Report

RMS Air Quality Data Analysis

Document control number: AQU-QLD-003-0438117

Date: 11 May 2018

Pacific Environment
an ERM Group company

www.pacific-environment.com

Project name: RMS Air Quality Data Analysis

Document control number: AQU-QLD-003-0438117

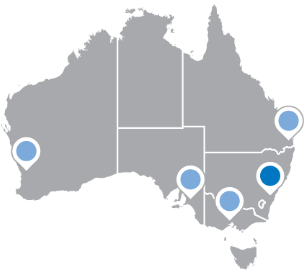
Prepared for: Roads and Maritime Services

Approved for release by: Bethany Warren

Disclaimer & copyright:

Document Control

Version	Date	Comment	Prepared by	Reviewed by
01	18.04.18		Jing Wang Bethany Warren	Paul Boulter
02	18.04.18		Bethany Warren	Paul Boulter
03	11.05.18		Jing Wang	Bethany Warren



Adelaide

5 Peel Street,
Adelaide SA 5000
PO Box 3187, Norwood SA 5067
Ph: +61 8 8332 0960
Fax: +61 7 3844 5858

Brisbane

Level 4, 201 Leichhardt Street
Spring Hill Qld 4004
Ph: +61 7 3839 8393
Fax: +61 7 3839 8381

Melbourne

Level 6, 99 King Street
Melbourne Vic 3000
Ph: +61 3 9696 8011
Fax: +61 3 9696 8022

Perth

Level 18, 180 St Georges Terrace,
Perth WA 6000
Ph: +61 8 6467 1600
Fax: +61 8 9321 5262

Sydney Head Office

Level 15, 309 Kent Street
Sydney, NSW 2000
Ph: +61 2 8584 8888
Fax: +61 2 9299 7502

Disclaimer

Pacific Environment acts in all professional matters as a faithful advisor to the Client and exercises all reasonable skill and care in the provision of its professional services.

Reports are commissioned by and prepared for the exclusive use of the Client. They are subject to and issued in accordance with the agreement between the Client and Pacific Environment. Pacific Environment is not responsible for any liability and accepts no responsibility whatsoever arising from the misapplication or misinterpretation by third parties of the contents of its reports.

Except where expressly stated, Pacific Environment does not attempt to verify the accuracy, validity or comprehensiveness of any information supplied to Pacific Environment for its reports.

Reports cannot be copied or reproduced in whole or part for any purpose without the prior written agreement of Pacific Environment.

Where site inspections, testing or fieldwork have taken place, the report is based on the information made available by the client or their nominees during the visit, visual observations and any subsequent discussions with regulatory authorities. The validity and comprehensiveness of supplied information has not been independently verified and, for the purposes of this report, it is assumed that the information provided to Pacific Environment is both complete and accurate. It is further assumed that normal activities were being undertaken at the site on the day of the site visit(s), unless explicitly stated otherwise.

Table of contents

List of Figures

List of Tables

1 Introduction

New South Wales (NSW) Office of Environment and Heritage (OEH), NSW Roads and Maritime Services (RMS) and Sydney Motorway Corporation (SMC) have established an air quality monitoring network in Sydney to understand air quality concentrations and to address community concerns. The monitoring stations include both urban ‘background’ location and ‘peak’ roadside sites.

RMS engaged Pacific Environment to analyse the ambient air quality and meteorology data from several stations of the network. The main objectives of the analysis were to provide a standardised data pack for each measured substance, and to understand the long-term trends in air quality and meteorology in Sydney. Additionally, where possible, the data analysis included identification of potential improvement to the utility of the data for various RMS activities.

2 Monitoring sites

Air quality and meteorological parameters are measured automatically and (usually) continuously at various monitoring stations across Sydney. RMS provided raw data for the monitoring sites and periods listed in Table 2.1. The locations of the sites are shown in Figure 2.1.

The siting and classification of air quality monitoring stations is governed, as far as practicable, by the requirements of Australian Standard *AS/NZS 3580.1.1:2007 - Methods for sampling and analysis of ambient air - Guide to siting air monitoring equipment*. The Standard recognises that air quality is monitored for different purposes, and for convenience it classifies monitoring stations as follows based on functional requirements:

- **Peak stations**. These are located where the highest concentrations and exposures are expected to occur (such as near busy roads or industrial sources).
- **Neighbourhood stations.** These are located in areas which have a broadly uniform land use and activity (e.g. residential areas or commercial zones).
- **Background stations.** These stations are located in urban or rural areas to provide information on air quality away from specific sources of pollution such as major roads or industry.

Most of the air quality monitoring in Sydney has focussed on background sites within urban communities, but away from specific sources such as major roads. Seven background monitoring stations are operated by OEH, and these have provided a long and vital record of regional air quality. The OEH sites at Chullora, Earlwood, Randwick and Rozelle are relatively close to the recent motorway and tunnel projects in Sydney, including the M4 widening, the M4 East tunnel, the New M5 tunnel and the M4-M5 Link tunnel. The sites at Lindfield, Liverpool and Prospect are further away from the major road and tunnel projects, but are still considered to be important in terms of characterising air quality in the wider Sydney region.

RMS has established six long-term monitoring stations since January 2008 in response to public concerns relating to the ventilation outlet of the M5 East tunnel, and to monitor operational compliance of the tunnel with ambient air quality standards. Four of the RMS M5 East sites (CBMS, T1, U1, X1) are in the vicinity of the ventilation outlet, where sites U1 and X1 are set on a ridge to the north of the outlet. However, the practical impacts of the tunnel outlets at these monitoring sites are very small, and these could effectively be considered as urban background sites. The other two RMS M5 East sites (F1 and M1) are near the M5 East tunnel portals, which are very close to busy roads.

Shorter-term data from other RMS air quality monitoring stations were also included in the analysis. Five air quality monitoring stations, including three background sites and two roadside sites, were established for the NorthConnex project, with data being available from December 2013 to January 2015. An additional roadside monitoring site (Aristocrat) was operated by RMS between 2008 and 2009, which was located near the junction of Epping Road and Longueville Road.

SMC has recently established a WestConnex monitoring network, covering both urban background and near-road sites to support the development and assessment of the SMC projects, including M4 East (five stations), New M5 (seven stations) and M4-M5 Link (two stations). Some of the M4 East and New M5 monitoring stations were subsequently relocated or decommissioned. These stations became operational from August 2014 onwards.

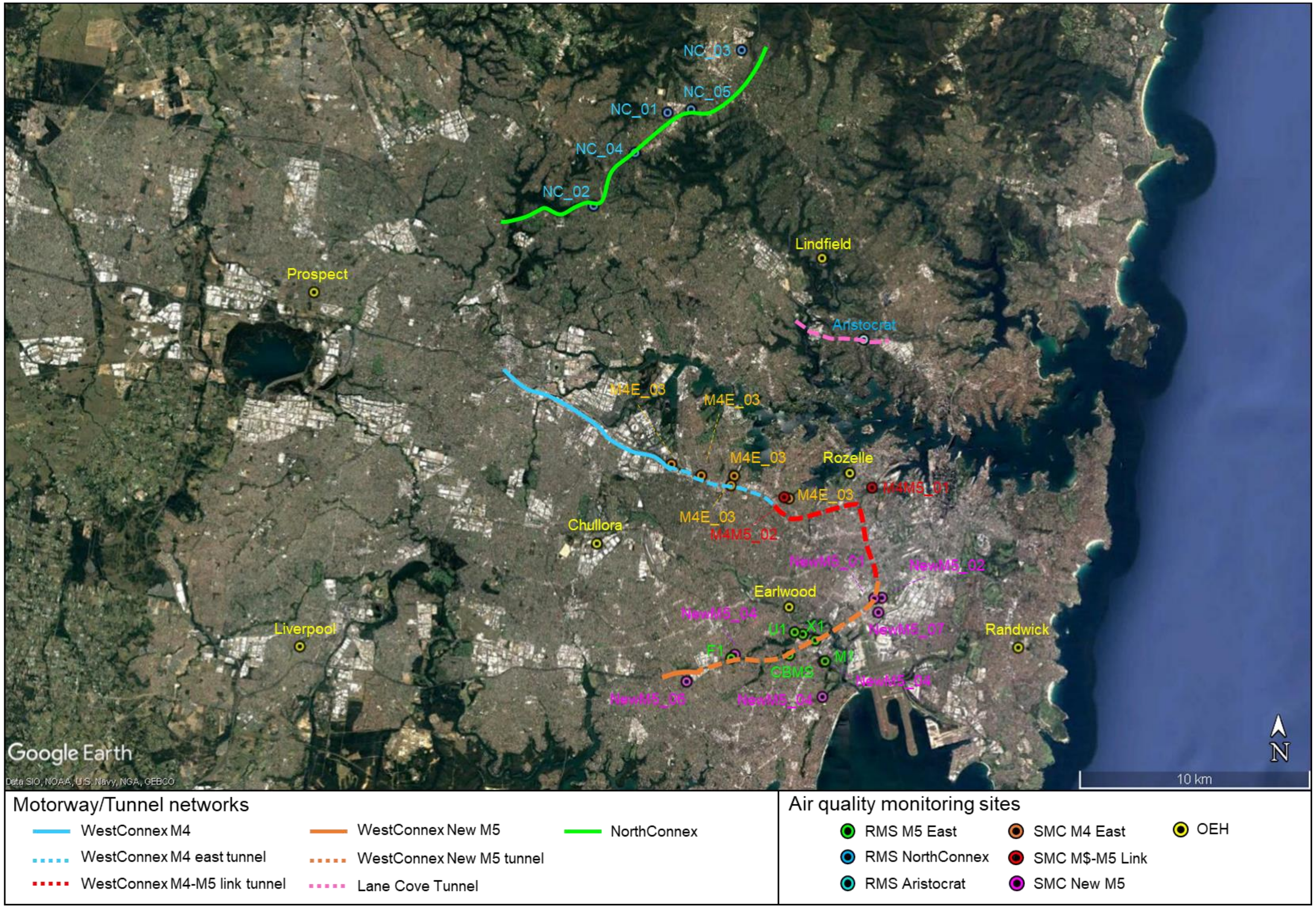
.

Table 2.1 *Air quality monitoring sites*

Organisation	Project	Site name	Site type	Location	Easting	Northing	Period covered in analysis
OEH	N/A	Chullora	BG	Southern Sydney TAFE - Worth St	319315	6248145	Jan 2004 to Feb 2017
		Earlwood	BG	Beaman Park	327663	6245576	Jan 2004 to Feb 2017
		Lindfield	BG	Bradfield Road	328802	6260577	Jan 2004 to Feb 2017
		Liverpool	BG	Rose Street	306573	6243485	Jan 2004 to Feb 2017
		Prospect	BG	William Lawson Park	306901	6258703	Jan 2004 to Feb 2017
		Randwick	BG	Randwick Barracks	337588	6244021	Jan 2004 to Feb 2017
		Rozelle	BG	Rozelle Hospital	330169	6251372	Jan 2004 to Feb 2017
RMS	M5 East tunnel	M5E: CBMS	BG	Gipps Street, Bardwell Valley	327713	6243517	Jan 2004 to Dec 2016
		M5E: T1	BG	Thompson Street, Turrella	328820	6244172	Jan 2004 to Dec 2016
		M5E: U1	BG	Jackson Place, Earlwood	328277	6244422	Jan 2004 to Dec 2016
		M5E: X1	BG	Wavell Parade, Earlwood	327923	6244507	Jan 2004 to Dec 2016
		M5E: F1	NR	Flat Rock Rd, Kingsgrove (M5 East F'way)	325204	6243339	Jan 2004 to Dec 2016
		M5E: M1	RD	M5 East tunnel portal	329258	6243283	Jan 2004 to Dec 2016
	NorthConnex	NC-01	BG	Headen Sports Park	322016	6266696	Dec 2013 to Jan 2015
		NC-02	BG	Rainbow Farm Reserve	318901	6262641	Dec 2013 to Jan 2015
		NC-03	BG	James Park	325165	6269440	Dec 2013 to Jan 2015
		NC-04	RD	Observatory Park	320643	6264950	Dec 2013 to Jan 2015
		NC-05	RD	Brickpit Park	323027	6266847	Dec 2013 to Jan 2015
	Lane Cove Tunnel	Aristocrat	RD	Longueville Road / Epping Road	330661	6257118	Oct 2008 to Nov 2009
SMC	WestConnex M4 East	M4E: 01	RD	Wattle Street, Haberfield	327563	6250234	Aug 2014 to Mar 2016
		M4E: 02	NR	Edward Street, Concord	323764	6251146	Sep 2014 to Mar 2016
		M4E: 03	NR	Bill Boyce Reserve, Homebush	322467	6251602	Sep 2014 to Mar 2016
		M4E: 04	RD	Concord Oval, Concord	325030	6250752	Nov 2014 to Sep 2017
		M4E: 05	BG	St Lukes Park, Concord	325187	6251158	Nov 2014 to Sep 2017
		New M5: 01	BG	St Peters Public Sch., Church St, St Peters	331330	6246007	Aug 2015 to Sep 2017
		New M5: 02	RD	Princes Highway, St Peters	331661	6246053	Jul 2015 to Apr 2016
		New M5: 03	RD	West Botany St, Arncliffe	329182	6243268	Aug 2015 to Jun 2016
		New M5: 04	BG	Bestic St, Rockdale	329175	6241749	Jul 2015 to Sep 2016
		New M5: 05	RD	Bexley Rd, Kingsgrove	325359	6243491	Jul 2015 to Apr 2016
		New M5: 06	BG	Beverly Hills Park, Beverly Hills	323296	6242297	Jul 2015 to Sep 2016
		New M5: 07	RD	Canal Rd, St Peters	331520	6245420	Jul 2015 to Apr 2016
		M4-M5: 01	RD	Rozelle, City W Link	331142	6250768	Apr 2016 to Sep 2017
		M4-M5: 02	RD	Haberfield, Ramsay Street	327363	6250306	Apr 2016 to Sep 2017

BG = Background; NR = Near Roadside; RD = Roadside

Figure 2.1 *Locations of air quality monitoring sites.*



3 Measured parameters and calculation method

The ambient air quality data includes the continuous measurements of:

- CO carbon monoxide
- NO_2 nitrogen dioxide
- NO_x nitrogen oxides
- O_3 ozone
- SO_2 sulfur dioxide
- PM_{10} particulate matter with an aerodynamic diameter less than 10 µm
- $PM_{2.5}$ particulate matter with an aerodynamic diameter less than 2.5 µm
- BTEX benzene, toluene, ethylbenzene and xylene *(not continuously measured)*
- VOCs methane - CH_4; non-methane hydrocarbons – NMHC; total hydrocarbons - THC

The meteorology data includes the continuous measurements of the following parameters:

- Wind speed
- Wind direction
- Temperature
- Humidity
- Solar radiation

The air quality and meteorology parameters measured at each monitoring station are presented in Table 3.1. NO_2 and NOx were measured at all the sites, while PM_{10} was measured at all the sites but one (Aristocrat). CO, O_3, PM_{10} and $PM_{2.5}$ were measured at most of the stations. SO_2 was only measured at six of the OEH sites (excluding the Earlwood site). Hydrocarbons were not measured routinely at the OEH and RMS M5 East sites. VOCs (CH_4, NMHC and THC) were measured at the SMC M4 East, New M5 and M4-M5 Link sites for a short period between 2014 to 2017. There were no continuous measurements for BTEX; instead, it was measured on a weekly basis for a total period of four weeks (between 11 January 2017 and 1 February 2017) at three sites, including two SMC M4-M5 Link sites and one SMC New M5 site at St Peter’s Public School.

It is important to mention that the available time series of data varied considerably from site to site, and there were some differences in instrumentation as well, especially for the measurement of particulate matter.

Table 3.1: *Parameters measured at each monitoring station*[(a)]

Organisation	Site name	CO	NO_2/ NO_x	O_3	SO_2	PM_{10}	$PM_{2.5}$	VOCs	BTEX	WS/WD (a)	Temp at 2 m	Temp at 10 m	Solar	Rainfall	Humidity	Press[(c)]
OEH	Chullora	√√	√√	√√	√√	√√	√√	-	-	√√	-	√√	√√	-	√√	-
	Earlwood	×	√√	√√		√√	√√	-	-	√√	-	√√	-	-	√√	-
	Lindfield	-	√√	√√	√√	√√	-	-	-	√√	-	√√	-	-	√√	-
	Liverpool	√√	√√	√√		√√	√√	-	-	√√	-	√√	-	-	√√	-
	Prospect	√√	√√	√√	√√	√√	√	-	-	√√	-	√√	√√	-	√√	-
	Randwick	-	√√	√√	√√	√√	-	-	-	√√	-	√√	-	-	√√	-
	Rozelle	√√	√√	√√		√√	√	-	-	√√	-	√√	√√	-	√√	-
RMS	M5E: CBMS	√√	√√	-	-	√√	-	-	-	√√	√√	√√	√√	-	√√	-
	M5E: T1	√√	√√	-	-	√√	-	-	-	√√	√√	√√	√√	-	-	-
	M5E: U1	√√	√√	-	-	√√	-	-	-	√√	√√	√√	√√	-	√√	-
	M5E: X1	√√	√√	-	-	√√	-	-	-	√√	√√	√√	√√	-	√√	-
	M5E: F1	√√	√√	-	-	√√	-	-	-	√√	√√	√√	√√	-	√√	-
	M5E: M1	√√	√√	-	-	√√	-	-	-	√√	√√	√√	√√	-	√√	-
	NC-01	√	√	√	-	√	√	-	-	√	-	√	-	-	√	-
	NC-02	√	√	√	-	√	√	-	-	√	-	√	-	-	√	-
	NC-03	√	√	√	-	√	√	-	-	√	-	√	-	-	√	-
	NC-04	√	√	√	-	√	√	-	-	√	-	√	-	-	√	-
	NC-05	√	√	√	-	√	√	-	-	√	-	√	-	-	√	-
	Aristocrat	×	×	-	-	-	-	-	-		√	√		-		-
SMC	M4E: 01	√	√	√	-	√	√	√	-	√	√	√	√	√	√	√
	M4E: 02	√	√	√	-	√	√	√	-	√	√	-	√	√	√	√
	M4E: 03	√	√	√	-	√	√	√	-	√	√	-	√	√	√	√
	M4E: 04	√	√	√	-	√	√	√	-	√	√	-	√	√	√	√
	M4E: 05	√	√	√	-	√	√	√	-	√	√	√	√	√	√	√
	New M5: 01	√	√	√	-	√	√	√	√	√		√	√	√		
	New M5: 02	√	√	√	-	√	√	-	-	√	√	-	√	√	√	√
	New M5: 03	√	√	√	-	√	√	-	-	√	√	-	√	√	√	√
	New M5: 04	√	√	√	-	√	√	-	-	√	√	√	√	√	√	√
	New M5: 05	√	√	√	-	√	√	-	-	√	√	-	√	√	√	√
	New M5: 06	√	√	√	-	√	√	-	-	√	√	√	√	√	√	√
	New M5: 07	√	√	√	-	√	√	-	-	√	√	-	√	√	√	√
	M4-M5: 01	√	√	√	-	√	√	√	√	√	√	√	√	√	√	√
	M4-M5: 02	√	√	√	-	√	√	√	√	√	√	√	√	√	√	√

(a) "√√" long-term data; "√" short-term data; %; "-" no data; (b) WS = wind speed; WD = wind direction; (c) Pres = pressure

The raw ambient air quality and meteorology data standardisation was undertaken using Microsoft Excel. The formatting of the data was agreed with RMS. For gases, any volumetric concentrations (e.g. ppm or ppb) were converted to mass-based units (e.g. mg/m^3 or $\mu g/m^3$) as agreed with RMS. For consistency, an ambient pressure of one atmosphere and a temperature of 0°C were assumed throughout for the conversions. In the NSW Approved Methods, for some pollutants a conversion temperature of 25°C is used, which gives slightly lower mass concentrations. The use of 0°C in this project is therefore slightly conservative for applications such as air quality assessments.

The raw continuous data were processed to give 1-hour average values, which then formed the basis of the subsequent calculations and analyses. Calculations were only deemed to be valid where there was at least 75% of data available for a given averaging period[1]. Exceptional events (e.g. dust storms, bush fires, etc.) were identified during the data analysis.

For the air quality parameters, the following list of calculations were performed in Microsoft Excel:

- Annual average (all data)
- Monthly and weekly average (all data)
- Daily average (PM_{10}, $PM_{2.5}$)
- Rolling 4-hour average (O_3)
- Rolling 8-hour average (CO)
- Number of valid measurements (all data)
- Maximum of (all data)
- Percentiles of 1-hour averages (99.9th, 99th, 98th, 75th, 50th) (all data)
- Number of exceedance of relevant criterion

The resulting values are summarised in Microsoft Excel ‘data packs’ by substance and included as part of the project deliverables. These data were used for the analysis completed in the following section.

[1] Clause 18 (5) of the AAQ NEPM specifies that the annual report for a pollutant must include the percentage of data available in the reporting period. An average concentration can be valid only if it is based on at least 75 per cent of the expected samples in the averaging period. The 75 per cent data availability criterion is specified as an absolute minimum requirement for data completeness (PRC, 2001).

4 Long-term trends analysis

A long-term trend analysis was performed for each substance using Microsoft Excel. Only sites with significant amounts of data were included in the analysis. The analysis included plotting the time series of the relevant statistics based on the NSW air quality criteria (NSW EPA, 2016) and NEPM guidelines and goals (NEPM, 2016). The significances of any trends in concentration were determined using the Mann-Kendall test.

4.1 Carbon monoxide

Long-term continuous CO monitoring data were available for four OEH sites (excluding Earlwood, Lindfield and Randwick) and all six RMS M5 East sites, including both background and roadside sites.

4.1.1 Annual mean concentration

Although there is no air quality criterion for the annual mean CO concentration in NSW, such long-term trends and patterns are still of interest. The annual mean CO concentrations at the OEH and RMS M5 East background monitoring sites are shown in Figure 4.1, and the corresponding statistics are provided in Table 4.1.

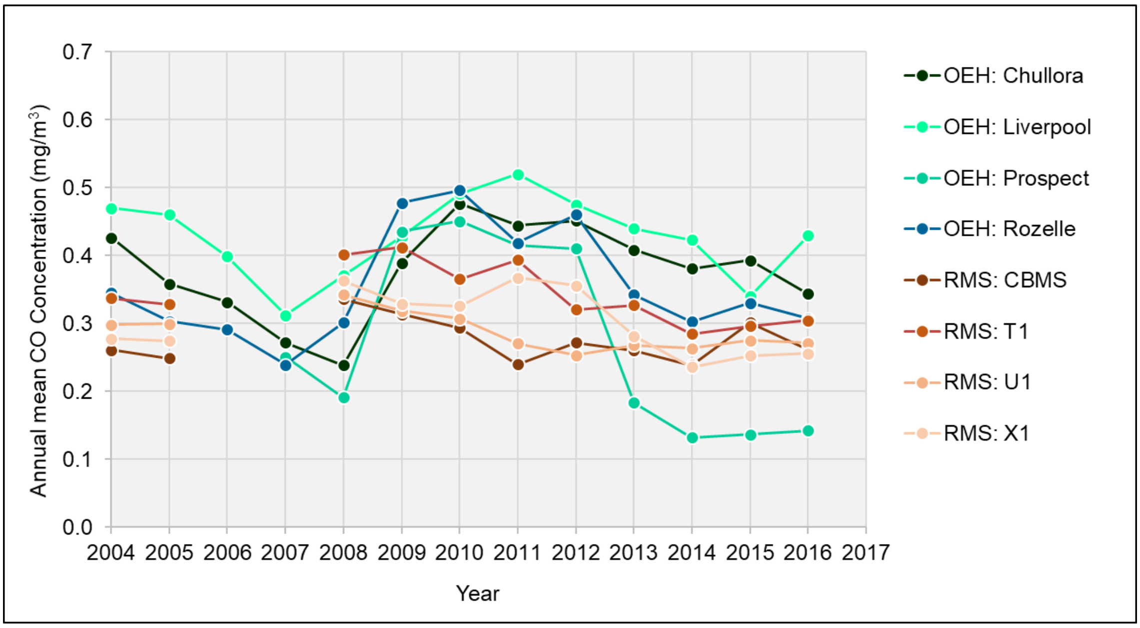


Figure 4.1 *Trend in annual mean CO concentration at OEH and RMS M5 East background sites*

Table 4.1. *Annual mean CO concentration at OEH and RMS M5 East background sites*

Year	Annual mean CO concentration (mg/m^3)[(a)]										
	OEH Chullora	OEH Earlwood	OEH Lindfield	OEH Liverpool	OEH Prospect	OEH Randwick	OEH Rozelle	RMS CBMS	RMS T1	RMS U1	RMS X1
2004	0.43	-	-	0.47	-	-	0.34	0.26	0.34	0.30	0.28
2005	0.36	-	-	0.46	-	-	0.30	0.25	0.33	0.30	0.27
2006	0.33	-	-	0.40	-	-	0.29	-	-	-	-
2007	0.27	-	-	0.31	0.25	-	0.24	-	-	-	-
2008	0.24	-	-	0.37	0.19	-	0.30	0.34	0.40	0.34	0.36
2009	0.39	-	-	0.43	0.44	-	0.48	0.31	0.41	0.32	0.33
2010	0.48	-	-	0.49	0.45	-	0.50	0.29	0.37	0.31	0.33
2011	0.44	-	-	0.52	0.42	-	0.42	0.24	0.39	0.27	0.37
2012	0.45	-	-	0.48	0.41	-	0.46	0.27	0.32	0.25	0.36
2013	0.41	-	-	0.44	0.18	-	0.34	0.26	0.33	0.27	0.28
2014	0.38	-	-	0.42	0.13	-	0.30	0.24	0.28	0.26	0.24
2015	0.39	-	-	0.34	0.14	-	0.33	0.30	0.30	0.27	0.25
2016	0.34	-	-	0.43	0.14	-	0.31	0.26	0.30	0.27	0.26
2017	-	-	-	-	-	-	-	-	-	-	-
Mean (2008-16)	0.39	-	-	0.44	0.28	-	0.38	0.28	0.35	0.29	0.31
Mean (2004-16)	0.38	-	-	0.43	-	-	0.36	0.28	0.34	0.29	0.30
Significance[(b)]	◄►	-	-	◄►	▼	-	◄►	▼	▼	▼	▼

(a) Only years with >75 per cent complete data shown
(b) ▼ = significantly decreasing, ▲ = significantly increasing, ◄► = stable/no trend

Two RMS M5 East roadside sites (F1 and M1) were set at the portals of the M5 East Tunnel to monitoring the impact of the motorway/tunnel on air quality. The annual mean CO concentration recorded at these sites are presented in Figure 4.2, and the corresponding statistics are listed in Table 4.2.

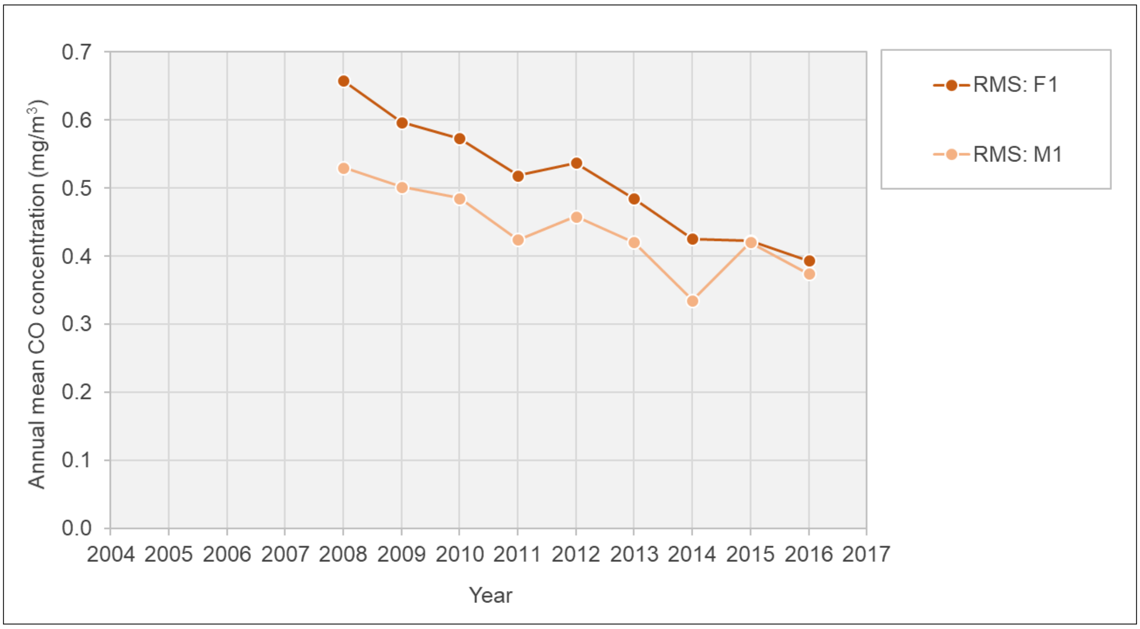


Figure 4.2 *Trend in annual mean CO concentration at RMS roadside sites*

Table 4.2 *Annual mean CO concentration at RMS roadside sites*

Year	Annual mean CO concentration (mg/m^3)[(a)]	
	RMS F1	RMS M1
2004	-	-
2005	-	-
2006	-	-
2007	-	-
2008	0.66	0.53
2009	0.60	0.50
2010	0.57	0.49
2011	0.52	0.42
2012	0.54	0.46
2013	0.48	0.42
2014	0.43	0.34
2015	0.42	0.42
2016	0.39	0.37
2017	-	-
Mean (2008-16)	0.51	0.44

(a) Only years with >75 per cent complete data shown

There is a decreasing trend in CO annual mean concentration at both RMS roadside sites. Between 2008 and 2016 the CO concentration was markedly reduced (by approximately 40% at the F1 site and 30% at M1 site, respectively). Additionally, the CO annual mean concentrations at the RMS roadside sites were higher than those at the RMS and OEH background sites, which indicates that vehicle emissions are directly influencing the monitoring stations.

4.1.2 Maximum one-hour mean concentration

The long-term trend in the maximum one-hour mean CO concentration at the OEH and the RMS M5 East background sites are provided in Figure 4.3, and the corresponding statistics are summarised in Table 4.3. All the values were between 2 to 8 mg/m^3, and therefore well below the NSW air quality criterion of 30 mg/m^3. The values at the OEH sites exhibited a decreasing trend until 2016. The patterns for the RMS M5 East background sites were relatively steady.

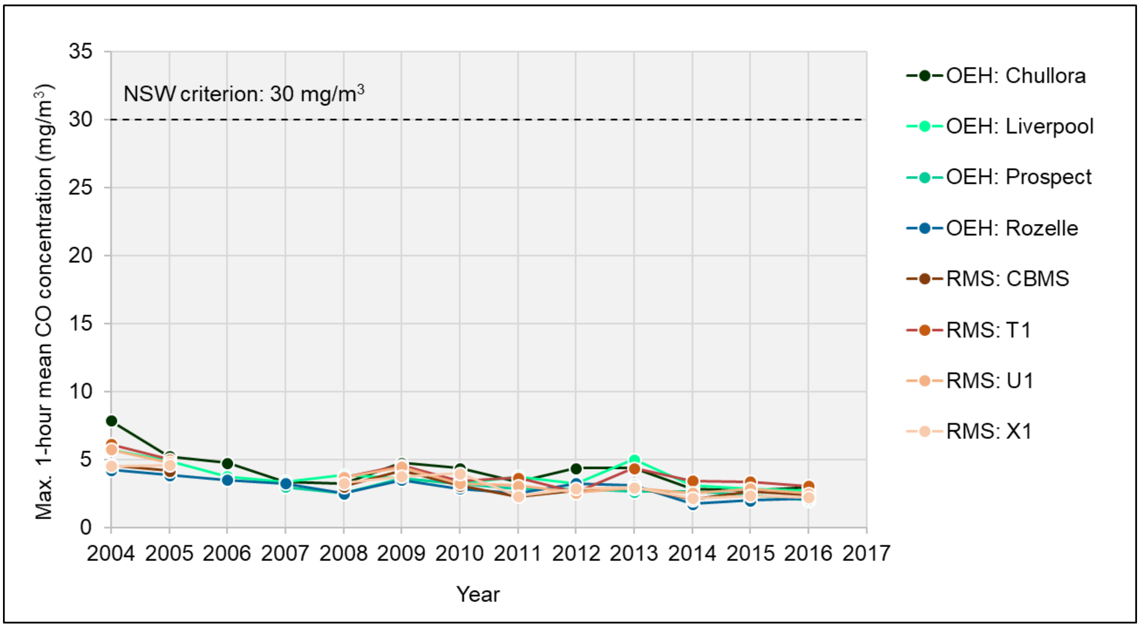


Figure 4.3 *Trend in maximum one-hour mean CO concentration at OEH and RMS M5 East background sites*

Table 4.3 *Maximum one-hour mean CO concentration at OEH and RMS M5 East background sites*

Year	Maximum one-hour mean CO concentration (mg/m³)(a)										
	OEH Chullora	OEH Earlwood	OEH Lindfield	OEH Liverpool	OEH Prospect	OEH Randwick	OEH Rozelle	RMS CBMS	RMS T1	RMS U1	RMS X1
2004	7.87	-	-	5.75	-	-	4.25	4.60	6.15	5.75	4.54
2005	5.25	-	-	4.87	-	-	3.87	4.17	5.01	4.80	4.58
2006	4.75	-	-	3.75	-	-	3.50	-	-	-	-
2007	3.37	-	-	3.37	3.00	-	3.25	-	-	-	-
2008	3.25	-	-	3.87	2.50	-	2.50	3.03	3.66	3.69	3.30
2009	4.75	-	-	3.62	3.62	-	3.50	4.18	4.55	4.47	3.77
2010	4.37	-	-	3.25	3.25	-	2.87	3.10	3.43	3.24	3.98
2011	3.37	-	-	3.75	2.87	-	2.50	2.29	3.65	3.09	2.33
2012	4.37	-	-	3.25	2.87	-	3.25	2.73	2.57	2.58	2.87
2013	4.37	-	-	5.00	2.62	-	3.12	3.00	4.36	2.89	2.95
2014	2.87	-	-	3.12	2.62	-	1.75	2.06	3.45	2.56	2.15
2015	2.75	-	-	2.87	2.37	-	2.00	2.68	3.37	2.88	2.34
2016	3.00	-	-	2.75	2.00	-	2.12	2.38	3.06	2.52	2.22
2017	-	-	-	-	-	-	-	-	-	-	-
Mean (2008-16)	3.68	-	-	3.50	2.75	-	2.62	2.83	3.57	3.10	2.88
Mean (2004-16)	4.18	-	-	3.79	-	-	2.96	3.11	3.93	3.50	3.18
Significance(c)	▼	-	-	▼	▼	-	▼	▼	◄►	▼	▼

(a) Only years with >75 per cent complete data shown

(b) ▼ = significantly decreasing, ▲ = significantly increasing, ◄► = stable/no trend

The long-term trends in the maximum one-hour mean CO concentration at the RMS roadside sites are shown in Figure 4.4, and the corresponding statistics are listed in Table 4.4. All values were well below the NSW air quality criterion of 30 mg/m³, and exhibited a general downward pattern at both sites. The values at the F1 site were higher than those at the RMS and OEH background sites, which indicates direct measurement of vehicle emissions and that this site may have a stronger road traffic influence than the M1 site.

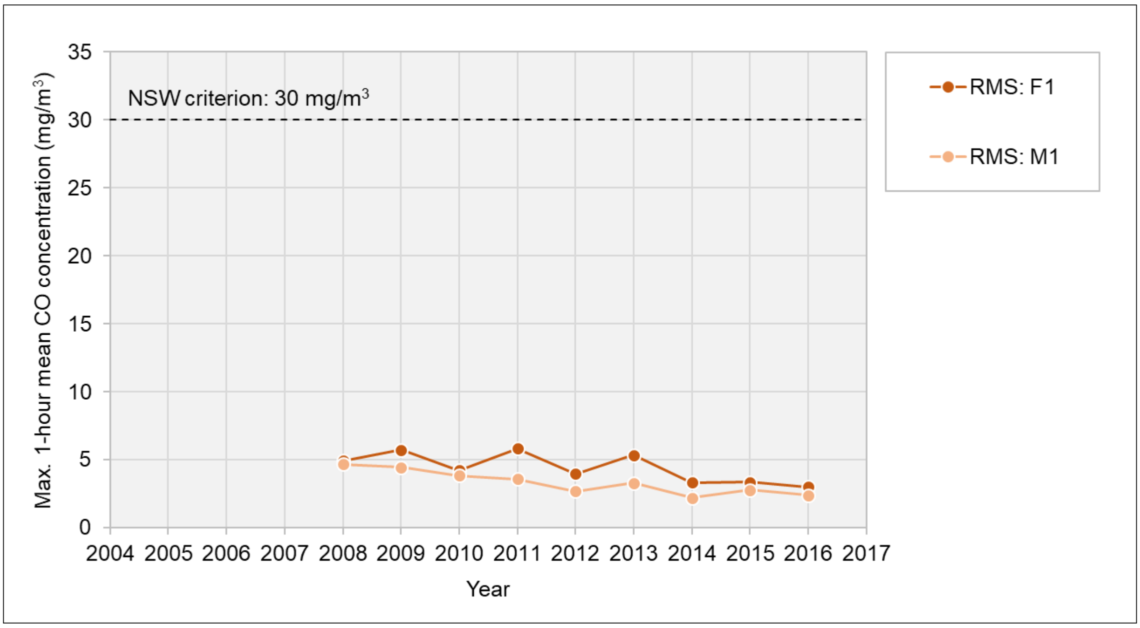


Figure 4.4 *Trend in maximum one-hour mean CO concentration at RMS roadside sites*

Table 4.4 *Maximum one-hour mean CO concentration at RMS roadside sites*

Year	Maximum one-hour mean CO concentration (mg/m^3)[(a)]	
	RMS F1	RMS M1
2004	-	-
2005	-	-
2006	-	-
2007	-	-
2008	4.92	4.66
2009	5.74	4.46
2010	4.21	3.83
2011	5.83	3.57
2012	3.98	2.68
2013	5.36	3.28
2014	3.32	2.22
2015	3.36	2.77
2016	3.00	2.39
2017	-	-
Mean (2008-16)	4.41	3.32

(a) Only years with >75 per cent complete data shown

4.1.3 Maximum rolling 8-hour mean concentration

The results from the OEH and the RMS M5 East background monitoring sites are given in Figure 4.5, and the corresponding statistics are shown in Table 4.5. All values were well below the NSW air quality criterion of 10 gm/m^3. The results show a slight decreasing trend at the OEH sites and the RMS M5 East background sites.

