NSW GOVERNMENT
Environment, Climate Change & Water

Current air quality in New South Wales

A technical paper supporting the Clean Air Forum 2010

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Published by:

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ISBN 978 1 74232 903 1
DECCW 2010/728
August 2010

Printed on recycled paper

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1 Introduction

Everyone has a right to breathe clean air, and air pollution is a concern to many people living in Sydney and other populated regions in New South Wales.

Air pollution comes from various sources: industrial sources such as factories, power plants, and smelters; mobile sources such as cars, buses, trucks, planes, ships, and trains; and natural sources such as bushfires, windblown dust, and biogenic emissions from vegetation. The release of pollutants into the atmosphere and their removal are on-going processes affected by source strengths, sunlight, moisture, clouds, rain, geography, and regional and local weather patterns.

Exposure to air pollution is associated with numerous effects on human health, including respiratory problems, hospitalisation for heart and lung diseases and even premature death. Children are at greater risk because they are generally more active outdoors and their lungs are still developing. The elderly and people with heart and lung diseases are also more sensitive to some types of air pollution.

The air we breathe today is substantially cleaner than it was in the 1980s and 1990s. The NSW Government's 25 year Air Quality Management Plan, *Action for Air,* begun in 1998 and most recently updated in 2009, continues to bring forward new programs to reduce emissions from industry, business, homes and transport.

However, NSW still faces significant challenges in meeting health-based national air quality goals. Of the six key air pollutants included under the National Environment Protection Measure for Ambient Air Quality (the 'Air NEPM'[1]), only two – photochemical smog (as ozone) and to a lesser extent, fine particles (as PM_{10}) – remain significant issues for NSW. This is particularly apparent in the case of photochemical smog in western Sydney and fine particles in regional NSW.

Air quality monitoring has been undertaken in Sydney since the early 1950s. The Department of Environment, Climate Change and Water NSW (DECCW) currently operates a comprehensive statewide air quality monitoring network (AQMN). The network has sites throughout the State, with particular focus on the main population centres of Sydney, the lower Hunter and the Illawarra. Data from the network are used to determine the state of air quality in NSW and help develop programs to reduce the burden of air pollutants, address key air issues, and assess the effectiveness of policy and programs.

This background report has been prepared to show the changes and improvements in ambient air quality for the period covering the first 12 years of the *Action for* Air plan. It also uses our air quality monitoring data and airshed computer simulation tools to address the question of the scale of emission reductions required to ensure we meet the Air NEPM standards and goals in the future.

This analysis will assist us in making informed decisions on what needs to be done to protect and improve the air quality for all communities in NSW.

[1] 'Air NEPM' is the abbreviation for the *National Environment Protection (Ambient Air Quality) Measure* (NEPC 2003).

Previous and current strategies have been effective in reducing pollutants. However, gains have been reduced due to growth in emissions sources, and further reductions in the future will be affected by the impacts of climate change.

1.1 Air quality monitoring in NSW

DECCW operates a comprehensive air quality monitoring network throughout the State, focused on the main population centres of Sydney, the lower Hunter, and the Illawarra. The monitoring network is shown in Figure 1.1.

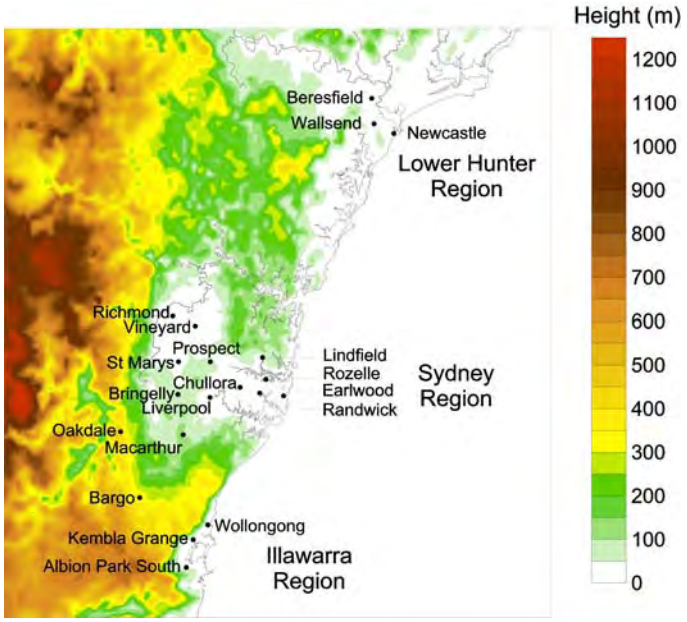
Air quality monitoring in NSW began in the early 1950s. As part of the Metropolitan Air Quality Study (MAQS) undertaken from 1992 to 1995, the monitoring network was expanded to include monitoring in the urban growth areas in the west, north-west and south-west of Sydney; to provide additional monitoring in the Illawarra; and to commence monitoring in the lower Hunter. Since early 1994, NSW has had a comprehensive monitoring network for the Greater Metropolitan Region (GMR)[2] measuring concentrations of the major air pollutants: particles, carbon monoxide, sulfur dioxide, nitrogen dioxide, ozone and lead.

The air monitoring network also delivers the information needed to meet the reporting commitments made when NSW signed the Air NEPM in 1998.

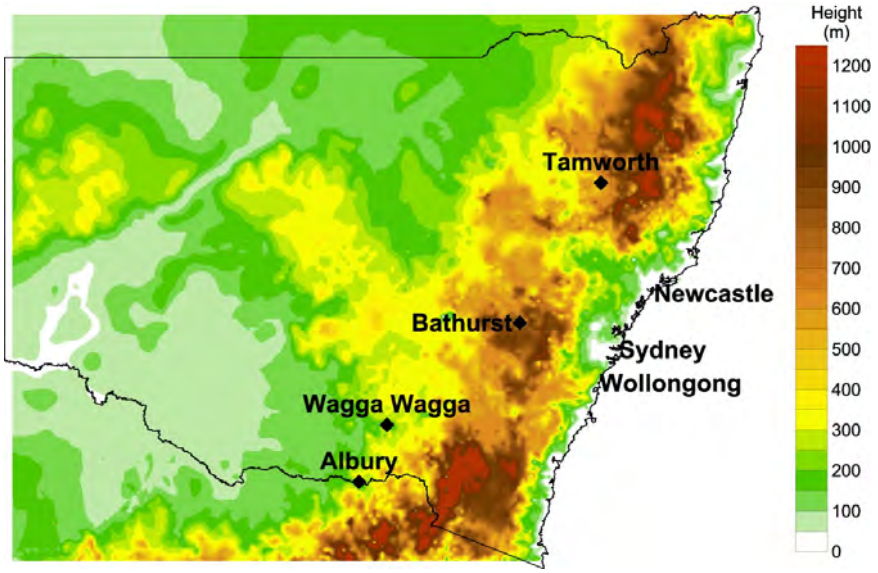
The Air NEPM has also led to monitoring in regional centres. Monitoring of PM_{10} – particulate matter with an aerodynamic diameter of up to 10 µm – continues in Albury, Bathurst, Tamworth and Wagga Wagga. Ozone monitoring was undertaken at Bathurst in the summers of 2000–01, 2001–02 and from September 2002 to July 2007.

The current NSW air quality monitoring network has, as its basis, a core of 14 sites in the Sydney region, three in the Illawarra, three in the lower Hunter and four in rural population centres.

[2] The Greater Metropolitan Region extends from the upper Hunter Valley in the north to just south of Wollongong and includes the four major population centres of NSW: Sydney, Newcastle, the Central Coast and Wollongong. See Figure 1.2.



(a) Greater Metropolitan Region (GMR)



(b) Rural population centres

Figure 1.1: Current measurement sites in NSW

1.1.1 Sydney region

The Sydney region is the largest population centre in NSW. The Sydney basin is bound by elevated terrain to the north, west and south. Its northern coastal strip extends into the southern part of the Central Coast urban region.

In the west of the region is the Hawkesbury Basin, which is separated from the rest of the region by the Blacktown Ridge. Air quality data show that the north and south of the Hawkesbury Basin have distinct patterns of air pollutant concentration, largely because the sea breeze is generally north-easterly.

DECCW operates 14 measurement stations in the Sydney region (Figure 1.1a).

1.1.2 Illawarra region

The Illawarra (Wollongong) region is the fourth largest population centre of NSW.[3] The region is located on a thin coastal strip with a steep escarpment to the west. The width of the coastal strip increases from north to south until it terminates in a ridge of hills running from the escarpment to the sea. As the significant topographic feature, the escarpment is a major influence on meteorology and hence on air quality in the region: a temperature inversion can form at the top of the escarpment, limiting the dispersion of pollutants within the Illawarra region.

Sea breezes are the dominant meteorological influence on elevated concentrations of ozone in the region. Westerly drainage flows have been observed to develop in the region overnight and have some influence on air quality. The Illawarra region is only 80 km to the south of the Sydney region and pollutants can be transported between the two, particularly from Sydney to the Illawarra. Most ozone events in the Illawarra occur as a result of local emissions combined with pollution transported from other regions.

DECCW operates three measurement stations in the Illawarra region (Figure 1.1a).

1.1.3 Lower Hunter region

The lower Hunter (Newcastle) region is the second most populated region in NSW, with a regional population estimated at over 350,000. The lower Hunter region is defined to be that part of the Hunter River valley where it opens out to a coastal plain. It is bounded to the east by the coast and inland by the higher terrain enclosing the coastal plain. It is separated from the remainder of the Hunter River valley by the rise in the valley floor north-west of Maitland. The coastal strip extends to the south to include the northern part of the Central Coast urban centre.

DECCW operates three measurement stations in the lower Hunter region (Figure 1.1a).

1.1.4 Proposed upper Hunter monitoring

DECCW is currently finalising plans to significantly expand the existing air quality monitoring network to cover the upper Hunter region of NSW.

1.1.5 Rural population centres

Monitoring for Air NEPM purposes is required for every region with a population of 25,000 or more. Monitoring sites have been established at Albury, Wagga Wagga, Bathurst and Tamworth to meet this requirement (Figure 1.1b).

Albury (and its Victorian counterpart Wodonga) is located some 450 kilometres to the south-south-west of Sydney straddling the Murray River. Elevated ground to the north, east and south of the Murray River forms Albury's southern boundary. The populated area extends into the higher ground rather than to the west where the elevation is lower.

Bathurst is located about 150 km west of Sydney in the Central Tablelands, on the banks of the Macquarie River. Higher ground rises to the south-west of the city centre.

[3] The third largest population centre is the Central Coast. The lower Hunter is the second largest.

Tamworth is located about 300 km north of Sydney in the North-West Slopes, on the local flood plain of the Peel River. It lies within its own airshed, with no other significant urban centre nearby. The city has hills to the north and west. There are no significant industrial sources of pollution in the region.

Wagga Wagga is located about 400 km south-west of Sydney in the South-West Slopes, on the banks of the Murrumbidgee River.

1.2 National standards and goals

1.2.1 Air quality standards

The Air NEPM specifies air quality standards which the NSW Government and other jurisdictions have adopted (NEPC 1998). The environmental objective of this NEPM is ambient air quality that provides adequate protection of human health. The Air NEPM standards and goals are set out in Table 1.1. In 2003 the Air NEPM was varied (NEPC 2003) to include advisory reporting standards for particles as $PM_{2.5}$. These are set out in Table 1.2.

Table 1.1: National ambient air quality standards and goals

Pollutant	Averaging period	Maximum concentration	Goal within 10 years (Maximum allowable exceedences)
Carbon monoxide	8 hours	9.0 ppm	1 day a year
Nitrogen dioxide	1 hour	0.12 ppm	1 day a year
	1 year	0.03 ppm	none
Photochemical oxidants (as ozone)	1 hour	0.10 ppm	1 day a year
	4 hours	0.08 ppm	1 day a year
Sulfur dioxide	1 hour	0.20 ppm	1 day a year
	1 day	0.08 ppm	1 day a year
	1 year	0.02 ppm	none
Lead	1 year	0.50 µg/m^3	none
Particles as PM_{10}	1 day	50 µg/m^3	5 days a year

Table 1.2: Advisory reporting standards and goal for particles as $PM_{2.5}$

Pollutant	Averaging period	Maximum concentration	Goal
Particles as $PM_{2.5}$	1 day	25 µg/m^3	Goal is to gather sufficient data nationally to facilitate a review of the Advisory Reporting Standards as part of the review of this Measure scheduled to commence in 2005
	1 year	8 µg/m^3	

1.2.2 Air toxics

In 2004 a national framework for monitoring, assessing and reporting the concentrations of selected air toxics was agreed to in the National Environment Protection (Air Toxics) Measure (NEPC 2004) (the 'Air Toxics NEPM'). The Air Toxics NEPM establishes monitoring investigation levels (MILs) for five air toxics relevant to human health (Table 1.3). The MILs are chosen conservatively so that, on current information, exposure at these concentrations is unlikely to result in adverse health effects (NSW Health 2004).

Table 1.3: Air Toxics NEPM monitoring investigation levels (MILs)

Pollutant	Averaging period	MIL	Goal
Benzene	annual average	0.003 ppm	Eight-year goal is to gather sufficient data nationally to facilitate development of a standard
Benzo[α]pyrene	annual average	0.3 ng/m^3	
Formaldehyde	24 hours	0.04 ppm	
Toluene	24 hours annual average	1.0 ppm 0.1 ppm	
Xylenes (total of ortho, meta and para isomers)	24 hours annual average	0.25 ppm 0.20 ppm	

1.3 Inventory of major emission sources in the GMR

Air pollution arises from a range of emissions including both natural and human sources. DECCW has developed a detailed **air emissions inventory** that gives as complete a picture as possible of emissions being released into the atmosphere – by type, source, location and over time. The inventory covers the Greater Metropolitan Region (GMR) and its domain is shown in Figure 1.2. The base year of the inventory represents activities that took place during 2003.

The inventory is constructed by combining information from industry, government departments, surveys and estimates. Data are assigned to map reference points (1-km^2 grid cells) and are calculated for different time periods according to typical activity patterns.

Emission categories include:

- biogenic (natural) sources, e.g. bushfires and vegetation
- industrial premises, e.g. oil refineries and power stations
- commercial businesses, e.g. quarries, service stations, smash repairers
- domestic activities, e.g. house painting, lawn mowing, wood heaters
- on-road mobile sources, e.g. buses, cars, trucks
- off-road mobile sources, e.g. aircraft, trains, recreational boats.

The inventory accounts for over 90 air pollutants, including:

- criteria pollutants (those covered by the Air NEPM) – carbon monoxide (CO), sulfur dioxide (SO_2), lead, oxides of nitrogen (NO_x), PM_{10} and $PM_{2.5}$
- volatile organic compounds (VOCs)
- metal air toxics, e.g. antimony, arsenic, beryllium, chromium and nickel
- organic air toxics, e.g. benzene, formaldehyde, polycyclic aromatic hydrocarbons (PAHs), toluene and xylenes.

Ozone, the main component of photochemical smog, is a secondary pollutant formed from emissions of VOCs and NO_x. It is not emitted directly from a particular source or activity, so it is not listed in the inventory as an air pollutant. Strategies for managing ozone (smog) depend on reducing emissions of VOCs and NO_x.

By showing in detail where the air pollution is coming from, the emissions inventory can be used to help develop better approaches to improving air quality. It can also be used to forecast future air quality conditions, with or without proposed mitigation actions, using emission projections in yearly increments up to 2031.

The current air emissions inventory (base year 2003) took three years to develop and was published as a series of technical reports. Detailed data and summary reports covering all pollutants in the new emissions inventory were released in 2007 and are available from the DECCW website www.environment.nsw.gov.au/air/airinventory.htm. A search tool for examining data by local government area gives users a greater ability to target management actions and view trends in emissions over time. This report includes only broad inventory findings for the key ambient air pollutants.

