 nm wavelength gives a measure of the “UV component” of the aerosol[14].

The FIDAS unit employs a white light LED light scatter method that offers additional information on both particle size distribution from 0.18 to 30 microns (PM_1, $PM_{2.5}$, PM_4, PM_{10} and Total Suspended Particles (TSP). This analyser has demonstrated equivalence to EN12341:2015, and is certified for use in UK monitoring networks under the MCERTS for UK PM certification scheme.

Appendix 3 – Quality assurance and Quality control

Ricardo Energy & Environment operates air quality monitoring stations within a tightly controlled and documented quality assurance and quality control (QA/QC) system. These procedures are documented in the AURN QA/QC manual[8].

Elements covered within this system include: definition of monitoring objectives, equipment selection, and site selection, protocols for instrument operation calibration, service and maintenance, integrity of calibration gas standards, data review, scrutiny and validation.

All gas calibration standards used for routine analyser calibration are certified against traceable primary gas calibration standards at the Gas Standards Calibration Laboratory at Ricardo Energy & Environment. The calibration laboratory operates within a specific and documented quality system and has UKAS accreditation for calibration of the gas standards used in this survey.

An important aspect of QA/QC procedures is the regular six-monthly inter calibration and audit check undertaken at every monitoring site. This audit has two principal functions: firstly to check the instruments and the site infrastructure, and secondly to recalibrate the transfer gas standards routinely used on-site, using standards recently checked in the calibration laboratory. Ricardo Energy & Environment's audit calibration procedures are UKAS accredited to ISO 17025.

In line with current operational procedures within the Defra AURN, full inter calibration audits take place at the end of winter and summer. At these visits, the essential functional parameters of the monitors such as noise, linearity and, for the NO_x monitor, the efficiency of the NO_2 to NO converter are fully tested. In addition, the on-site transfer calibration standards are checked and re-calibrated if necessary, the air intake sampling system is cleaned and checked and all other aspects of site infrastructure are checked.

All air pollution measurements are reviewed daily by experienced staff at Ricardo Energy & Environment. Data are compared with corresponding results from AURN monitoring stations and with expected air pollutant concentrations under the prevailing meteorological conditions. This review process rapidly highlights any unusual or unexpected measurements, which may require further investigation. When such data are identified, attempts are made to reconcile the data against known or possible local air pollution sources or local meteorology, and to confirm the correct operation of all monitors. In addition, the results of the daily automatic instrument calibrations (see Appendix 2) are examined to identify any possible instrument faults. Should any faults be identified or suspected, arrangements are made for Ricardo Energy & Environment personnel or equipment service contractors to visit the site as soon as possible.

At the end of every quarter, the data for that period are reviewed to check for any spurious values and to apply the best daily zero and sensitivity factors, and to account for information which only became available after the initial daily processing. At this time, any data gaps are filled with data from the data logger back-up memory to produce as complete a data record as possible.

Finally, the data are re-examined on an annual basis, when information from the six-monthly inter calibration audits can be incorporated. After completion of this process, the data are fully validated and finalised, for compilation in the annual report.

Following these three-stage data checking and review procedures allows the overall accuracy and precision of the data to be calculated. The accuracy and precision figures for the pollutants monitored at Heathrow are summarised in Table 3.1 on page 9.

Method

All of the air quality monitoring equipment at both sites is housed in purpose-built enclosures. The native units of the analysers are volumetric (e.g. ppb). Conversion factors from volumetric to mass concentration measurement for gaseous pollutants are provided below:

- NO 1 ppb = 1.25 µg m^{-3}
- NO_2 1 ppb = 1.91 µg m^{-3}

In this report, the mass concentration of NO_x has been calculated as follows:

NO_x µg m^{-3} = (NO ppb + NO_2 ppb) *x* 1.91.

This complies with the requirements of the Air Quality Directive[3] and is also the convention generally adopted in air quality modelling.

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