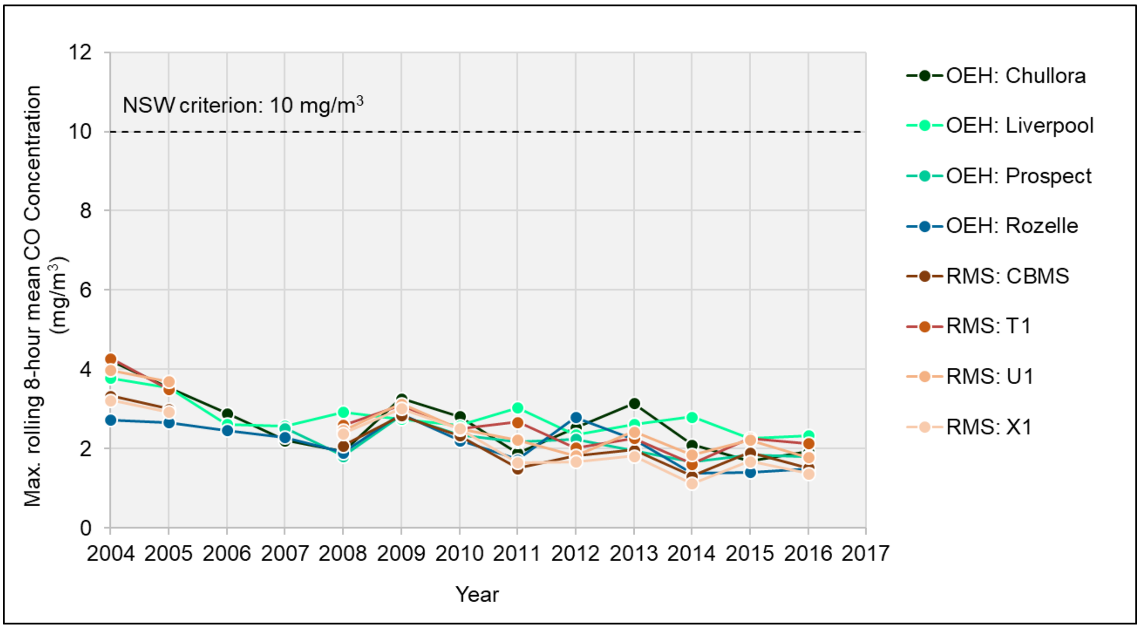


Figure 4.5 *Trend in maximum rolling 8-hour mean CO concentration at OEH and RMS M5 East background sites*

Table 4.5 *Maximum rolling 8-hour mean CO concentration at OEH and RMS M5 East background sites*

Year	Maximum rolling 8-hour mean CO concentration (mg/m^3)(a)										
	OEH Chullora	OEH Earlwood	OEH Lindfield	OEH Liverpool	OEH Prospect	OEH Randwick	OEH Rozelle	RMS CBMS	RMS T1	RMS U1	RMS X1
2004	4.22	-	-	3.78	-	-	2.73	3.34	4.28	3.98	3.22
2005	3.53	-	-	3.54	-	-	2.66	3.00	3.50	3.69	2.93
2006	2.89	-	-	2.62	-	-	2.46	-	-	-	-
2007	2.22	-	-	2.57	2.52	-	2.28	-	-	-	-
2008	1.93	-	-	2.93	1.82	-	1.91	2.08	2.60	2.46	2.38
2009	3.27	-	-	2.75	2.83	-	2.87	2.84	3.10	3.14	3.01
2010	2.82	-	-	2.59	2.35	-	2.21	2.33	2.51	2.50	2.51
2011	1.89	-	-	3.03	2.18	-	1.73	1.51	2.67	2.23	1.66
2012	2.53	-	-	2.36	2.25	-	2.79	1.81	2.02	1.83	1.68
2013	3.14	-	-	2.62	1.96	-	2.23	1.97	2.27	2.43	1.82
2014	2.11	-	-	2.80	1.68	-	1.37	1.31	1.61	1.84	1.13
2015	1.70	-	-	2.27	1.84	-	1.41	1.91	2.27	2.22	1.69
2016	1.93	-	-	2.34	1.80	-	1.50	1.52	2.13	1.79	1.38
2017	-	-	-	-	-	-	-	-	-	-	-
Mean (2008-16)	2.37	-	-	2.63	2.08	-	2.00	1.92	2.35	2.27	1.92
Mean (2004-16)	2.63	-	-	2.78	-	-	2.17	2.15	2.63	2.56	2.13
Significance(c)	▼	-	-	▼	▼	-	▼	▼	▼	▼	▼

(a) Only years with >75 per cent complete data shown

(b) ▼ = significantly decreasing, ▲ = significantly increasing, ◄► = stable/no trend

The long-term patterns in the maximum rolling 8-hour mean CO concentration at the two RMS roadside sites are shown in Figure 4.6, and the corresponding statistics are presented in Table 4.6. The concentrations were between 1.63 and 4.32 mg/m^3, which are well below the NSW air quality criterion of 10 mg/m^3. An obvious decreasing trend was revealed at both sites. Comparing with the values at the OEH and RMS M5 East background sites, values at the RMS roadside sites were higher, which is a result of the road traffic impact .

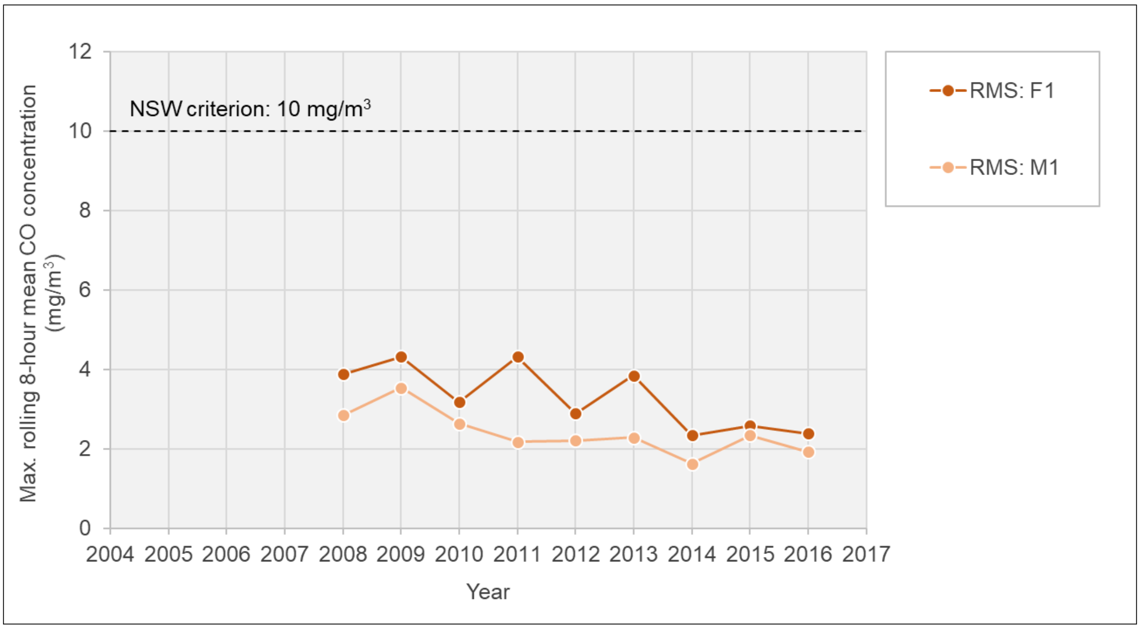


Figure 4.6 *Trend in maximum rolling 8-hour mean CO concentration at RMS roadside sites*

Table 4.6 *Maximum rolling 8-hour mean CO concentration at RMS roadside sites*

Year	Maximum rolling 8-hour mean CO concentration (mg/m^3)(a)	
	RMS F1	RMS M1
2004	-	-
2005	-	-
2006	-	-
2007	-	-
2008	3.88	2.85
2009	4.32	3.54
2010	3.17	2.64
2011	4.32	2.17
2012	2.89	2.21
2013	3.85	2.29
2014	2.35	1.63
2015	2.59	2.34
2016	2.39	1.92
2017	-	-
Mean (2008-16)	3.31	2.40

(a) Only years with >75 per cent complete data shown

4.1.4 Exceedance of air quality criteria

Between 2004 and 2016, there were no exceedances of the rolling 8-hour mean criterion for CO of 10 mg/m^3, or the maximum one-hour criterion of 30 mg/m^3, at any of the OEH and the RMS M5 East background and roadside sites.

4.2 Nitrogen dioxide

4.2.1 Annual mean concentration

Multi-year data for NO_2 were only recorded at the OEH and the RMS M5 East sites between 2004 and 2016. The long-term trends in annual mean NO_2 concentrations at the background sites are presented in Figure 4.7, and the corresponding statistics are provided in Table 4.7. The NO_2 concentrations at all sites were well below the NSW air quality assessment criterion of 62 µg/m^3.

There was a systematic downward trend at the OEH sites between 2004 and 2008, with a reduction ranging between 16.4% to 24.4%. However, the NO_2 concentration started to be stabilised in recent years with some fluctuations. At the RMS M5 East sites, a downward trend can be seen at the CBMS site (reduced 14.2%) and T1 site (reduced 12.3%), while the trends at U1 site and X1 site were quite stable.

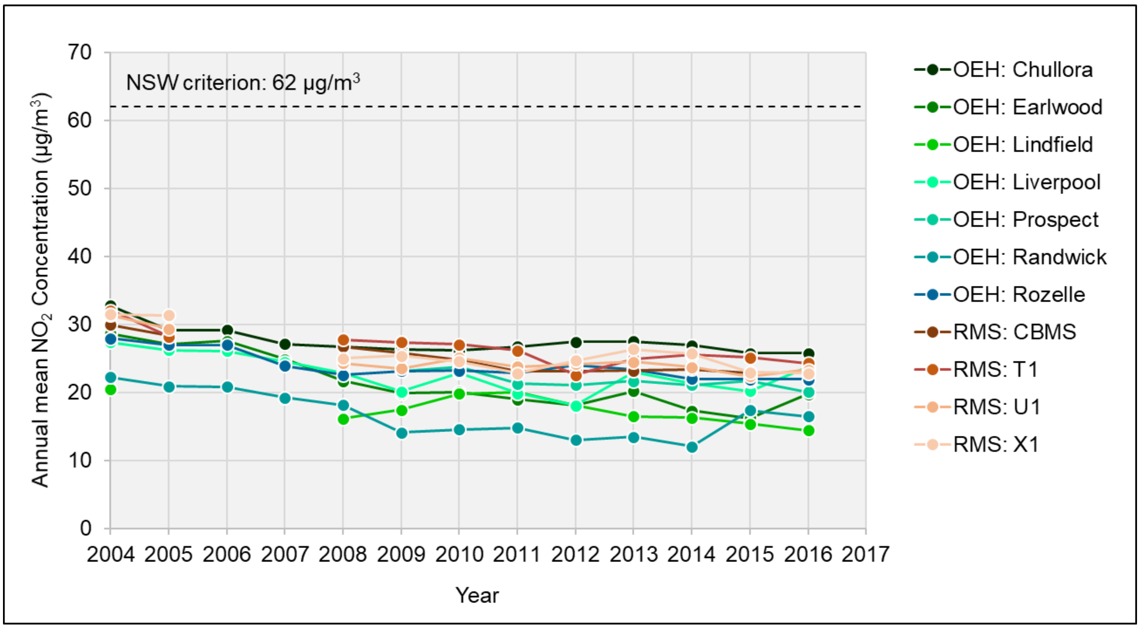


Figure 4.7 *Trend in annual mean NO_2 concentration at OEH and RMS M5 East background sites*

Table 4.7 *Annual mean NO_2 concentration at OEH and RMS M5 East background sites*

Year	Annual mean NO_2 concentration (µg/m^3)[(a)]										
	OEH Chullora	OEH Earlwood	OEH Lindfield	OEH Liverpool	OEH Prospect	OEH Randwick	OEH Rozelle	RMS CBMS	RMS T1	RMS U1	RMS X1
2004	32.8	28.7	20.4	27.4	-	22.2	27.9	29.9	32.0	31.3	31.4
2005	29.1	27.1	-	26.2	-	20.9	27.0	28.3	28.2	29.4	31.3
2006	29.2	27.6	-	26.1	-	20.8	27.0	-	-	-	-
2007	27.1	24.9	-	24.5	-	19.2	23.9	-	-	-	-
2008	26.7	21.7	16.1	22.9	-	18.1	22.6	26.7	27.7	24.3	25.0
2009	26.3	19.9	17.4	20.1	23.1	14.1	23.1	25.7	27.4	23.5	25.4
2010	26.2	20.1	19.8	22.9	23.7	14.6	23.2	24.8	27.1	25.1	24.5
2011	26.8	18.9	20.0	19.9	21.3	14.8	22.9	23.1	26.1	23.8	22.8
2012	27.4	18.1	18.0	18.1	21.1	13.0	24.0	23.1	22.5	24.2	24.7
2013	27.5	20.2	16.5	22.9	21.7	13.5	23.4	23.2	25.0	24.5	26.3
2014	26.9	17.3	16.3	21.3	21.1	12.1	21.9	23.4	25.5	23.7	25.7
2015	25.8	16.2	15.4	20.2	21.6	17.4	21.9	22.9	25.1	22.4	23.0
2016	25.8	19.8	14.4	23.8	20.1	16.4	21.9	-	24.3	23.3	22.8
2017	-	-	-	-	-	-	-	-	-	-	-
Mean (2008-16)	26.6	19.1	17.1	21.3	21.7[(b)]	14.9	22.8	24.1	25.6	23.9	24.5
Mean (2004-16)	27.5	21.6	-	22.8	-	16.7	23.9	25.1	26.4	25.0	25.7
Significance[(c)]	▼	▼	▼	▼	◀▶	▼	▼	▼	▼	◀▶	◀▶

(a) Only years with >75 per cent complete data shown
(b) Mean (2009-16)
(c) ▼ = significantly decreasing, ▲ = significantly increasing, ◀▶ = stable/no trend

The long-term trend in annual mean NO_2 concentration at the RMS roadside sites are shown in Figure 4.8, and the corresponding statistics are listed in Table 4.8. All values were well below the NSW air quality criterion of 62 µg/m^3, and there was no trend between 2008 and 2016. The long-term average of NO_2 concentrations at these two roadside sites were 34 and 37 µg/m^3 respectively, which were approximately 10-20 µg/m^3 higher than that of the background sites, indicating the presence of vehicle emissions.

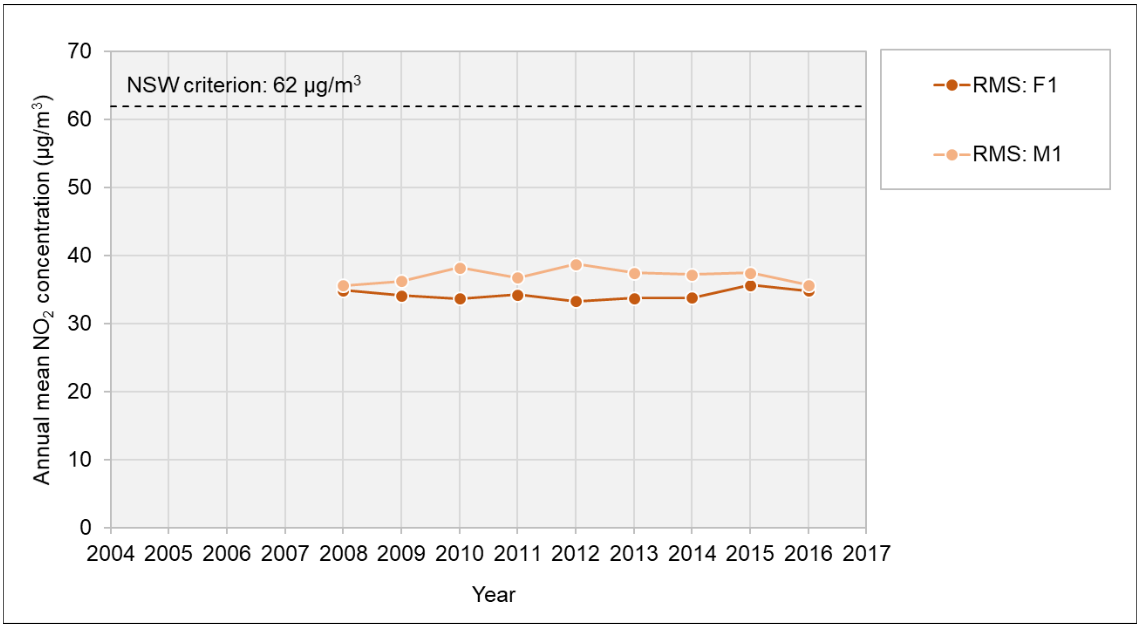


Figure 4.8 *Trend in annual mean NO_2 concentration at RMS roadside sites*

Table 4.8 *Annual mean NO_2 concentration at RMS roadside sites*

Year	Annual mean NO_2 concentration (µg/m³)[(a)]	
	RMS F1	RMS M1
2004	-	-
2005	-	-
2006	-	-
2007	-	-
2008	34.9	35.6
2009	34.1	36.3
2010	33.7	38.2
2011	34.3	36.8
2012	33.3	38.8
2013	33.8	37.5
2014	33.8	37.2
2015	35.7	37.5
2016	34.8	35.6
2017	-	-
Mean (2008-16)	34.3	37.1

(a) Only years with >75 per cent complete data shown

4.2.2 Maximum one-hour mean concentration

The long-term trends in maximum one-hour NO_2 concentration at the OEH and the RMS M5 East background sites are provided in Figure 4.9, and the corresponding statistics are shown in Table 4.9. The values were all well below the NSW air quality criteria of 246 µg/m³. At the OEH sites, downward trends were shown between 2004 and 2008. However, since 2008 the profiles for all the OEH and the RMS M5 East sites were generally stable, with an average maximum one-hour mean NO_2 concentration of approximately 100 µg/m³.

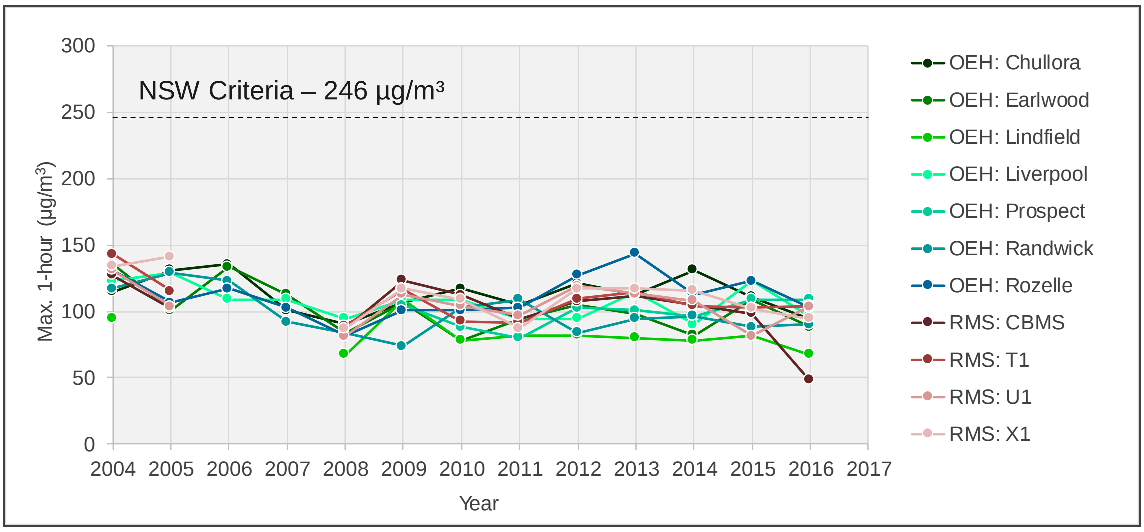


Figure 4.9 *Trend in maximum one-hour mean NO_2 concentration at OEH and RMS M5 East background sites*

Table 4.9 *Maximum one-hour mean NO_2 concentration at OEH and RMS M5 East background sites*

Year	Maximum one-hour NO_2 concentration (µg/m^3)[(a)]										
	OEH Chullor	OEH Earlwoo	OEH Lindfiel	OEH Liverpo	OEH Prospe	OEH Randwi	OEH Rozelle	RMS CBMS	RMS T1	RMS U1	RMS X1
2004	114.9	135.5	94.4	123.1	-	117.0	131.4	127.3	143.3	131.1	134.3
2005	131.4	100.6	-	129.3	-	129.3	106.7	102.3	115.2	103.6	148.1
2006	135.5	133.4	-	108.8	-	123.1	117.0	-	-	-	-
2007	100.6	112.9	-	108.8	-	92.4	102.6	-	-	-	-
2008	90.3	84.1	67.7	94.4	-	84.1	82.1	87.3	89.1	81.5	87.3
2009	106.7	106.7	108.8	108.8	104.7	73.9	100.6	123.6	116.6	112.6	117.4
2010	117.0	78.0	78.0	108.8	88.3	102.6	100.6	112.5	92.8	104.4	109.2
2011	104.7	94.4	82.1	94.4	80.0	108.8	102.6	94.7	91.4	96.7	87.5
2012	121.1	104.7	82.1	94.4	102.6	84.1	127.2	107.7	109.5	119.0	117.1
2013	112.9	98.5	80.0	114.9	100.6	94.4	143.7	111.8	114.9	113.1	117.1
2014	131.4	82.1	78.0	90.3	96.5	96.5	112.9	105.3	104.1	107.8	115.9
2015	110.8	108.8	82.1	123.1	108.8	88.3	123.1	98.6	102.7	81.5	102.2
2016	94.4	88.3	67.7	96.5	108.8	90.3	102.6	-	104.4	103.7	94.7
2017	-	-	-	-	-	-	-	-	-	-	-
Mean (2008-16)	109.9	94.0	80.7	102.8	98.8[(b)]	91.4	110.6	105.2	102.8	102.3	105.4
Mean (2004-16)	113.2	102.1	-	107.4	-	98.8	111.8	107.1	107.6	105.0	119.2-

(a) Only years with >75 per cent complete data shown
(b) Mean (2009-16)

The trends at the RMS roadside sites between 2008 and 2016 are shown in Figure 4.10, and the corresponding summarised are listed in Table 4.10. Systematic upward trends were found at both sites but still all well below the NSW air quality criteria of 246 µg/m^3. The average maximum one-hour NO_2 concentration were 120.4 µg/m^3 for F1 site and 134.9 µg/m^3 for M1 site respectively, which was approximately 15-45 µg/m^3 higher than that of the background sites.

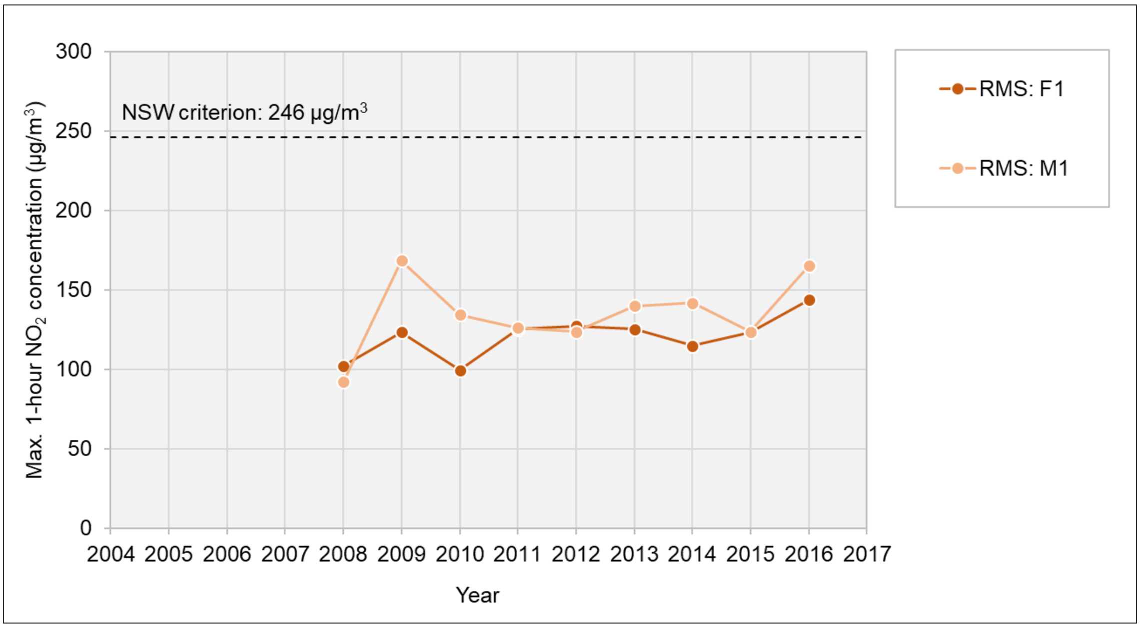


Figure 4.10 *Trend in maximum one-hour mean NO_2 concentration at RMS roadside sites*

Table 4.10 *Annual mean NO_2 concentration at RMS roadside sites*

Year	Maximum one-hour mean NO_2 concentration ($\mu g/m^3$)[a] RMS F1	RMS M1
2004	-	-
2005	-	-
2006	-	-
2007	-	-
2008	102.0	92.3
2009	123.2	168.4
2010	99.3	134.2
2011	125.1	126.1
2012	127.2	123.4
2013	125.3	139.8
2014	114.9	141.7
2015	123.2	123.4
2016	143.6	165.0
2017	-	-
Mean (2008-16)	120.4	134.9

(a) Only years with >75 per cent complete data shown

4.2.3 Exceedance of air quality criteria

During whole monitoring period, there were no exceedances of the annual mean criterion for NO_2 of 62 $\mu g/m^3$, or the maximum one-hour criterion of 246 $\mu g/m^3$ at any of the OEH and the RMS M5 East background and roadside sites.

4.3 Nitrogen oxides

4.3.1 Annual mean concentration

The long-term annual mean NO_X concentrations at the OEH and the RMS M5 East background monitoring sites are provided in Figure 4.11**,** and the corresponding statistics are presented in Table 4.11. There is no air quality criterion for NO_x in NSW, but it is important to understand NO_X in order to characterise NO_2.

Systematic downward patterns were observed at all background sites between 2004 and 2016. At the OEH sites, the concentrations decreased by around 40% from 2004 to 2016, although the reductions at Liverpool and prospect sites were only 27% and 21% respectively. At the RMS M5 East sites, the reductions in concentration between 2008 and 2016 were not that dramatic, but still in the range of 15-24%.

On the other hand, the annual mean NO_x concentration varied markedly from site to site. For the OEH sites, the highest average value of 53.8 $\mu g/m^3$ was obtained at Chullora, while the lowest value was only about a half at Lindfield (26.3 $\mu g/m^3$). The concentration variation was lower at the RMS M5 East sites, with all the annual mean NO_x concentrations being between 42 to 53 $\mu g/m^3$.

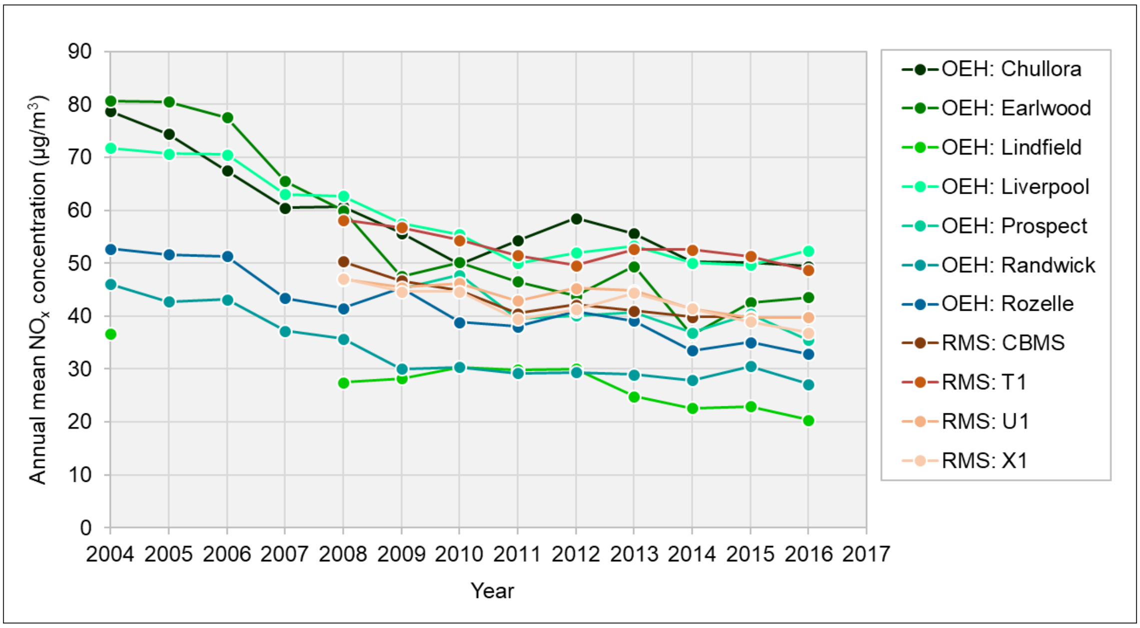


Figure 4.11 *Trend in annual mean NOx concentration at OEH and RMS M5 East background sites*

Table 4.11 *Annual mean NOx concentration at OEH and RMS M5 East background sites*

Year	Annual mean NO_x concentration (µg/m^3)[(a)]									
	OEH Chullora	OEH Earlwood	OEH Lindfield	OEH Liverpool	OEH Prospect	OEH Randwick	OEH Rozelle	RMS CBMS	RMS T1	RMS U1	RMS X1
2004	78.7	80.6	36.6	71.8		46.0	52.7	-	-	-	-
2005	74.4	80.5		70.7		42.7	51.7	-	-	-	-
2006	67.5	77.5		70.5		43.2	51.3	-	-	-	-
2007	60.4	65.5		63.0		37.2	43.4	-	-	-	-
2008	60.7	60.0	27.5	62.7		35.8	41.5	50.3	58.2	47.0	47.1
2009	55.7	47.5	28.2	57.5	45.1	30.1	45.4	46.7	56.7	45.5	44.6
2010	49.7	50.2	30.4	55.4	47.7	30.4	38.9	44.8	54.3	46.2	44.6
2011	54.3	46.5	29.9	50.0	39.5	29.2	38.0	40.5	51.5	42.9	39.4
2012	58.5	43.8	30.0	52.0	40.1	29.4	40.9	42.2	49.6	45.3	41.3
2013	55.6	49.4	24.8	53.3	40.8	28.9	39.1	41.0	52.7	44.8	44.4
2014	50.2	36.5	22.6	50.1	36.9	27.9	33.5	39.8	52.5	41.4	41.4
2015	50.1	42.6	22.9	49.6	40.5	30.6	35.1	39.9	51.3	39.7	38.9
2016	49.4	43.6	20.4	52.4	35.5	27.1	32.8	-	48.7	39.7	36.9
2017	-	-	-	-	-	-	-	-	-	-	-
Mean (2008-16)	53.8	46.7	26.3	53.7	40.8[(b)]	29.9	38.3	43.1	52.8	43.6	42.1
Mean (2004-16)	58.9	55.7		58.4		33.7	41.9	-	-	-	-
Significance[(c)]	▼	▼	▼	▼	◄►	▼	▼	▼	▼	▼	▼

(a) Only years with >75 per cent complete data shown
(b) Mean (2009-16)
(c) ▼ = significantly decreasing, ▲ = significantly increasing, ◄► = stable/no trend

The trends in annual mean NO_x concentration at the RMS roadside sites between 2008 and 2016 are shown in Figure 4.12, and the corresponding statistics are provided in Table 4.12. A general decreasing trend was observed at both sites, and similar average values were obtained (103.3 µg/m^3 and 101.4 µg/m^3 for the F1 and M1 site respectively). The increments at the roadside sites were about 60 µg/m^3 compared with the RMS M5 East background sites, suggesting a positive influence of road transportation.

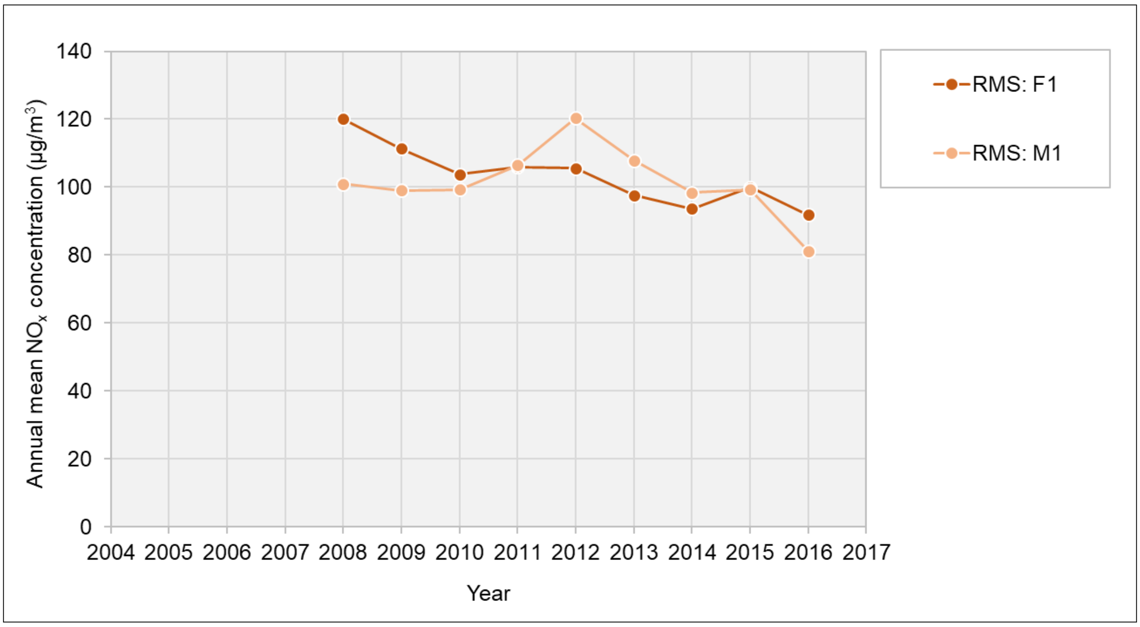


Figure 4.12 *Trend in annual mean NOx concentration at RMS roadside sites*

Table 4.12 *Annual mean NOx concentration at RMS roadside sites*

Year	Annul mean NO_x concentration (µg/m³)[(a)]	
	RMS F1	RMS M1
2004	-	-
2005	-	-
2006	-	-
2007	-	-
2008	120.0	100.9
2009	111.3	99.0
2010	103.7	99.3
2011	106.0	106.5
2012	105.6	120.3
2013	97.7	107.9
2014	93.7	98.3
2015	100.0	99.3
2016	91.8	81.1
2017	-	-
Mean (2008-16)	103.3	101.4

(a) Only years with >75 per cent complete data shown

4.3.2 Maximum one-hour mean concentration

Figure 4.13 provides the long-term trends in the maximum one-hour mean NO_x concentration at the OEH and the RMS M5 East background sites, and the corresponding statistics are shown in Table 4.13.

At the OEH sites, there was an overall downward trend. However, the peak concentrations were relatively stable in recent years. The overall reductions were significant between 2004 and 2016 (decreased by approximately 30-60%). At the RMS M5 East sites, similar undulated profiles were shown for all sites.

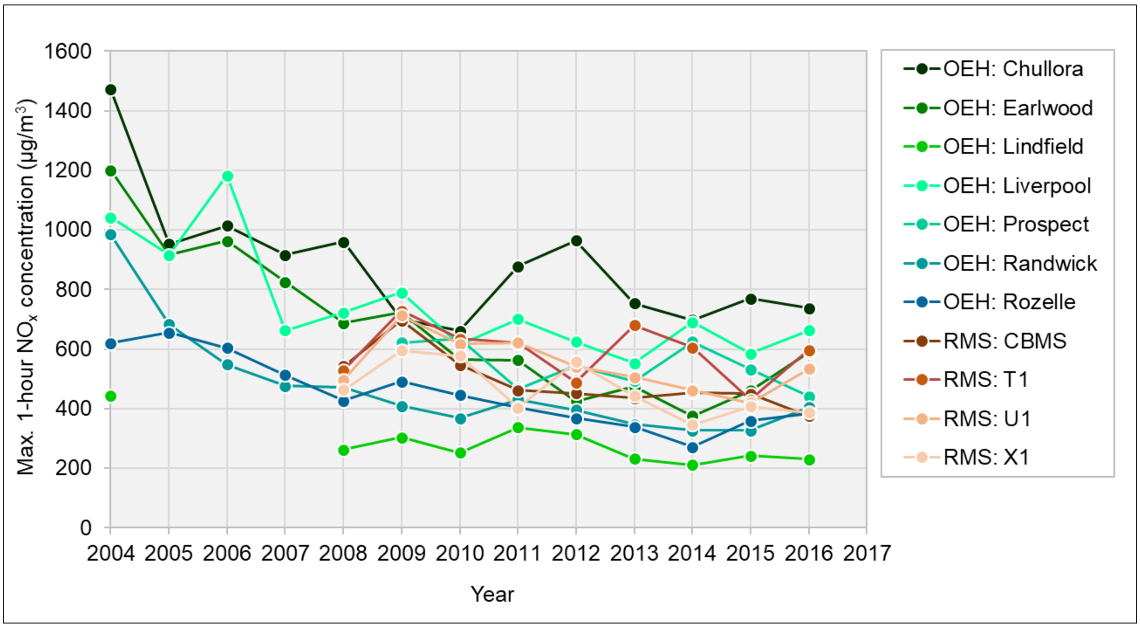


Figure 4.13 *Trend in maximum one-hour mean NOx concentration at OEH and RMS M5 East background sites*

Table 4.13 *Maximum one-hour mean NOx concentration at OEH and RMS M5 East background sites*

Year	Maximum one-hour mean NO_x concentration (µg/m³)[(a)]										
	OEH Chullora	OEH Earlwood	OEH Lindfield	OEH Liverpool	OEH Prospect	OEH Randwick	OEH Rozelle	RMS CBMS	RMS T1	RMS U1	RMS X1
2004	1471.5	1200.6	443.3	1042.6	-	985.1	619.8	-	-	-	-
2005	952.3	915.4	-	915.4	-	683.4	654.7	-	-	-	-
2006	1013.9	962.6	-	1182.2	-	548.0	603.4	-	-	-	-
2007	915.4	825.0	-	662.9	-	476.1	513.1	-	-	-	-
2008	960.5	687.5	262.7	722.4	-	472.0	426.9	542.2	529.6	496.4	463.0
2009	699.9	724.5	303.7	790.2	621.9	408.4	490.5	696.5	728.9	712.1	595.0
2010	660.9	566.5	252.4	613.7	634.2	367.4	445.4	546.0	634.2	617.6	576.8
2011	878.4	562.3	336.6	699.9	465.9	431.0	404.3	461.1	619.8	621.2	402.5
2012	964.6	424.8	314.0	623.9	543.9	396.1	367.4	451.3	488.1	541.0	557.0
2013	753.2	474.1	231.9	552.1	492.6	346.8	338.6	435.6	679.4	505.9	442.4
2014	697.8	375.6	211.4	689.6	623.9	326.3	270.9	454.9	605.4	461.6	346.4
2015	769.6	459.7	242.2	584.9	531.6	326.3	359.2	449.6	429.4	419.0	407.5
2016	736.8	589.0	229.9	662.9	441.3	404.3	383.8	374.9	596.7	533.8	386.4
2017	-	-	-	-	-	-	-	-	-	-	-
Mean (2008-16)	791.3	540.5	265.0	659.9	544.4[(b)]	386.5	387.4	490.2	590.2	545.4	464.1
Mean (2004-16)	882.7	674.4	-	749.4	-	474.7	452.2	-	-	-	-

(a) Only years with >75 per cent complete data shown
(b) Mean (2009-16)

The trends at the RMS roadside sites are presented in Figure 4.14, and the corresponding statistics are shown in Table 4.14. The peak concentrations generally decreased between 2008 and 2016, but with some fluctuations. The maximum one-hour mean NOx concentrations recorded at F1 site were higher than those at the M1 site. Meanwhile, the average values at the roadside sites were substaintially higher than that at the background sites, showning the influence from road traffic.