The air emissions inventory is currently being updated with data from 2008. The inventory methodology used in this update is being refined to allow more detailed analysis of emissions and their sources across the GMR.

Figure 1.2: Delineation of the Greater Metropolitan Region (GMR), lower Hunter (Newcastle), Sydney and Illawarra (Wollongong) regions

2 Carbon monoxide

Carbon monoxide (CO) is a colourless, odourless gas and is the most common pollutant by mass in the atmosphere. It can have harmful effects on human health. These effects, which depend on exposure time and the gas's concentration in the air, are related to the formation of carboxyhaemoglobin in the blood, which reduces the capacity of the blood to carry oxygen.

CO is a product of the incomplete burning of fossil fuels. The main sources of CO in the GMR are industrial premises and on-road mobile, whereas in Sydney the dominant source is on-road mobile. Generally, in NSW, elevated concentrations of CO have occurred only in areas with high traffic density and poor dispersion.

2.1 CO monitoring in NSW

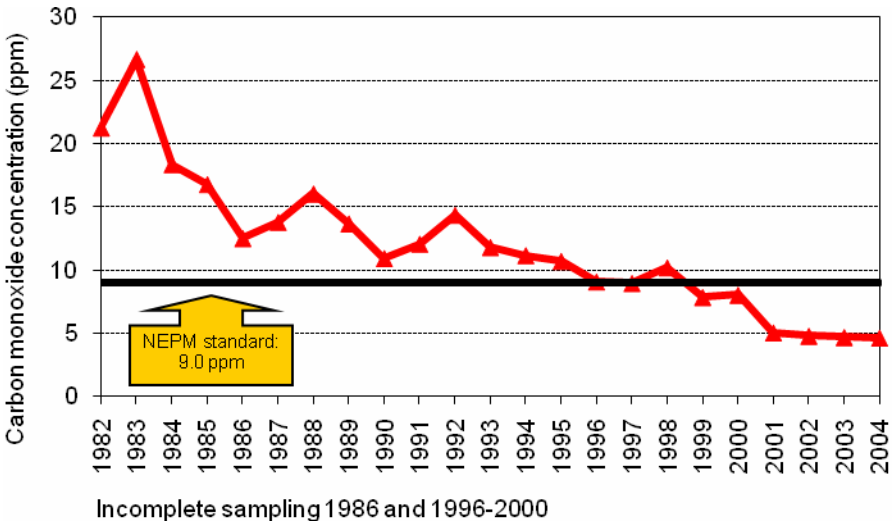
CO is currently monitored at five stations in the Sydney region (Chullora, Liverpool, Macarthur, Prospect and Rozelle) and one in each of the Illawarra (Wollongong) and lower Hunter (Newcastle) regions.

CO was monitored in the Sydney CBD until 2004. The station was located on George Street at a height just above that of bus and truck exhaust pipes and where high-rise buildings limit dispersion. It was chosen as a peak site intended to capture the highest CO concentrations occurring in the Sydney region. The station collected over 20 years of data before being closed in August 2004. Figure 2.1a shows a consistent fall in CO concentrations at this site from 1994–2004.

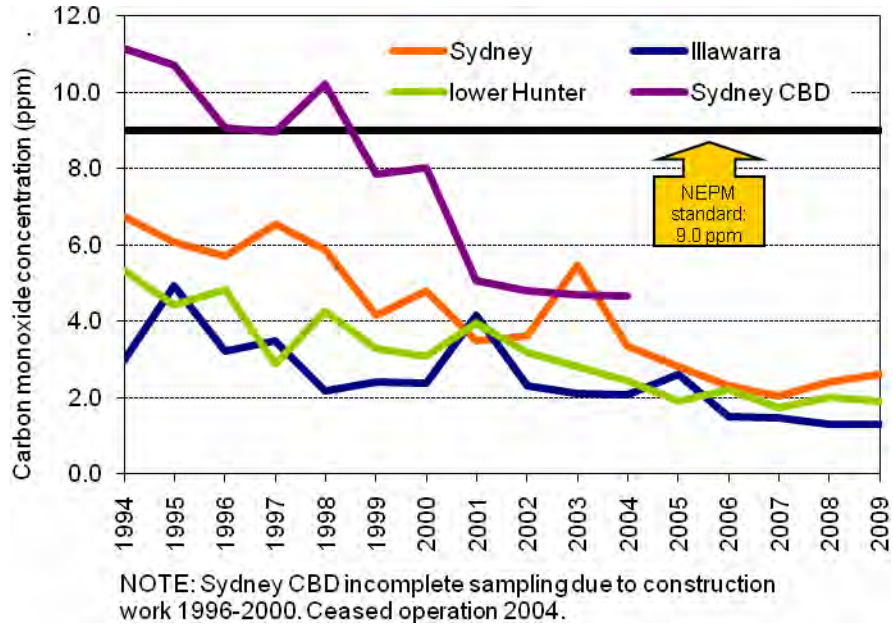
2.2 CO concentrations in NSW

During the 1980s, CO concentrations in the CBD exceeded the standard on up to 109 days per year, and the maximum concentration of 26.7 parts per million (ppm) was almost three times the standard (Figure 2.1a). Since the introduction of unleaded petrol and catalytic converters in 1985, peak CO concentrations in the CBD have plummeted. The last exceedence of the CO standard in NSW was recorded in 1998, and since 2002, maximum 8-hour concentrations have been half the standard or less.

As shown in Figure 2.1b, apart from the CBD peak monitoring station, concentrations of CO at the other stations have never exceeded the standard and have fallen considerably over the past 13 years. The maximum recorded values in these areas are now typically less than 30% of the standard.



(a) Maximum 8-hour average CO concentrations in the Sydney CBD (peak site) (1982–2004)



(b) Maximum 8-hour average CO concentrations in NSW

Figure 2.1: CO concentrations in NSW (1994–2009)

2.3 CO summary

Since the 1980s there has been a significant fall in maximum 8-hour CO concentrations in the CBD. The introduction of unleaded petrol and improved engine emission controls has greatly reduced CO emissions from motor vehicles. The Air NEPM standard for CO is no longer exceeded at any NSW monitoring station.

3 Lead

Lead is a highly toxic metal that is poisonous in all forms. Lead is absorbed into the human body through both ingestion and inhalation It accumulates in the body and the toxic effects are numerous and severe. The main concern about lead in air is its potential to impair intellectual development in children. At high concentrations, lead can also have a wide range of other health effects, particularly on the blood, central nervous system and gastrointestinal system.

Lead is emitted into the air from both mobile and stationary sources. In major cities, the dominant source of the lead to which humans are exposed has been emissions from motor vehicles operating on leaded petrol. Lead concentrations may also be locally elevated around industry sources such as metal smelters. The main source of lead emissions in the GMR and Sydney is off-road mobile, and 92% of this contribution comes from wheel-generated dust from industrial off-road vehicles and equipment.

3.1 Lead monitoring in NSW

Lead was measured from 1983 to 2005 at three sites in Sydney (the CBD, Earlwood and Rozelle) and at three peak monitoring sites in Port Kembla, close to industry sources in the Illawarra. Lead monitoring was undertaken at two more sites to meet the monitoring requirements of the Air NEPM – Wallsend in the lower Hunter region (2001–2004) and Warrawong in the Illawarra region (1998–2004).

Lead monitoring for the Air NEPM was phased out in 2004 with no further routine monitoring from 1 January 2005. A report summarising the case for discontinuing lead monitoring was presented to the National Environment Protection Council (NEPC).

3.2 Lead concentrations in NSW

Figure 3.1 shows the significant fall in annual concentrations of lead throughout the GMR from 1990 to 2004. By 2004, annual average data throughout NSW had decreased to typically less than 0.03 µg/m^3 and many 24-hour average data were below the minimum detection limit. The highest annual average since 2000 was 0.11 µg/m^3, recorded at Port Kembla during 2002. This annual average is only 22% of the national standard despite the Port Kembla monitoring site being located close to industrial sources of lead emissions at the time.

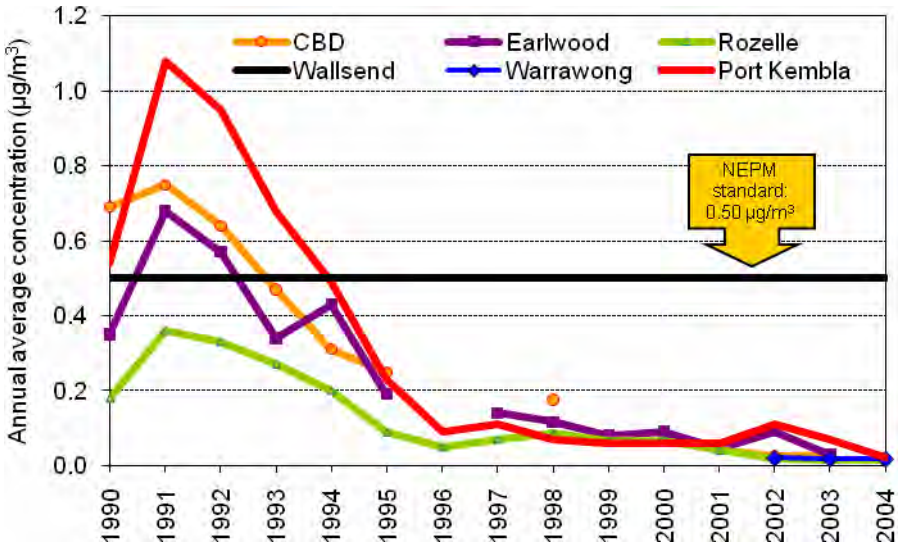


Figure 3.1: Annual average lead concentrations in NSW (1990–2004)

3.3 Lead summary

Monitoring of atmospheric lead was conducted in the Sydney region for over 20 years. During that time there was a significant fall in annual maximum concentrations of lead throughout the GMR.

The reduction in ambient concentration of lead in the GMR can be attributed to significant industry emission reductions, the introduction of unleaded petrol in 1985, the progressive reduction of the lead content of leaded petrol and the subsequent ban on lead in petrol from 2002. With a complete ban on lead in petrol in force, the primary source of lead in air at the regional level has now been eliminated.

4 Nitrogen dioxide

Oxides of nitrogen, collectively referred to as NO_x, are formed during combustion, by lightning strikes and as part of the normal chemistry of the upper atmosphere. Nitric oxide (NO) is the most abundant form of NO_x, and is the predominant form generated by combustion. Nitrogen dioxide (NO_2) is the other main form generated. Additional NO_2 is produced by oxidation of NO in atmospheric photochemical reactions.

The reactive nature of NO_2 makes it a particular concern for human health. NO_2 can cause inflammation of the respiratory system and increase susceptibility to respiratory infection. Exposure to elevated concentrations of NO_2 has also been associated with increased mortality, particularly related to respiratory disease, and increased hospital admissions for asthma and heart disease patients.

In addition to its adverse health effects, NO_2 is a key component of photochemical smog formation.

In urban areas, elevated concentrations of NO_2 can occur in the cooler months, when lower temperatures and less sunlight mean that the NO_2 is not as readily converted to ozone. Elevated concentrations of NO_2 tend to occur in or close to urban areas, under stable atmospheric conditions.

Industrial premises, in particular coal-fired power stations, are the most significant contributor to NO_x emissions in the GMR. The largest source of NO_x emissions in Sydney is the on-road mobile sector, which contributes more than 71% of these emissions.

4.1 NO_x monitoring in NSW

Nitrogen dioxide (NO_2) is measured as the difference between NO and NO_x, the instrument returning all three concentrations. Continuous NO_x monitoring has been conducted in NSW since the 1970s. NO_x is currently measured at fourteen sites in Sydney, three in the Illawarra and three in the lower Hunter.

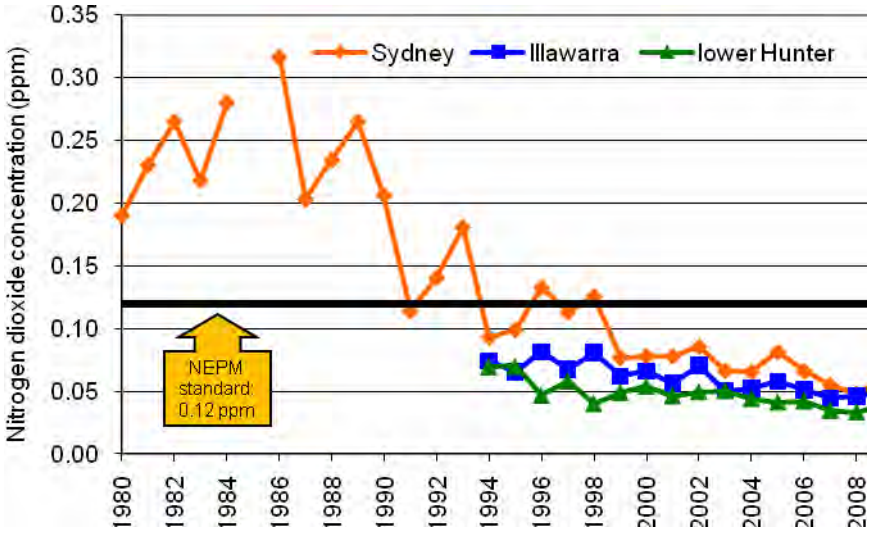
4.2 NO_2 concentrations in NSW

During the 1980s, exceedences of the 1-hour NO_2 standard were common in Sydney, particularly during winter. Since then, concentrations have fallen substantially and the 1-hour standard has not been exceeded in Sydney since 1998. Maximum 1-hour concentrations are now well below the standard (Figure 4.1a), and annual average concentrations are typically less than half the standard (Figure 4.1b). NO_2 concentrations in the Illawarra and lower Hunter are even lower than those in Sydney.

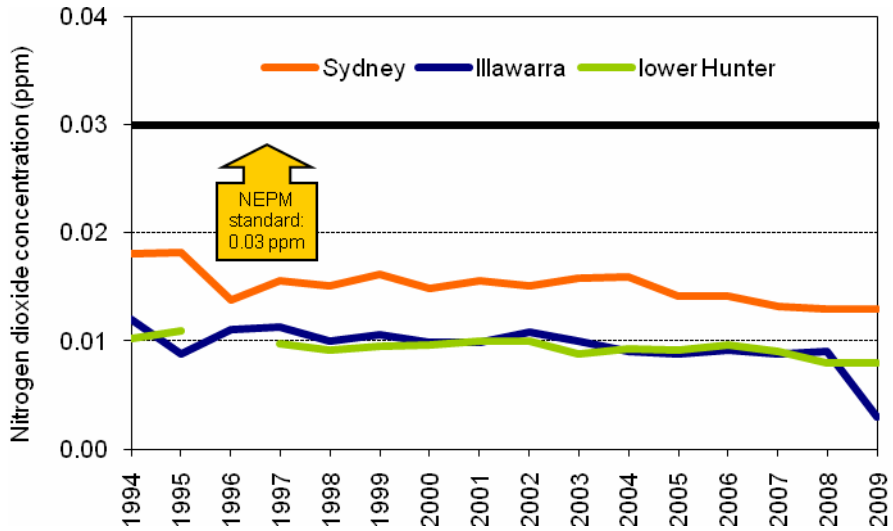
4.3 NO_2 summary

NSW has met the Air NEPM goal for nitrogen dioxide since 1994. Current maximum NO_2 concentrations are well below both the 1-hour and annual standards. The last single recorded exceedence of the 1-hour standard was in 1998.

On-road motor vehicles are the biggest source of NO_x in the Sydney region. Stricter fuel standards and lower emission limits have reduced the amount of NO_2 emitted per kilometre travelled. Total emissions from this sector are projected to fall even though total motor vehicle usage is expected to increase as cars travel further on average and there are more of them. The reduction in total emissions arises from greatly reduced emissions per kilometre travelled due to current and proposed vehicle emission standards.



(a) Maximum 1-hour average NO_2 concentrations (1980–2009)



(b) Maximum annual average NO_2 concentrations (1994–2009)

Figure 4.1: Nitrogen dioxide concentrations in NSW

5 Sulfur dioxide

Sulfur dioxide (SO_2) is a colourless gas. Elevated SO_2 concentrations can lead to a range of health effects, and emissions of SO_2 have the potential to mix with water vapour to form acids (acid rain) that can damage vegetation, alter the mineral content in soils and corrode materials.

Industrial premises are the major source of SO_2 emissions in both the GMR and Sydney. Elevated concentrations of SO_2 detected around Australia are generally associated with the combustion of coal in power stations and the smelting of metal ores rich in sulfur, such as lead and copper sulfides. The presence of SO_2 in the air can also be the result of the combustion of fuels containing sulfur. Since Australian fuels are relatively low in sulfur, high ambient concentrations are not common in most cities.

5.1 SO_2 monitoring in NSW

Monitoring of sulfur dioxide is currently carried out at eight stations in the Sydney region (Bargo, Bringelly, Chullora, Macarthur, Prospect, Randwick, Richmond and Vineyard), two in the Illawarra (Albion Park South and Wollongong) and three in the lower Hunter (Beresfield, Newcastle and Wallsend).

5.2 SO_2 concentrations in NSW

Since SO_2 monitoring began, there have been no exceedences recorded of either the 24-hour or the annual standard in NSW. Typically, maximum 24-hour averages are between 8–12% of the standard, while maximum annual averages are between 5–10% of the standard.

In Sydney and the lower Hunter, no exceedences of the 1-hour SO_2 standard have been recorded since measurements began (Figure 5.1). The maximum 1-hour concentrations are typically less than 20% and 30% of the standard, for Sydney and the lower Hunter respectively.

In the Illawarra, exceedences of the 1-hour standard have been recorded at stations that were affected by local emissions from primary metal smelting industries. No exceedence of the 1-hour standard has been recorded in the Illawarra since 1993, following the closure of major copper smelting operations in the Port Kembla region. Maximum annual and 24-hour concentrations are now comparable to elsewhere in NSW. Hourly maximum concentrations are now well below the standard and comparable to the lower Hunter region, reflecting the higher proportion of industry in the Illawarra and lower Hunter compared to Sydney.

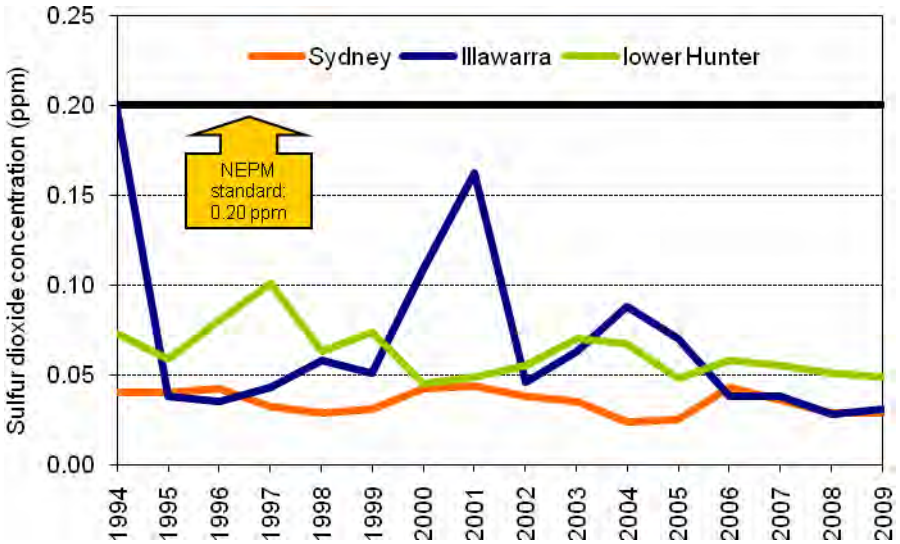


Figure 5.1: Maximum 1-hour average sulfur dioxide concentrations in NSW (1994–2009)

5.3 SO_2 summary

Historically, with the exception of stations located close to major industrial sources, SO_2 concentrations in NSW have been well below the Air NEPM standards. The closure of major copper smelting operations in the Port Kembla region and improved emission control technology at the steelworks has greatly reduced peak SO_2 concentrations in the Illawarra. Exceedences of the 1-hour standard no longer occur in the Illawarra. There is no significant trend in SO_2 concentrations in Sydney or the lower Hunter where concentrations are well below the standards and are expected to remain low in future.

6 Air toxics

Air toxics are pollutants present in the atmosphere in low concentrations that are known or suspected to cause serious health or environmental problems. Air toxics include volatile and semi-volatile organic compounds, polycyclic aromatic hydrocarbons (PAHs), heavy metals and aldehydes. The main concerns about many air toxics are the health effects associated with long-term exposure. There is evidence that exposure to these substances is linked to cancer, birth defects, genetic damage, immunodeficiency, and respiratory and nervous system disorders.

Motor vehicle exhaust and petroleum fuels are the major sources of benzene, toluene and xylenes. Motor vehicles and the burning of coal and wood for domestic heating are significant sources of benzo[α]pyrene. Motor vehicles and aircraft exhaust are the major sources of formaldehyde.

6.1 Air toxics monitoring in NSW

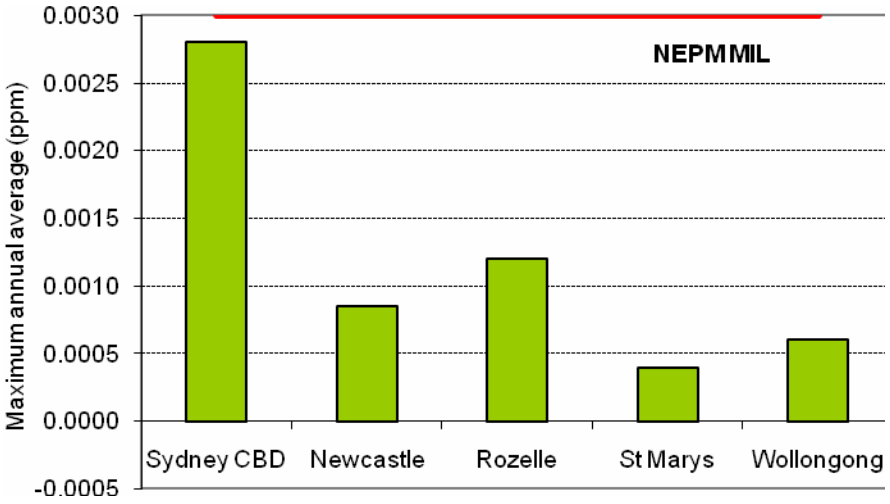
Between 1996 and 2001, the then EPA conducted the Air Toxics Monitoring Project (ATMP) which investigated concentrations of 17 dioxins, 41 organic compounds, 11 PAHs and 12 heavy metals (EPA 2002). More than 1 400 samples were collected at 25 sites.

The *Ambient Air Quality Monitoring and Fuel Quality Testing Project* (AAQMFQTP) collected data for a one-year period from October 2008 to October 2009. This project collected 24-hour concentrations of formaldehyde, acetaldehyde, and 34 organic compounds at two locations in Sydney every sixth day, and 19 PAHs at one location on the same days. Sixty-one samples were collected at each location during the sampling period. Findings from the study are provided in the report *Ambient air quality monitoring and fuel quality testing program 2008-09,* DECCW (2010a) (in press).

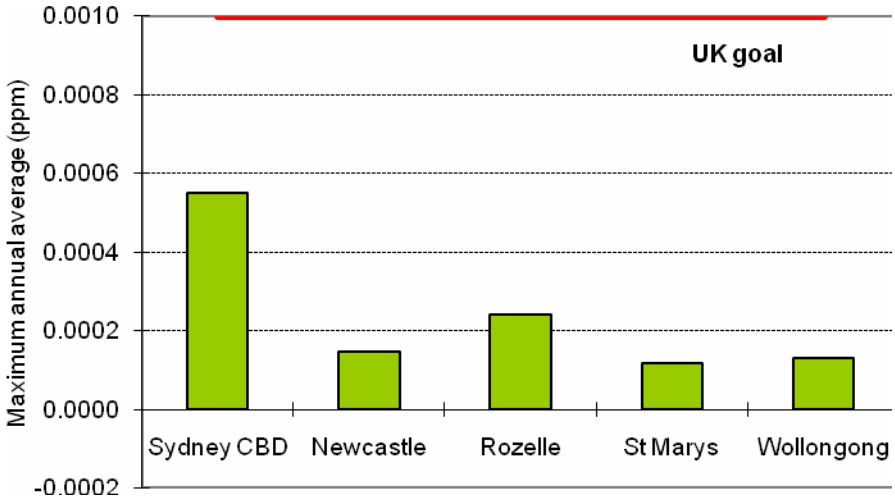
6.2 Air toxics concentrations in NSW

The ATMP found ambient concentrations of most tested substances were very low, and well below the international goals at the time. Some 23 compounds were never, or rarely, detected. Annual average concentrations of benzene were below the Air Toxics NEPM monitoring investigation level (MIL) (0.003 ppm or 3 ppb) at all sites (Figure 6.1a). Indeed, other than the peak CBD site, concentrations were less than the European Commission's more stringent long-term (2010) annual average goal of 1.5 parts per billion (ppb) by volume. Annual average concentrations of 1,3-butadiene were less than 60% of the current UK goal (DEFRA 2002) (Figure 6.1b). The maximum annual concentrations of toluene and xylenes were less than 5% of the MILs and maximum 24-hour concentrations were less than 2% and 4% of the MILs respectively.

The AAQMFQTP also found low concentrations of all chemical pollutants, with many observations below the detection limit. Concentrations of the five air toxics noted in the Air Toxics NEPM were low compared to the MIL set out for each in the Air Toxics NEPM.



(a) benzene



(b) 1,3-butadiene

Figure 6.1: Maximum annual average concentrations of two air toxics in NSW (1996–2001)

The concentration of organic pollutants generally halved between the two studies (Table 6.1). Improved engine technology and a greater proportion of the vehicle fleet being fitted with catalysts have reduced emissions from the on-road mobile sector by about 35%. Benzene concentrations show a larger decrease, about 70%. This is expected, given the reduction in the maximum permissible benzene concentration in automotive fuels required since January 2006. Table 6.1 compares results for selected air toxics.

Table 6.1: Average concentrations of selected organic pollutants

	ATMP (1996–2001)			AAQMFQTP (2008–2009)	
	Sydney CBD	**Rozelle**	**St Marys**	**Turrella**	**Rozelle**
Benzene	2.3	1.1	0.4	0.4	0.3
Toluene	4.2	2.2	0.8	1.8	0.9
Xylene (m+p)	2.2	1.0	0.4	0.7	0.5
Xylene (o)	0.8	0.4	0.1	0.3	0.2
1,3-butadiene	0.4	0.2	0.1	*(<0.1)**	*(<0.1)**

All concentrations are shown as ppbV.

Averages equal to or less than the detection limit are shown in italic typeface and parentheses.

* No samples in the study reported a 1,3-butadiene concentration above the detection limit. The limit quoted is for samples in 2009. The detection limit for samples from 1 October 2008 to 31 December 2008 was 0.4 ppb.

The AAQMFQTP provides the first ambient measurements of formaldehyde and acetaldehyde for NSW. Concentrations were low: the highest formaldehyde concentration was only 11% of the MIL for this substance. Results of the monitoring are shown in Table 6.2.

Table 6.2: Year statistics for formaldehyde and acetaldehyde

	NEPM MIL* ($\mu g/m^3$)	**Turrella**		**Rozelle**[§]	
		Year[#] average ($\mu g/m^3$)	**Year maximum** ($\mu g/m^3$)	**Year[#] average** ($\mu g/m^3$)	**Year maximum** ($\mu g/m^3$)
Formaldehyde	54	1.9	5.9	1.8	4.3
Acetaldehyde	–	1.0	3.8	1.1	2.9

* MIL is given as 0.04 ppm. This was converted to $\mu g/m^3$ at 0°C and standard pressure. Exact comparison would use the temperature and pressure at the time of sampling. Variation in conversion between these units for the range of ambient temperatures and pressures is less than 10% (49 $\mu g/m^3$ at 25°C).

[#] The sampling period covers a full year: October 2008 to September 2009.

[§] Rozelle has two samples in October 2009 to replace two samples contaminated in the laboratory; contaminated sample results have been excluded.

The ATMP sampled for particulate benzo[α]pyrene mainly during winter when concentrations were expected to be greatest. At sites in the GMR, winter average concentrations ranged from 0.14 to 0.77 nanograms per cubic metre (ng/m^3), while for regional centres winter average concentrations ranged from 1.12 to 4.21 ng/m^3. These concentrations suggest that annual average concentrations may exceed the MIL at some regional sites.

The AAQMFQTP sampled gaseous and particulate PAHs at one site in suburban Sydney. Benzo[a]pyrene was found above the detection limit in 16 of the 61 samples. The highest concentration found was 0.4 ng/m^3 and the average for the year was 0.12 ng/m^3. These concentrations are similar to those found in the ATMP at an outer Sydney site and somewhat lower than similar suburban sites at that time.

The ATMP found that dioxin concentrations in the air in NSW were very low compared to concentrations measured internationally. Monitoring undertaken in Sydney for the National Dioxins Program in 2002–03 also recorded very low concentrations of dioxins, supporting the findings of the ATMP. The National Dioxins Program also highlighted a seasonal cycle in dioxin concentrations, with higher concentrations in winter most likely due to smoke from solid-fuel heaters.

6.3 Air toxics summary

Ambient concentrations of most air toxics in NSW are very low, and are well below international goals. A small number of air toxics – benzene, 1,3-butadiene and benzo[α]pyrene require ongoing assessment to ensure they remain at acceptable concentrations in the future.

Strategies such as increasingly stringent regulation of fuel and motor vehicle emissions and improvements to combustion in solid-fuel heaters will assist in controlling concentrations of air toxics.

7 Fine particles

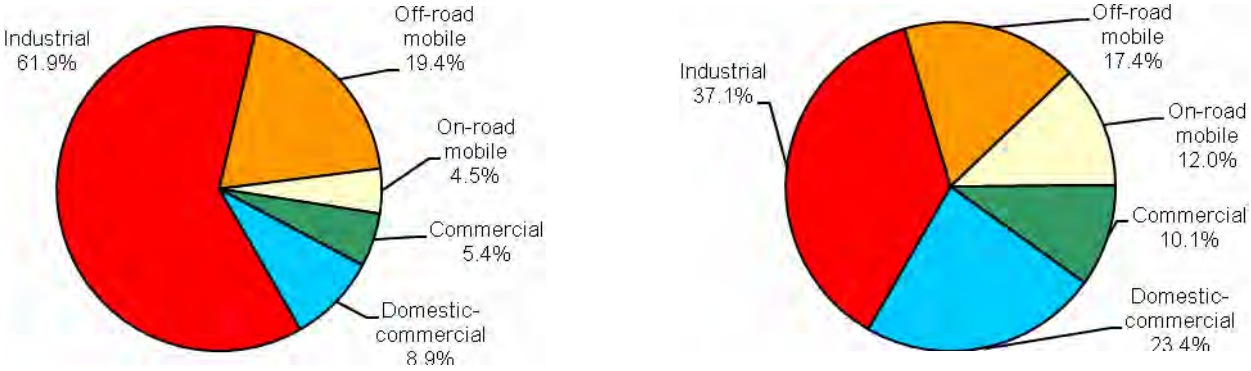
Particle pollution refers to matter suspended in the air, including solid particles, liquid drops and aggregates of particles and liquids. While most particles are emitted directly, they can also be formed by the chemical reaction of gaseous pollutants. Particles in the air range in diameter from 0.01 µm to about 50 µm. Typically, larger particles are deposited within hours while smaller particles can stay suspended in the air for days or weeks until removed by rain.