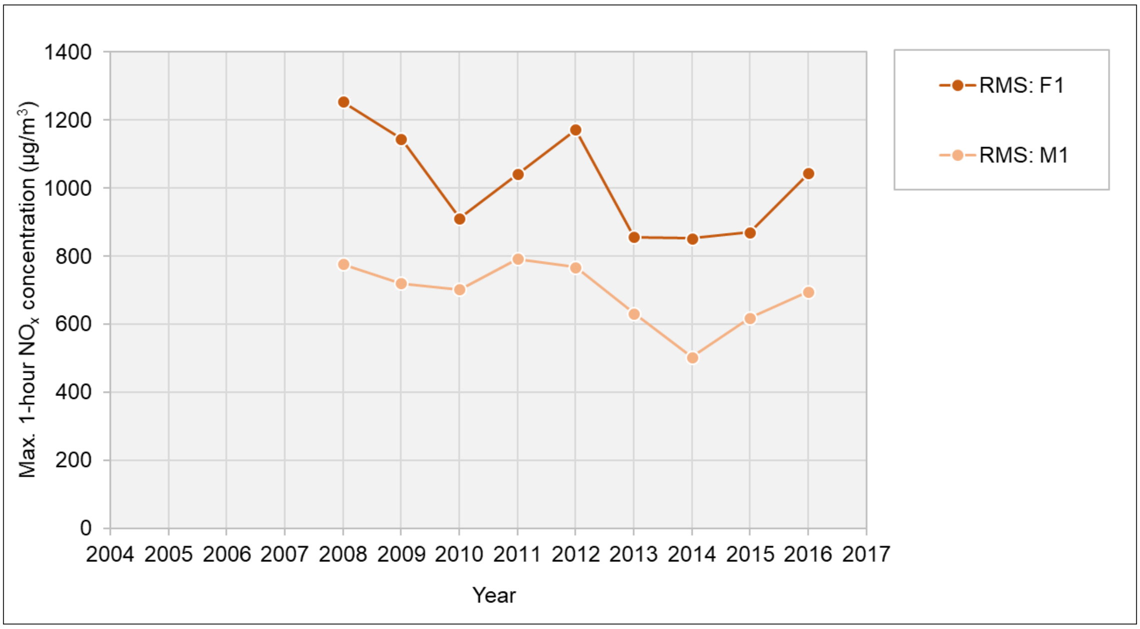


Figure 4.14 *Trend in maximum one-hour mean NOx concentration at OEH and RMS M5 East background sites*

Table 4.14 *Maximum one-hour mean NOx concentration at OEH and RMS M5 East background sites*

Year	Annul mean NO_x concentration ($\mu g/m^3$)[(a)]	
	RMS F1	RMS M1
2004	-	-
2005	-	-
2006	-	-
2007	-	-
2008	1253.3	776.1
2009	1144.3	720.8
2010	911.4	702.5
2011	1041.2	792.2
2012	1172.3	767.7
2013	856.1	632.3
2014	852.5	503.4
2015	870.6	619.6
2016	1043.4	696.3
2017	-	-
Mean (2008-16)	1016.1	690.1

(a) Only years with >75 per cent complete data shown

4.4 Ozone

4.4.1 Annual mean concentration

Long-term O_3 data were only available at the OEH sites. The annual mean O_3 concetrations are provided in Figure 4.15, and the corresponding statistics are listed in Table 4.15. Generally, the values were relatively steady between 2004 and 2016 except for Linfield site, which showed a slight upward trend. The annual mean O_3 cocnentration at most OEH sites were typically in the range of approximately 27 to 37 µg/m³. The one exception was Randwick, where the values were much higher at around 40 µg/m³. This is likely to be due to the coastal nature of Randwick (Figure 2.1), with easterly winds from the ocean having low concentrations of ozone-scavenging species, notably NOx (seen in Figure 4.11).

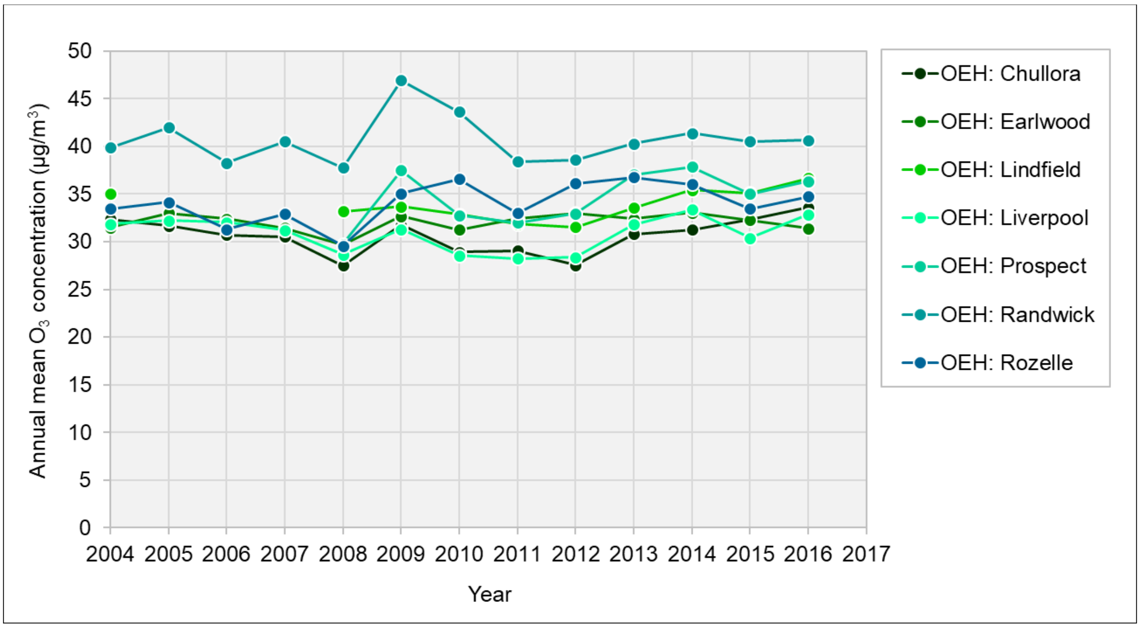


Figure 4.15 *Trend in annual mean O_3 concentration at OEH background sites*

Table 4.15 *Annual mean O_3 concentration at OEH background sites*

Year	Annual mean O_3 concentration ($\mu g/m^3$)[(a)]						
	OEH Chullora	OEH Earlwood	OEH Lindfield	OEH Liverpool	OEH Prospect	OEH Randwick	OEH Rozelle
2004	32.3	31.5	35.0	31.8	-	39.8	33.5
2005	31.6	33.0	-	32.2	-	42.0	34.2
2006	30.7	32.4	-	32.0	-	38.3	31.3
2007	30.5	31.4	-	31.2	-	40.5	32.9
2008	27.5	29.7	33.2	28.7	29.8	37.8	29.6
2009	31.8	32.7	33.7	31.3	37.5	46.9	35.1
2010	28.9	31.3	32.9	28.6	32.8	43.6	36.6
2011	29.0	32.4	31.9	28.2	32.0	38.4	33.0
2012	27.5	33.0	31.5	28.4	33.0	38.6	36.1
2013	30.8	32.4	33.5	31.8	37.0	40.3	36.8
2014	31.3	33.0	35.4	33.4	37.9	41.4	36.0
2015	32.3	32.2	35.1	30.4	35.0	40.5	33.5
2016	33.6	31.4	36.7	32.9	36.3	40.6	34.7
2017	-	-	-	-	-	-	-
Mean (2008-16)	30.3	32.0	33.8	30.4	34.6	40.9	34.6
Mean (2004-16)	30.6	32.0	-	30.8	-	40.7	34.1
Significance[(b)]	◀▶	◀▶	◀▶	◀▶	◀▶	◀▶	▲

(a) Only years with >75 per cent complete data shown

(b) ▼ = significantly decreasing, ▲ = significantly increasing, ◀▶ = stable/no trend

4.4.2 Maximum one-hour mean concentration

The long-term trends of maximum one-hour mean O_3 concentration are shown in Figure 4.16, and the corresponding statistics are provided in Table 4.16. Compared with NSW air quality criterion of 214 $\mu g/m^3$, all the sites have experienced exceedances except at Rozelle. Fluctuation were seen at all sites but relatively stable at Chullora, Earlwood and Rozelle. There were general decreasing trends at Liverpool and Prospect sites, but an upward was found at Lindfield site, and a first decreasing then increasing trend was discovered at Randwick station.

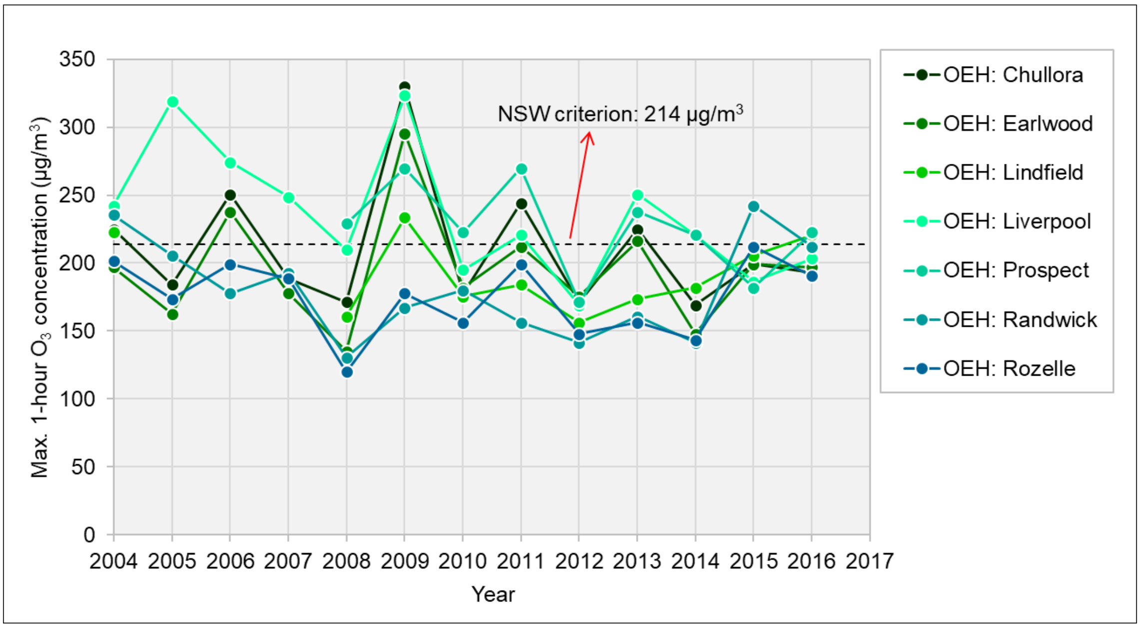


Figure 4.16 *Trend in maximum one-hour mean O_3 concentration at OEH background sites*

Table 4.16 *Maximum one-hour mean O_3 concentration at OEH background sites*

Year	Maximum one-hour mean O_3 concentration (µg/m^3)(a)						
	OEH Chullora	OEH Earlwood	OEH Lindfield	OEH Liverpool	OEH Prospect	OEH Randwick	OEH Rozelle
2004	224.9	197.0	222.7	242.0	-	235.6	201.3
2005	184.2	162.8	-	319.1	-	205.6	173.5
2006	250.6	237.7	-	274.1	-	177.8	199.2
2007	188.5	177.8	-	248.4	-	192.7	188.5
2008	171.3	134.9	160.6	209.9	229.2	130.6	119.9
2009	329.8	295.5	233.4	323.4	269.8	167.0	177.8
2010	177.8	182.0	175.6	194.9	222.7	179.9	156.3
2011	244.1	212.0	184.2	220.6	269.8	156.3	199.2
2012	171.3	175.6	156.3	169.2	171.3	141.3	147.8
2013	224.9	216.3	173.5	250.6	237.7	160.6	156.3
2014	169.2	147.8	182.0	220.6	220.6	141.3	143.5
2015	199.2	199.2	205.6	186.3	182.0	242.0	212.0
2016	192.7	197.0	220.6	203.5	222.7	212.0	190.6
2017	-	-	-	-	-	-	-
Mean (2008-16)	208.9	195.6	188.0	219.9	225.1	170.1	167.0
Mean (2004-16)	209.9	195.0	-	235.6	-	180.2	174.3

(a) Only years with >75 per cent complete data shown

4.4.3 Maximum rolling 4-hour mean concentration

Figure 4.17 is the trends in maximum rolling 4-hour mean O_3 cocnetration, and Table 4.17 presents the corresponding statistics. Exceedancse of NSW air quality criterion of 171 µg/m^3 were seen at Chullora, Earlwood, Liverpool, Prospect sites. The profiles were similar to that of the maximum one-hour mean O_3 cocentration. Values were retively steady at Chullora, Earlwood, Randwick and Rozelle, while a upward rend occurred at Linfield and downward trends were seen at Liverpool and Prospect sites.

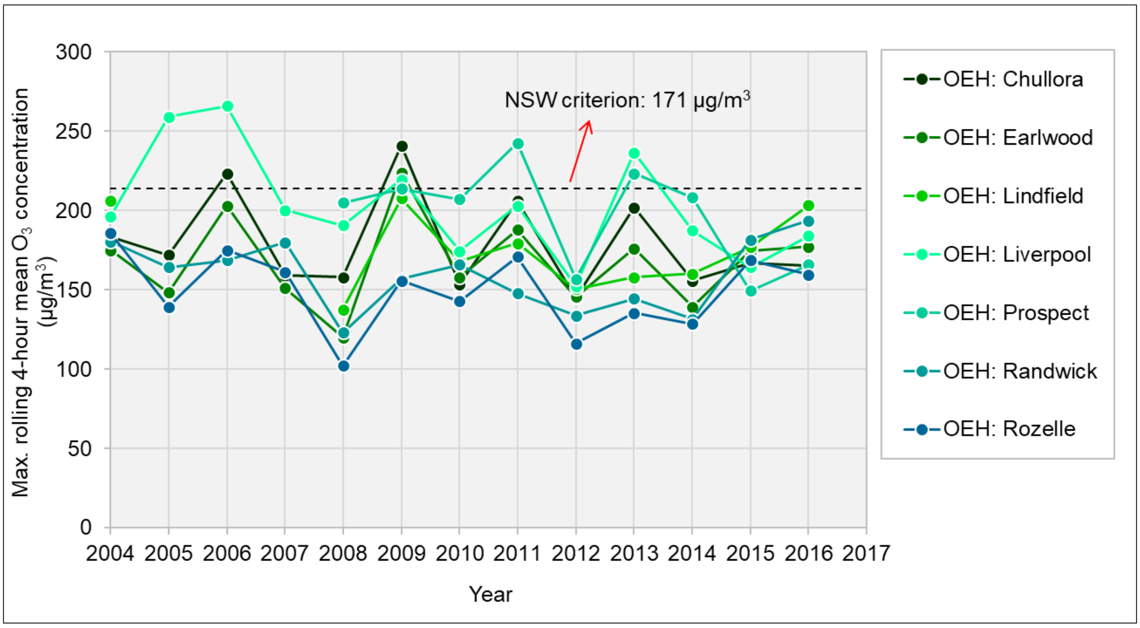


Figure 4.17 *Trend in maximum rolling 4-hour mean O_3 concentration at OEH background sites*

Table 4.17 *Maximum rolling 4-hour mean O_3 concentration at OEH background sites*

Year	Maximum rolling 4-hour mean O_3 concentration ($\mu g/m^3$)[(a)]						
	OEH Chullora	OEH Earlwood	OEH Lindfield	OEH Liverpool	OEH Prospect	OEH Randwick	OEH Rozelle
2004	183.6	175.1	206.1	196.5	-	180.4	185.8
2005	171.9	148.3	-	259.1	-	164.4	139.2
2006	223.3	202.9	-	266.1	-	168.7	175.1
2007	159.0	151.0	-	200.2	-	179.9	161.2
2008	157.9	119.9	137.6	190.6	204.9	123.1	102.3
2009	240.9	223.8	207.7	219.5	213.6	156.9	155.8
2010	153.7	157.9	168.1	174.5	207.2	166.0	143.0
2011	206.1	187.9	179.4	202.9	242.5	147.8	170.8
2012	145.1	145.6	150.4	152.6	156.9	133.8	116.2
2013	201.8	176.1	157.9	236.6	223.3	144.6	135.5
2014	155.8	139.2	160.1	187.4	208.3	131.7	128.5
2015	167.0	174.5	177.0	164.4	149.4	181.5	168.7
2016	165.4	177.2	203.5	184.2	166.0	193.8	159.5
2017	-	-	-	-	-	-	-
Mean (2008-16)	177.1	166.9	171.3	190.3	196.9	153.2	142.2
Mean (2004-16)	179.4	167.7	-	202.7	-	159.4	149.3

(a) Only years with >75 per cent complete data shown

4.4.4 Exceedance of air quality criteria

There were exceedances of one-hour and rolling 4-hour criteria at many of the OEH sites, the statistics are provided in Table 4.18 and Table 4.19 respectively.

Table 4.18 *Exceedance of one-hour mean O_3 concentration at OEH background sites*

Year	Number of exceedances of one-hour mean O_3 concentration (µg/m^3)[(a)]						
	OEH Chullora	OEH Earlwood	OEH Lindfield	OEH Liverpool	OEH Prospect	OEH Randwick	OEH Rozelle
2004	**2**	0	**1**	**5**	-	**2**	0
2005	0	0	-	**3**	-	0	0
2006	**3**	**2**	-	**11**	-	0	0
2007	0	0	-	**3**	-	0	0
2008	0	0	0	0	**1**	0	0
2009	**3**	**3**	**1**	**3**	**4**	0	0
2010	0	0	0	0	**3**	0	0
2011	**1**	0	0	**1**	**5**	0	0
2012	0	0	0	0	0	0	0
2013	**1**	**1**	0	**5**	**2**	0	0
2014	0	0	0	**1**	**2**	0	0
2015	0	0	0	0	0	**1**	0
2016	0	0	**1**	0	**1**	0	0
2017	-	-	-	-	-	-	-
Total	10	6	3	32	18	3	0

(a) Only years with >75 per cent complete data shown

Table 4.19 *Exceedance of rolling 4-hour mean O_3 concentration at OEH background sites*

Year	Number of exceedances of rolling 4-hour mean O_3 concentration (µg/m^3)[(a)]						
	OEH Chullora	OEH Earlwood	OEH Lindfield	OEH Liverpool	OEH Prospect	OEH Randwick	OEH Rozelle
2004	**7**	**1**	**5**	**11**	-	**2**	**2**
2005	**1**	0	-	**6**	-	0	0
2006	**10**	**4**	-	**17**	-	0	**2**
2007	0	0	-	**7**	-	**2**	0
2008	0	0	0	**1**	**2**	0	0
2009	**6**	**7**	**3**	**10**	**18**	0	0
2010	0	0	0	**1**	**7**	0	0
2011	**4**	**3**	**1**	**5**	**13**	0	0
2012	0	0	0	0	0	0	0
2013	**3**	**3**	0	**6**	**6**	0	0
2014	0	0	0	**3**	**5**	0	0
2015	0	**1**	**1**	0	0	**2**	0
2016	0	**2**	**4**	**3**	0	**3**	0
2017	-	-	-	-	-	-	-
Total	31	21	14	70	51	9	4

(a) Only years with >75 per cent complete data shown

4.5 PM_{10}

4.5.1 Annual mean concentration

Long-term PM_{10} data have been collected from all OEH and the RMS M5 East sites. Figure 4.18 shows the annual mean PM_{10} trends at the OEH and the RMS M5 East background sites, and Table 4.20 lists the corresponding statistics. Data during exceptional events (e.g.

bushfire, dust storm, etc.) were removed to more clearly evaluate the long-term trends in PM_{10}. All values were below NSW air quality criterion of 25 µg/m^3.

At several OEH sites - Chullora, Earlwood, Liverpool, Randwick and Rozelle - the concentrations between 2004 and 2016 exhibited a general downward trend, while the values were stable at the Lindfield and Prospect sites between 2008 and 2016. The annual mean PM_{10} concentrations at the OEH sites were typically in the range of 17-23 µg/m^3, but the values at the Lindfield site were much lower, at around 15 µg/m^3. At the RMS M5 East sites, the concentrations were relatively stable between 2008 and 2016, at approximately 15 µg/m^3. In 2009, it was a warm and dry year, hence the concentrations were higher than that of the adjacent years.

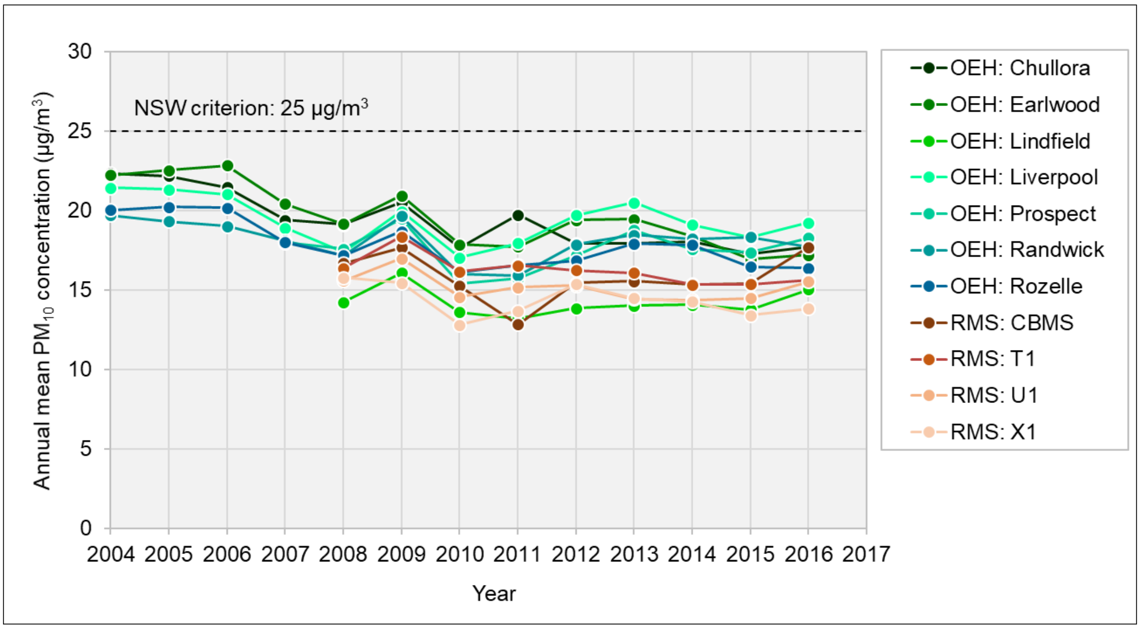


Figure 4.18 *Trend in annual mean PM_{10} concentration at OEH and RMS M5 East background sites*

Table 4.20 *Annual mean PM_{10} concentration at OEH and RMS M5 East background sites*

Year	Annual mean PM_{10} concentration (mg/m^3)[(a)]										
	OEH Chullora	OEH Earlwood	OEH Lindfield	OEH Liverpool	OEH Prospect	OEH Randwick	OEH Rozelle	RMS CBMS	RMS T1	RMS U1	RMS X1
2004	22.3	22.2	-	21.4	-	19.7	20.0	18.2	19.5	17.3	18.5
2005	22.2	22.5	-	21.3	-	19.3	20.2	17.9	18.3	16.7	17.6
2006	21.5	22.8	-	21.0	-	19.0	20.2	-	-	-	-
2007	19.4	20.4	-	18.9	18.0	18.1	18.0	-	-	-	-
2008	19.1	19.1	14.2	17.4	17.6	17.2	17.2	16.7	16.4	15.6	15.8
2009	20.5	20.9	16.1	20.0	19.5	19.6	18.7	17.7	18.3	17.0	15.5
2010	17.7	17.9	13.6	17.0	15.4	16.0	16.1	15.2	16.2	14.6	12.8
2011	19.7	17.7	13.2	18.0	15.7	15.9	16.6	12.8	16.6	15.2	13.7
2012	17.9	19.4	13.8	19.7	17.2	17.9	16.9	15.5	16.2	15.3	15.4
2013	17.9	19.4	14.0	20.5	18.8	18.5	17.9	15.6	16.1	14.4	14.5
2014	18.1	18.3	14.1	19.1	17.6	18.2	17.8	15.4	15.3	14.4	14.3
2015	17.3	16.9	13.8	18.3	17.4	18.3	16.5	15.4	15.4	14.5	13.4
2016	17.7	17.2	15.0	19.2	18.3	17.7	16.4	17.7	15.6	15.5	13.8
2017	-	-	-	-	-	-	-	-	-	-	-
Mean (2008-16)	18.4	18.6	14.2	18.8	17.5	17.7	17.1	15.8	16.2	15.2	14.3
Mean (2004-16)	19.3	19.6	-	19.4	-	18.1	17.1	16.2	16.7	15.5	15.0
Significance[(b)]	▼	▼	◀▶	▼	◀▶	▼	▼	◀▶	▼	▼	▼

(a) Only years with >75 per cent complete data shown, data during events were removed

(b) ▼ = significantly decreasing, ▲ = significantly increasing, ◀▶ = stable/no trend

The trends at the RMS roadside sites are shown in Figure 4.19, and the corresponding statistics are provided in Table 4.21. No exceedances of the criterion were recorded at either site. The concentrations showed gentle downward trends, and the values ranged from approximately 16 to 20 $\mu g/m^3$. The concentrations were slightly higher than those at the background sites. This indicates that vehicle emissions have a limited impact on PM_{10} concentrations.

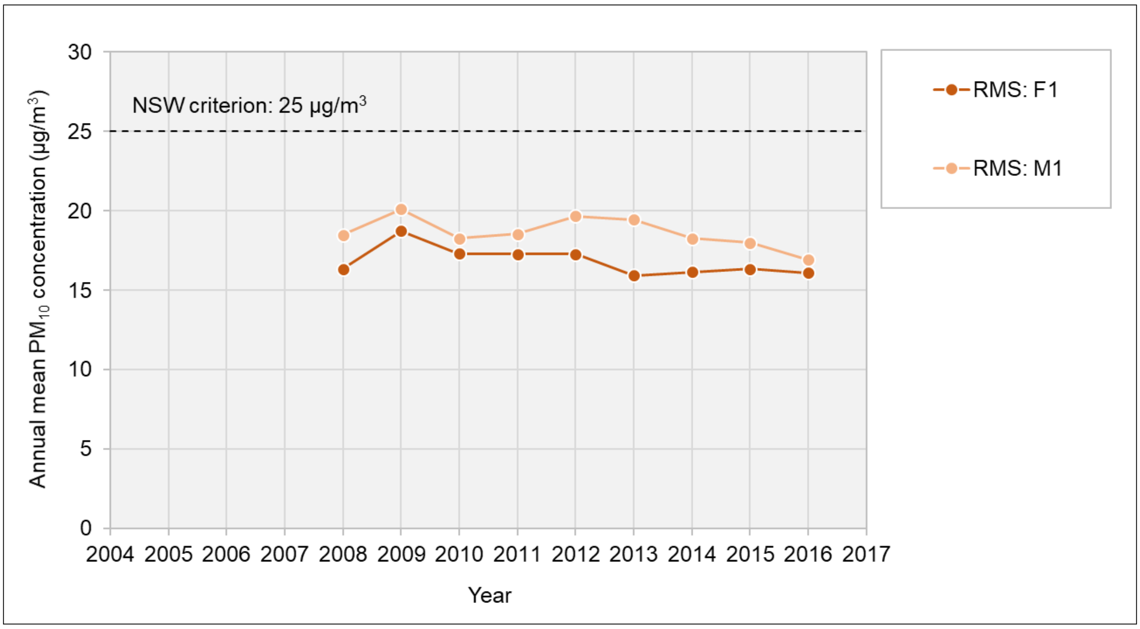


Figure 4.19 *Trend in annual mean PM_{10} concentration at RMS roadside sites*

Table 4.21 *Annual mean PM_{10} concentration at RMS roadside sites*

Year	Annul mean PM_{10} concentration ($\mu g/m^3$)[(a)] RMS F1	RMS M1
2004	-	-
2005	-	-
2006	-	-
2007	-	-
2008	16.3	18.5
2009	18.7	20.1
2010	17.3	18.3
2011	17.3	18.5
2012	17.3	19.7
2013	15.9	19.4
2014	16.2	18.3
2015	16.3	18.0
2016	16.1	16.9
2017	-	-
Mean (2008-16)	16.8	18.6

(a) Only years with >75 per cent complete data shown, data during events were removed

4.5.2 Maximum 24-hour mean concentration

The maximum 24-hour mean PM_{10} concentrations at the OEH and the RMS background sites are shown in Figure 4.20, and the corresponding statistics are in Table 4.22. Extremely high concentrations were observed at all site in 2009 as it was a warm and dry year. The concentrations exhibited an overall downward trend at the OEH sites, with a large variation from year to year. On the other hand, the concentrations at the RMS M5 East sites were relatively stable, and below the NSW air quality criterion of 50 $\mu g/m^3$ with an exception only in 2009.

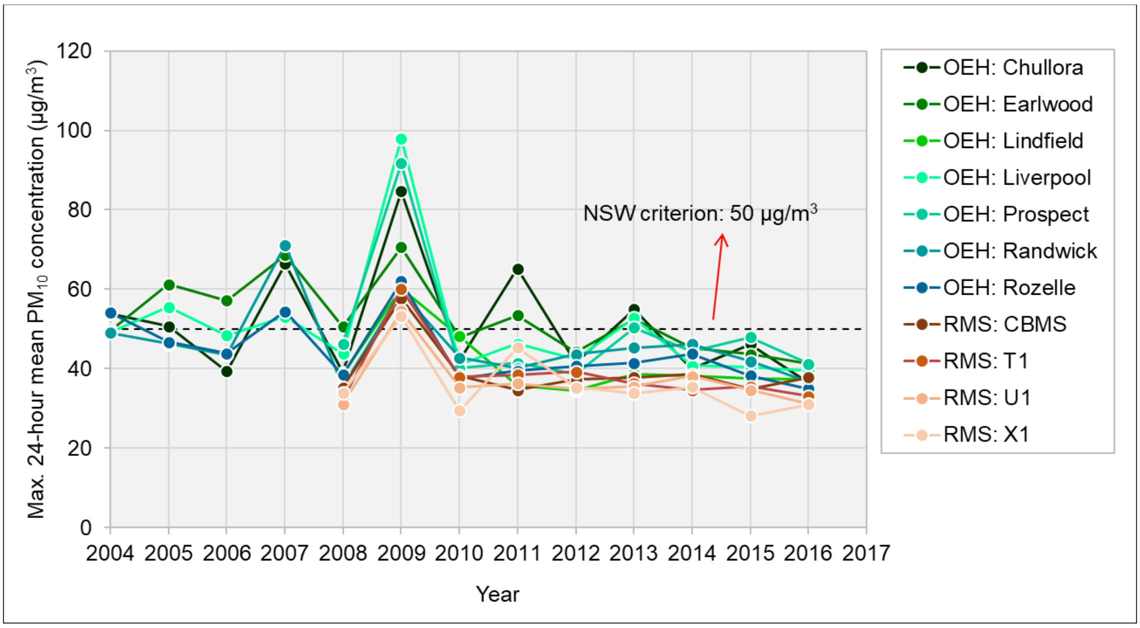


Figure 4.20 *Trend in maximum 24-hour mean PM_{10} concentration at OEH and RMS background sites*

Table 4.22 *Maximum 24-hour mean PM_{10} concentration at OEH and RMS background sites*

Year	Maximum 24-hour mean PM_{10} concentration (mg/m^3)[(a)]										
	OEH Chullora	OEH Earlwood	OEH Lindfield	OEH Liverpool	OEH Prospect	OEH Randwick	OEH Rozelle	RMS CBMS	RMS T1	RMS U1	RMS X1
2004	53.9	49.8	-	49.2	-	49.0	54.1	45.7	50.0	40.9	50.8
2005	50.7	61.2	-	55.5	-	46.3	46.8	42.0	42.0	39.2	41.6
2006	39.4	57.2	-	48.4	-	43.5	43.9	-	-	-	-
2007	66.5	68.6	-	53.1	-	71.2	54.4	-	-	-	-
2008	39.1	50.6	38.7	43.7	46.3	35.6	38.5	35.4	32.3	31.1	34.0
2009	84.7	70.6	60.3	98.0	91.7	59.3	62.1	57.8	60.2	54.5	53.2
2010	42.1	47.8	48.2	41.1	40.1	42.7	37.6	38.2	37.9	35.3	29.5
2011	65.2	53.4	35.7	46.3	41.5	40.1	39.4	34.7	38.5	36.3	45.3
2012	41.6	44.2	34.5	42.5	38.7	43.7	40.7	37.3	39.3	34.9	35.3
2013	55.0	52.6	38.8	52.8	50.4	45.3	41.4	37.8	36.3	35.6	33.9
2014	40.0	45.2	38.3	40.8	44.3	46.1	43.8	38.7	34.7	38.2	35.4
2015	46.2	43.7	37.5	40.5	48.0	41.9	38.3	34.9	35.5	34.7	28.2
2016	36.5	41.2	37.4	39.5	41.2	36.8	35.0	37.8	33.1	31.1	31.1
2017	-	-	-	-	-	-	-	-	-	-	-
Mean (2008-16)	50.0	49.9	41.0	49.5	49.1	43.5	41.9	39.2	38.6	36.8	36.2
Mean (2004-16)	50.8	52.8		50.1		46.3	44.3	40.0	40.0	37.4	38.0

(a) Only years with >75 per cent complete data shown, data during events were removed

Maximum 24-hour mean PM_{10} concentrations at the RMS roadside sites are shown in Figure 4.21, and the corresponding statistics are provided in Table 4.23. Similar to the background sites, peak concentrations in 2009 were also recorded at the roadside sites.There was a general downward trend at the F1 site, and the concentrations were relatively stable but with variations at the M1 site. Additionally, the concentrations were close that of the background sites suggesting, again, that vehicle emissions do not significnatly impact ambient PM_{10} concentrations.

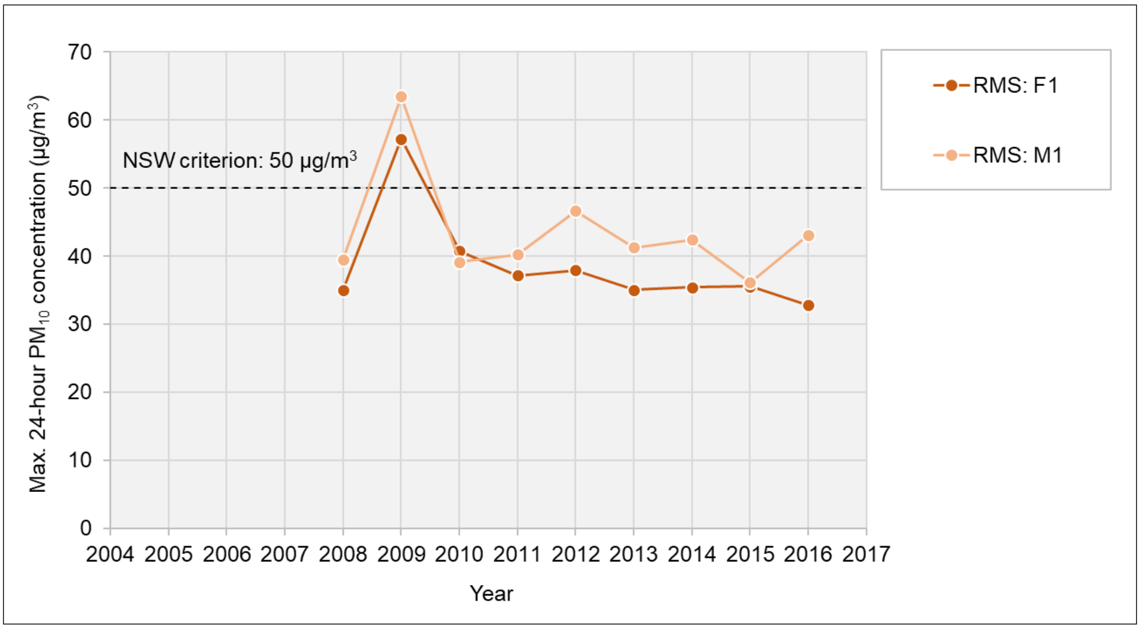


Figure 4.21 *Trend in maximum 24-hour mean PM_{10} concentration at RMS roadside sites*

Table 4.23 *Maximum 24-hour mean PM_{10} concentration at RMS roadside sites*

Year	Maximum 24-hour mean PM_{10} concentration (μg/m^3)[(a)]	
	RMS F1	RMS M1
2004	-	-
2005	-	-
2006	-	-
2007	-	-
2008	35.0	39.5
2009	57.3	63.5
2010	40.8	39.2
2011	37.2	40.3
2012	37.9	46.6
2013	35.1	41.3
2014	35.5	42.4
2015	35.5	36.1
2016	32.8	43.1
2017	-	-
Mean (2008-16)	38.6	43.6

(a) Only years with >75 per cent complete data shown, data during events were removed

4.5.3 Exceedances of air quality criteria

There has been no exceedance of annual mean PM_{10} concentration (NSW air quality criterion: 25 μg/m^3) at all the OEH and the RMS M5 East sites. However, the 24-hour average NSW criterion of 50 μg/m^3 was exceeded at various sites, as shown in Table 4.24. These exceedances occur even though days with bush fire, dust storm and planned fires were removed from analysis. The year 2009 was especially in the warm and dry, which resulted in elevated particulate matter concentrations.