Particles can harm human health when inhaled. Current medical research shows that particle pollution can exacerbate existing respiratory symptoms, and at high concentrations cause respiratory symptoms. Particles can also adversely impact cardiovascular health. No safe threshold has been identified for the human health effects of particles.

Particle pollution also reduces visual amenity – it causes the air to look dirty and reduces visibility.

7.1 Sources of fine particles

There are many sources of particles in the air, arising from both natural processes and human activity. The main sources of particle emissions from human activity in the GMR are industrial activities, mobile sources (both on- and off-road) and domestic sources (primarily the use of domestic solid-fuel heaters) (Figure 7.1). These emissions can be trapped below temperature inversions, particularly during winter. If this weather persists for several days, elevated concentrations of fine particles may occur.



(a) GMR (b) Sydney region

Figure 7.1: Annual anthropogenic sources of PM_{10} (2003)

Nearly 62% of PM_{10} emissions in the GMR are from industrial premises, primarily coal mining. The dominant source of PM_{10} in Sydney is also industrial premises (37%), although domestic sources and on-road mobile sources make up a greater proportion of PM_{10} emissions in Sydney than they do in the GMR. The annual domestic sector contribution to PM_{10} emissions in Sydney comes largely from wood heating (93%). The geographic distribution of annual emissions of PM_{10} for the Sydney region is shown in Figure 7.2.

Wood heating provides a good example of the seasonal variation in emissions. In Sydney, wood heaters account for 3% of total PM_{10} particle emissions in summer (January weekday) but 43% in winter (July weekday).

In rural areas, broadacre agricultural activities (e.g. crop stubble burning and cultivation) and the use of solid fuels for heating and cooking are the major anthropogenic sources of particles. Emissions from natural events, such as bushfires and dust storms, also contribute significantly to fine particle concentrations in NSW. Almost 20% of PM_{10} emissions in the GMR are from agricultural burning, bushfires, prescribed burning and windborne dust.

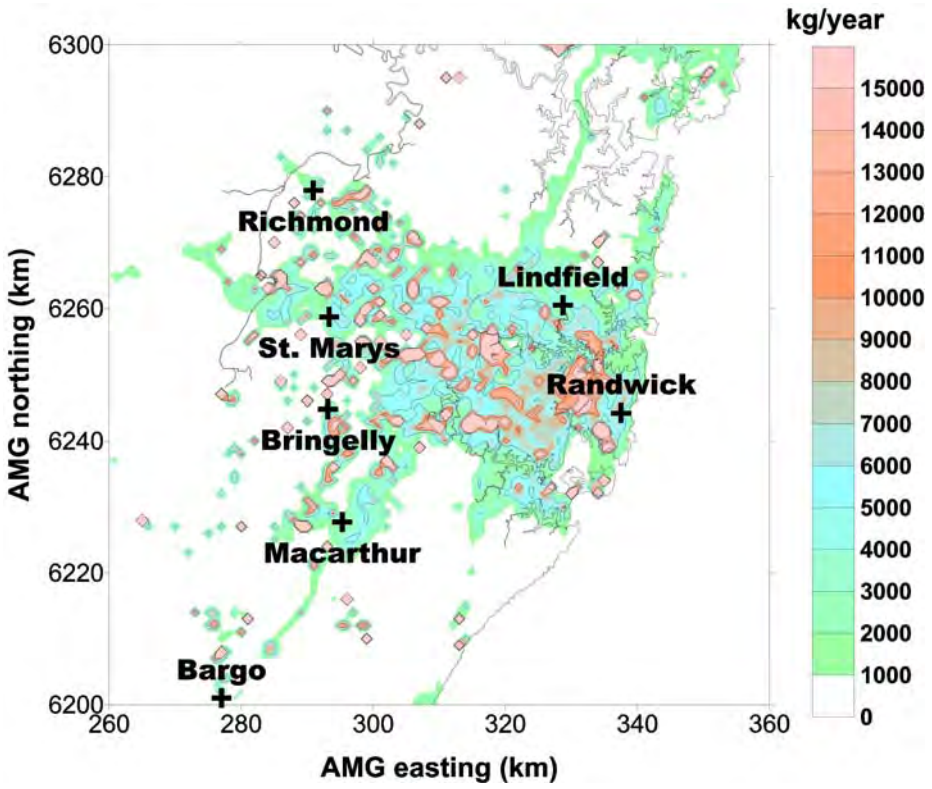


Figure 7.2: Geographic distribution of estimated annual emissions of PM_{10} in the Sydney region (2003)

Total emissions for the Sydney region in 2003 were estimated to be 21,969 tonnes.

7.2 Particle measurement techniques

Techniques for measuring particles in the air can be generally grouped into either optical or gravimetric techniques.

The most widely used optical technique for measuring particles in NSW is nephelometry, which measures the amount of light that is scattered by particles when a beam of light passes through the air. The technique does not measure particles directly and can only be used for qualitative assessment of fine particle concentrations (i.e. as a visibility index). There are no national standards or goals for visibility. NSW has a reporting goal for visibility of 2.1 bsp (co-efficient of backscattering by fine particles) which is equivalent to a visual amenity of approximately 10 km.

Particles less than 10 µm (PM_{10}) and less than 2.5 µm ($PM_{2.5}$) are measured in NSW using tapered-element oscillating microbalance (TEOM) instruments. This technique provides continuous, real-time measurement of the mass of particles in the air.

At present there is no Australian Standard method for measuring $PM_{2.5}$. A national program, the $PM_{2.5}$ Equivalence Program, is assessing the accuracy and precision of various $PM_{2.5}$ instruments. This assessment may recommend modifications to the TEOM method for measuring $PM_{2.5}$. In particular, it may recommend changing the adjustment (offset and linear factor) used in the instrument, an area which has been the subject of recent review. The data presented in this report are ‘unadjusted’ – i.e. the linear factor and offset have been removed from the instrument values.

The Air NEPM $PM_{2.5}$ advisory reporting standards (ARS) of 25 µg/m^3 for 24-hour averages and 8 µg/m^3 for annual averages are not based on $PM_{2.5}$ data measured by TEOM instruments. In this report, comparisons with the $PM_{2.5}$ ARS are **for interest only**.

7.3 Fine particle concentrations in NSW

Fine particle[4] concentrations in NSW are usually low. Figure 7.3 shows the frequency of 24-hour average PM_{10} concentrations for 1994 to 2009 by category. The categories are: 'Low' for concentrations up to two-thirds of the Air NEPM standard, 'Medium' for concentrations between two-thirds of the Air NEPM standard and the standard, and 'Exceeds' for concentrations greater than the Air NEPM standard. Monitoring sites in the Sydney, Illawarra, and lower Hunter regions are aggregated by defining the concentration for the region as the greatest concentration from any site in the region.

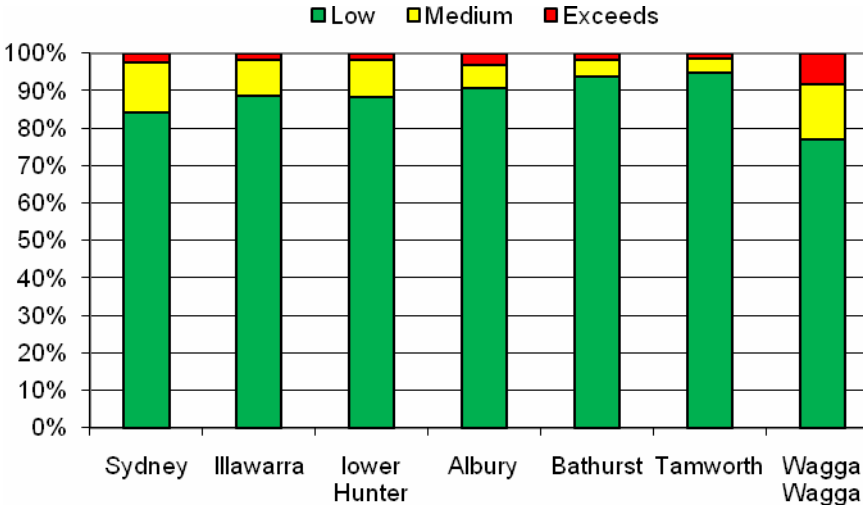


Figure 7.3: Category frequency of 24-hour average PM_{10} concentrations in NSW (1994–2009)

'Low' are concentrations up to 33 µg/m^3; 'Medium' are concentrations between 33 and 50 µg/m^3; 'Exceeds' are concentrations of more than 50 µg/m^3.

Over three-quarters of all days in the years 1994 to 2009 reported a concentration of less than two-thirds of the PM_{10} standard. Concentrations greater than the Air NEPM standard were uncommon. Such concentrations occurred on fewer than 2% of all days at Tamworth, Bathurst, and sites in the lower Hunter and Illawarra regions. There were exceedences on just over 3% of all days in Albury, while sites in the Sydney region reported exceedences on about 5% of all days. Wagga Wagga reported the most exceedence days in these years – 229 – about 8% of the 2,820 days of record at this site since 2001.

Figure 7.4 shows the category frequency of 24-hour average $PM_{2.5}$ concentrations using the reporting guideline (in a similar manner to the distributions shown in Figure 7.3). Ninety-two per cent of days in the Sydney region and over 96% of days in the

[4] Fine particles are particles with an aerodynamic diameter of less than 10 µm. This includes PM_{10} and $PM_{2.5}$.

Illawarra and lower Hunter regions reported a concentration less than two-thirds of the reporting guideline. Concentrations greater than the reporting guideline are rare, occurring on only 1.5% of days in Sydney and less than 1% of days in the Illawarra and lower Hunter regions.

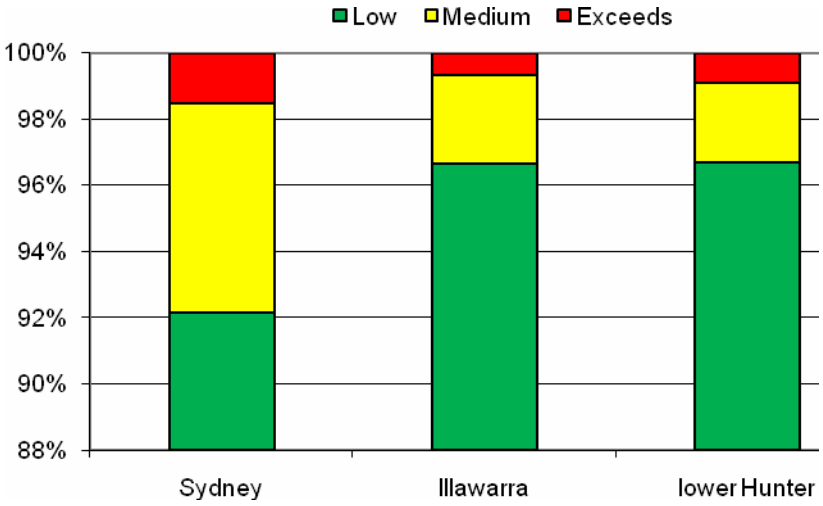


Figure 7.4: Category frequency of 24-hour average $PM_{2.5}$ concentrations in NSW (1994–2009)

'Low' are concentrations up to 16.5 µg/m^3; 'Medium' are concentrations between 16.5 and 25 µg/m^3; 'Exceeds' are concentrations of more than 25 µg/m^3.

Figure 7.5 shows the maximum annual average $PM_{2.5}$ concentration among sites in each region (for 1997 to 2009). The reporting guideline was exceeded in the Sydney region in seven of the thirteen years, in the Illawarra region in three of the thirteen years, and in the lower Hunter region in two of the thirteen years.

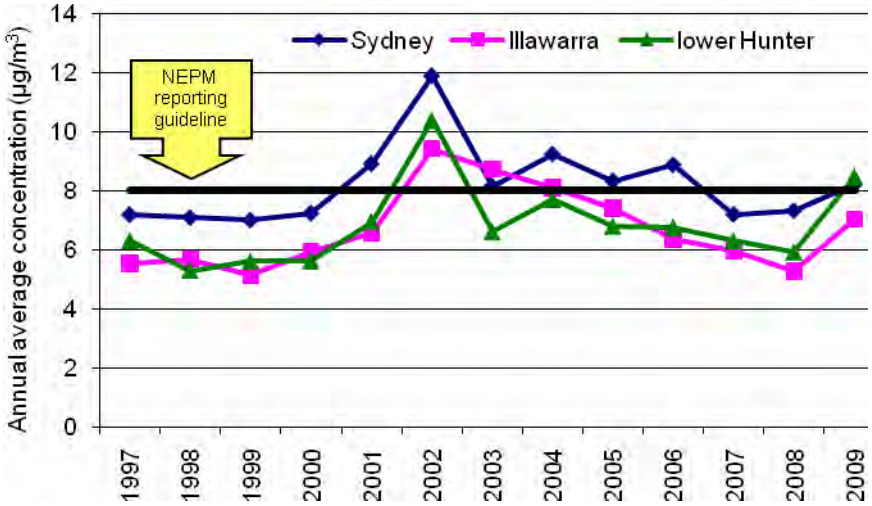
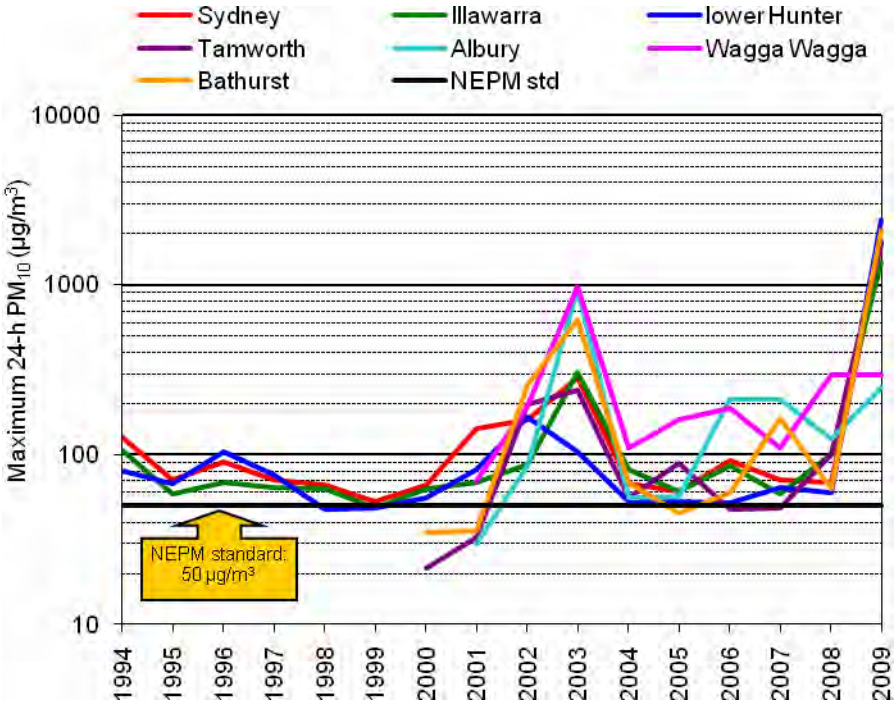
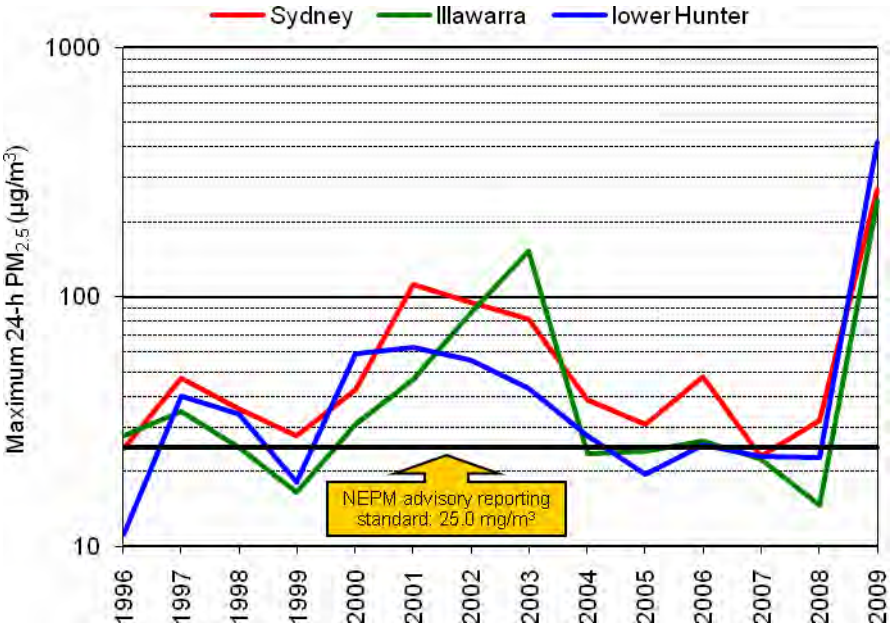