Table 4.24 *Exceedance of 24-hour mean PM_{10} concentration at OEH background sites*

Year	Number of exceedance of 24-hour mean PM_{10} concentration (mg/m^3)[(a)]												
	OEH Chullo	OEH Earlwo	OEH Lindfie	OEH Liverp	OEH Prosp	OEH Rand	OEH Rozell	RMS CBMS	RMS T1	RMS U1	RMS X1	RMS F1	RMS M1
2004	**2**	0	-	0	-	0	**1**	0	**1**	0	**1**	-	-
2005	**1**	**2**	-	**1**	-	0	0	0	0	0	0	0	0
2006	0	**4**	-	0	-	0	0	-	-	-	-	-	-
2007	**2**	**2**	-	**1**	-	**1**	**1**	-	-	-	-	-	-
2008	0	**2**	0	0	0	0	0	0	0	0	0	0	0
2009	**3**	**4**	**1**	**3**	**4**	**2**	**2**	**2**	**2**	**1**	**1**	**3**	**3**
2010	0	0	0	0	0	0	0	0	0	0	0	0	0
2011	**6**	**1**	0	0	0	0	0	0	0	0	0	0	0
2012	0	0	0	0	0	0	0	0	0	0	0	0	0
2013	**1**	**2**	0	**1**	**1**	0	0	0	0	0	0	0	0
2014	0	0	0	0	0	0	0	0	0	0	0	0	0
2015	0	0	0	0	0	0	0	0	0	0	0	0	0
2016	0	0	0	0	0	0	0	0	0	0	0	0	0
2017	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	15	17	1	6	5	3	4	2	2	1	1	3	3

(a) Only years with >75 per cent complete data shown, data during events were removed

4.6 $PM_{2.5}$

4.6.1 Annual mean concentration

Multi-year data were only available at three of the OEH sites: Chullora, Earlwood and Liverpool. The annual mean $PM_{2.5}$ concentrations ware shown in Figure 4.22, and the corresponding statistics are presented in Table 4.25. The values first decreased between 2004 and 2008, followed by a fluctuated period between 2008 and 2011, then experienced an upward trend in recent years. The values in 2009 were relatively higher than that of the adjacent year, which was most likely due to the warm and dry weather.

It is important to note that during 2012 OEH replaced its continuous TEOM $PM_{2.5}$ monitors with US EPA-equivalent BAMs, which could be a reason for the increase in the measured concentrations in recent years. It is well documented that there are considerable uncertainties in the measurement of $PM_{2.5}$ (e.g. AQEG, 2012).

The increasing of $PM_{2.5}$ concentrations in recent year has led to the exceedance of NEPM standard of 8 µg/m^3 as well as NEPM long term goal of 7 µg/m^3.

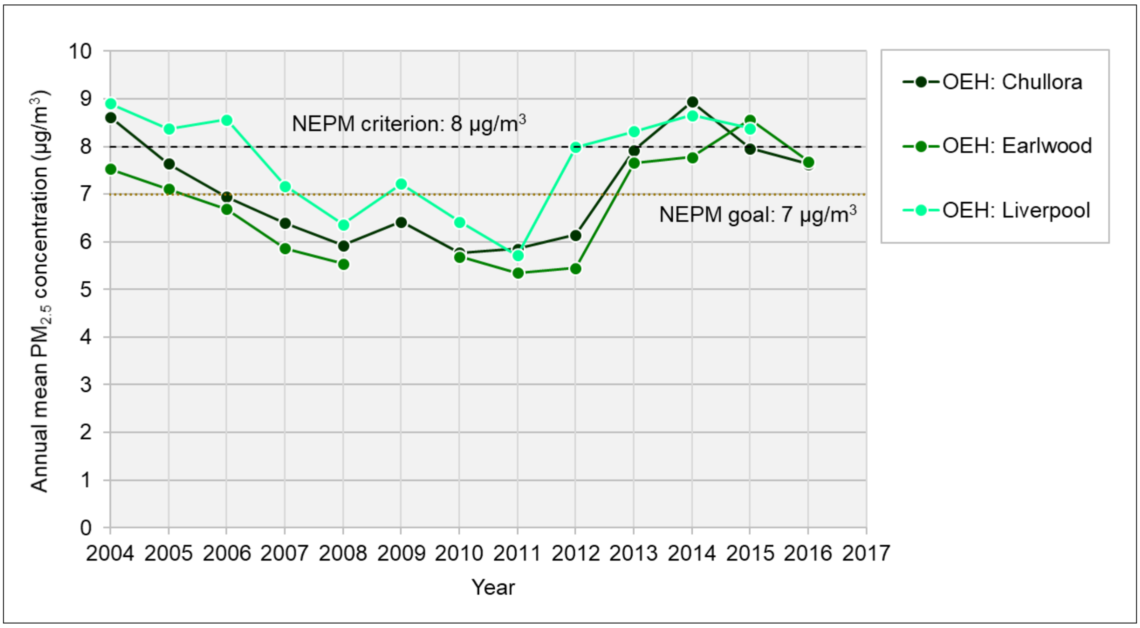


Figure 4.22 *Trend in annual mean $PM_{2.5}$ concentration at OEH background sites*

Table 4.25: *Annual mean $PM_{2.5}$ concentration at OEH background stations*

Year	Annual mean concentration (µg/m³) (a)						
	Chullora	Earlwood	Lindfield	Liverpool	Prospect	Randwick	Rozelle
2004	8.6	7.5	-	8.9	-	-	-
2005	7.6	7.1	-	8.4	-	-	-
2006	6.9	6.7	-	8.6	-	-	-
2007	6.4	5.9	-	7.2	-	-	-
2008	5.9	5.5	-	6.4	-	-	-
2009	6.4	-	-	7.2	-	-	-
2010	5.8	5.7	-	6.4	-	-	-
2011	5.9	5.3	-	5.7	-	-	-
2012	6.1	5.5	-	8.0	-	-	-
2013	7.9	7.7	-	8.3	-	-	-
2014	8.9	7.8	-	8.7	-	-	-
2015	8.0	8.6	-	8.4	8.1	-	7.1
2016	7.6	7.7	-	-	8.0	-	6.9
Mean (2004-16)	**7.1**	**6.7**	**-**	**7.7**	**-**	**-**	**-**
Significance(b)	◀▶	◀▶	-	◀▶	-	-	-

(a) Only years with >75 per cent complete data shown

(b) ▼ = significantly decreasing, ▲ = significantly increasing, ◀▶ = stable/no trend

4.6.2 Maximum 24-hour mean concentration

Long-term trends in maximum 24-hour mean $PM_{2.5}$ concentration are shown in Figure 4.23. The concentrations varied from year to year between 2004 and 2016, and no trend could be detremined. Exceedances of NSW/NEPM stabdard of 25 µg/m³ were found at all three sites in multiple years, and in most cases the maximum concentrations were above the NEPM goal of 20 µg/m³.

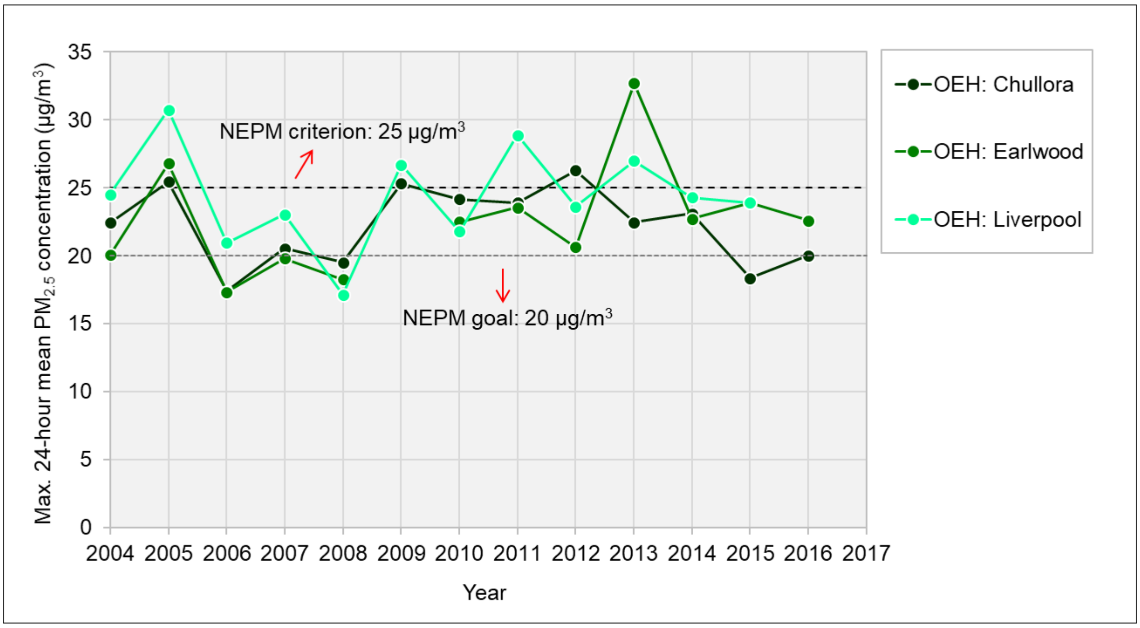


Figure 4.23 *Trend in maximum 24-hour mean $PM_{2.5}$ concentration at OEH background sites*

4.6.3 Exceedance of air quality criteria

As discussed earlier, there have been some exceedances of the NEPM standard (8 µg/m³) for the annual mean $PM_{2.5}$ concentration, which is further summarised in Table 4.26. According to the trends shown in Figure 4.22, such exceedances are likely to continue in the future.

Table 4.26 *Exceedance of annual mean $PM_{2.5}$ concentration at OEH background sites*

Year	Exceedance of annual mean $PM_{2.5}$ concentration (µg/m³)[(a)]		
	OEH Chullora	OEH Earlwood	OEH Liverpool
2004	Exceed	No	Exceed
2005	No	No	Exceed
2006	No	No	Exceed
2007	No	No	No
2008	No	No	No
2009	No	-	No
2010	No	No	No
2011	No	No	No
2012	No	No	No
2013	No	No	Exceed
2014	Exceed	No	Exceed
2015	No	Exceed	Exceed
2016	No	No	-
2017	-	-	-

(a) Only years with >75 per cent complete data shown, data during events were removed

As shown in Table 4.27, there were also exceedances of the 24-hour mean $PM_{2.5}$ concentration compared with the NEPM standard of 25 µg/m³, but the numbers of exceedance for all three sites are no more than five.

Table 4.27 *Exceedance of 24-hour mean $PM_{2.5}$ concentration at OEH background sites*

Year	Exceedance of 24-hour mean $PM_{2.5}$ concentration (µg/m³)[(a)]		
	OEH Chullora	OEH Earlwood	OEH Liverpool
2004	0	0	0
2005	2	2	2
2006	0	0	0
2007	0	0	0
2008	0	0	0
2009	1	-	1
2010	0	0	0
2011	0	0	1
2012	1	0	0
2013	0	1	1
2014	0	0	0
2015	0	0	0
2016	0	0	-
2017	-	-	-
Total	4	3	5

(a) Only years with >75 per cent complete data shown, data during events were removed

4.7 Sulfur dioxide

4.7.1 Annual mean concentration

Long-term measurements of SO_2 were only available for four of the OEH sites: Chullora, Lindfield, Prospect and Randwick. The results are presented in Figure 4.24. All the values were stable and lower than 5 µg/m^3 (far below the NSW criterion of 60 µg/m^3).

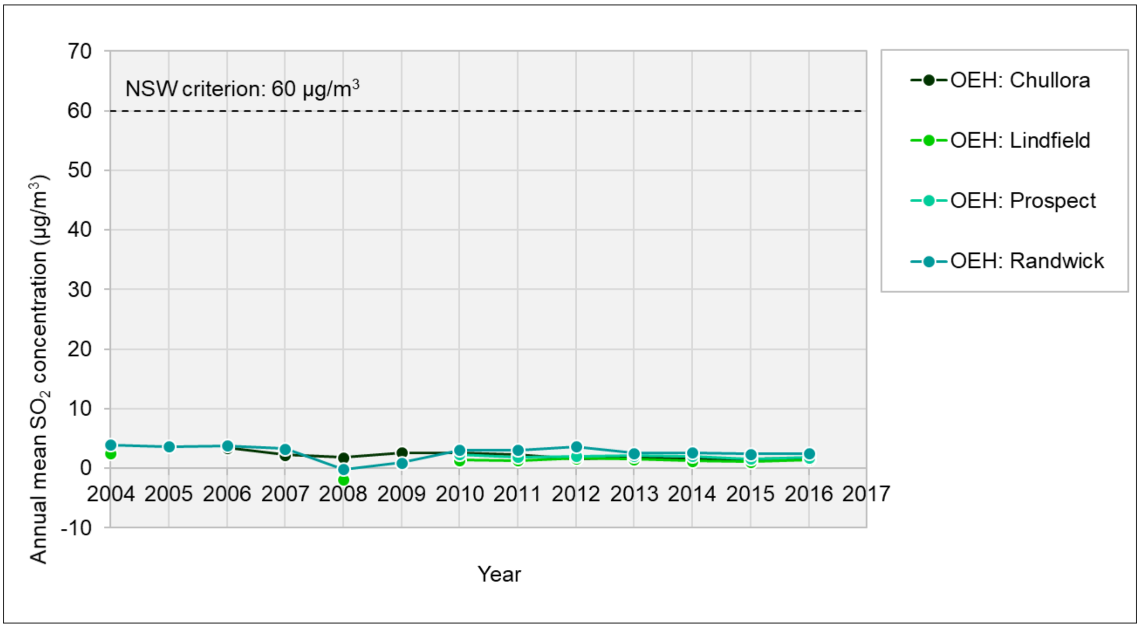


Figure 4.24 *Trend in annual mean SO_2 concentration at OEH background sites*

4.7.2 Maximum 24-hour mean concentration

The trends in maximum 24-hour mean SO_2 concentration at the OEH sites are shown in Figure 4.25. Overall downward trends were found at the Chullora and Randwick sites, while the values at Lindfield and Prospect were relatively stable, except that the concentration at Prospect in 2014 reached a much higher peak concentrations. Most importantly, all the concentrations were well below the NSW criterion of 228 µg/m^3 between 2004 and 2016.

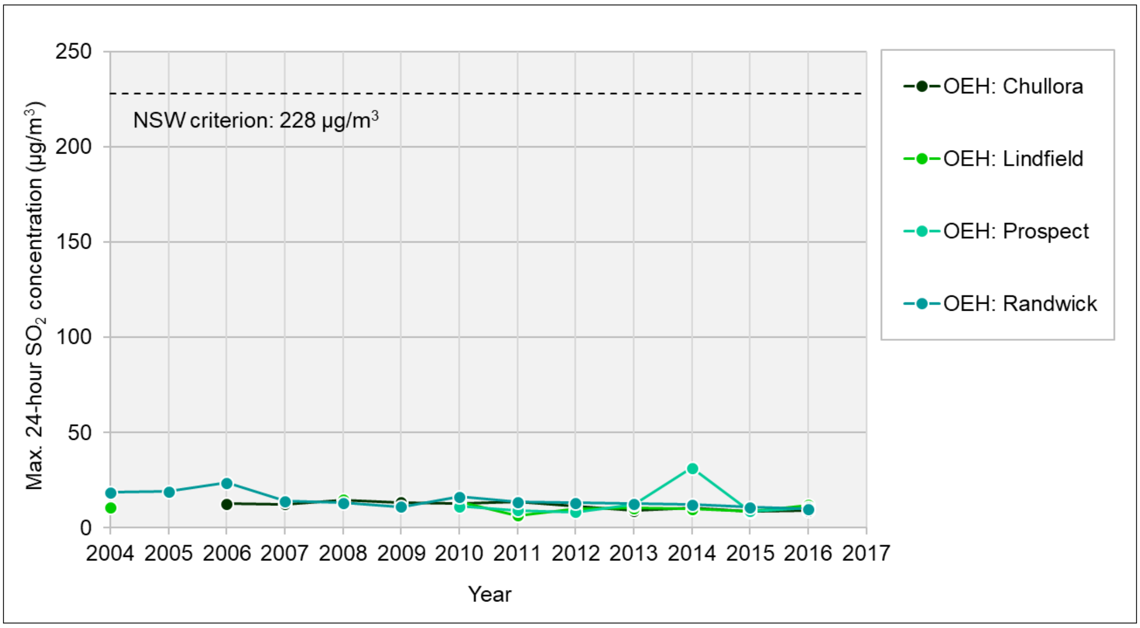


Figure 4.25 *Trend in maximum 24-hour mean SO_2 concentration at OEH background sites*

4.7.3 Maximum one-hour mean concentration

Trends in the maximum one-hour mean SO_2 concentration are presented in Figure 4.26. There were overall stable trends at all sites between 2004 and 2016, and all the concentrations were well below NSW criterion of 570 µg/m^3. There was one extreme case, that the maximum one-hour mean SO_2 concentration tripled at Prospect station in 2014 compared with other years.

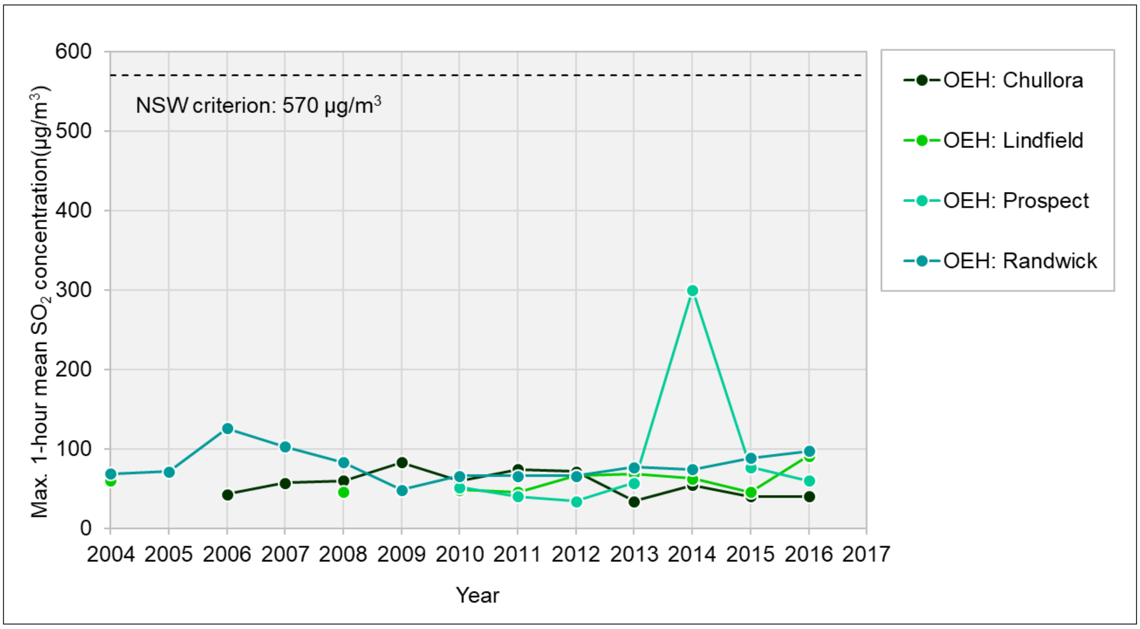


Figure 4.26 *Trend in maximum one-hour mean SO_2 concentration at OEH background sites*

4.7.4 Exceedance of air quality criteria

At all four OEH sites, there was no exceedance of annul mean, 24-hour mean or one-hour mean SO_2 concentrations, and all the values were well below the NSW air quality criteria.

4.8 VOCs

Concentrations of CH_4, NMHC and THC were continuously monitored at the WestConnex M4 East, New M5 and M4-M5 Link stations between 2014 and 2017. However, the valid measurements in some cases were less than 75 percent and therefore excluded from analysis. The annual mean and maximum one-hour mean VOCs concentrations are summarised in Table 4.28 and Table 4.29 respectively. The concentrations for each type of compound remained stable at all the sites in the past three years. There are no air quality criterion for CH_4, NMHC and THC.

Table 4.28 *Annual mean VOCs concentrations*

Compound	Year	Annual mean VOCs concentration (ppm)[(a)]							
		SMC M4E_01	SMC M4E_02	SMC M4E_03	SMC M4E_04	SMC M4E_05	SMC NewM5_0	SMC M4M5_01	SMC M4M5_02
CH4	2015	2.1	2.5	2.0	1.9	2.1	-	-	-
	2016	-	-	-	1.9	2.4	2.0	-	-
	2017	-	-	-	-	-	2.0	2.3	1.6
NMHC	2015	0.7	1.1	0.8	0.7	0.8	-	-	-
	2016	-	-	-	0.8	1.3	0.3	-	-
	2017	-	-	-	-	-	0.5	0.8	0.4
THC	2015	2.8	3.6	2.9	2.6	2.9	-	-	-
	2016	-	-	-	2.7	3.7	2.3	-	-
	2017	-	-	-	-	-	2.4	3.1	2.0

(a) Only years with >75 per cent complete data shown

Table 4.29 *Maximum one-hour mean VOCs concentrations*

Compound	Year	Maximum one-hour mean VOCs concentration (ppm)[(a)]							
		SMC M4E_01	SMC M4E_02	SMC M4E_03	SMC M4E_04	SMC M4E_05	SMC NewM5_0	SMC M4M5_01	SMC M4M5_02
CH4	2015	6.9	6.8	4.4	5.9	5.3	-	-	-
	2016	-	-	-	3.9	6.2	4.7	-	-
	2017	-	-	-	-	-	4.1	4.2	3.1
NMHC	2015	4.2	5.1	5.1	3.4	2.5	-	-	-
	2016	-	-	-	3.3	5.9	2.1	-	-
	2017	-	-	-	-	-	2.0	2.0	4.8
THC	2015	2.8	3.6	2.9	2.6	2.9	-	-	-
	2016	-	-	-	2.7	3.7	2.3	-	-
	2017	-	-	-	-	-	2.4	3.1	2.0

(b) Only years with >75 per cent complete data shown

4.9 BTEX

BTEX concentrations were measured in 2017 at three monitoring stations - NewM5_01, M4M5_01 and M4M5_02. These locations are shown in Figure 2.1 and include both background and roadside locations.

Samples of air were collected and analysed for BTEX compounds on a weekly basis for a period of four weeks between 11 January and 1 February of 2017. Table 4.30 summaries the BTEX data. As limited data were available, long-term statistics were not determined.

Table 4.30 *Results of BTEX sampling*

Site	Monitoring event	24-hour average concentration ($\mu g/m^3$) [(a)]			
		Benzene	Toluene	Ethylbenzene	Xylenes
NewM5_01	Round 1	< 1.6	< 1.9	< 2.2	< 6.6
	Round 2	< 1.6	**5.3**	< 2.2	< 6.6
	Round 3	< 1.6	< 1.9	< 2.2	< 6.6
	Round 4	< 1.6	< 1.9	< 2.2	< 6.6
M4M5_01	Round 1	< 1.6	**3.4**	< 2.2	< 6.6
	Round 2	< 1.6	**4.9**	< 2.2	< 6.6
	Round 3	< 1.6	**2.6**	< 2.2	< 6.6
	Round 4	< 1.6	**3.0**	< 2.2	< 6.6
M4M5_02	Round 1	< 1.6	< 1.9	< 2.2	< 6.6
	Round 2	< 1.6	**4.5**	< 2.2	< 6.6
	Round 3	< 1.6	**2.2**	< 2.2	< 6.6
	Round 4	< 1.6	< 1.9	< 2.2	< 6.6

(a) "<" less than Limit of Reporting (LOR), detections highlighted in bold

In many cases, the concentration for a given compound was lower than the corresponding Limit of Reporting (LOR), only several concentrations exceeded the LOR were recorded for Toluene. Meanwhile, all the values were well below the NEPM air toxic monitoring investigation levels (24-hour average of 3,770 $\mu g/m^3$ for Toluene and 1,085 $\mu g/m^3$ for Xylene). The results therefore confirm that the concentrations of BTEX in Sydney are very low.

5 Openair analysis

Air quality data and meteorology data were systematically analysed using the Openair software (Version 3.4.3). The evaluation focused mainly on time variation (variation by time of day, day of week and month of year), bivariate polar plots (concentration by wind direction and wind speed), polar annulus plots (concentration by wind direction and time), and wind roses. The substances analysed were selected to include CO, NO_2, O_3 and PM_{10} as these substances are most likely influenced by motor vehicle emissions. Additionally, only data collected from the OEH sites were analysed due to long-term data availability. The detailed results are discussed below. Each plot was created based on all the data available between 2004 and 2017.

5.1 Bivariate polar plots

Polar plots for the OEH monitoring sites were created using the Openair software. These plots assist in the understanding of differences between air quality concentrations at the different sites.

Some examples of polar plots are shown in Figure 5.1. These indicate how concentrations vary by wind speed and wind direction, with statistical smoothing techniques giving a continuous surface. The monitoring station is located at the centre of each plot. The axes show the directions from which the wind is coming, and the distance from the origin indicates the wind speed; the further from the centre that concentrations appear, the higher the wind speeds when they were measured. Calm conditions appear close to the centre. The examples are for $PM_{2.5}$ at the Chullora site in 2015. The Figure shows that in 2015 the highest $PM_{2.5}$ concentrations were associated with light-moderate winds (2-5 metres per second) from the north-west and during the summer months.

The polar plot is a useful diagnostic tool for understanding potential sources of air pollutants at a given site. For many situations an increasing wind speed generally results in lower concentrations due to increased dilution through advection and increased turbulence. Ground-level, non-buoyant sources - such as road traffic – therefore tend to have highest concentrations under low wind speed conditions, but various processes can lead to other concentration-wind speed dependencies. For example, buoyant plumes from tall outlets can be brought down to ground level, resulting in high concentrations under high wind speed conditions. Wind-blown dust (*e.g.* from exposed areas of soil) also increases with increasing wind speed, and particle suspension can be important close to coastal areas where higher wind speeds generate more sea spray (Carslaw, 2015).

Some typical features of polar plots include the following:

- A maximum concentration, or a ‘smeared’ peak, at low wind speed, which is indicative of a local, ground-level source such as road traffic. As the wind speed increases concentrations due to a road source will tend to decrease due to the increased dilution of the plume.
- Highly resolved features at high wind speeds, but possibly low concentrations, which indicate more distant sources.

- Relationships between pollutants which provide information on the emission characteristics of different sources. For example, a site with high ‘smeared’ NO_X concentrations at low wind speeds, is likely to be a nearby road.

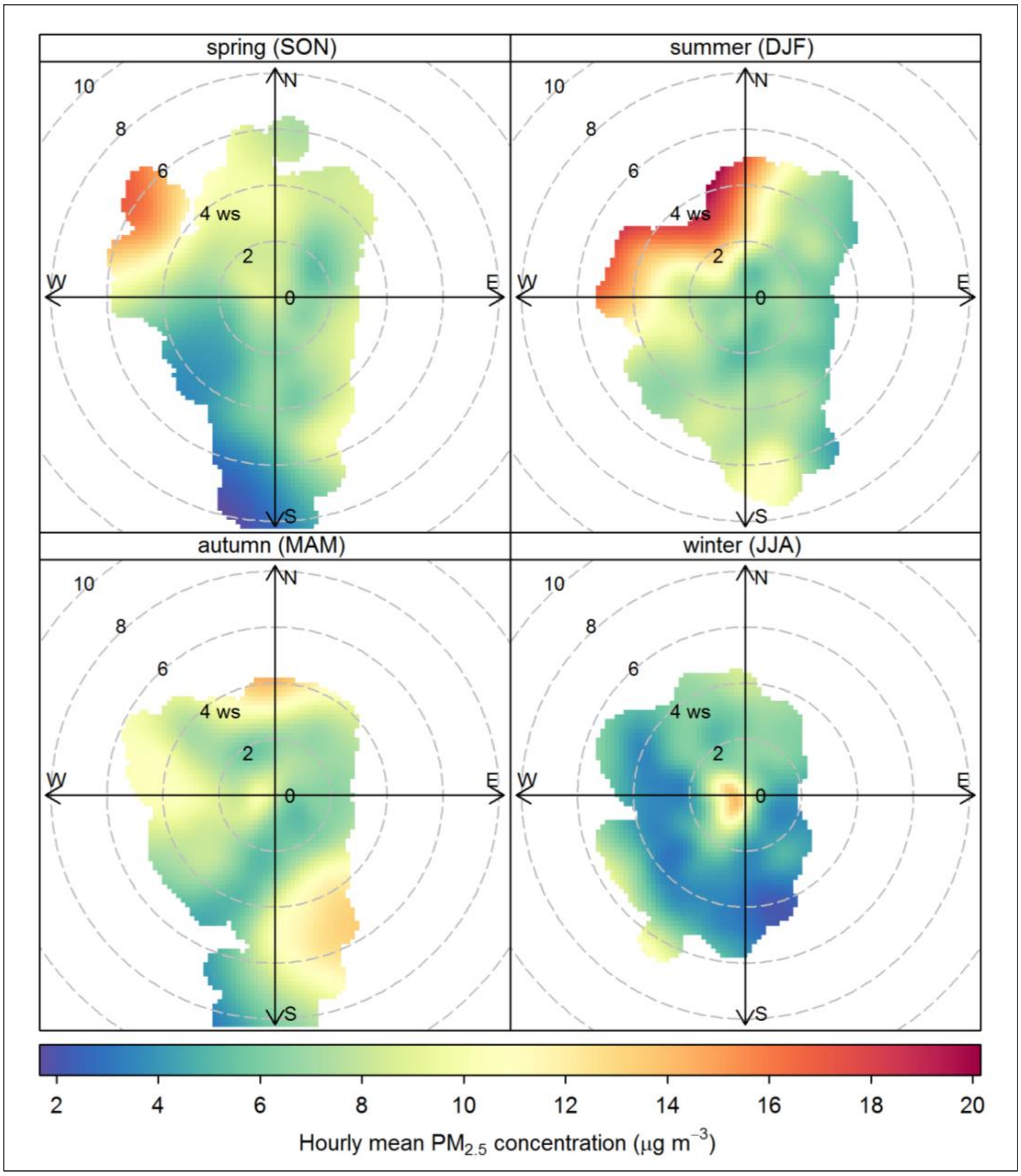


Figure 5.1 *Polar plots of $PM_{2.5}$ concentration by season at Chullora in 2015*

5.2 Wind roses

Wind speed and wind direction data have been continuously monitored at the OEH monitoring stations for multiple years. Wind roses for each site are provided in Figure 5.2, which were created based on all the available data between 2004 and 2017. Take the pattern of Earlwood site as an example, the prevailing wind direction was northwest and west, which is likely to result in low CO and NO_2/NO_x pollution as the major traffic is to the east of the Earlwood monitoring station.

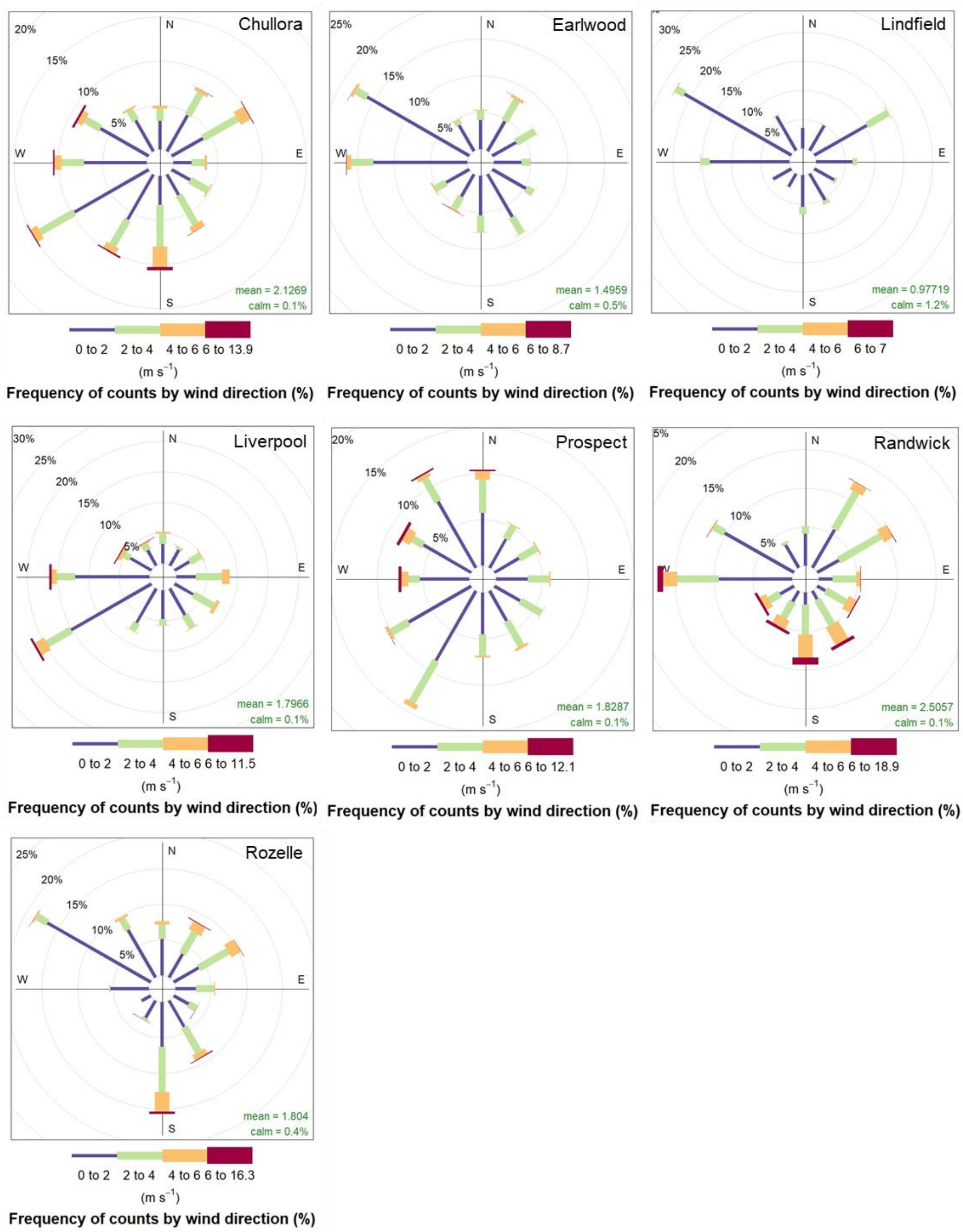


Figure 5.2 *Wind roses of OEH monitoring sites*

5.3 Carbon monoxide

Long-term CO data were only available at the OEH Chullora, Liverpool, Prospect and Rozelle monitoring stations, hence Openair analyses were only conducted for the data collected at these four sites.

5.3.1 Time variation plots

The time variation patterns at four OEH sites were found to be similar. The results for Chullora site are provided in Figure 5.3 as an example, and the other profiles are provided in Appendix A. The patterns indicate how CO concentration changed by time of day, day of week and month of year.

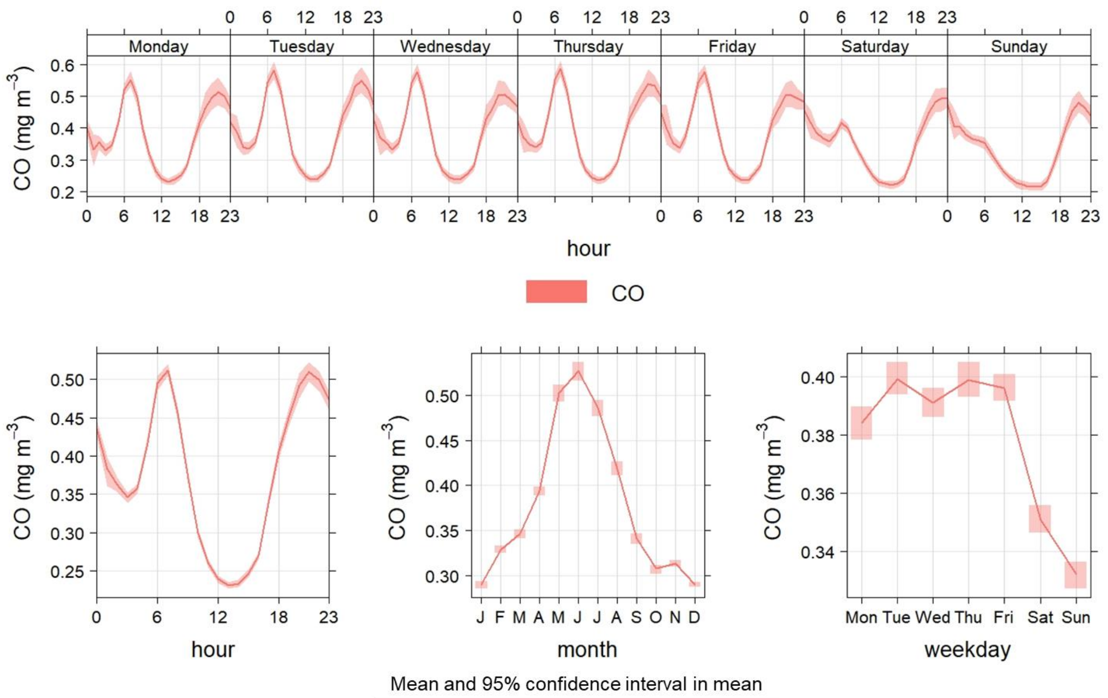


Figure 5.3 *Time variation plots of CO concentration at Chullora site*

In a typical workday, it clearly showed two peaks in terms of CO concentration, one in the morning at around hour 7, the other at around hour 21. The CO concentrations during morning peak were general higher than that of the evening peak. The lowest CO concentration was usually during the middle of the day. The peak CO concentration (approximately 0.57 mg/m^3) could be over twice higher than that of the lowest (approximately 0.25 mg/m^3). On the other hand, the time of day patterns were quite different during the weekend. There was no clear morning peak, only a small secondary peak could be seen on Saturday at around 6 am. The highest CO concentration (about 0.5 mg/m^3) appeared during the evening at around hour 21, and the lowest CO concentration (about 0.22 mg/m^3) was still observed during noon.