Figure 7.5: Maximum annual average $PM_{2.5}$ concentrations (1997–2009)

Highest exposure to fine particles in NSW occurs during severe bushfires and dust storms. During these events, peak PM_{10}, $PM_{2.5}$ and nephelometer readings can greatly exceed the relevant standards, reporting guideline or goal. Dust storms are responsible for the greatest spatial extent and bushfires for the longest exposure to elevated concentrations of fine particles in NSW. Figure 7.6 shows the maximum concentrations of PM_{10} and $PM_{2.5}$ for each year (between 1994 and 2009) in the Sydney, Illawarra, and lower Hunter regions.



(a) PM_{10} (1994–2009)



(b) $PM_{2.5}$ (1996–2009)

Figure 7.6: Trends in maximum 24-hour average PM_{10} and $PM_{2.5}$

The greatest 24-hour average PM_{10} concentration recorded in NSW during this period was 2,426.8 µg/m^3. This was recorded at Newcastle on 23 September 2009 during a severe dust storm (see Section 7.4). This dust storm resulted in the highest PM_{10} concentrations throughout the network in the years 1994 to 2009, except for Wagga Wagga and Albury. The highest PM_{10} ever recorded at Albury (940.2 µg/m^3) and Wagga Wagga (970.0 µg/m^3) was on 19 March 2003, also due to a dust storm. It is clear that while large dust storms are uncommon events, they can result in widespread exposure to extreme concentrations of fine particles.

Severe bushfires can cause high concentrations of fine particles that persist above the relevant standards for several weeks. From late November 2006 to January 2007, severe bushfires in Gippsland and the Australian Alps contributed to exceedences of the PM_{10} standard on 15 days at Albury and 31 days at Wagga Wagga. Smoke from these fires was also transported as far as the Illawarra and Sydney regions, causing exceedences of standards.

During the worst bushfire years, PM_{10} concentrations exceeded the Air NEPM standard concentration on up to 26 days in the GMR (lower Hunter) and 36 days in Wagga Wagga (Figure 7.7).

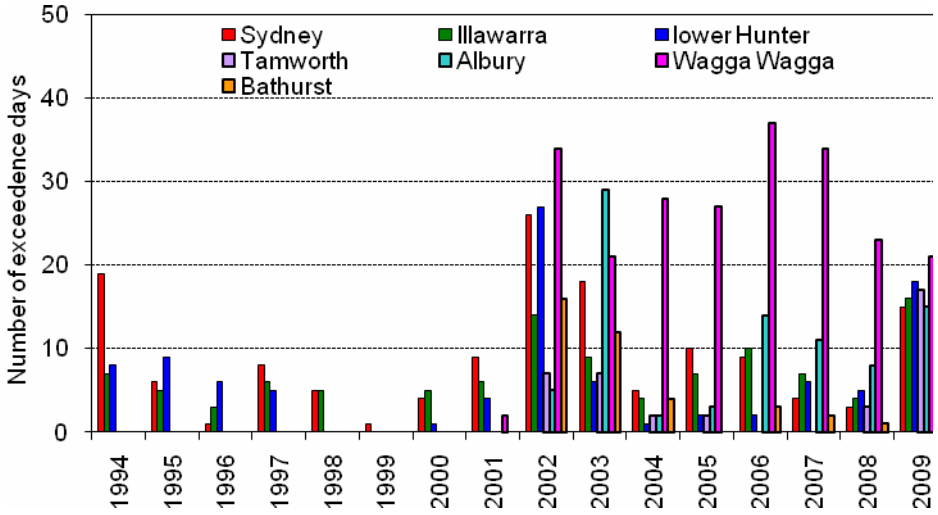


Figure 7.7: Number of days PM_{10} concentrations exceeded the Air NEPM standard (1994–2009)

In these years, the numbers of days with readings above the Air NEPM $PM_{2.5}$ advisory reporting standard and the NSW nephelometer goal were also the greatest (Figures 7.8 and 7.9).

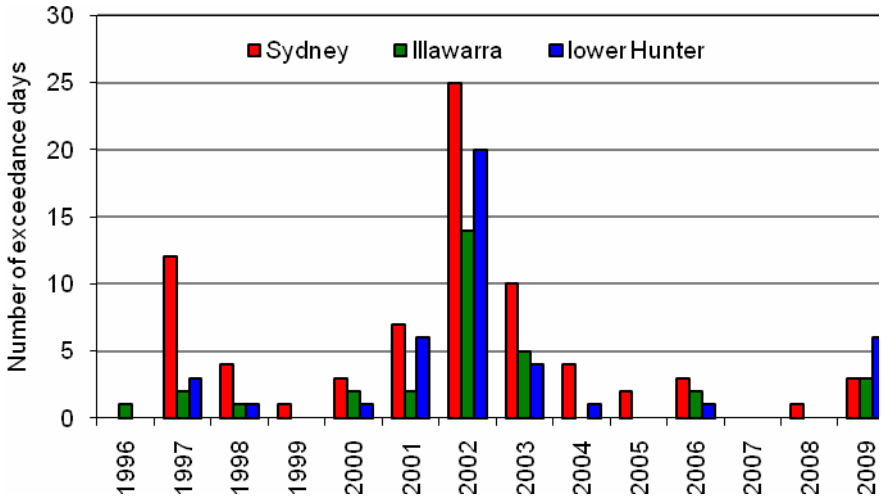


Figure 7.8: Number of days $PM_{2.5}$ concentrations exceeded the Air NEPM advisory reporting standard (1996–2009)

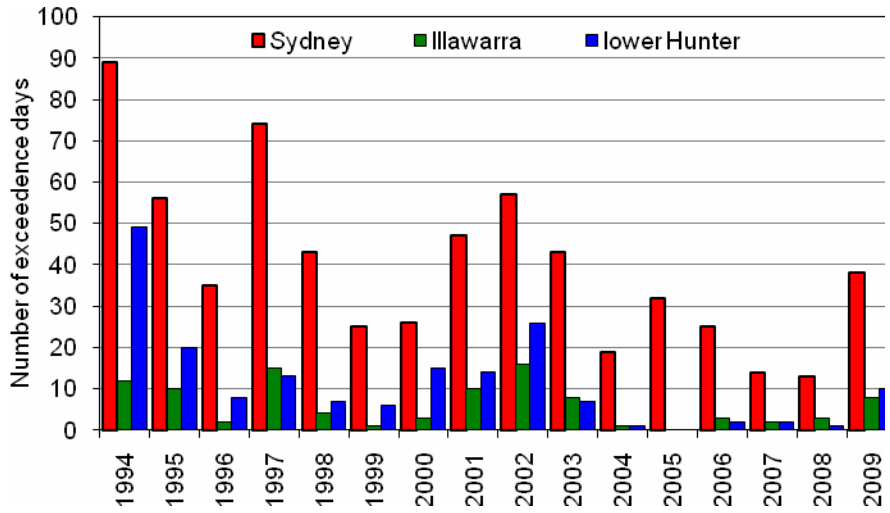
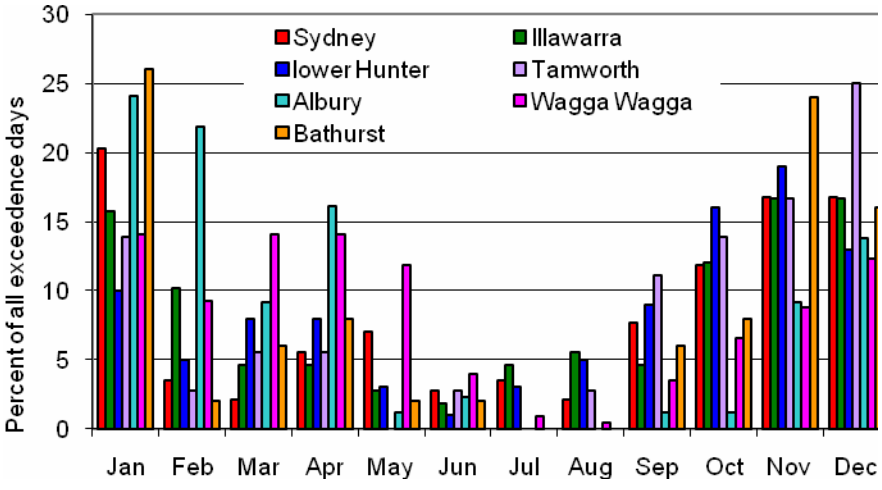
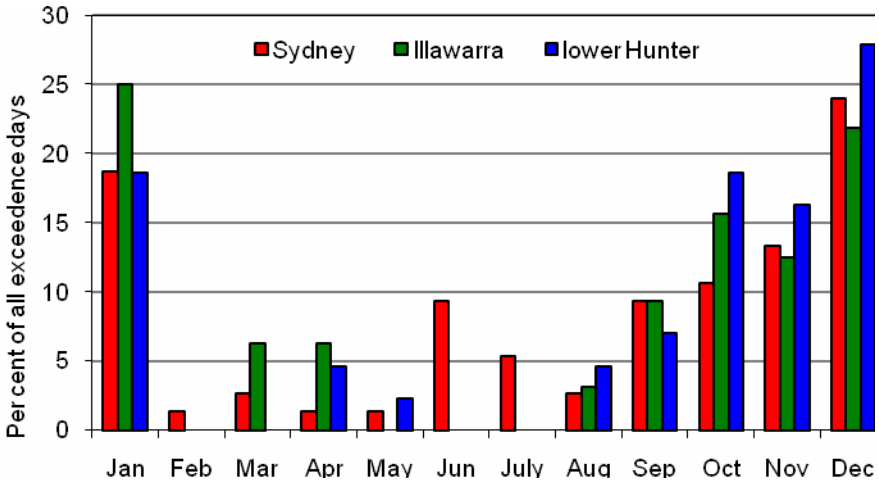


Figure 7.9: Number of days visibility exceeded the NSW nephelometer goal (1994–2009)

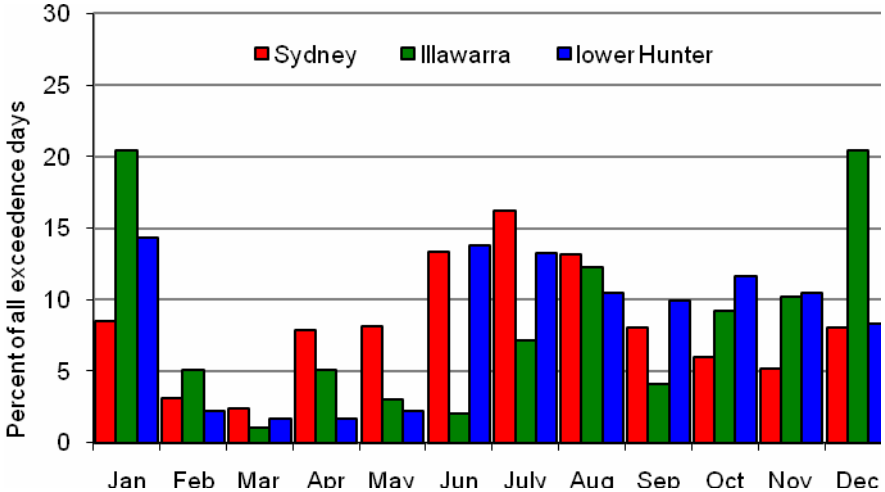
The use of solid-fuel heaters during winter – particularly older, inefficient models – can be a significant source of fine particle emissions throughout NSW. However, PM_{10} data shows there are relatively few exceedences of the PM_{10} standard during the cool winter months (Figure 7.10). Rather, exceedences are more likely in the warmer months of the year. At most sites this is October to March. Wagga Wagga reports exceedences occurring from October through to May and exceedences from this site dominate autumn statistics. Winter exceedences in Sydney occur on average less than one day per year, and the frequency is even lower in the Illawarra and lower Hunter regions.



(a) PM_{10}



(b) $PM_{2.5}$



(c) Visibility

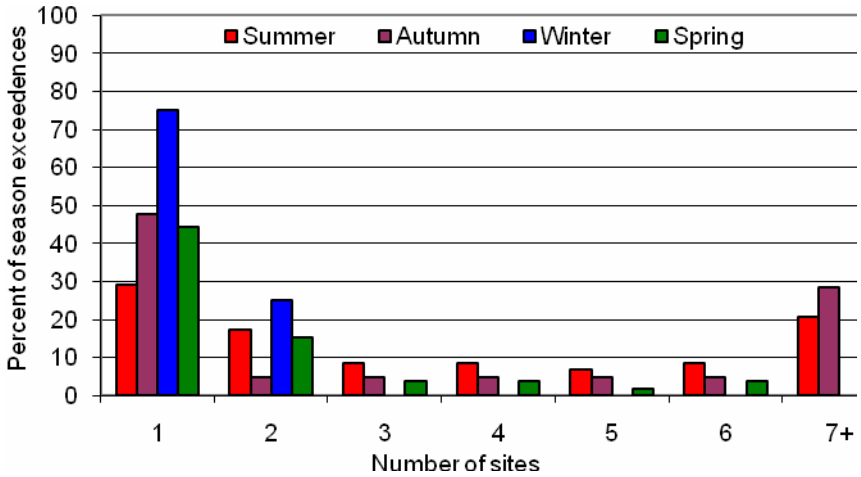
Figure 7.10: Distribution throughout the year of days above the PM_{10} standard, days above the $PM_{2.5}$ advisory reporting standard and days above the NSW nephelometer goal (1994–2009)

Compared to PM_{10}, a greater proportion of exceedence days occur in winter for both the $PM_{2.5}$ advisory reporting standard and the NSW nephelometer goal. For sites in the Sydney region, winter has less than 9% of PM_{10} exceedence days, about 17% of $PM_{2.5}$ exceedence days, but over 40% of nephelometer exceedence days. Nephelometer exceedence days in Sydney are most likely in June to August while $PM_{2.5}$ exceedence days are most likely in December to January.

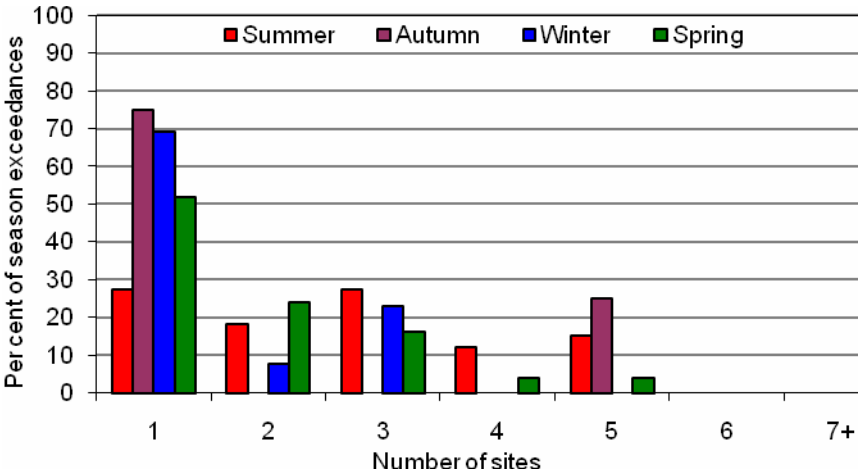
Sites in the Illawarra and lower Hunter regions show that, as for PM_{10}, $PM_{2.5}$ exceedences are more likely in the warmer months but, compared to PM_{10}, $PM_{2.5}$ has a greater proportion of exceedence days occurring in the cooler months. A significant proportion of nephelometer exceedence days occur in winter for sites in both these regions.

Analysis of data from the Sydney region shows that PM_{10} exceedences are strongly local, particularly in autumn and winter. Fifty-nine of the 143 exceedence days in the years 1994 to 2009 occurred at only one site, with a further 22 at two sites. Widespread events (occurring at eight or more sites) are rare, being only 27 of the 143 exceedence days (19%). Figure 7.11 shows the spatial extent of exceedence days for each of the three particle measurement techniques. For all three measures, exceedences are generally confined to a few sites. Note that at most there have been five monitoring sites for $PM_{2.5}$.

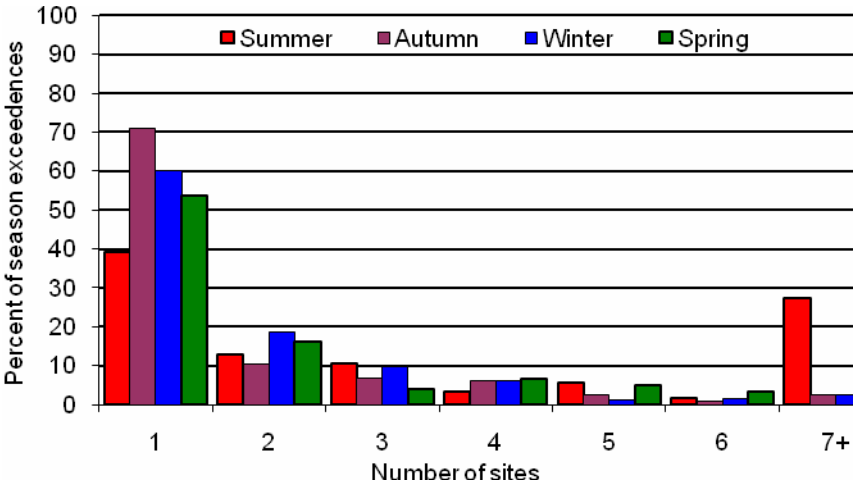
Further analysis of fine particle composition would enable a better understanding of the contribution made by various sources in NSW.



(a) PM_{10}



(b) $PM_{2.5}$



(c) Visibility

Figure 7.11: Spatial extent of exceedence days by number of sites in Sydney for PM_{10}, $PM_{2.5}$ and visibility by nephelometer (1994–2009)

7.4 Dust storms and particles

On 23 September 2009, NSW experienced a severe dust storm with extraordinarily high dust concentrations recorded in the Sydney, Illawarra and lower Hunter regions and the rural cities of Bathurst and Tamworth. For some centres including Sydney, dust concentrations were the highest on record since monitoring began in the early 1950s. This was followed by a smaller but significant dust storm on 26 September 2009.

The 23 September dust plume was more than 500 km wide and 2,000 km long. The dust in the plume came from the Lower Lake Eyre Basin in South Australia and north-western NSW. Figure 7.12 is a satellite image showing generation of the dust cloud the day before.

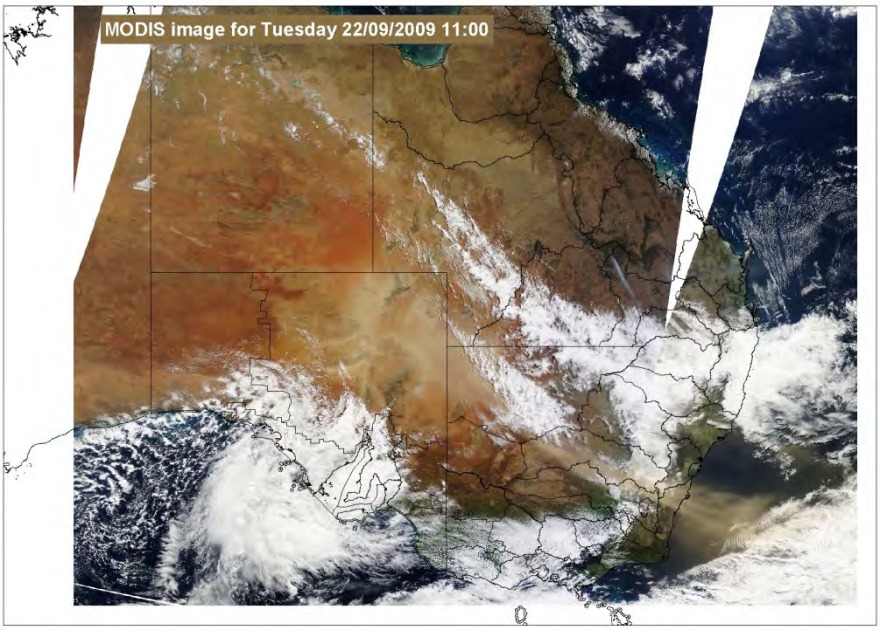


Figure 7.12: Satellite image of dust generation over Lake Eyre and western NSW on 22 September 2009

Image taken by the MODIS instrument on NASA's Aqua satellite. Image received and processed by the Bureau of Meteorology. (Photograph courtesy of NASA/GSFC, MODIS Rapid Response and the Bureau of Meteorology)

During the peak of the storm in Sydney, the Australian continent was estimated to be losing 75,000 tonnes of dust with a particle size less than 10 µm per hour off the NSW coast between Wollongong and Newcastle. Reduced ground cover exacerbated by extended drought and very high winds (80–90 km/h) were the cause of these storms.

Very high particle concentrations persisted for up to eight hours in Sydney and other locations in NSW. Figure 7.13 shows the 1-hour average PM_{10} concentrations during the dust storm. Peak concentrations of around 15,400 µg/m^3 (1,500 times normal concentrations) were recorded at Bathurst. Normal days register up to 20 µg/m^3 and bushfires generate around 500 µg/m^3.

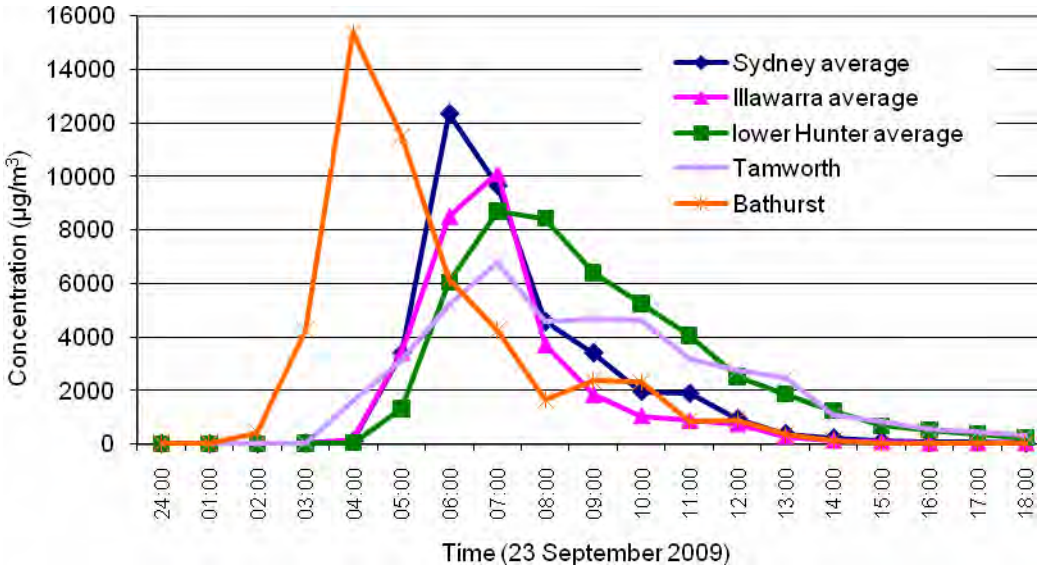


Figure 7.13: 1-hour average PM_{10} concentrations on 23 September 2009

Figure 7.14: Dust particle pollution in Sydney on 23 September 2009
(Photograph courtesy of Rae Doble)

The impacts on the community and environment of dust events such as these are many and include: soil and nutrient loss from farming land, infrastructure damage both on-farm and in the city, transport disruptions, dust pollution, health problems associated with fine particles, and changes in the radiation balance of the atmosphere. The visual impact in Sydney is shown in Figure 7.14.

Climate change has the potential to increase the frequency, intensity and distribution of weather-related natural hazards. Some parts of NSW are expected to have less rainfall, longer dry periods and higher temperatures, making the drought conditions contributing to these recent dust storms more common (CSIRO 2007).

7.5 Wagga Wagga fine particle study

Wagga Wagga reported the most exceedences of the Air NEPM PM_{10} standard concentration for the period 2003 to 2009. There were few exceedences in the winter months; exceedences tended to occur from December to May (Figure 7.10a).

CSIRO's Marine and Atmospheric Research (Meyer *et al.* 2008) conducted a study during 2008 investigating the composition of particles at Wagga Wagga with the intention of determining their source. Two tracers – laevoglucosan and non-sea-salt potassium ($nssK^+$) – were analysed to determine the presence of smoke or dust, or both. Laevoglucosan is formed from burning carbohydrates such as cellulose and is a marker for woodsmoke. Non-sea-salt potassium is a marker for dust and smoke from biomass burning.

Figure 7.15 shows the ratio of laevoglucosan to PM_{10} and the ratio of nssK+ to PM_{10} for each weekly sampling period in 2008. A significant increase in laevoglucosan and nssK+ concentrations was observed in May and concentrations remained elevated until September indicating that up to half the particulate mass may have been from biomass combustion. Since fire activity was low during those months, the high laevoglucosan and nssK+ to PM_{10} ratios may have been due to the use of wood heaters.

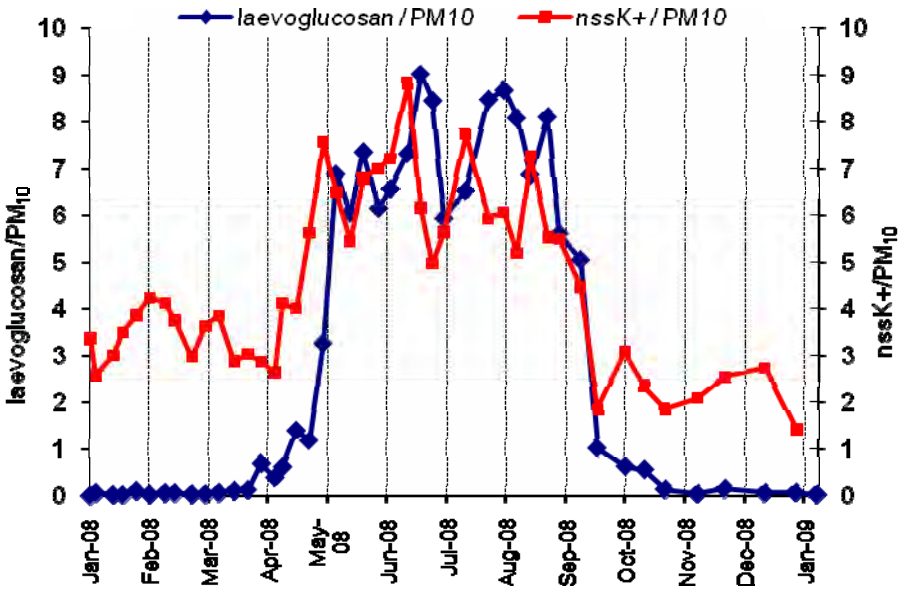


Figure 7.15: Weekly measurements of the ratios (by mass) of laevoglucosan (LG) and non-sea-salt potassium (nssK+) concentrations to PM_{10} concentrations

The presence of both laevoglucosan and nssK+ in the cooler months indicates that woodsmoke was the main source of the particle concentrations during this time. The graph shows clearly that the composition of particle pollution in the winter months differed from the rest of the year.

Outside the winter period, nssK+ concentrations remained elevated while laevoglucosan concentrations were low. This suggests that the particles were mainly dust, smoke from a different source, or both.

7.6 Fine particles summary

Exceedences of the PM_{10} standard have been recorded in all monitored regions. Readings above the NSW nephelometer goal and the Air NEPM $PM_{2.5}$ advisory reporting standard are regularly recorded in the GMR. Other than events due to bushfire or dust storm, exceedences of particle standards are usually local and limited to one or two monitoring sites.

There is significant seasonality to particle concentrations in NSW. PM_{10} exceedences and days above the Air NEPM $PM_{2.5}$ advisory reporting standard occur most often in the warmer months. Nephelometer exceedences are most often observed in winter. The NSW nephelometer goal is exceeded on many more days than the Air NEPM PM_{10} standard or the Air NEPM $PM_{2.5}$ advisory reporting standard. Although background concentrations of fine particles in Sydney increase during the cooler months, exceedences of fine particle standards in winter are primarily local events.

Extreme concentrations of PM_{10} – many times the Air NEPM standard – have been recorded during the warmer months. These extreme concentrations are the result of natural events such as dust storms and bushfires. The severe drought conditions experienced across NSW over the past few years have contributed significantly to an increased incidence of PM_{10} concentrations above the standard. Climate modelling indicates increasing fire risk across south-east Australia as a result of climate change (Hennessy *et al.* 2005).

While the incidence of elevated PM_{10} during summer is heavily influenced by bushfire activity, the contribution of secondary particles – created during photochemical smog formation – is uncertain.

Investigation of the source of particles in Wagga Wagga in 2008 found that particles in winter differed from other times of year, suggesting wood heating in homes as a significant source of winter particle pollution.

A detailed examination of particle observations since 1994 is in preparation (DECCW 2010b).

8 Ground-level ozone

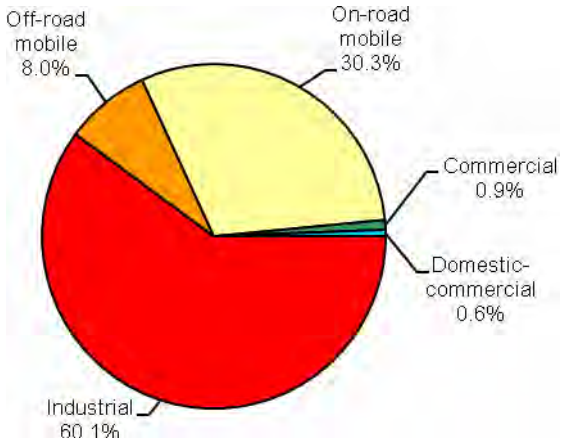
Ozone (O_3) is a colourless strongly oxidising gas. Ozone occurs in both the upper atmosphere (the ozone layer) and at ground level. The ozone layer in the upper atmosphere is beneficial to life by shielding the Earth from harmful ultraviolet radiation from the Sun. However, at ground level, human exposure to ozone causes health problems because it damages lung tissue and reduces lung function. High concentrations of ozone affect not only people with impaired respiratory systems, such as asthmatics, but healthy adults and children as well.