Such patterns are in relation to the time variation of various parameters, including road traffic, solar radiation, boundary layer height, dispersion condition and so on. Between 6 am to 9 am people intensively travel to work at workdays, which leads to a dramatic increasing in vehicles use, hence a significant increasing of exhaust gas emission. In the morning hours, solar radiation is usually low, the consumption of CO through photochemical reaction is less than the CO generated from exhaust gas emission. Meanwhile, the boundary layer height is at its lowest, and wind speed at horizontal level is low. Such meteorology condition is not in favour of CO dispersion. As a result, CO accumulates rapidly in ambient, leading to a peak concentration. After the morning hours, the number of road traffic decreases, solar radiation increases leading to an increase of CO consumption through photochemical reaction. Also, boundary layer height raises and atmospheric convection improves. Therefore, the CO concentration starts to drop, and reaches the lowest point at noon. Near evening, road traffic increases again as people leave from work, and the meteorology conditions start to turn against CO dispersion. Hence, CO concentration increases rapidly after around hour 16 and reaches a secondary peak at around hour 21. During the weekends, people travel is not as consistent as during the workday, leading to leading less obvious trends.

When it comes to day of week, the average CO concentrations during workdays were about 14% higher than that of weekends. The CO concentration on Monday was slightly lower than that of the other workdays.

The time variation plots also revealed a strong seasonal influence of CO concentration, with the value being the highest in winter and lowest in summer. The peak CO concentration was found in June, which was about 0.53 mg/m^3, while the lowest concentration (approximately 0.28 mg/m^3) is during December and January, which is about half of that in June. This correlates to the cooperative effects of human activities and meteorology conditions. In winter, people's demand in using heating system increases. At the same time, the solar radiation is the lowest, which markedly reduces the consumption of CO by photochemical reaction. Additionally, the weather is usually more stable and the boundary layer is generally lower in winter, which causing difficulty for CO dispersion. As a result, CO accumulates in ambient easily, leading to a peak CO concentrations during June.

5.3.2 Bivariate polar plots

Bivariate polar plot reveals the trend of concentration in relation with wind direction and wind speed. The result of Chullora site is shown in Figure 5.4 as an example. The axes show the directions from which the wind is coming, and the distance from the origin indicates the wind speed; the further from the centre that concentrations appear, the higher the wind speeds when they were measured. Calm conditions appear close to the centre.

The figure indicates that the CO concentration was typically much higher (between 0.5 and 0.7 mg/m^3) during calm weather (wind speed < 1 m/s). During high-speed winds (> 6 m/s) from east and southeast, the CO concentration reached the highest (>0.6 mg/m^3). Additionally, northern and southern winds generally bring higher CO concentrations (between 0.3 and 0.5 mg/m^3), while the CO concentrations were typically very low (< 0.2 mg/m^3) during westerly wind.

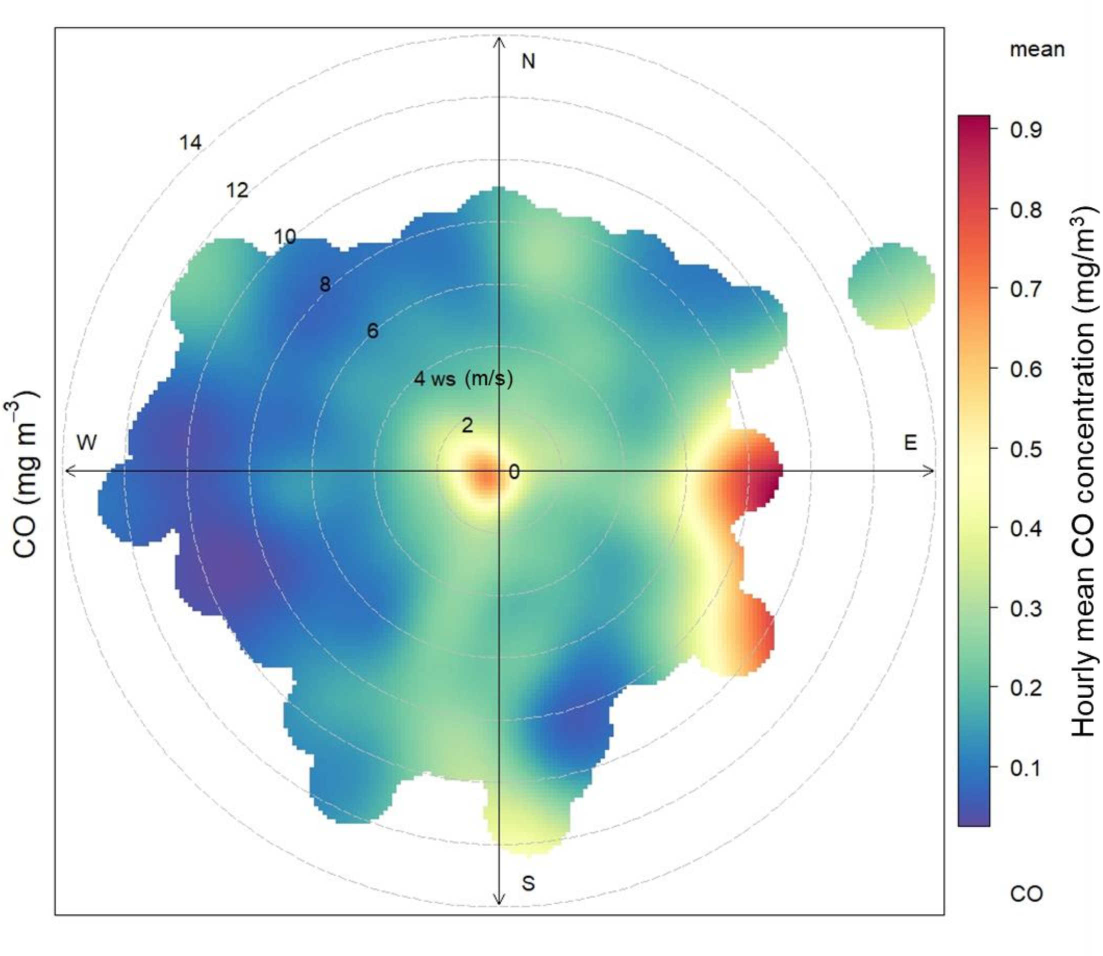


Figure 5.4 *Bivariate polar plots of CO concentration at Chullora site*

CO concentration is usually higher near roads due to traffic exhaust emission. As a result, when Chullora site is downwind of the closest roadways there is an increase of CO concentrations. For roads at a greater distance, CO concentrations only increase when there are strong winds. The west side of Chullora station is mainly residential area with limited CO sources, which means there is minimal CO coming from the west.

5.3.3 Polar annulus plots

Polar annulus plots were created to determine the relationships between concentration, wind direction and time of day. The patterns were generally similar for four OEH sites - the plot of Chullora is presented in Figure 5.5 as an example. The CO concentrations are typically higher at early morning and late evening, which is consistent with the time variation plots.

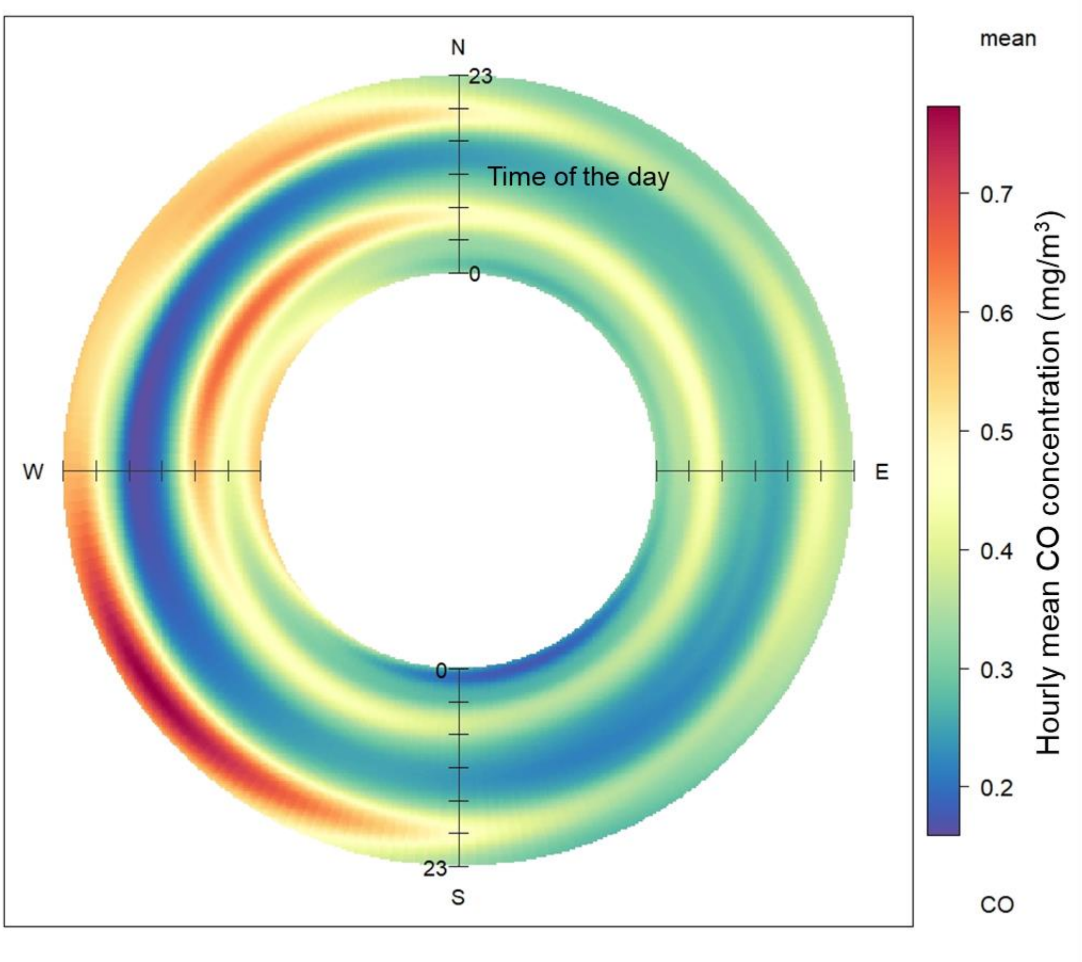


Figure 5.5 *Polar annulus plots of CO concentration at Chullora site*

5.4 Nitrogen dioxide

NO_2 concentration was measured continuously between 2004 and 2016 at all the OEH monitoring stations.

5.4.1 Time variation plots

The change of NO_2 concentration by time showed similar patterns for all the OEH sites. An example of the time variation plots is given in Figure 5.6, in this case the OEH Chullora site. Results for the other OEH sites are provided in Appendix A.

The time variation profiles for NO_2 concentrations at Chullora site were very similar to that of CO. There were two peaks (around 38 µg/m^3) in a typical workday, one at around 6 am in the morning and the second peak between hours 20 and 21,in the evening. The lowest NO_2 concentration (around 16 µg/m^3) appeared at around 1 pm, which was less than half of the peak concentration. During weekends, one peak occurred during evening at around hour 22, and a secondary peak could be seen only on Saturday at around 6 am in the morning. The reasons for these phenomenon is similar as discussed above for CO time variation patterns. It is a combine effect of several parameters, including road traffic, solar radiation, boundary layer height, dispersion condition and so on.

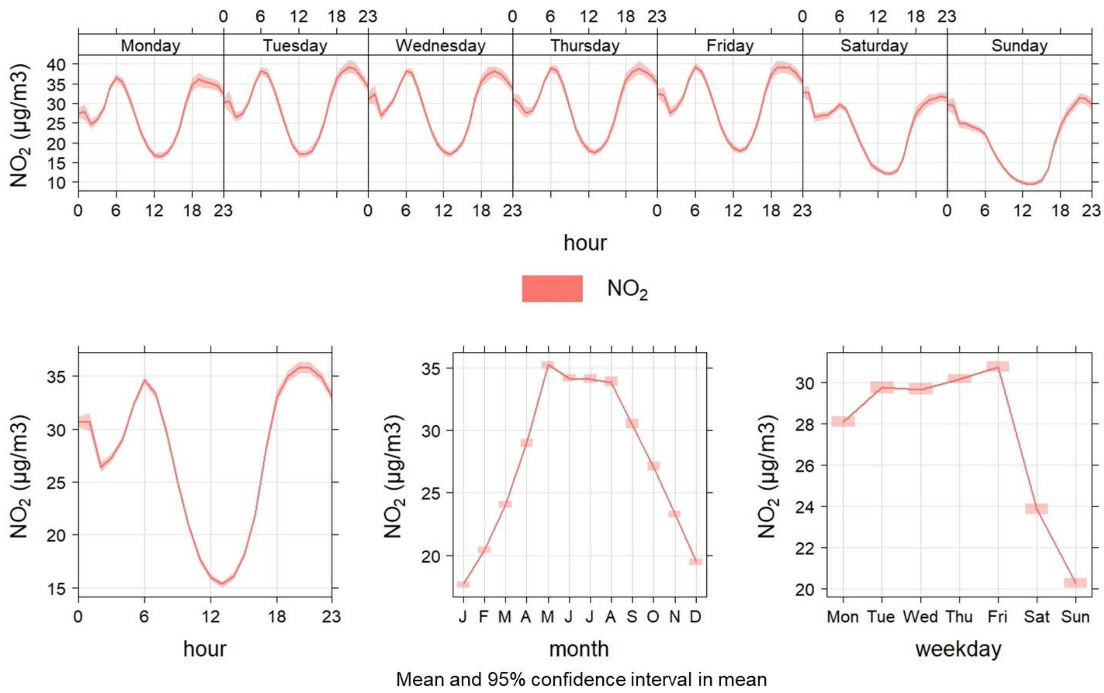


Figure 5.6 *Time variation plots of NO_2 concentration at Chullora site*

During a 7-day week, NO_2 concentrations were much higher on weekdays (between 28 and 33 µg/m^3) than on weekends (around 24 µg/m^3 on Saturday and 20 µg/m^3 on Sunday). This difference is associated with weekdays and weekend traffic volumes.

A seasonal variation in NO_2 concentration shows the highest values in winter, lowest in summer. The peak NO_2 concentration in a year were found during the period between March and August (around 34-35 µg/m^3), while the lowest value was in January (around 16 µg/m^3). In winter, people use heating system more frequently producing more emissions of NOx. Solar radiation is at the lowest, which reduced the photo-dissociation of NO_2 to NO. In addition, the weather is usually more stable and the boundary layer is generally lower in winter. These conditions work together and lead to higher NO_2 concentration in wintertime.

5.4.2 Bivariate polar plots

The bivariate polar plots of NO_2 concentration at Chullora station is provided in Figure 5.7, as an example, which shows a strong similarity to that of the CO profile. The highest NO_2 concentrations (> 30 µg/m^3) occurred at low wind speeds (< 2 m/s). Additionally, high values (> 25 µg/m^3) were also associated with high-speed winds (> 6 m/s) from the east and southeast. There was also a tendency for elevated concentrations from the northern and southern wind directions.

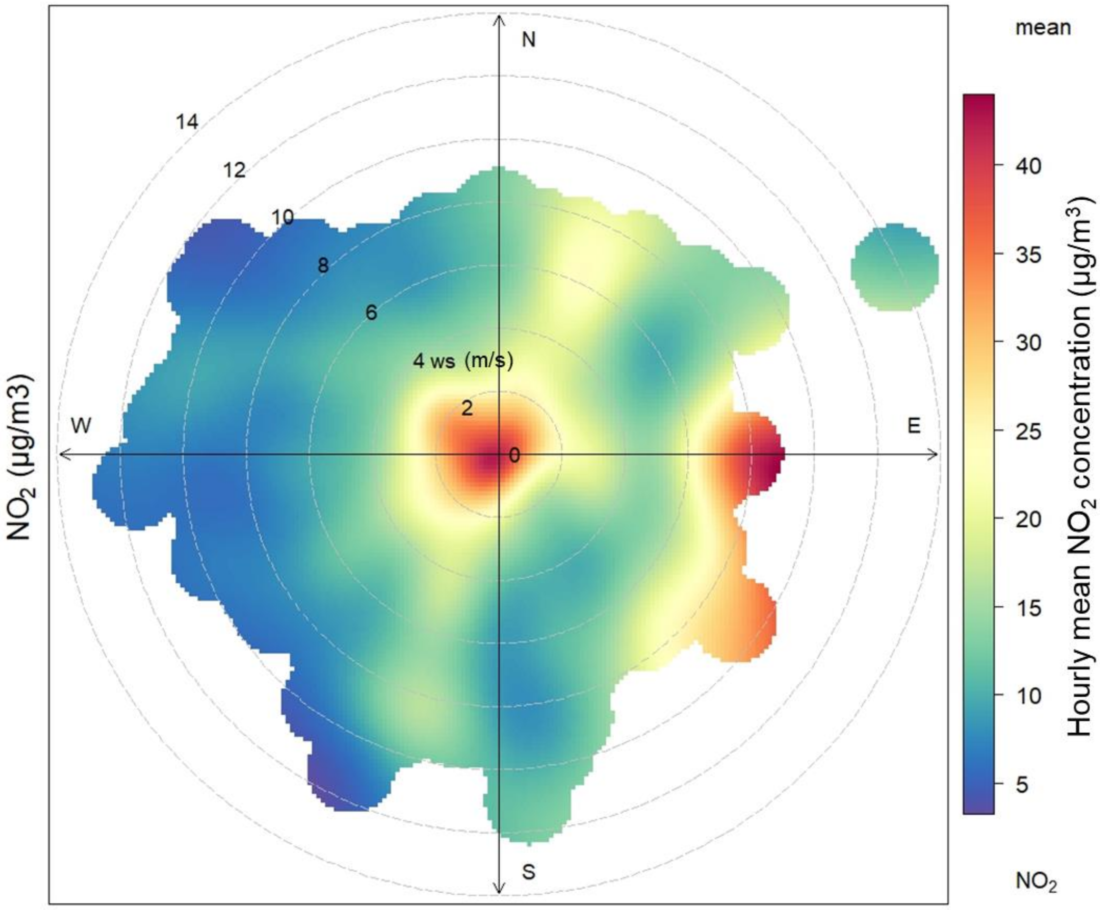


Figure 5.7 *Bivariate polar plots of NO_2 concentration at Chullora site*

5.4.3 Polar annulus plots

The polar annulus plot of NO_2 concentration at Chullora site is given in Figure 5.8, as an example, which shows a similarity with CO. Two peak NO_2 concentrations were obtained in the early morning and at late night. The high concentrations are typically from westerly winds.

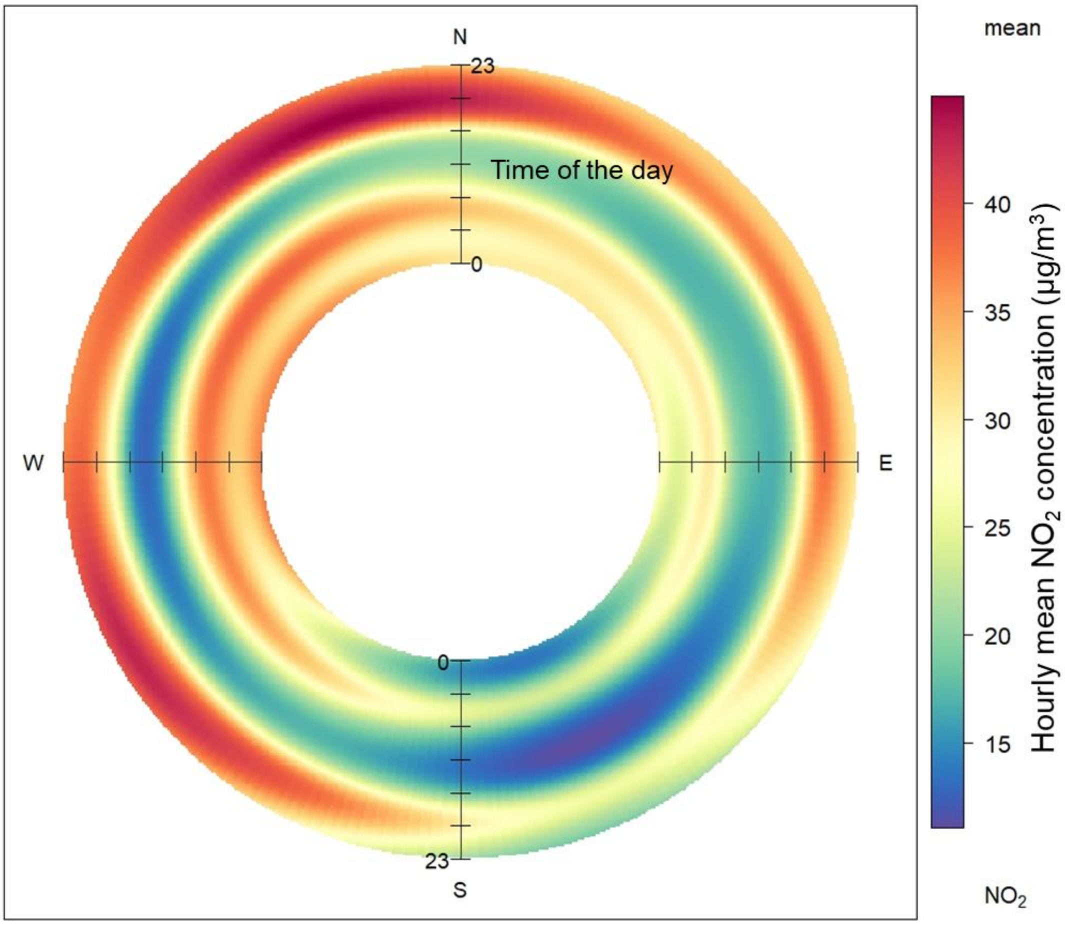


Figure 5.8 *Polar annulus plots of NO_2 concentration at Chullora site*

5.5 Ozone

Ozone concentrations were continuously monitored at all the OEH sites between 2004 and 2016.

5.5.1 Time variation plots

The time variation profiles of O_3 concentration for all the OEH sites are very similar. Results of Chullora site is given in Figure 5.9 as an example.

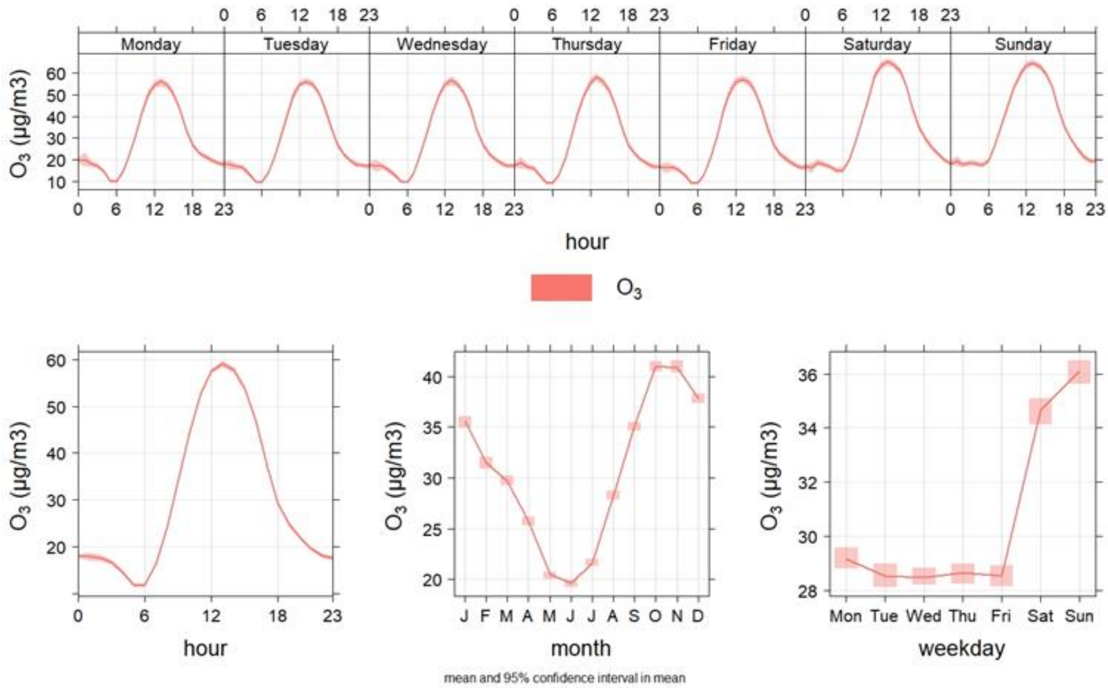


Figure 5.9 *Time variation plots of O_3 concentration at Chullora site*

In a typically day, the change of O_3 concentrations clearly showed a single peak pattern. The peak concentration of around 60 µg/m^3 appeared at around noon, which was about six times higher than that of the lowest value (approximately 10 µg/m^3) at around hour 6 in the morning. Ozone is a typical secondary pollutant, which relies mainly on the photochemical reaction of nitrogen oxides and VOCs at high solar radiation. Therefore, the peak O_3 concentration formed during noon when the solar radiation was the highest during a day. At night, the O_3 is not generated as there is no solar radiation, but other chemical reaction kept consuming O_3, which led to a lowest O_3 concentration in the early morning.

Comparing the concentrations on weekends and weekdays, it indicated that the O_3 concentrations on weekends are about 17% higher than that of workdays, and the highest value was on Sunday. The O_3 concentrations also vary by season where the highest concentrations are in late spring and early summer, when photochemical activity is high due to strong solar radiation, and the lowest values were in late autumn and winter.

5.5.2 Bivariate polar plots

Figure 5.10 shows the bivariate polar plot for O_3 concentration by wind speed and wind direction at Chullora monitoring station as an example. It appeared a reverse pattern between O_3 and NO_2/CO, which was also the case for the other OEH sites. O_3 concentrations were the lowest (< 20 µg/m^3) during calm weather (wind speed < 1 m/s). When winds came from the west, the concentrations were relatively higher (typically above 50 µg/m^3) and increased as wind speed increased. East and southeast winds brought O_3 concentration that were generally higher at medium wind speed (around 4-6 m/s), but very low when wind speed was greater than 6 m/s.

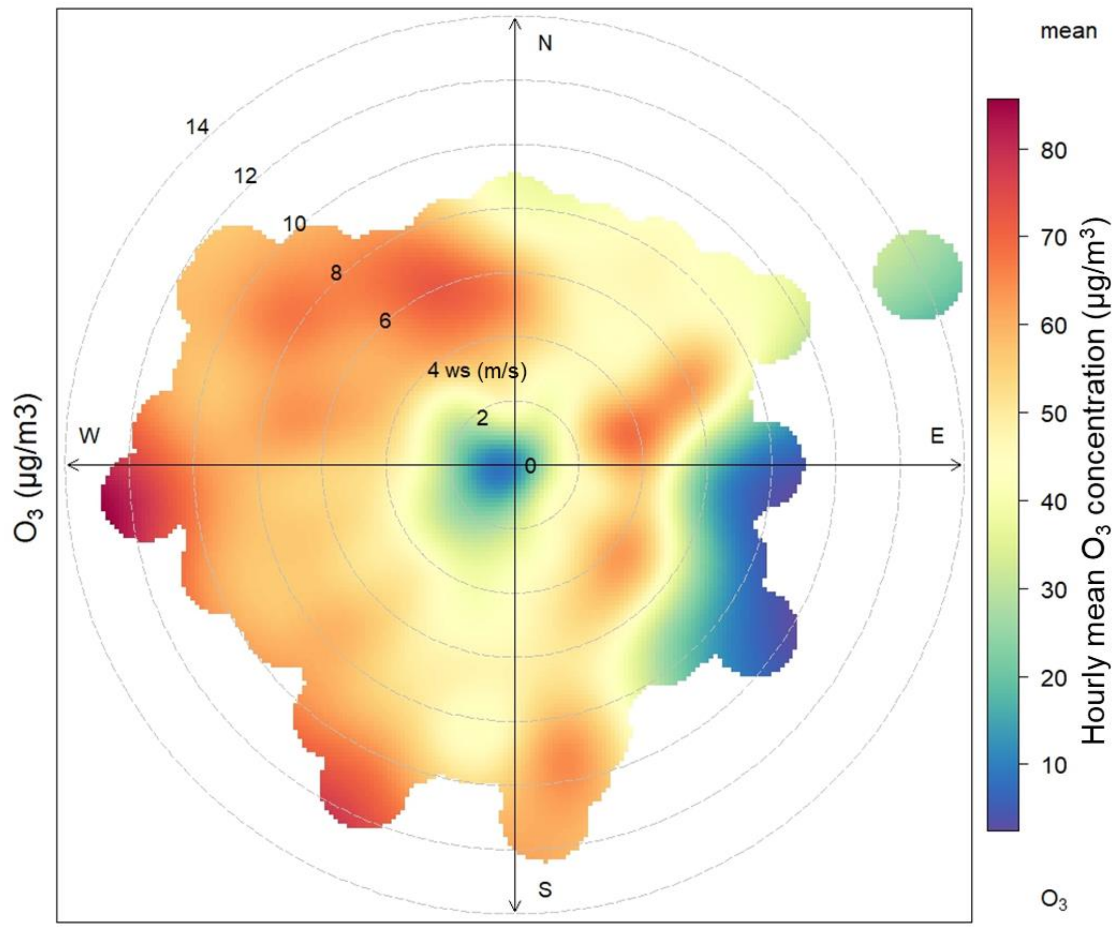


Figure 5.10 *Bivariate polar plots of O_3 concentration at Chullora site*

5.5.3 Polar annulus plots

Figure 5.11 presents an example polar annulus plots of O_3 concentration at Chullora station. Unlike CO and NO_2 patterns, the single peak of O_3 concentration occurred between around 10 am and 15 pm regardless of the wind direction, with the highest concentration under broad north wind.

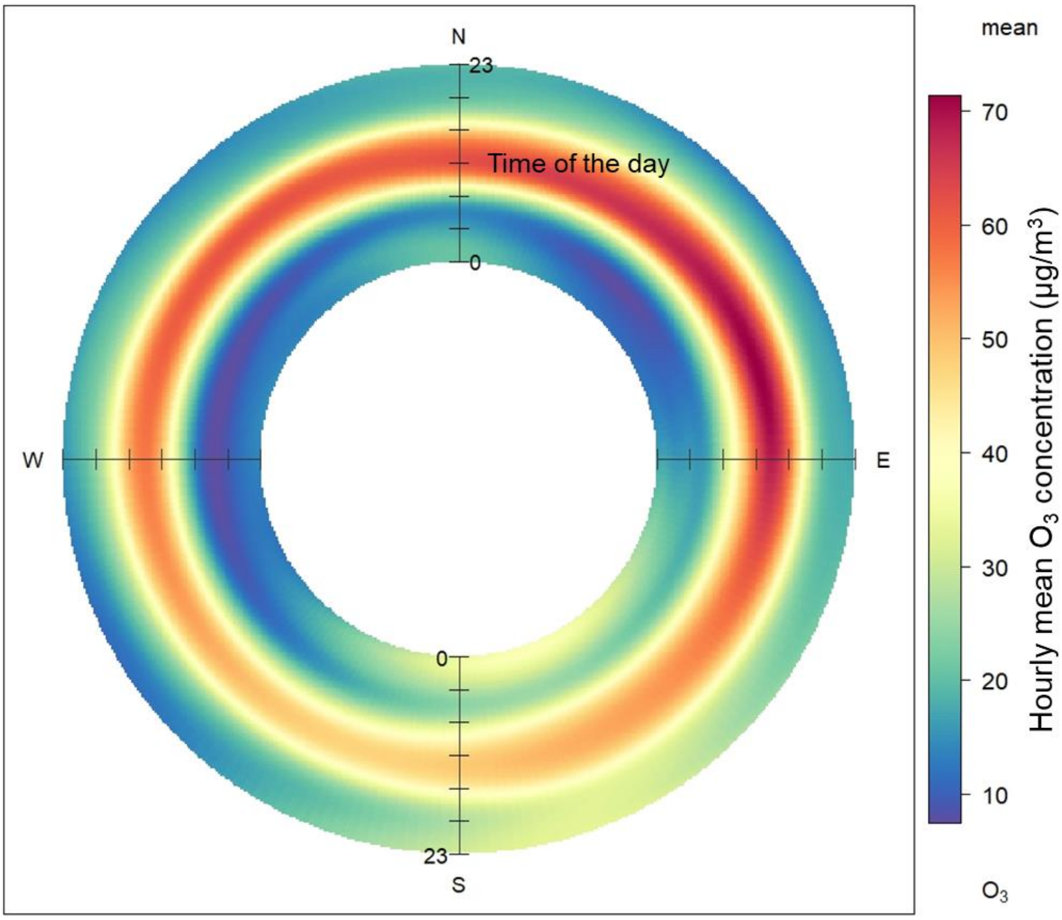


Figure 5.11 *Polar annulus plots of O_3 concentration at Chullora site*

5.6 PM_{10}

PM_{10} concentrations were continuosly monitored at all the OEH sites between 2004 and 2016.

5.6.1 Time variation plots

Time variation plots for all the OEH sites appeared very similar with slightly differences as a result of diverse sources near each monitoring station. The results of Chullora site is given in Figure 5.12 as an example.

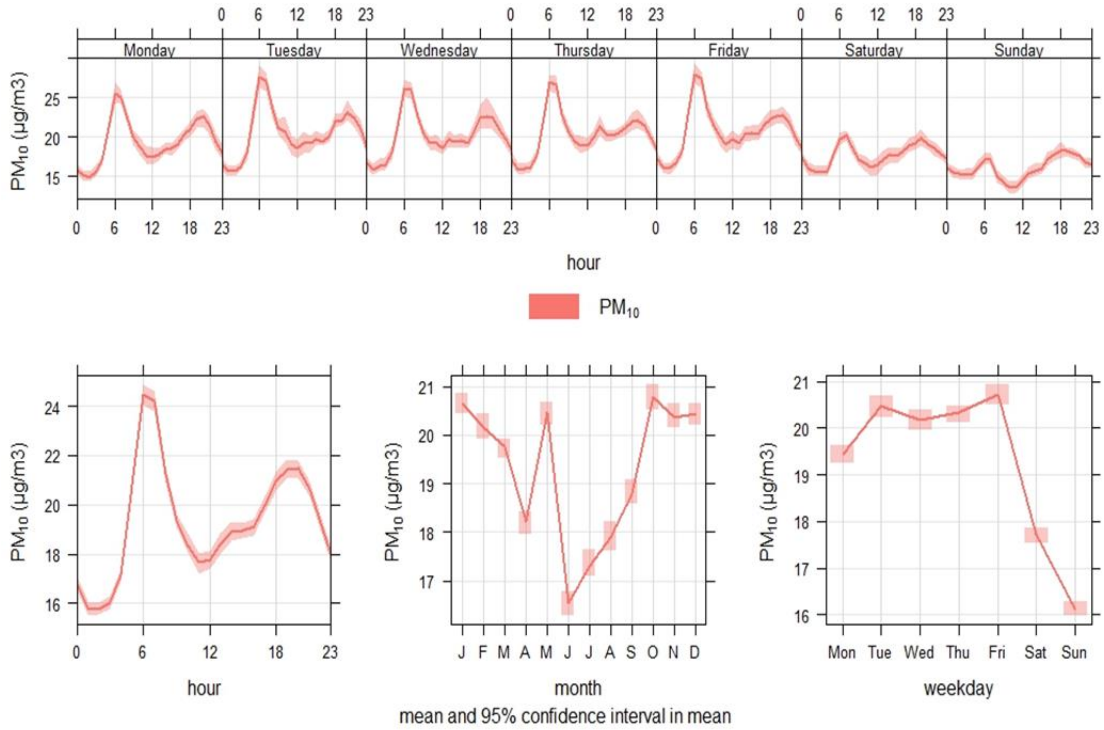


Figure 5.12 *Time variation plots of PM_{10} concentration at Chullora site*

On weekdays, the highest PM_{10} concentration (> 25 µg/m^3) generally occurred at around 6 am in the morning, and a secondary peak (around 22 µg/m^3) took place typically between around 18 pm and 20 pm. The lowest values were found during the mid of the night at around 2 am. The concentrations on weekends did not change as dramatically as on the weekdays, two broad peaks could be seen at around 6 am and 18 pm.

The PM_{10} concentrations were about 12% and 20% lower on Saturday and Sunday, respectively, compared to the weekdays, and concentrations on Monday were slightly lower than that on other weekdays.

There were also seasonal differences in the PM_{10} data, the highest PM_{10} concentrations (around 20.5 µg/m^3) were in summer while the lowest (around 16.5 µg/m^3) in winter.

PM_{10} particles are primarily generated from combustion and non-combustion processes, including motor vehicle engines, industrial process, windblown dust and bush fire. The chances of fires and dust storms are typically higher in the summer, which leads to higher PM_{10} concentrations.