Ozone is the primary constituent of photochemical smog but it is not emitted directly. It is a secondary pollutant formed in sunlight by chemical reactions between oxides of nitrogen (NO_x) and volatile organic compounds (VOCs). Emissions of NO_x and VOCs are distributed unevenly throughout the urban area and vary throughout the day.

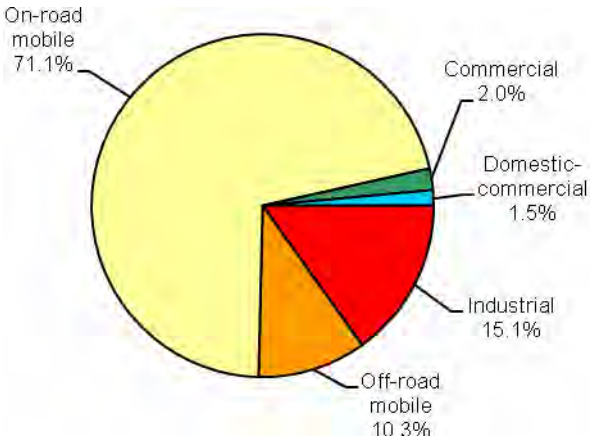
Complicating this further is the temporal and spatial variation in meteorological processes. Ozone formation is non-linear, so reducing or adding NO_x or VOC emissions to the air does not necessarily result in an equivalent decrease or increase in ozone concentration. This non-linearity makes it difficult to develop management scenarios for ozone control.

8.1 Sources of ozone precursors – VOCs and NO_x

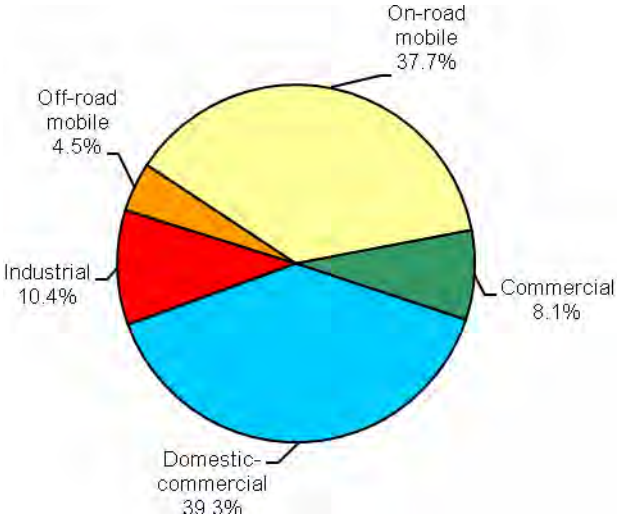
The main anthropogenic sources of VOCs and NO_x in the GMR are on-road mobile, industrial premises, and domestic sources (Figure 8.1).



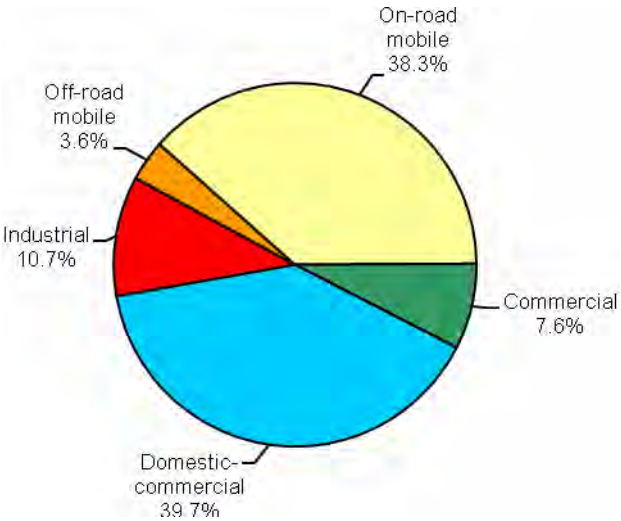
(a) NO_x emissions GMR



(b) NO_x emissions Sydney



(c) VOC emissions GMR



(d) VOC emissions Sydney

Figure 8.1: Annual anthropogenic emissions by source category (2003)

In the GMR, industrial premises – especially coal-fired power stations – are the most significant source of NO_x emissions. However, in Sydney the largest source of anthropogenic NO_x emissions are on-road motor vehicles, which contribute over 71% of total NO_x emissions.

On-road mobile (38%), domestic–commercial (39%) and commercial (8%) sectors are the main sources of anthropogenic VOC emissions in the GMR.

A large part of the contribution from the domestic–commercial sector comes from everyday use of aerosols and solvents (39%), surface coatings such as paint (25%), and solid-fuel burning (wood heaters: 19%). The key commercial sources that contribute to VOC emissions in the GMR are automotive fuel retailing (petrol stations: 41%) and smash repair shops (39%).

Across the GMR, biogenic (natural) sources such as vegetation are estimated to contribute over half of total VOC emissions into the atmosphere (for example, the Blue Mountains appear blue because of the VOCs naturally emitted there). In the Sydney region, the biogenic contribution to VOC emissions is 21%.

8.2 Ozone formation in Sydney and the Illawarra

Ozone is formed when there are sufficient concentrations of NO_x and VOCs, adequate sunlight, and high enough temperatures to allow the photochemical reactions to occur. Elevated ozone concentrations occur when dispersion of the resulting pollution is constrained by meteorological conditions and local topography.

Ozone formation can occur under several different sets of meteorological conditions, and hence peak concentrations can be observed at different locations in Sydney and the Illawarra depending on the prevailing weather conditions.

8.3 Ozone monitoring in NSW

Formation of ozone pollution is the most complex of the air quality issues in the Sydney region and in other major cities throughout the world. Currently ozone is measured at fourteen sites in the Sydney region, three in the Illawarra, and three in the lower Hunter.

8.4 Analysis of ozone monitoring results

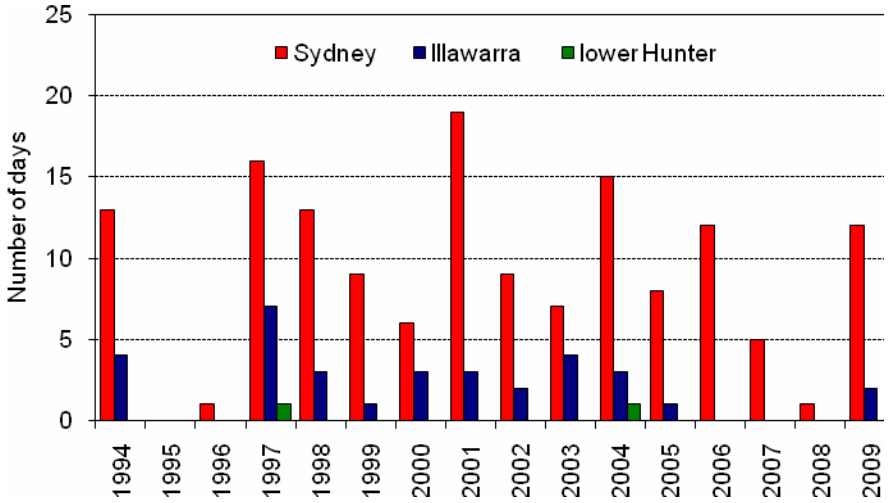
Ozone concentrations in the Sydney region have exceeded either or both of the Air NEPM ozone standards every year since 1994 (Figure 8.2). The number of days when the 1-hour standard was exceeded in Sydney ranged from none in 1995 to 19 in 2001. Maximum ozone concentrations each year are shown in Figure 8.3. Concentrations can be as much as double the Air NEPM standards.

Ozone exceedences are less frequent in the Illawarra, occurring on up to 7 days a year. The lower Hunter region has recorded only two exceedences of the 1-hour standard since 1999.

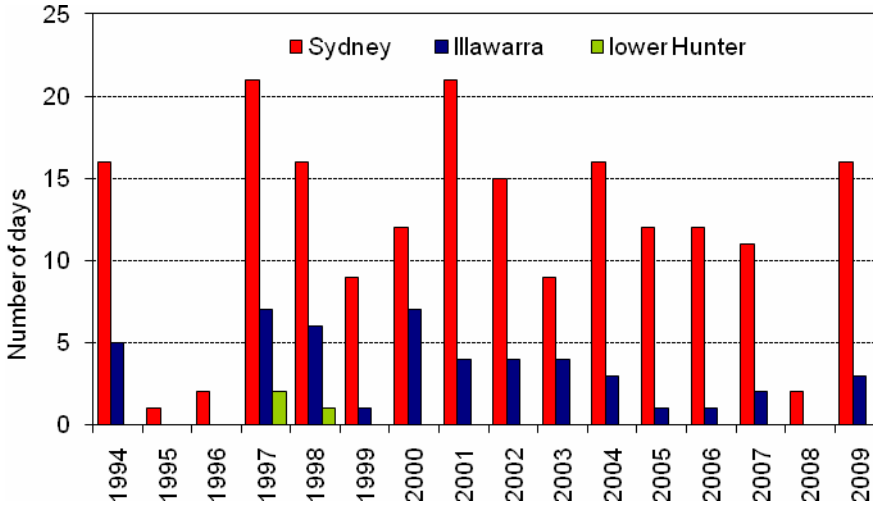
Both ozone standards are exceeded throughout the warmer months, from October to April, and peak between December and January. No significant trends are apparent in the number of exceedence days per year for either standard. The 1-hour standard is rarely exceeded without a corresponding exceedence of the 4-hour standard.

In general, ozone concentrations above the standard are relatively short-lived and occur in the early afternoon. The majority of exceedences have durations of 3 hours or less: over half of these events exceed the 1-hour standard for 1 hour only. On rare occasions, concentrations above the 1-hour standard can persist for up to 7 hours and concentrations above the 4-hour standard can persist for up to 10 hours.

The majority of the 1-hour and 4-hour ozone exceedences occur as single-day events. Of the 148 days when the 1-hour standard was exceeded in the years 1994 to 2009, 100 were single-day events. In the same years there were 202 days exceeding the 4-hour standard, 131 of which were single days. The longest run of consecutive days exceeding the Air NEPM ozone standards was 6 days. This has occurred twice in the years 1994 to 2009, the first in January 2001 and the second during the prolonged bushfires of December 2001 to January 2002. Both standards were exceeded for every day in those 6-day periods. Exceedences of both the 1-hour and 4-hour standard in the Sydney region can occur over a relatively large area, although most occur at a single station.

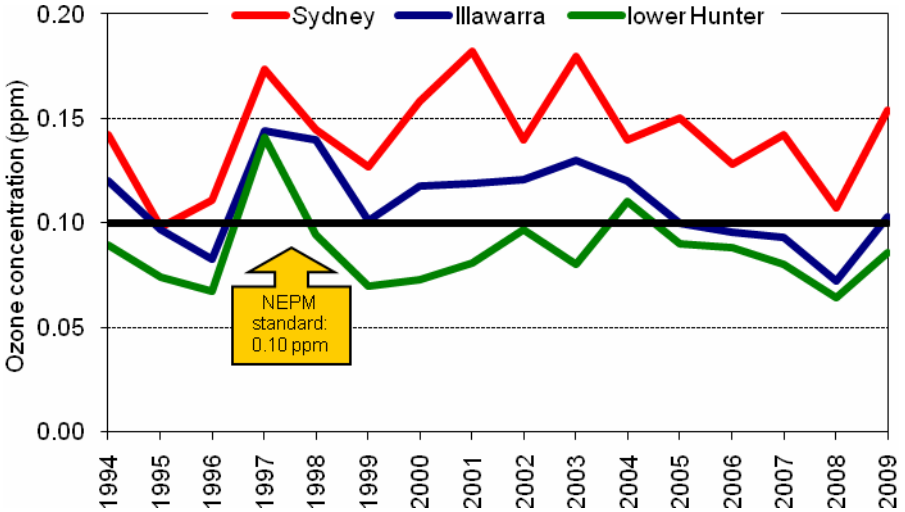


(a) Number of days ozone exceeded the 1-hour standard

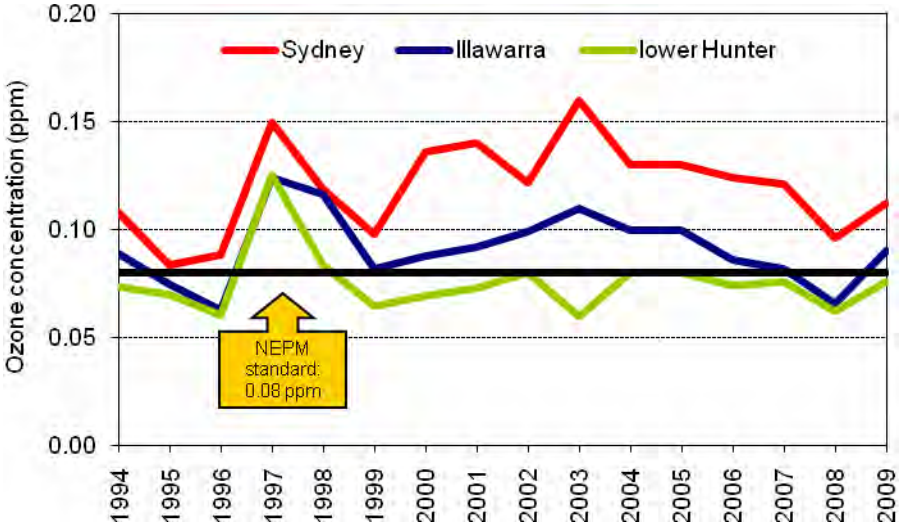


(b) Number of days ozone exceeded the 4-hour standard

Figure 8.2: Annual exceedences of the Air NEPM ozone standards (1994–2009)



(a) Maximum 1-hour ozone concentrations



(b) Maximum 4-hour ozone concentrations

Figure 8.3: Annual maximum ozone concentrations in NSW (1994–2009)

8.5 Spatial analysis of ozone exceedences in Sydney

Peak 1-hour ozone exceedences can occur at any location in Sydney. However, exceedences of both the 1-hour and 4-hour ozone standard occur more frequently in western Sydney.

Contour mapping of monitoring station data can be used to display the spatial extent of ozone exceedence days. The monitoring station data are interpolated to provide values on a regular grid. Note that the contour map is generated from the interpolated data and is an approximation based on the available observations. There are sufficient air quality monitoring stations throughout the Sydney basin to allow useful contour maps to be drawn, but these must be interpreted in light of the relatively few data points used. Contour maps of the number of exceedence days for 16 ozone seasons (October to March) from 1993–94 to 2008–09 are shown in Figures 8.4 (1-hour ozone concentrations) and 8.5 (4-hour ozone concentrations).