5.6.2 Bivariate polar plots

The PM_{10} bivariate polar plots do not share similar patterns as CO and NO_2. The plot of Chullora site is shown in Figure 5.13 as an example. It indicated that the PM_{10} concentration was significantly influenced by a distant source to the west of the monitoring station under strong wind (> 9m/s). The relatively higher PM_{10} concentrations (around 50-60 µg/m^3) under high-speed south wind (> 8m/s) suggested another distant source to the south of the station. Additionally, there should be some sources relatively close to the northwest and southwest of the station as the concentrations were relatively high under medium-speed wind (around 6-8 m/s).

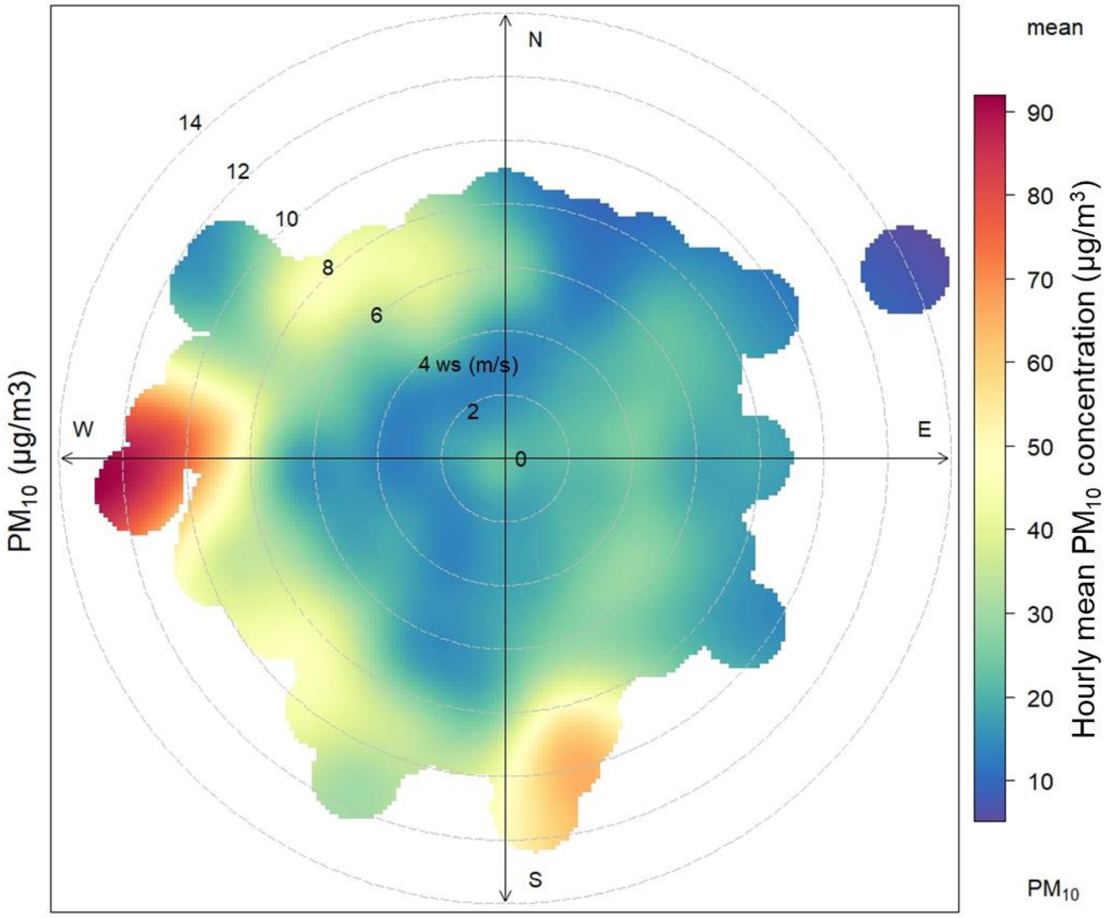


Figure 5.13 *Bivariate polar plots of PM_{10} concentration at Chullora site*

5.6.3 Polar annualus plots

The polar annulus plots of PM_{10} showed different patterns comparing with that of the gaseous substances. The result of Chullora site is shown in Figure 5.14 as an example. The PM_{10} concentrations reached a peak at around 6 am under winds from all directions. Additionally, winds from northeast to southwest directions at late night could lead to high PM_{10} concentrations. High concentrations (> 22 µg/m³) under east wind were also found to be between hour 11 and 15. Basically, east wind at any time of the day could cause high PM_{10} concentrations.

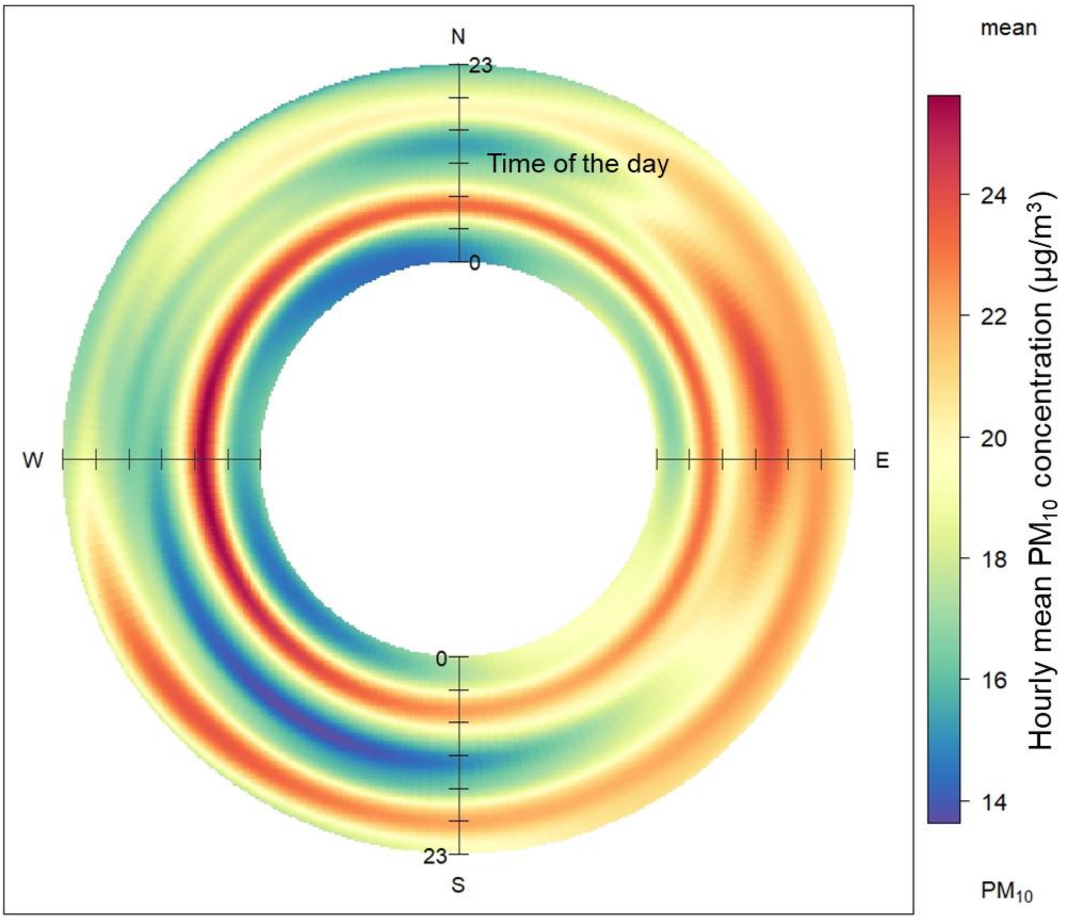


Figure 5.14 *Polar annulus plots of PM_{10} concentration at Chullora site*

6 Summary

The air quality analysis presented in this report has been used to understand the long term trends of air quality in NSW. These trends are summarised below.

Long term analysis showed the following trends:

- The long term trends show a general decrease in the CO, NOx, NO_2
- O_3 and SO_2 concentrations are relatively stable.
- PM_{10} and $PM_{2.5}$ concentrations are relatively stable and may be increasing slightly.

Roadside and near roadside analysis showed:

- PM_{10} concentrations are not significantly impacted by vehicle emissions, meaning the backgrounded sources are the dominant sources.
- NO_2 emissions at the near roadside and roadside monitors are 10-20 µg/m^3 higher than the background monitoring locations.
- BTEX concentrations are well below criteria values.

Analysis of the monitoring data and meteorological data found the following trends:

- There is a strong seasonal influence on CO, NO_X and NO_2 concentrations, with values being much higher in winter than in summer. This is due to a combination of winter-time factors such as an increase in combustion for heating purposes, elevated 'cold start' emissions from road vehicles, and more frequent and persistent temperature inversions in the atmosphere reducing the effectiveness of dispersion. Another contributing factor may be the reaction of NO_2 with the hydroxyl radical (OH) acting as a sink for NO_X. Concentrations of OH are highest in the summer.
- Ozone concentrations are highest in the late spring and early summer – when photochemical activity is high - and lowest in the autumn and winter.
- For PM_{10} there is a weaker seasonal effect than for the gaseous pollutants, with concentrations tending to be higher in summer and lower in winter.
- For $PM_{2.5}$ concentrations there are some differences between seasons, but they are not systematic.

Analysis of each OEH stations air quality data with the meteorological data is summarised below.

Earlwood

For the Earlwood station NO_X and NO_2 concentrations were highest when the winds were strong and from an easterly direction. This influence was especially strong during winter, hinting that this was an effect of combustion for heating purposes. PM_{10} concentrations were highest when the winds were strong and from a westerly direction (especially in winter and spring). $PM_{2.5}$ concentrations, while more evenly distributed than PM_{10}, were high when the winds were strong from a southerly direction (especially in summer).

Lindfield

For Lindfield the analysis for NO_X and NO_2 indicated the presence of a local ground-level source, as well as a diffuse source further afield to the north. This probably reflected the population distribution around the monitoring station. There was also an influence further way and to the west. PM_{10} concentrations were high when there was a strong westerly wind. This may have been due to wind-blown dust from open land immediately to the west of the monitoring station. There were no strong seasonal effects at the Lindfield station, apart from higher concentrations from the west under high wind speed conditions in spring, and higher concentrations from the south under high wind speed conditions in the summer. Again, these effects were not investigated further.

Randwick

At Randwick NO_X and NO_2 concentrations were highest when the wind speed was low and the wind was coming from the west. There was no seasonal effect for NO_X. The highest PM_{10} concentrations occurred when the wind speed was high and the wind was from three distinct directions.

Rozelle

At the Rozelle station there were multiple combustion sources affecting CO concentrations. The highest NO_X/NO_2 concentrations occurred when winds were along an east-west axis, which suggested contributions from the University campus and residential areas. The highest PM_{10} concentrations at the monitoring station were associated with strong southerly winds, especially in summer. As at the other OEH monitoring stations, this seemed to be due to wind-blown dust from open land to the south of the station.

7 References

AQEG (2012), *Fine Particulate Matter (PM2.5) in the United Kingdom*, report of the Air Quality Expert Group,cpublished by the Department for Environment, Food and Rural Affairs, London, UK.

Carslaw, K, et al. (2015), *Particulate matter, air quality and climate: lessons learned and future needs*, Atmospheric chemistry and physics 15.14.8217-8299. 24 July 2015.

NEPM (2016), *National Environment Protection (Ambient Air Quality) Measure,* 3 February 2016. https://www.legislation.gov.au/Details/F2016C00215

NSW (2016), *Approved Methods for the Modelling and Assessment of Air Pollutants in New South Wales,* NSW Department of Environment protection Authority, November 2016. https://www.epa.nsw.gov.au/-/media/epa/corporate-site/resources/air/approved-methods-for-modelling-and-assessment-of-air-pollutants-in-nsw-160666.pdf?la=en

…

Appendix A – Openair Analysis Results

A1 Chullora

A1.1 Time variation plots

The time variation plots of four pollutants (CO, NO_2, O_3 and PM_{10}) at OEH site Chullora are shown below.

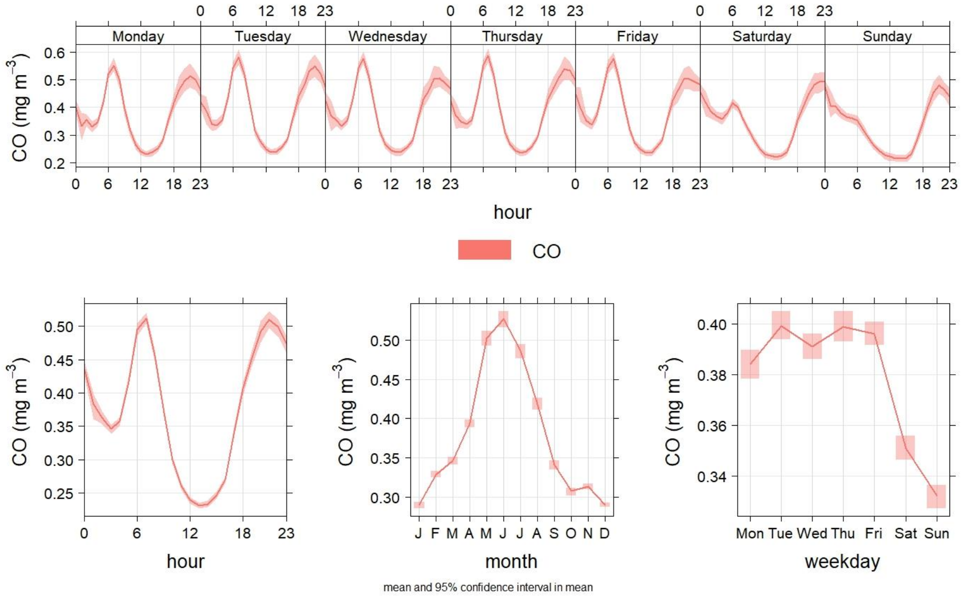


Figure A1-1 *Time variation plots of CO concentration at OEH Chullora site.*

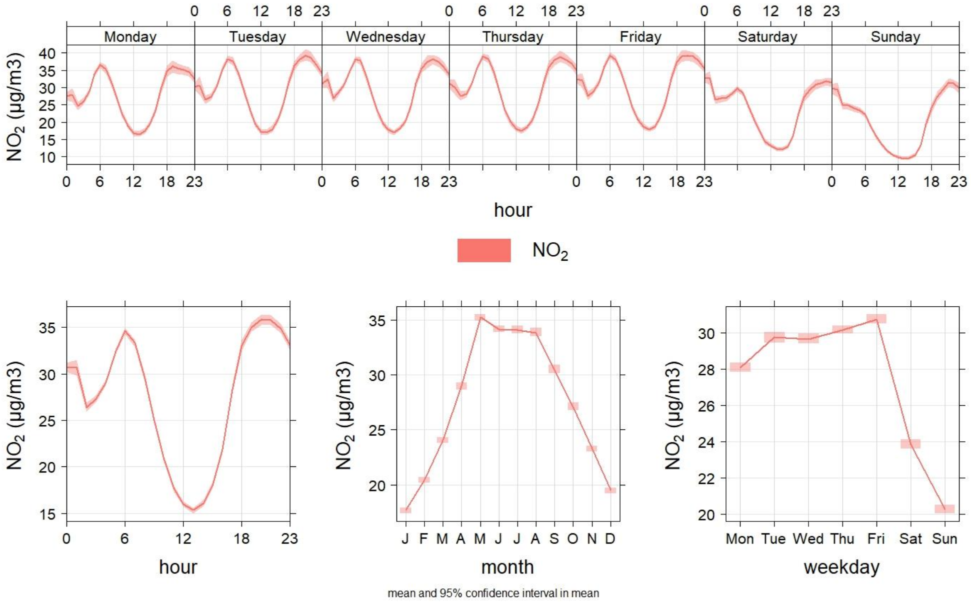


Figure A1-2 *Time variation plots of NO_2 concentration at OEH Chullora site.*

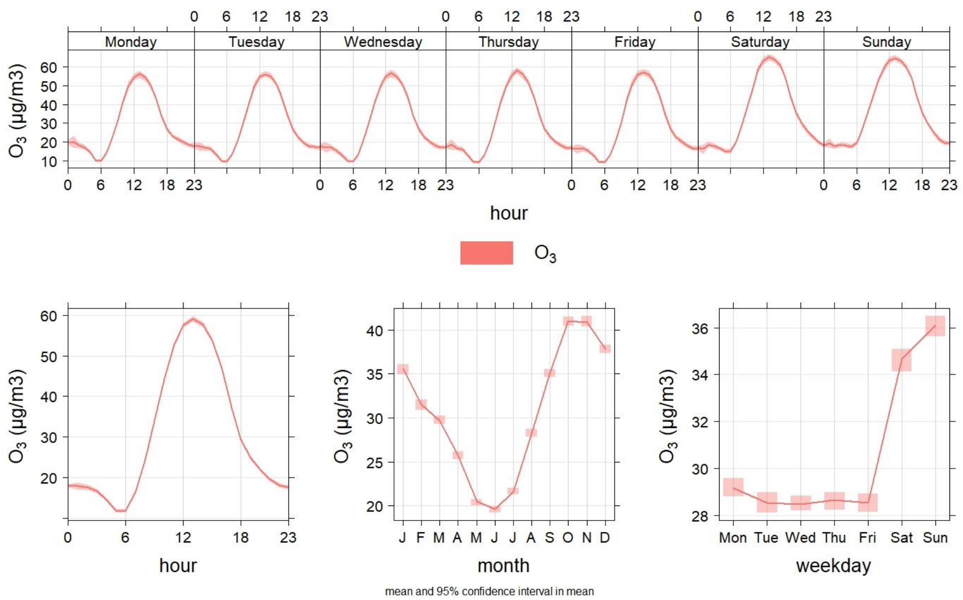


Figure A1-3 *Time variation plots of O_3 concentration at OEH Chullora site.*

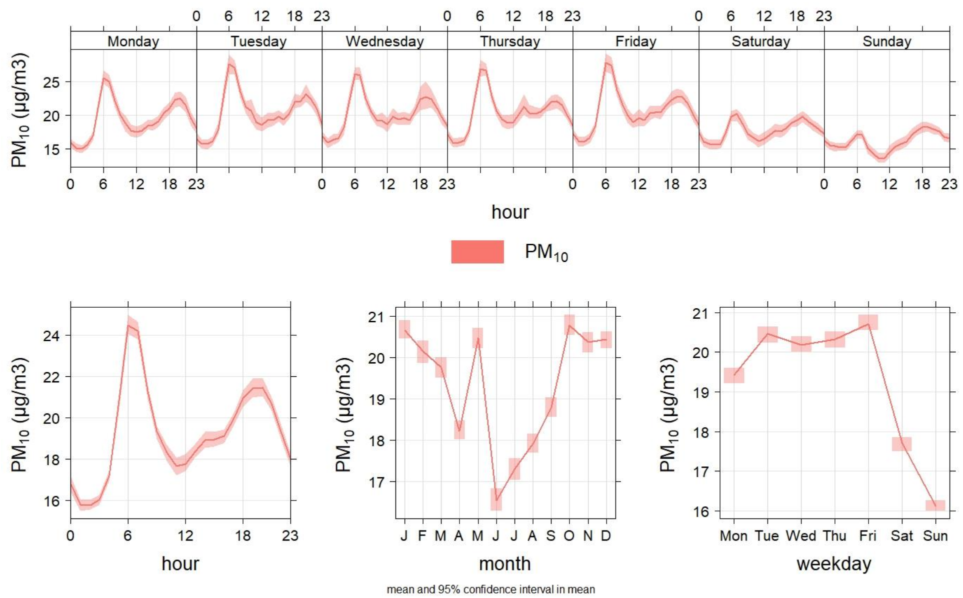


Figure A1-4 *Time variation plots of PM_{10} concentration at Chullora site.*

A1.2 Bivariate polar plots

The bivariate polar plots of CO, NO_2, O_3 and PM_{10} at OEH Chullora site is provided in Figure A1-5.

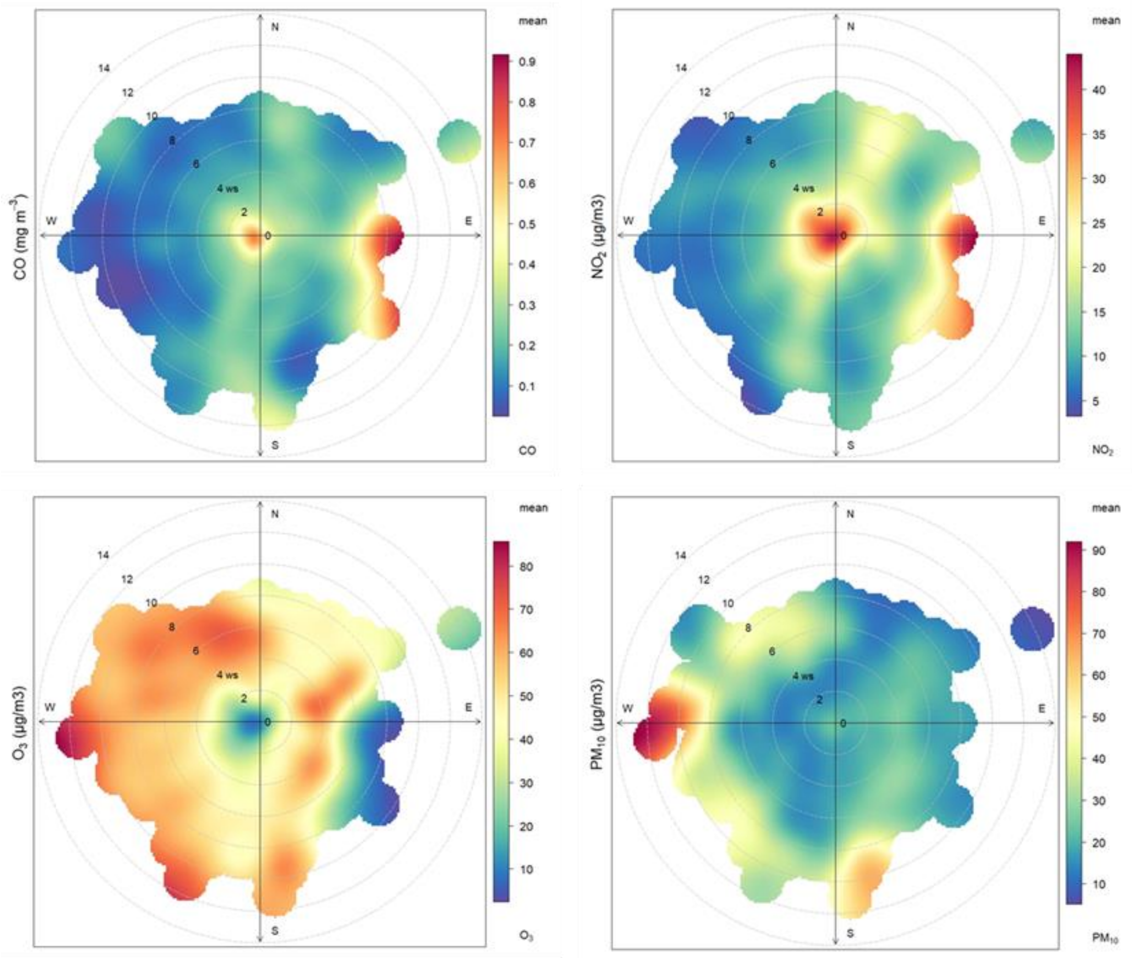


Figure A1-5 *Bivariate polar plots of CO, NO_2, O_3 and PM_{10} concentration at OEH Chullora site.*

A1.3 Polar annulus plots

Figure A1-6 is the polar annulus plots of CO, NO_2, O_3 and PM_{10} *concentration at OEH Chullora site.*

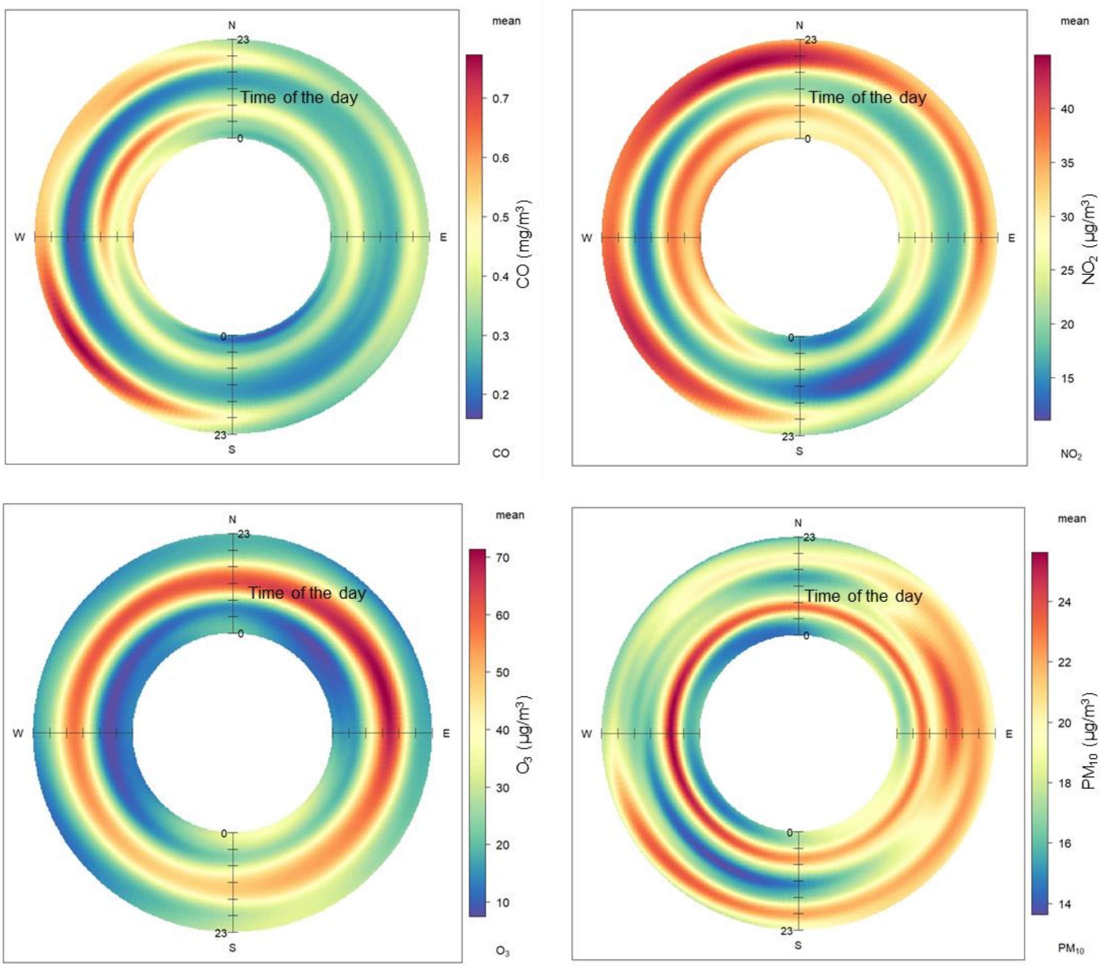


Figure A1-6 *Polar annulus plots of CO, NO_2, O_3 and PM_{10} concentration at OEH Chullora site.*

A2 Earlwood

A2.1 Time variation plots

The time variation plots of NO_2, O_3 and PM_{10} concentration at OEH site Earlwood are provided in Figure A2-1 to Figure A2-3.

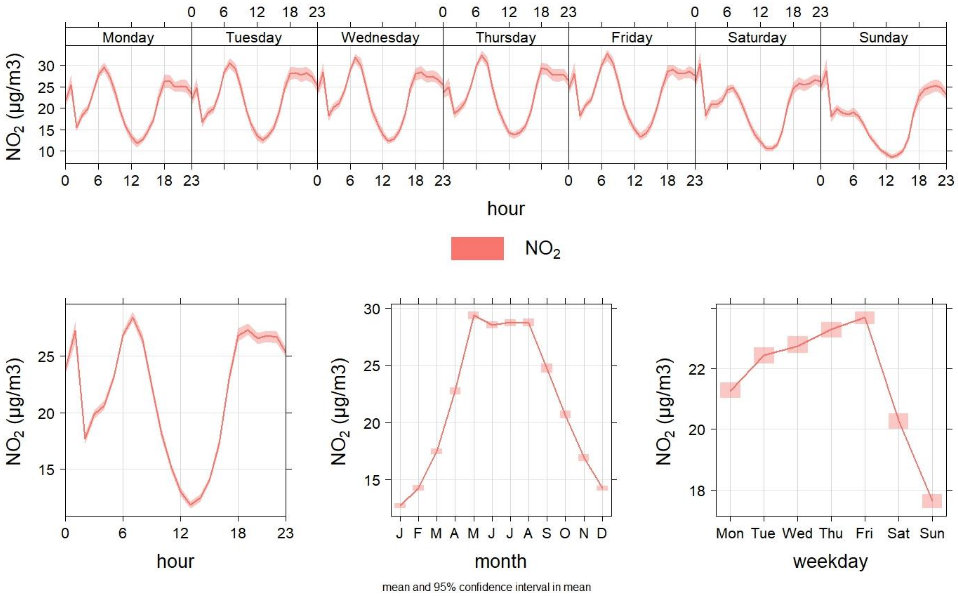


Figure A2-1 *Time variation plots of NO_2 concentration at OEH Earlwood site.*

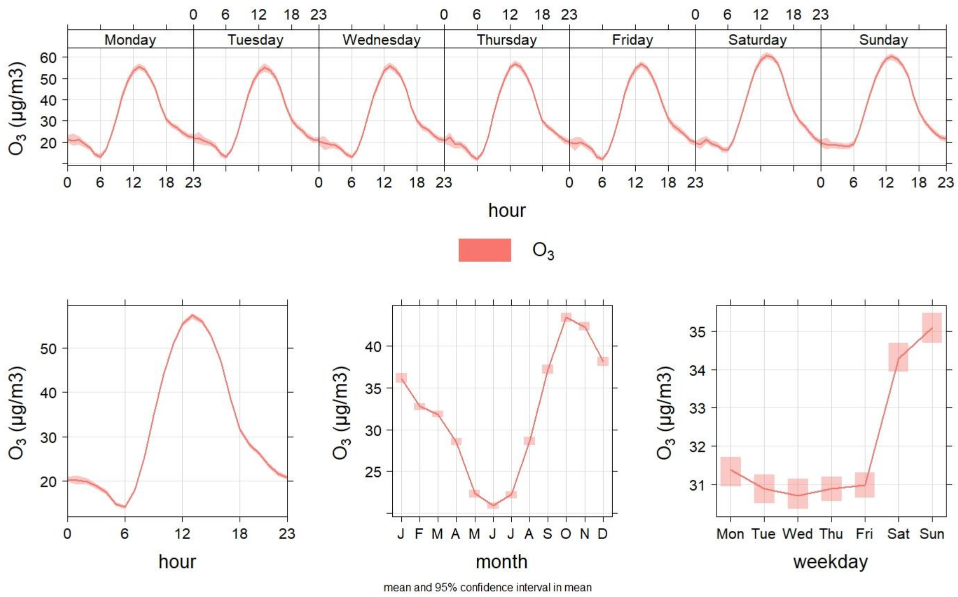


Figure A2-2 *Time variation plots of O_3 concentration at OEH Earlwood site.*

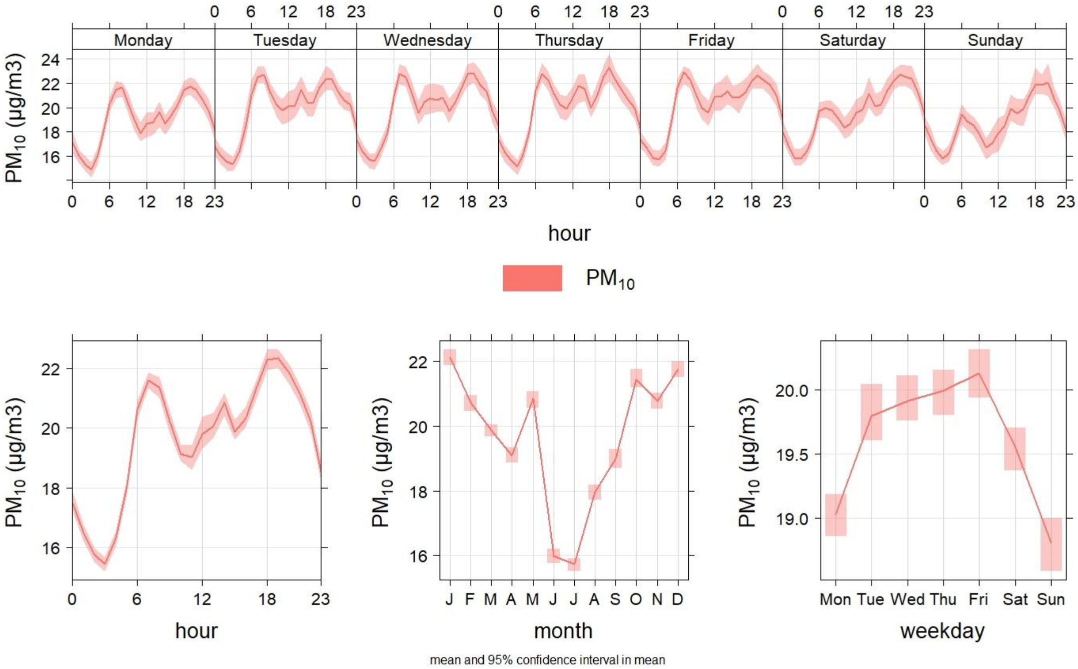


Figure A2-3 *Time variation plots of PM_{10} concentration at OEH Earlwood site.*

A2.2 Bivariate polar plots

The bivariate polar plots of NO_2, O_3 and PM_{10} concentration at OEH site Earlwood are presented in Figure A2-4.

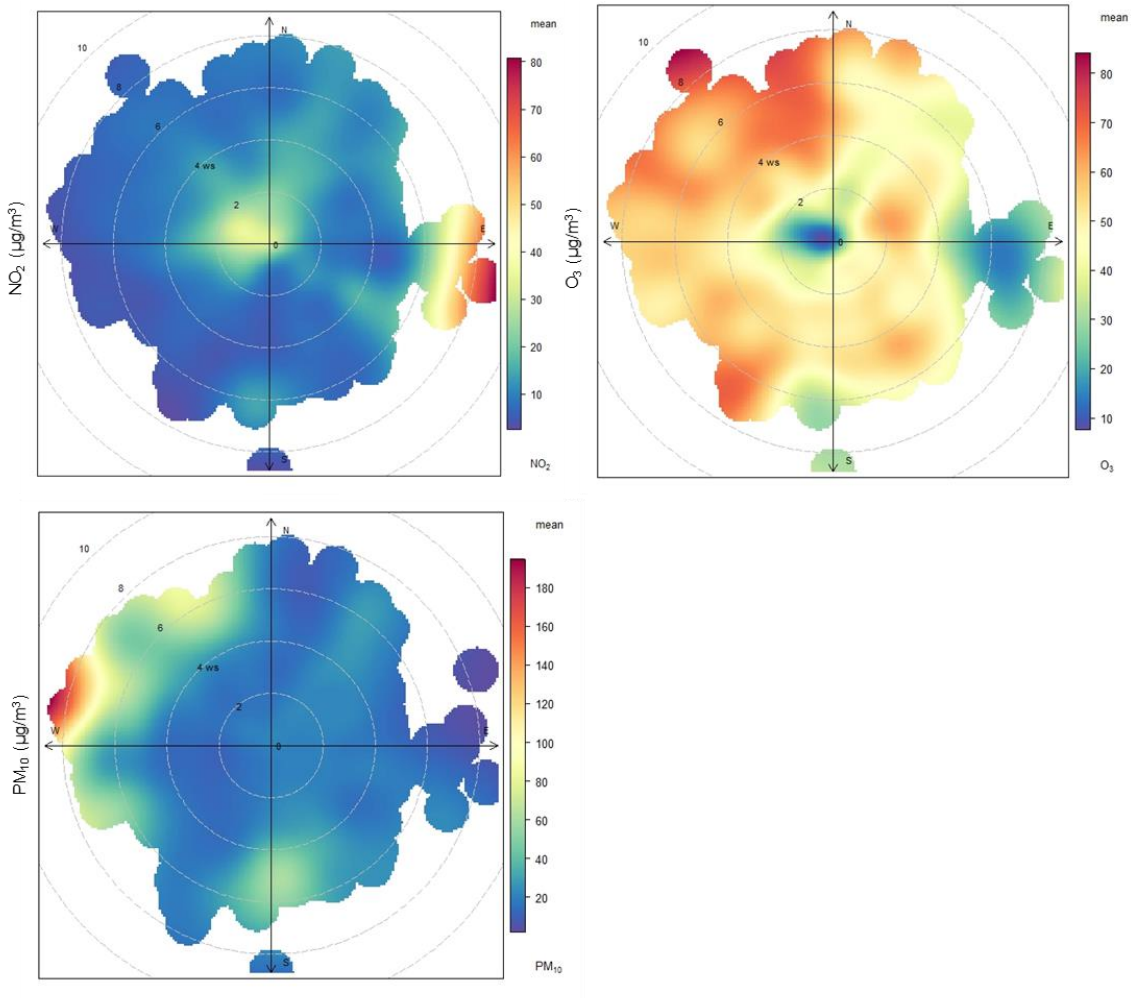


Figure A2-4 *Bivariate polar plots of NO_2, O_3 and PM_{10} concentration at OEH Earlwood site.*

A2.3 Polar annulus plots

The polar annulus plots of NO_2, O_3 and PM_{10} concentration at OEH site Earlwood are presented in Figure A2-5.

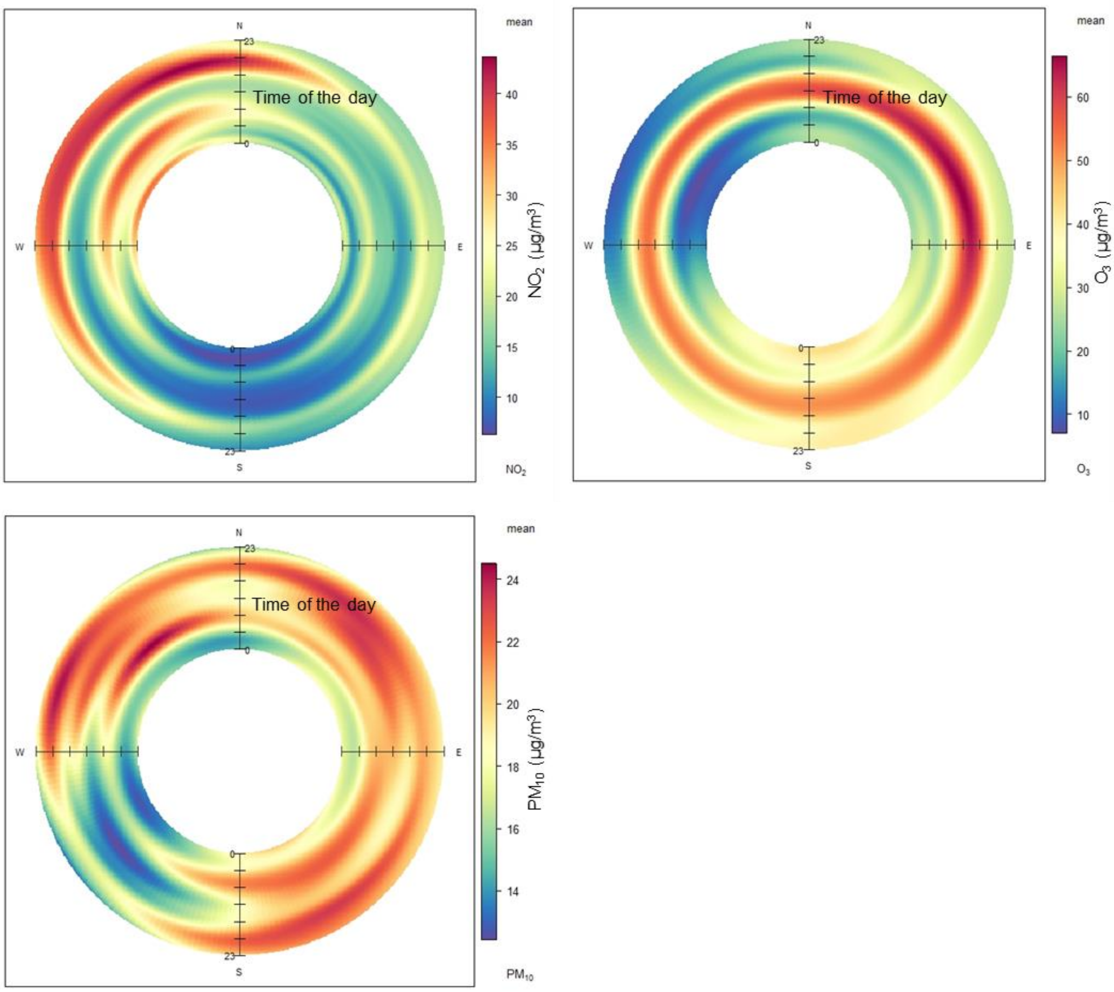


Figure A2-5 *Polar annulus plots of NO_2, O_3 and PM_{10} concentration at OEH Earlwood site.*

A3 Lindfield

A3.1 Time variation plots

The time variation plots of NO_2, O_3 and PM_{10} concentration at OEH site Lindfield are Shown in Figure A3-1 to Figure A3-3.

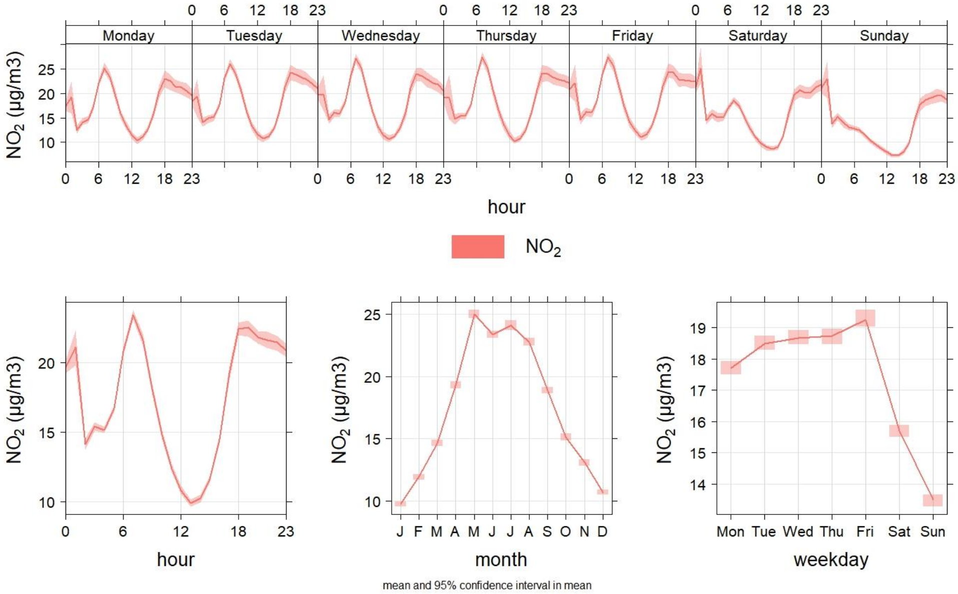


Figure A3-1 *Time variation plots of NO_2 concentration at OEH Lindfield site.*

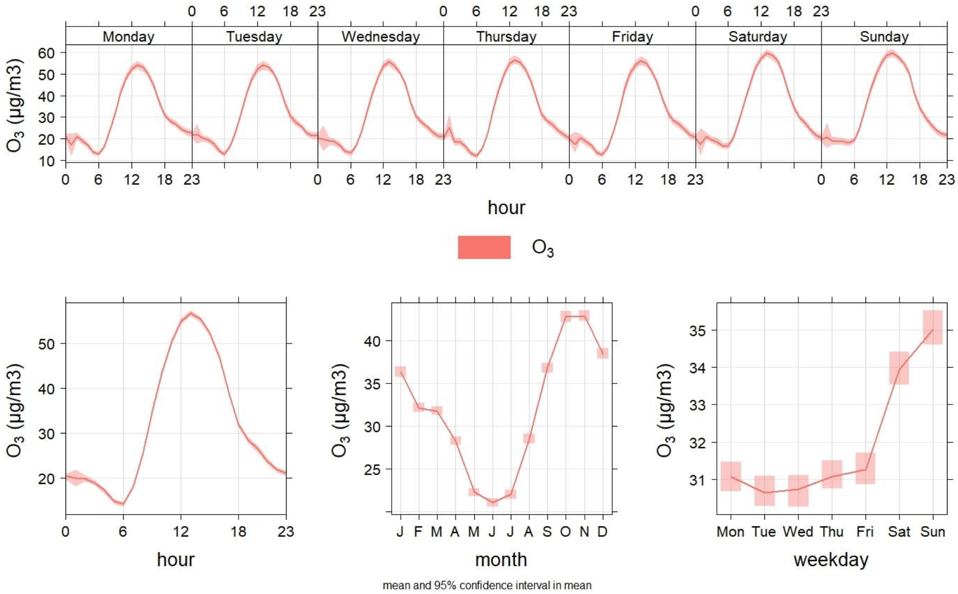


Figure A3-2 *Time variation plots of O_3 concentration at OEH Lindfield site.*

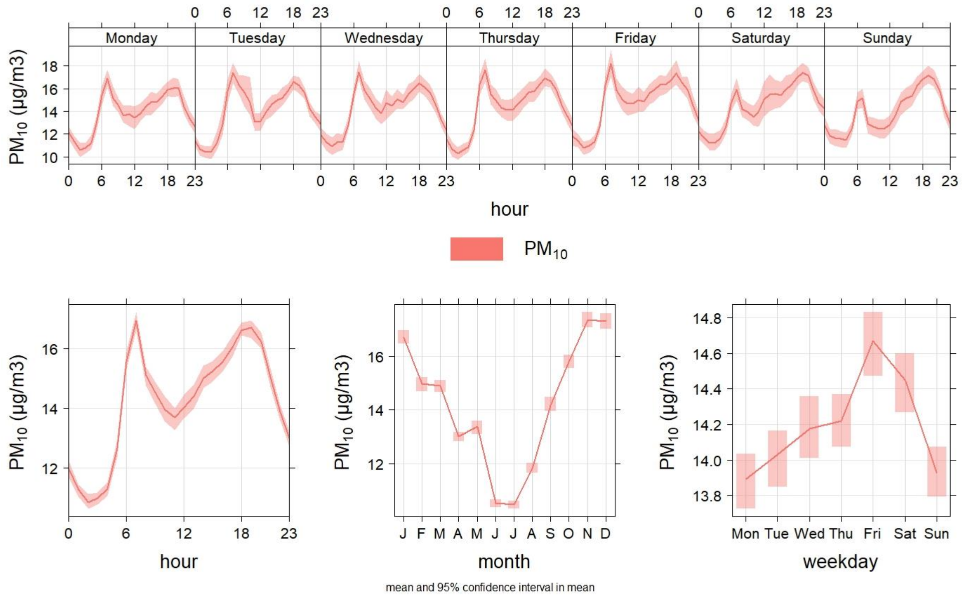


Figure A3-3 *Time variation plots of PM_{10} concentration at OEH Lindfield site.*

A3.2 Bivariate polar plots

The bivariate polar plots of NO_2, O_3 and PM_{10} concentration at OEH site Lindfield are provided in Figure A3-4.

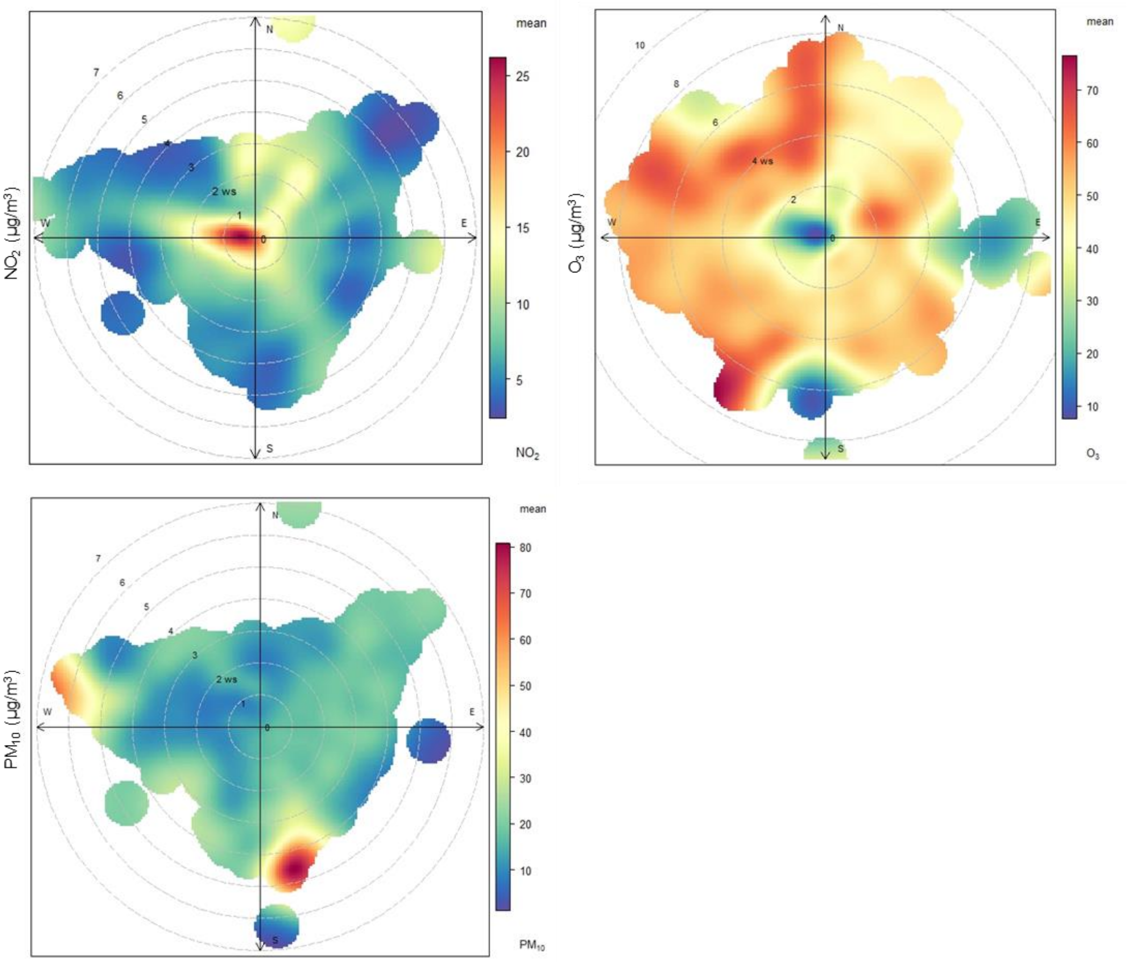


Figure A3-4 *Bivariate polar plots of NO_2, O_3 and PM_{10} concentration at OEH Lindfield site.*

A3.3 Polar annulus plots

The polar annulus plots of NO_2, O_3 and PM_{10} concentration at OEH site Lindfield are shown in Figure A3-5.

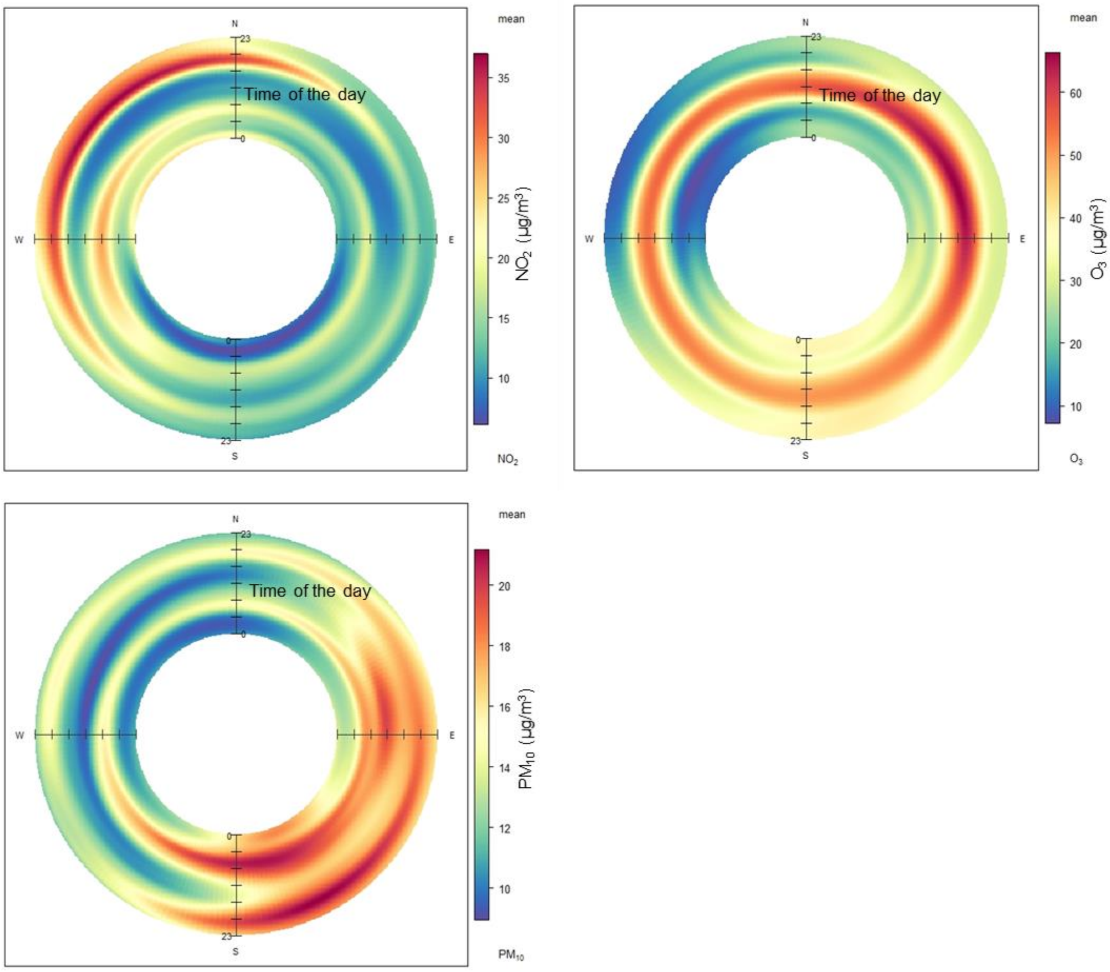


Figure A3-5 *Polar annulus plots of NO_2, O_3 and PM_{10} concentration at OEH Lindfield site.*

A4 Liverpool

A4.1 Time variation plots

The time variation plots of CO, NO_2, O_3 and PM_{10} concentration at OEH site Liverpool are shown in Figure A4-1 to Figure A4-4.

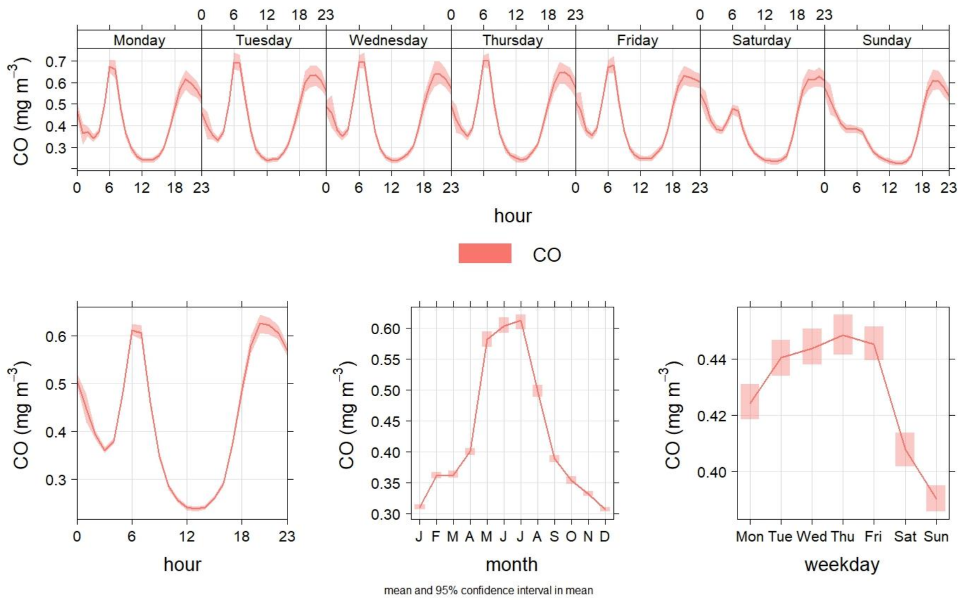


Figure A4-1 *Time variation plots of CO concentration at OEH Liverpool site.*

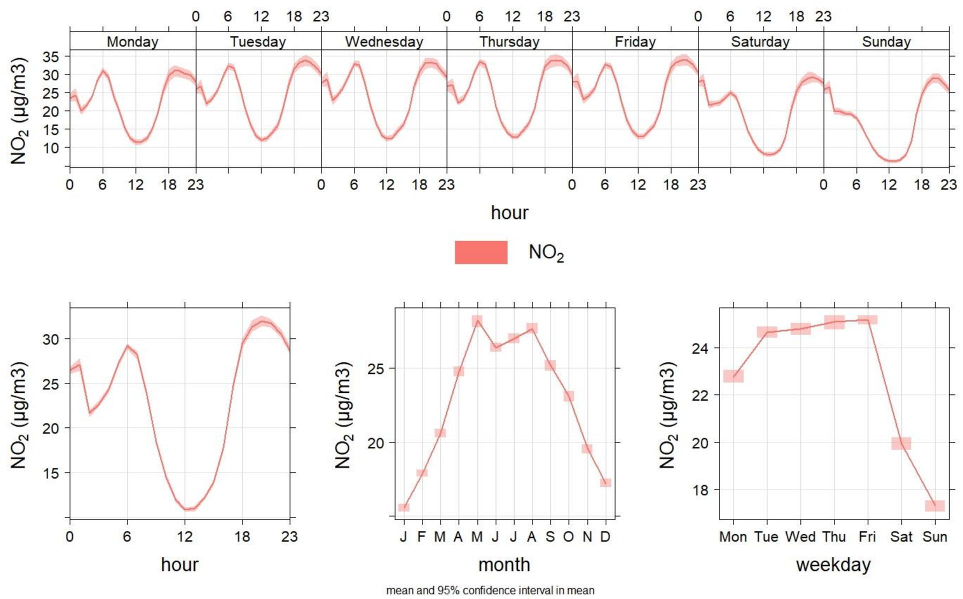


Figure A4-2 *Time variation plots of NO_2 concentration at OEH Liverpool site.*

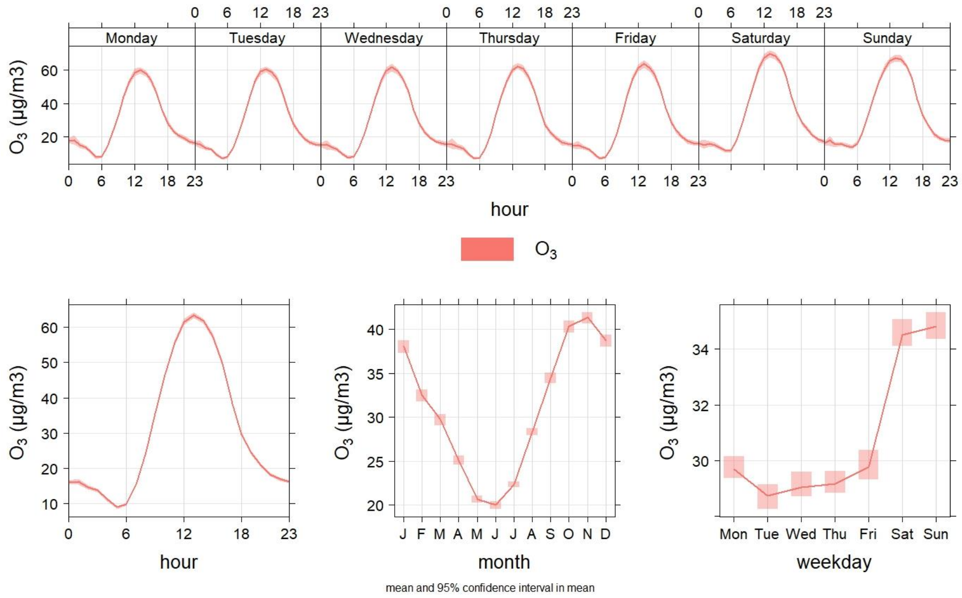


Figure A4-3 *Time variation plots of O_3 concentration at OEH Liverpool site.*

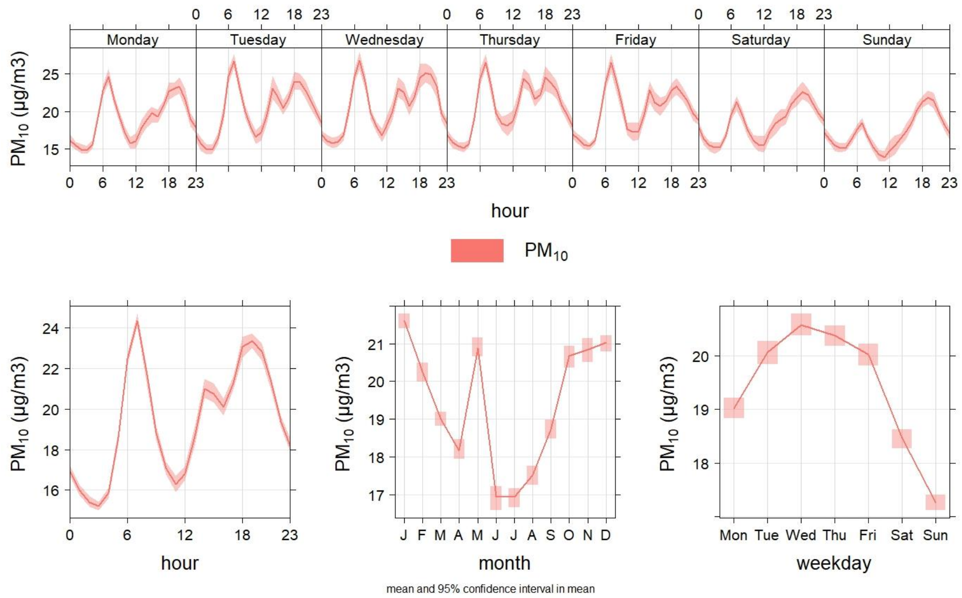


Figure A4-4 *Time variation plots of PM_{10} concentration at OEH Liverpool site.*

A4.2 Bivariate polar plots

The bivariate polar plots of CO, NO_2, O_3 and PM_{10} concentration at OEH Liverpool site is provided in Figure A4-5.

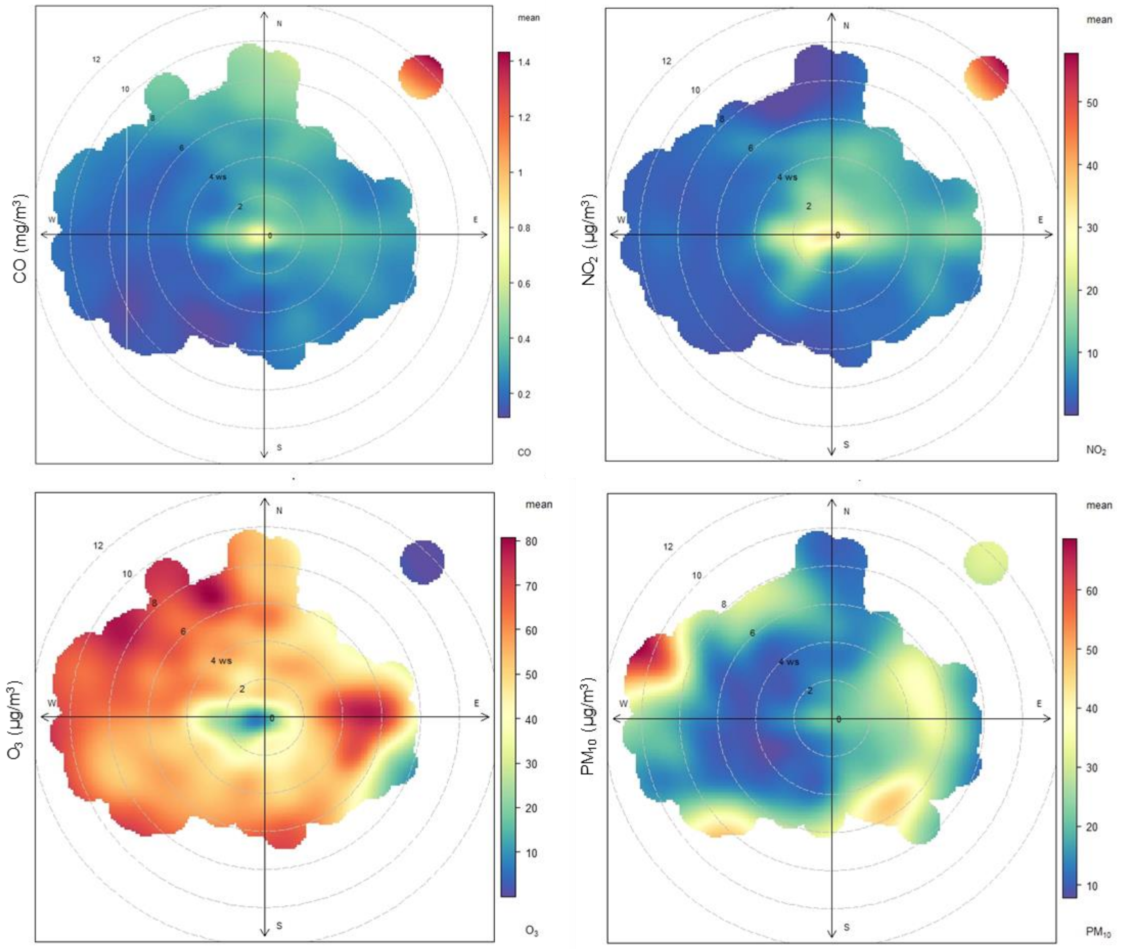


Figure A4-5 *Bivariate polar plots of CO, NO_2, O_3 and PM_{10} concentration at OEH Liverpool site.*

A4.3 Polar annulus plots

The polar annulus plots of CO, NO_2, O3 and PM_{10} concentration at OEH Liverpool site is provided in Figure A4-6.

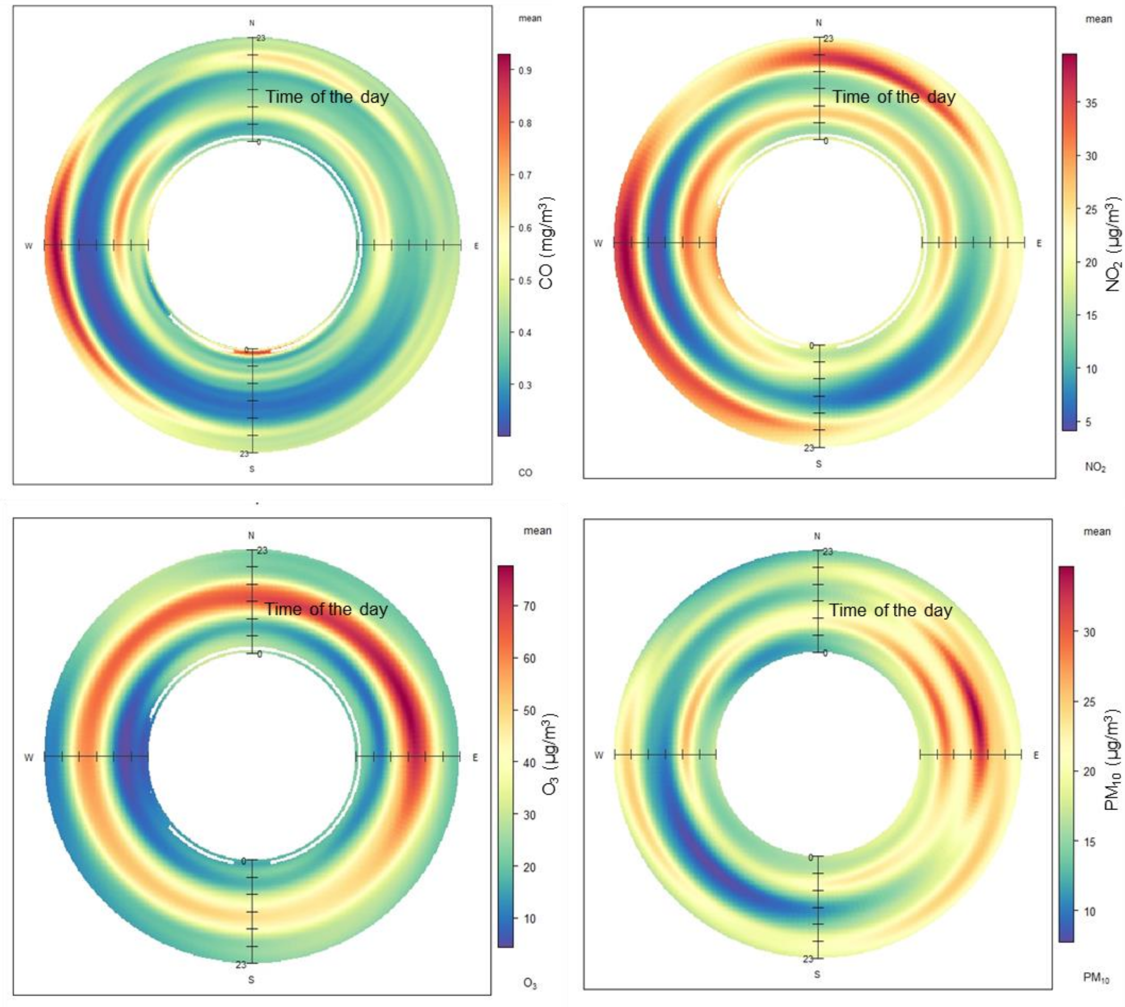


Figure A4-6 is the polar annulus plots of CO, NO_2, O_3 and PM_{10} *concentration at OEH Chullora site.*

A5 Prospect

A5.1 Time variation plots

The time variation plots of CO, NO_2, O_3 and PM_{10} concentration at OEH site Lindfield are Shown in Figure A5-1 to Figure A5-4.

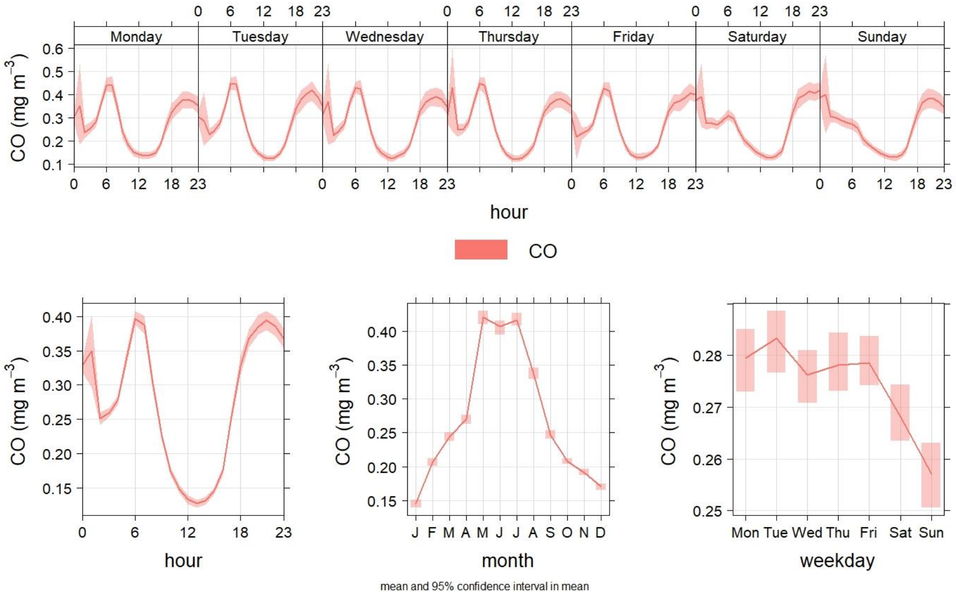


Figure A5-1 *Time variation plots of CO concentration at OEH Prospect site.*

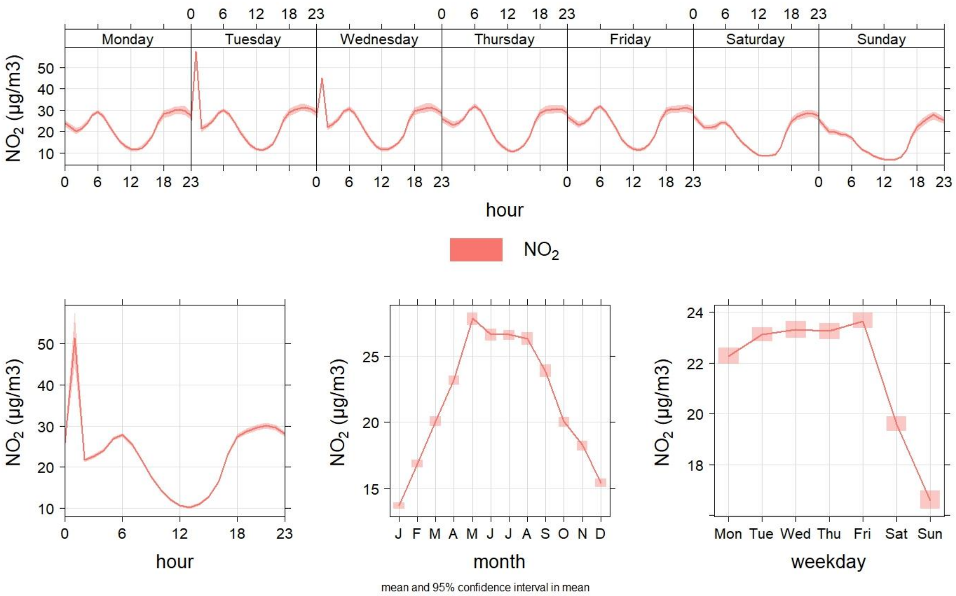


Figure A5-2 *Time variation plots of NO_2 concentration at OEH Prospect site.*

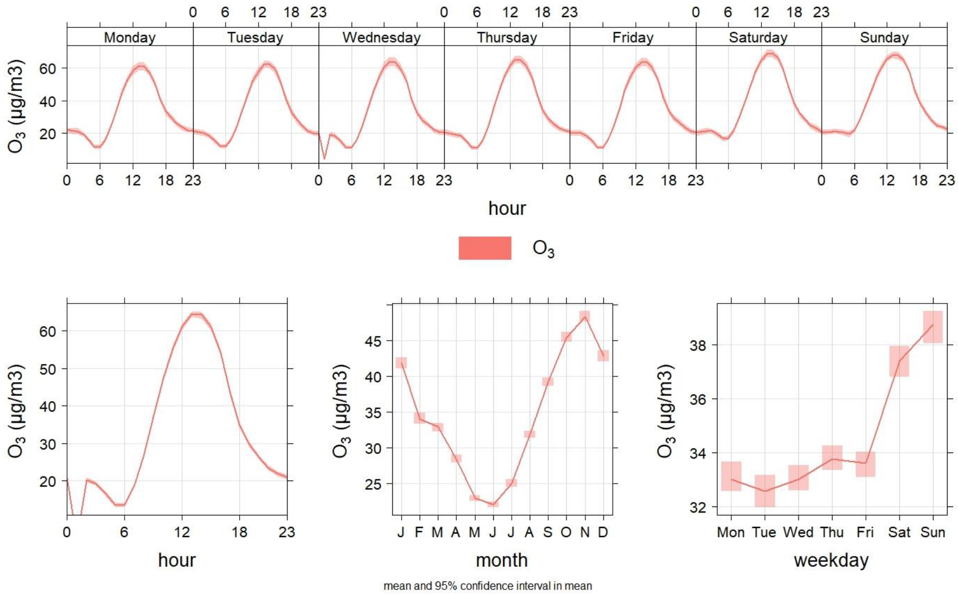


Figure A5-3 *Time variation plots of O_3 concentration at OEH Prospect site.*

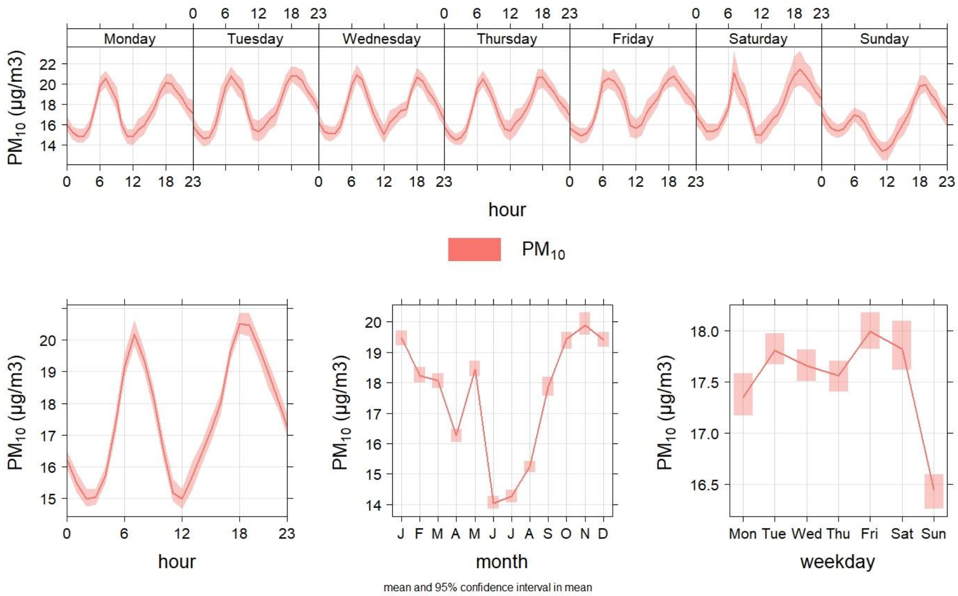


Figure A5-4 *Time variation plots of PM_{10} concentration at OEH Prospect site.*

A5.2 Bivariate polar plots

The bivariate polar plots of CO, NO_2, O_3 and PM_{10} concentration at OEH site Prospect are presented in Figure A5-5.

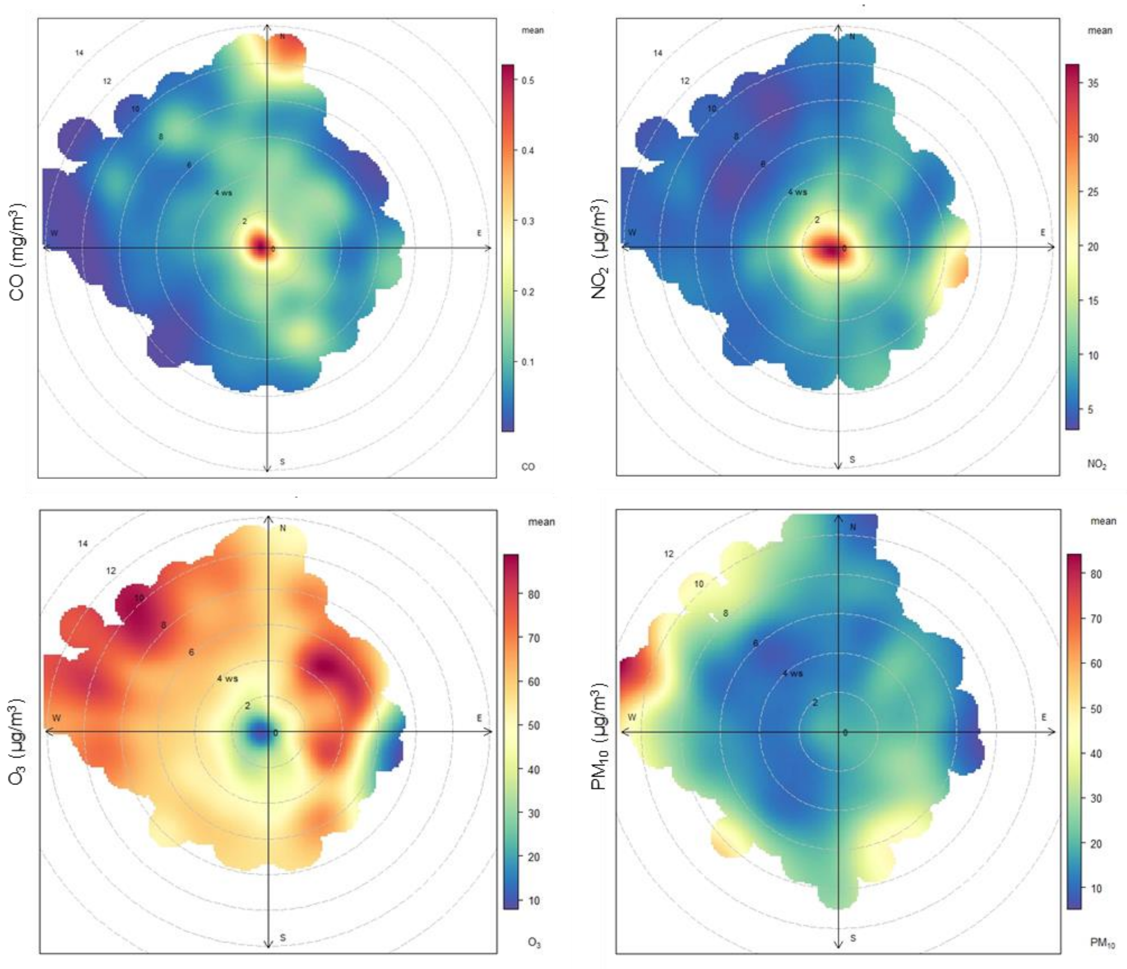


Figure A5-5 *Bivariate polar plots of CO, NO_2, O_3 and PM_{10} concentration at OEH Prospect site.*

A5.3 Polar annulus plots

The polar annulus plots of CO, NO_2, O_3 and PM_{10} concentration at OEH site Prospect are shown in Figure A5-6.

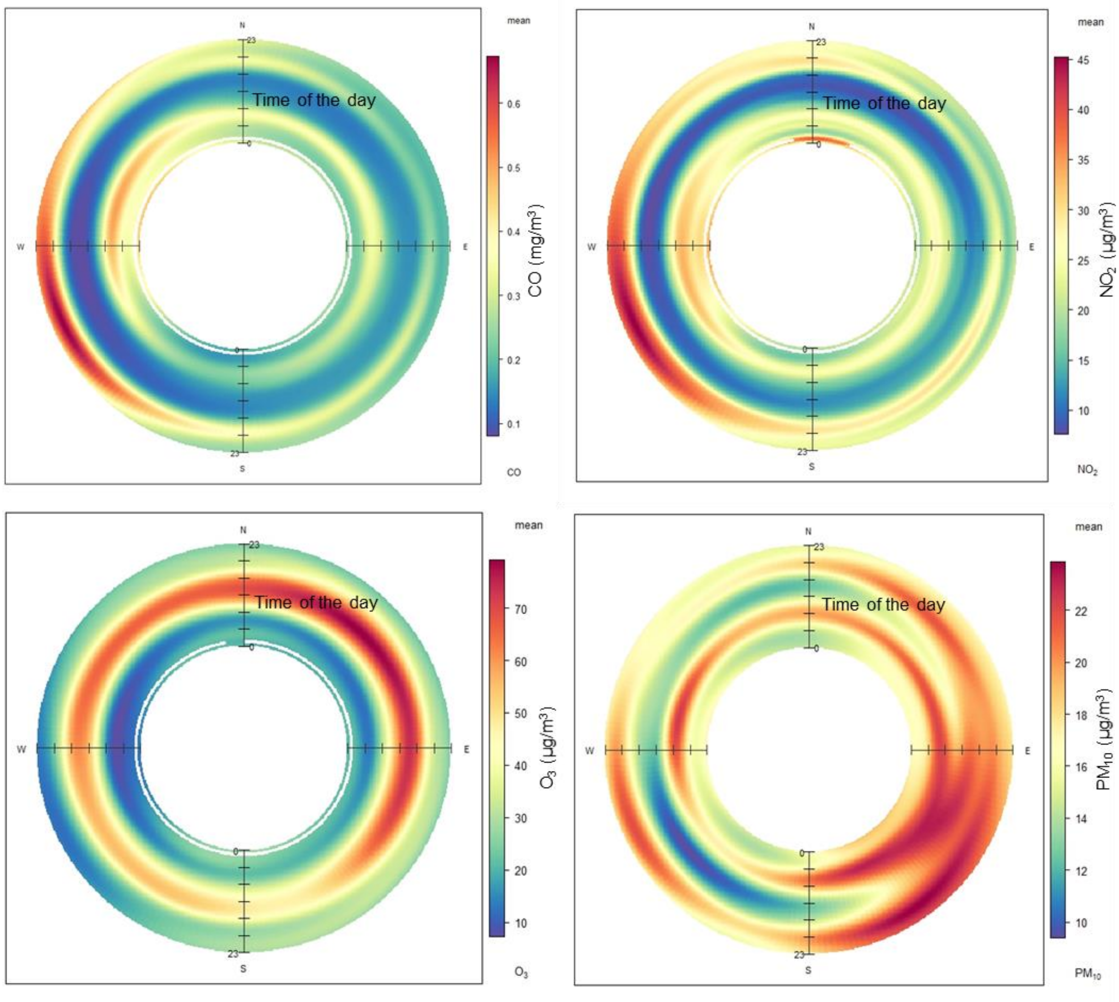


Figure A5-6 is the polar annulus plots of CO, NO_2, O_3 and PM_{10} *concentration at OEH Prospect site.*

A6 Randwick

A6.1 Time variation plots

The time variation plots of NO_2, O_3 and PM_{10} concentration at OEH site Randwick are provided in Figure A6-1 to Figure A6-3.

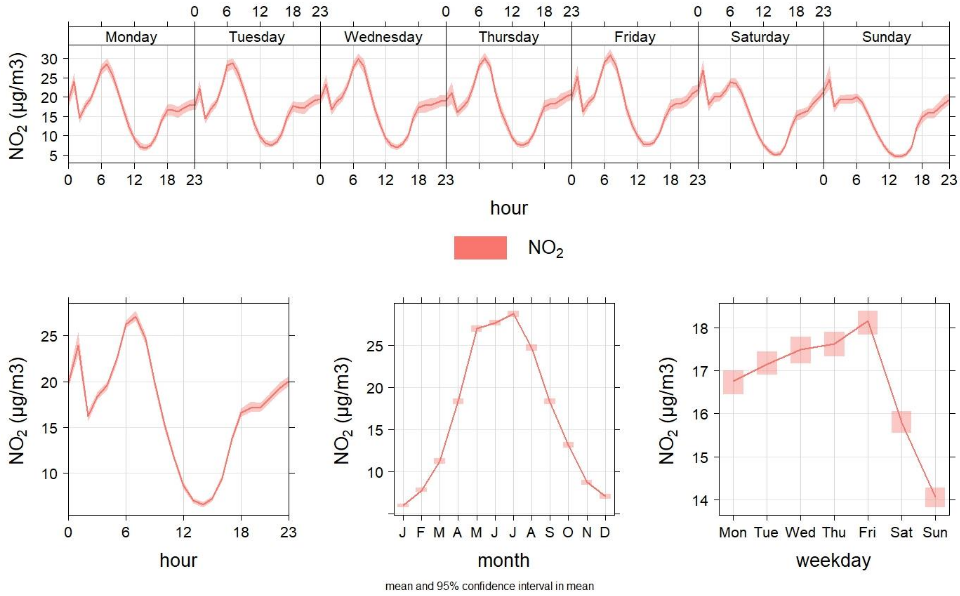


Figure A6-1 *Time variation plots of NO_2 concentration at OEH Randwick site.*

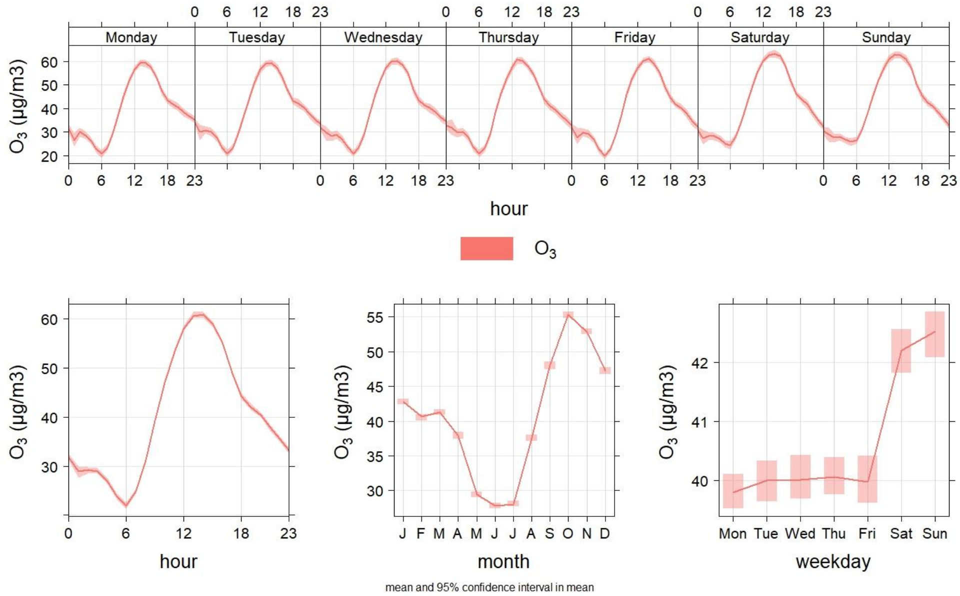


Figure A6-2 *Time variation plots of O_3 concentration at OEH Randwick site.*

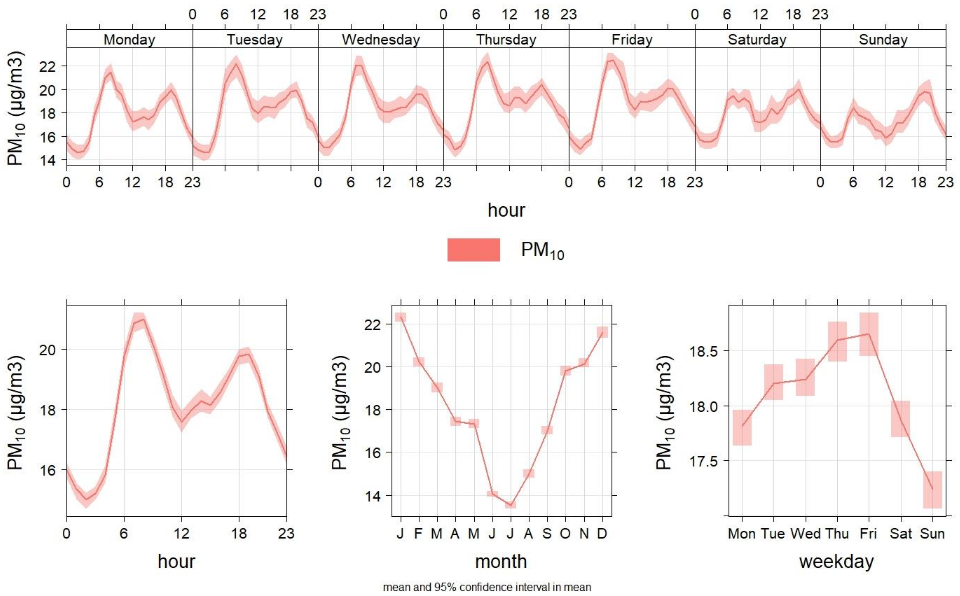


Figure A6-3 *Time variation plots of PM_{10} concentration at OEH Randwick site.*

A6.2 Bivariate polar plots

The bivariate polar plots of NO_2, O_3 and PM_{10} concentration at OEH Randwick site is provided in Figure A6-4.

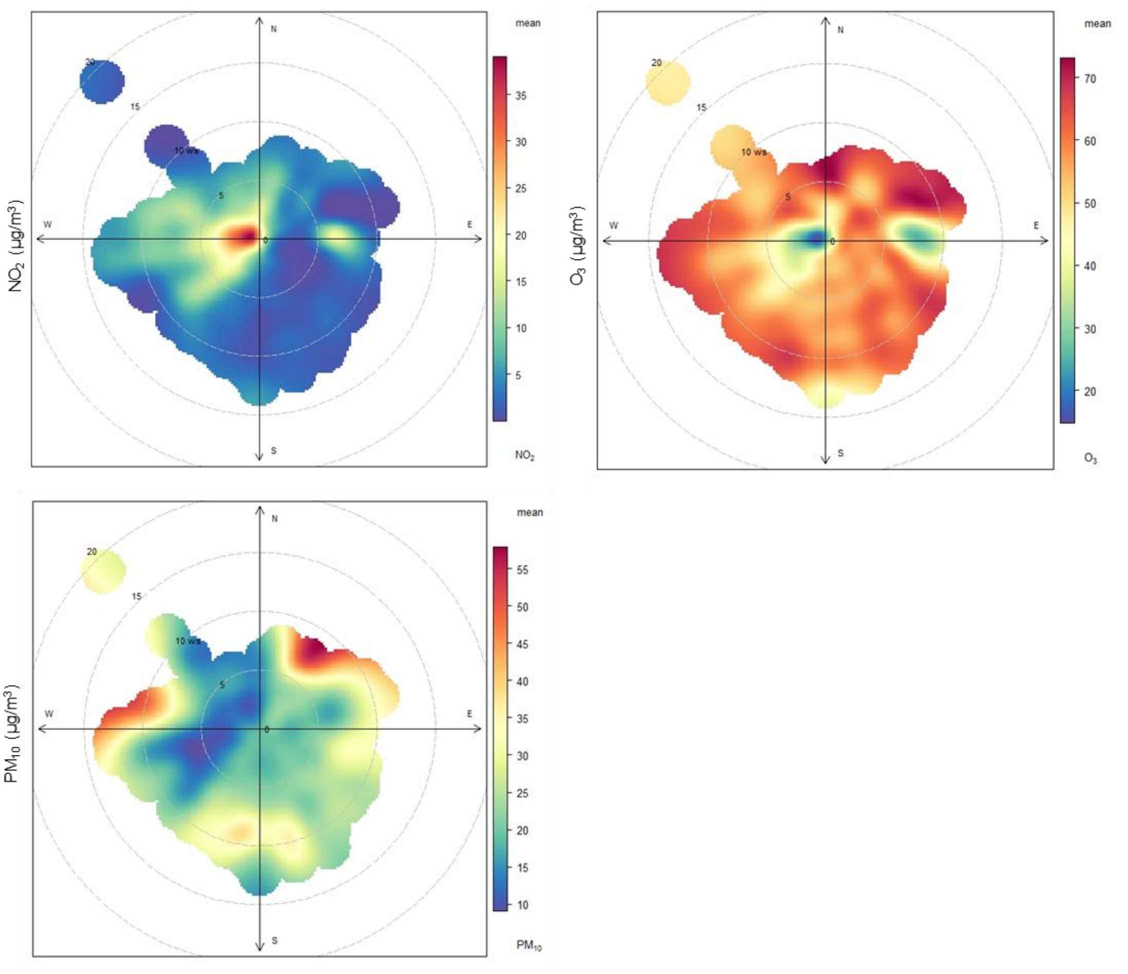


Figure A6-4 *Bivariate polar plots of NO_2, O_3 and PM_{10} concentration at OEH Randwick site.*

A6.3 Polar annulus plots

The polar annulus plots of NO_2, O_3 and PM_{10} concentration at OEH site Randwick are shown in Figure A6-5.

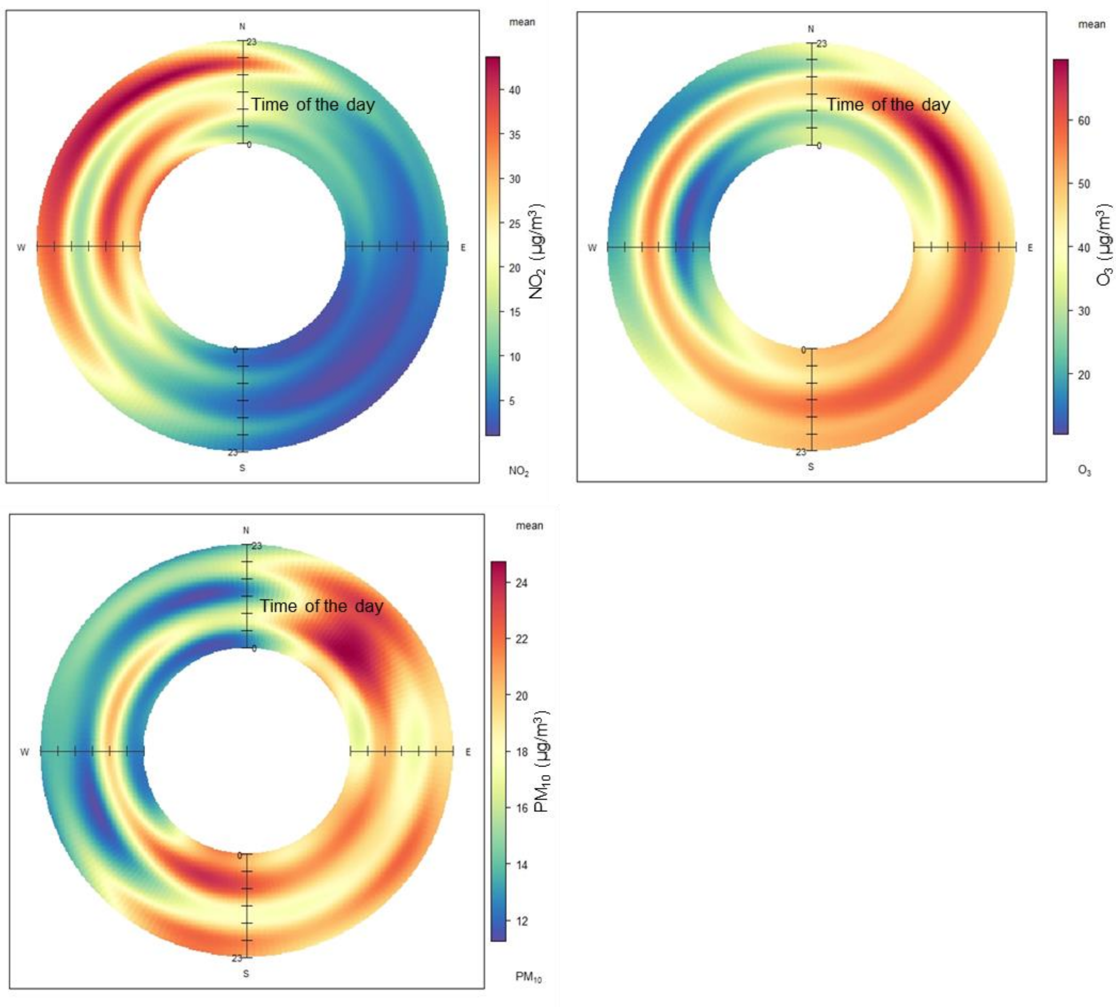


Figure A6-5 is the polar annulus plots of NO_2, O_3 and PM_{10} *concentration at OEH Randwick site.*

A7 Rozelle

A7.1 Time variation plots

The time variation plots of CO, NO_2, O_3 and PM_{10} concentration at OEH site Rozelle are Shown in Figure A7-1 to Figure A7-4.

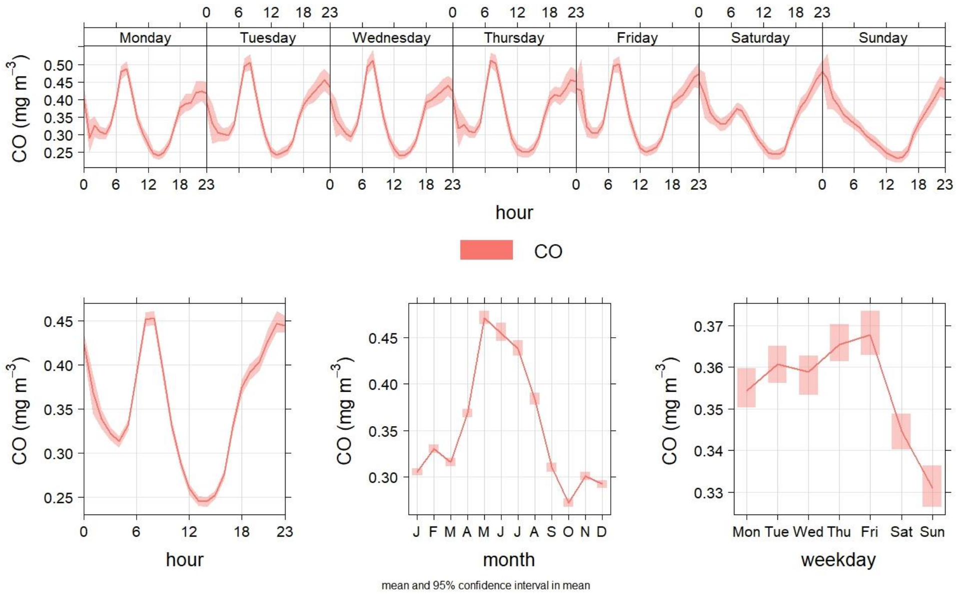


Figure A7-1 *Time variation plots of CO concentration at OEH Rozelle site.*

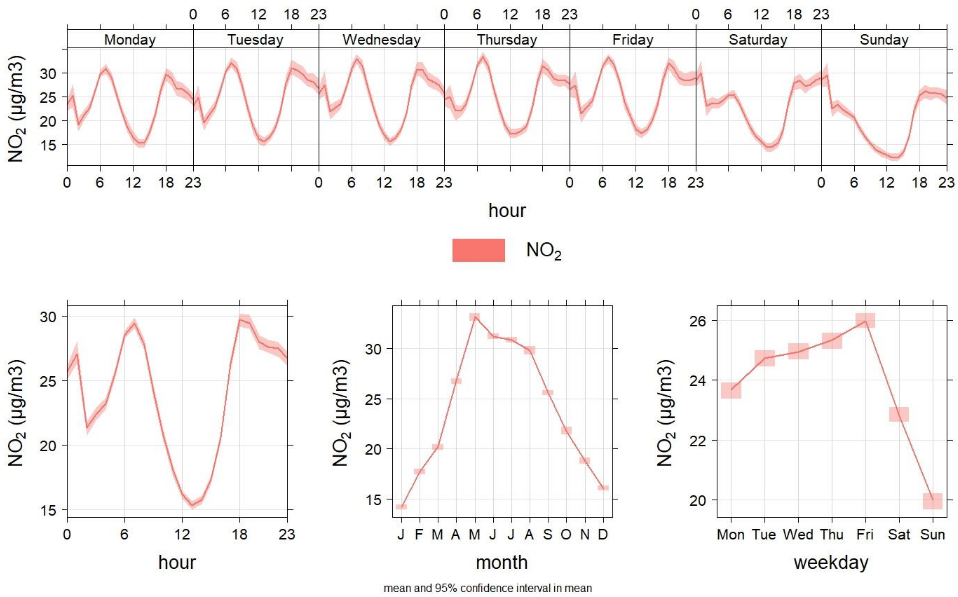


Figure A7-2 *Time variation plots of NO_2 concentration at OEH Rozelle site.*

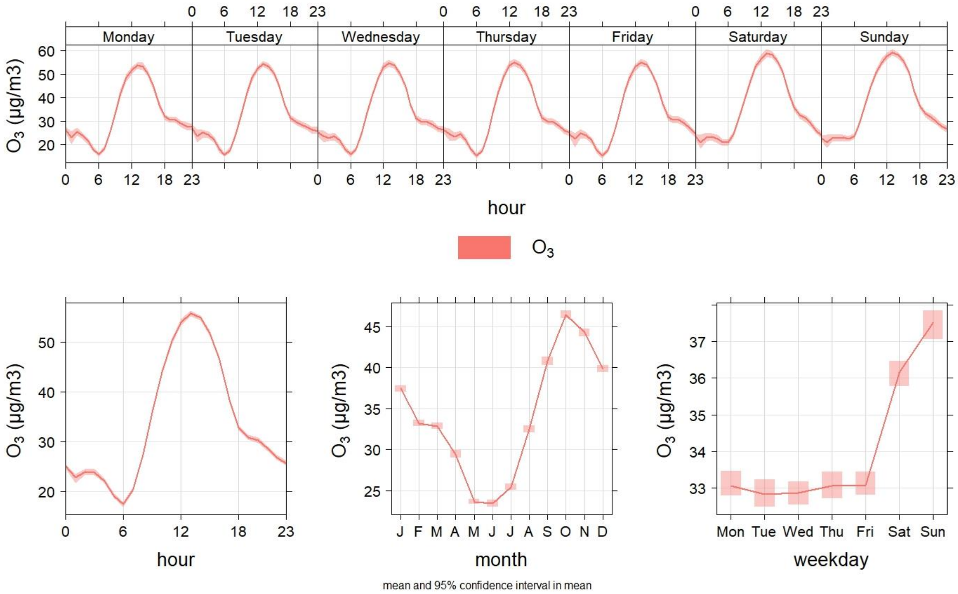


Figure A7-3 *Time variation plots of O_3 concentration at OEH Rozelle site.*

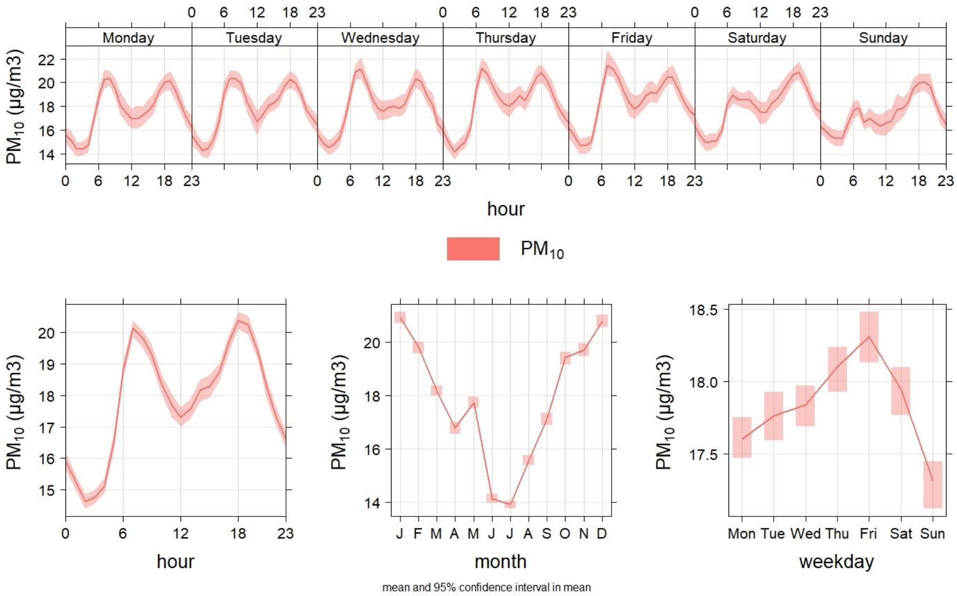


Figure A7-4 *Time variation plots of PM_{10} concentration at OEH Rozelle site.*

A7.2 Bivariate polar plots

The bivariate polar plots of CO, NO_2, O_3 and PM_{10} concentration at OEH site Rozelle are presented in Figure A7-5.

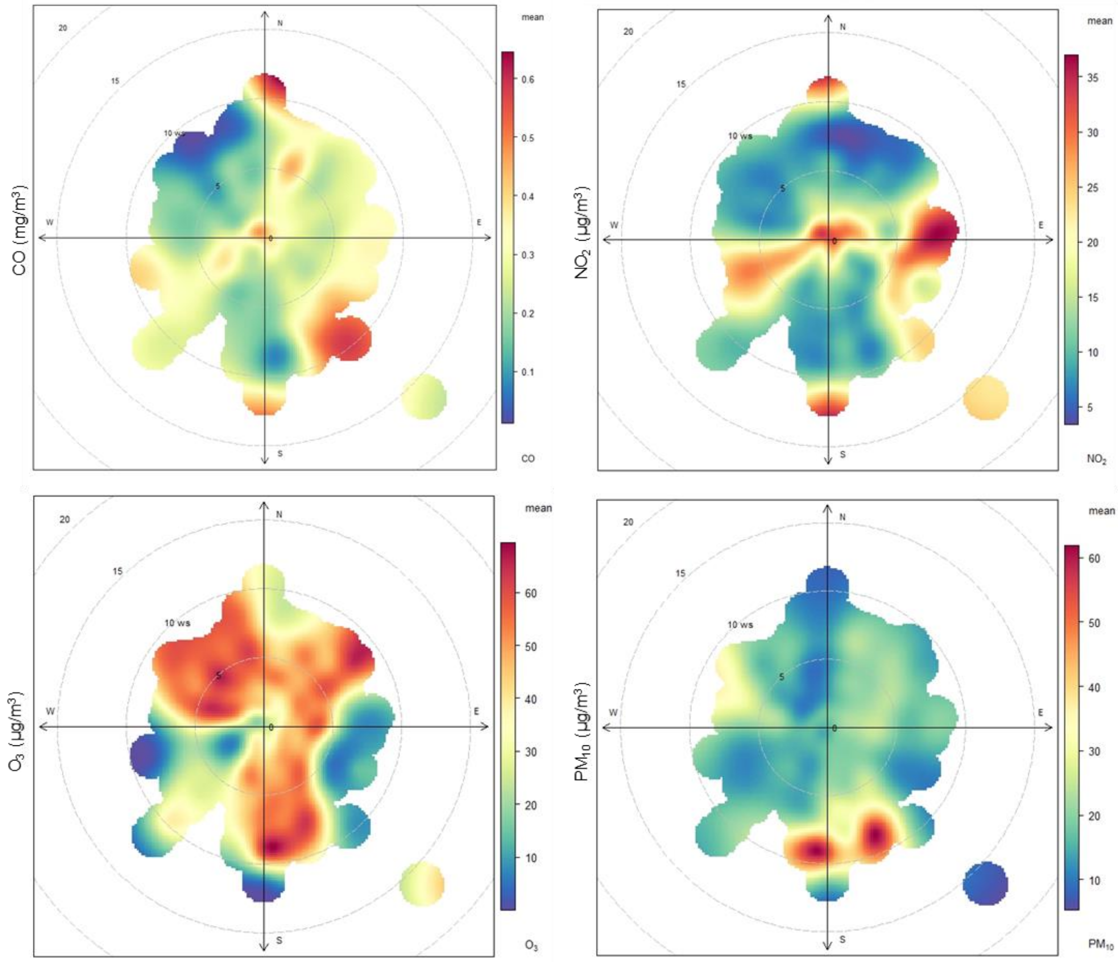


Figure A7-5 *Bivariate polar plots of CO, NO_2, O_3 and PM_{10} concentration at OEH Rozelle site.*

A7.3 Polar annulus plots

The polar annulus plots of CO, NO_2, O3 and PM_{10} concentration at OEH Rozelle site is provided in Figure A7-6.

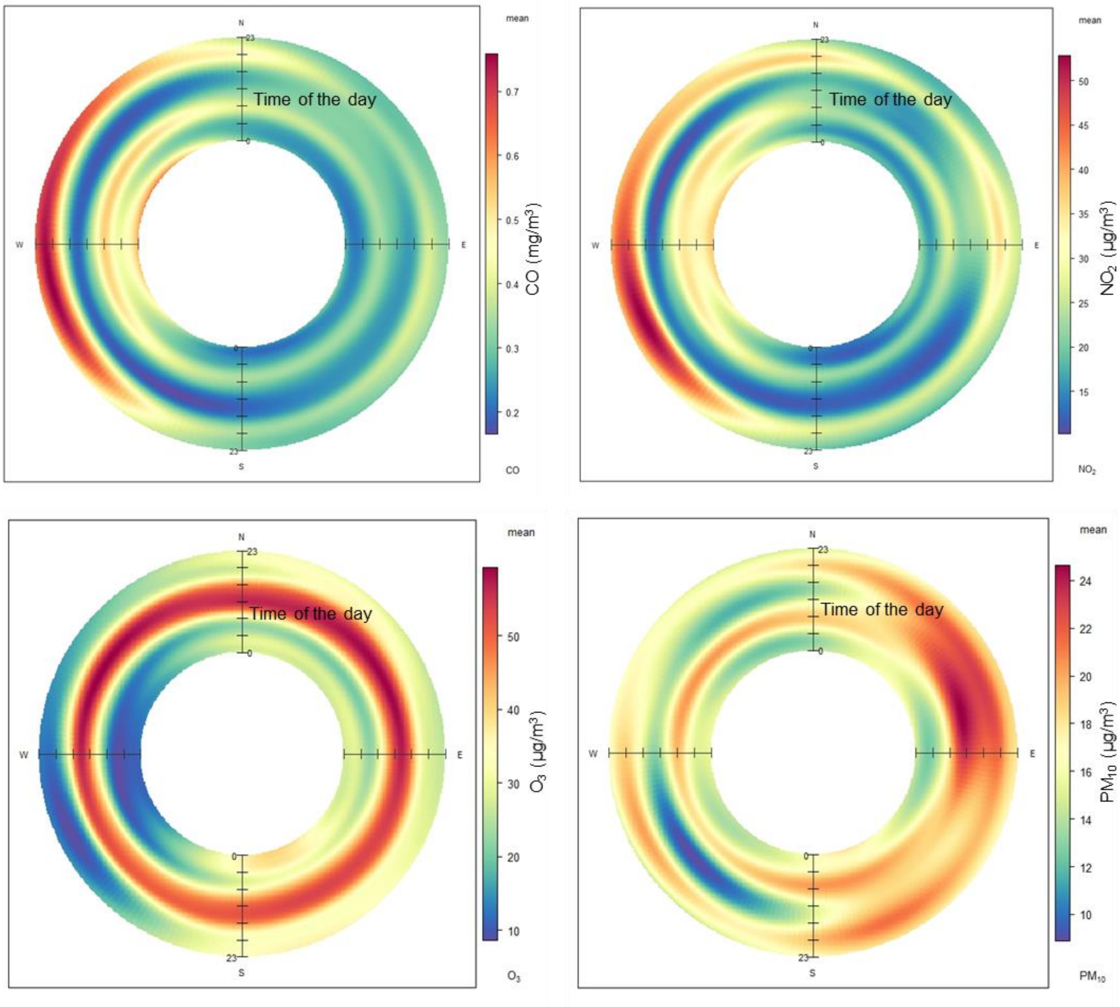


Figure A7-6 is the polar annulus plots of CO, NO_2, O_3 and PM_{10} *concentration at OEH Rozelle site.*