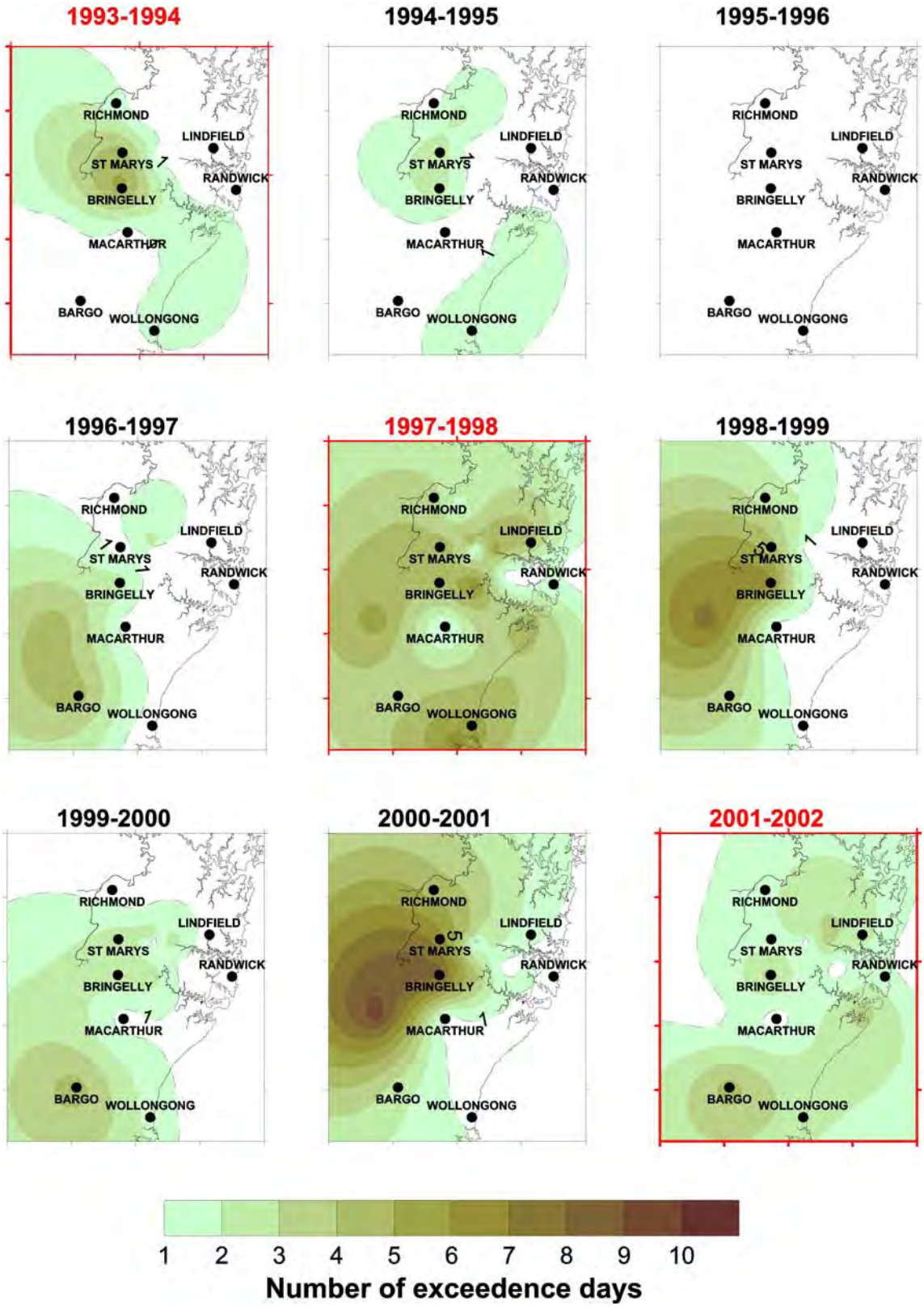


Figure 8.4a: Spatial extent of 1-hour ozone exceedence days in Sydney (October to March, 1993–94 to 2001–02)

Severe bushfire seasons are outlined and labelled in red.

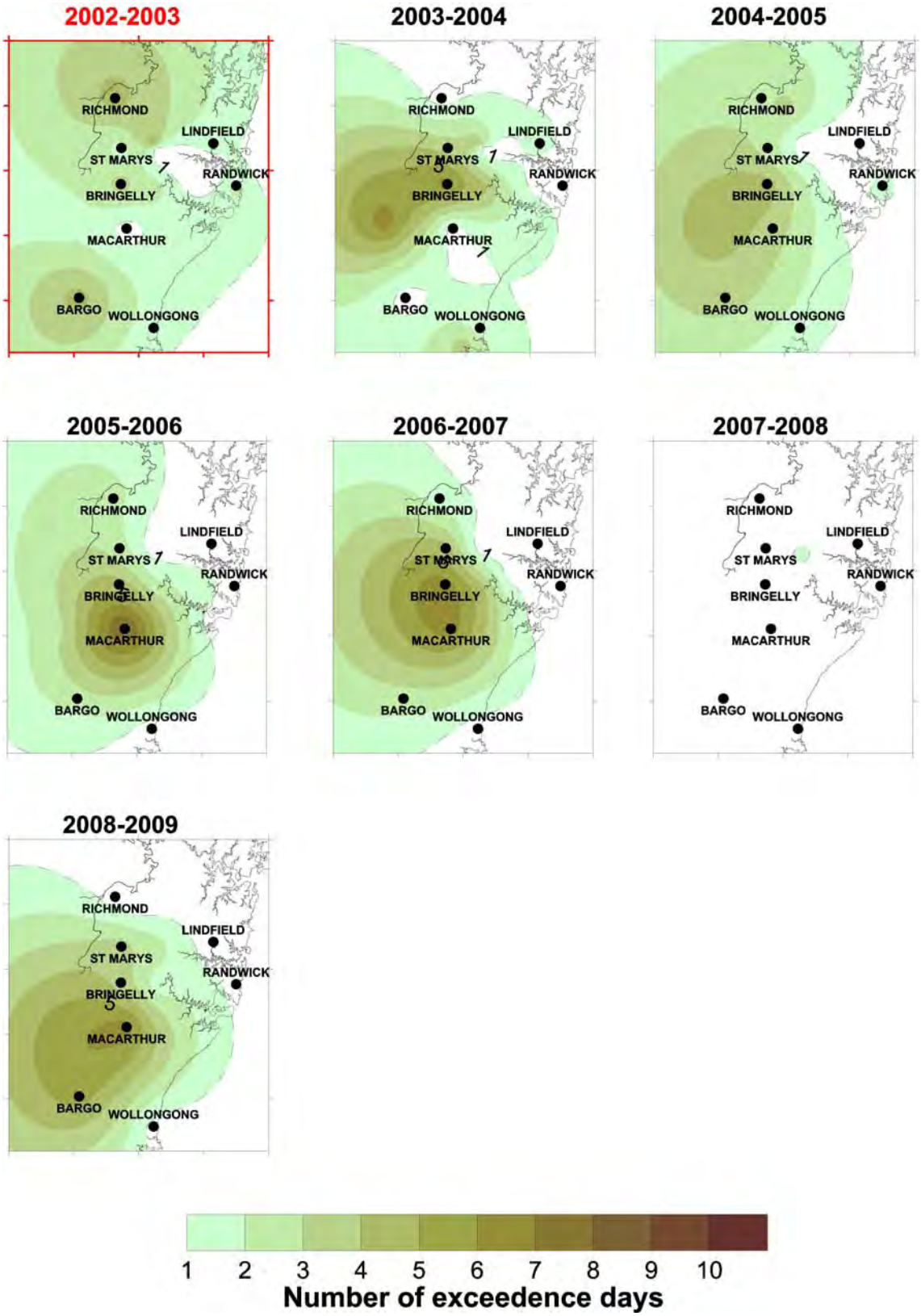


Figure 8.4b: Spatial extent of 1-hour ozone exceedence days in Sydney (October to March, 2002–03 to 2008–09)

Severe bushfire seasons are outlined and labelled in red

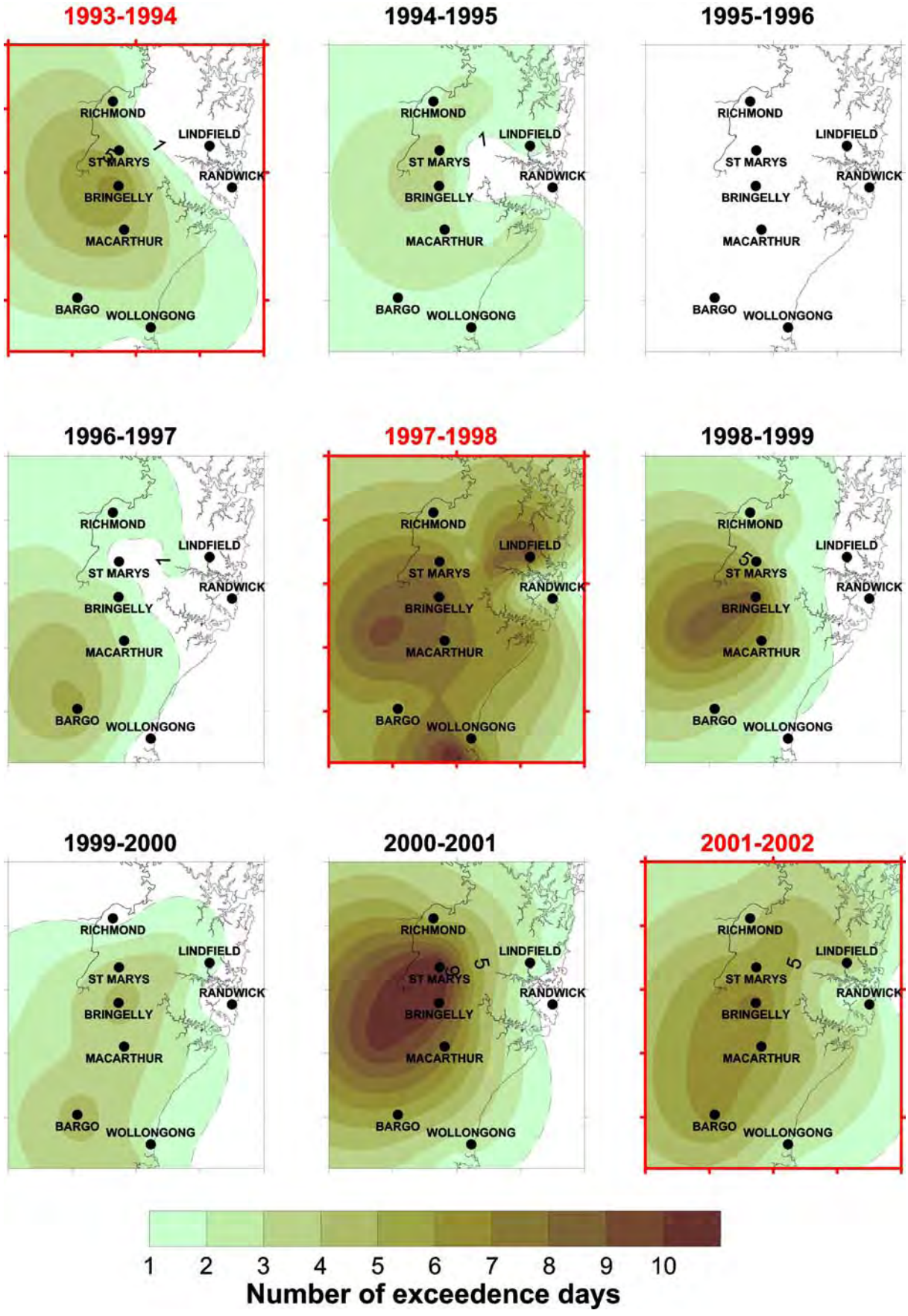


Figure 8.5a: Spatial extent of 4-hour ozone exceedence days in Sydney (October to March, 1993–94 to 2001–02)

Severe bushfire seasons are outlined and labelled in red

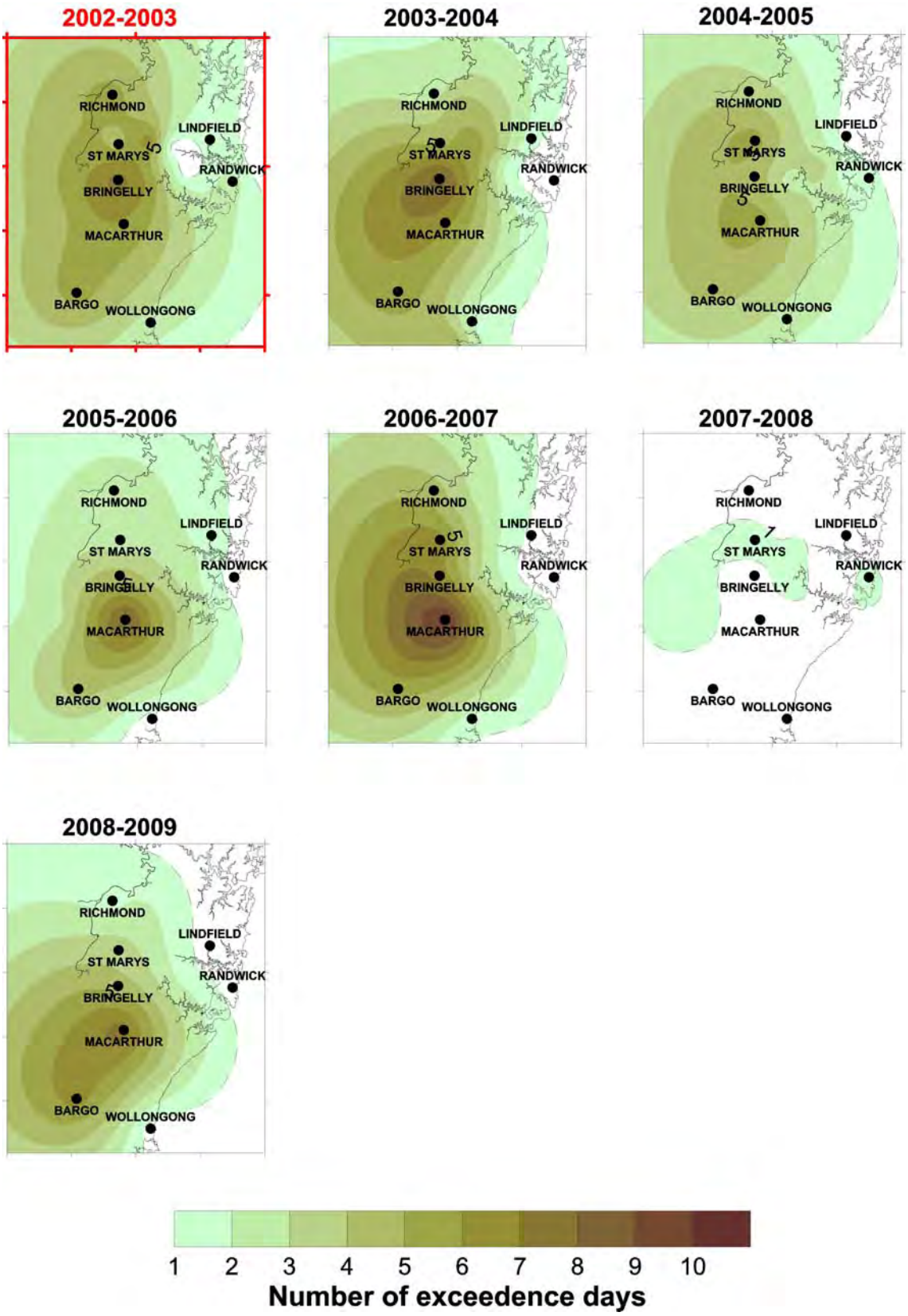


Figure 8.5b: Spatial extent of 4-hour ozone exceedence days in Sydney (October to March, 2002–03 to 2008–09)

Severe bushfire seasons are outlined and labelled in red

Figures 8.4 and 8.5 show:

- Exceedences of the two Air NEPM standards have similar shapes (spatial extents), the 4-hour exceedences being more widespread.
- Exceedences occur throughout the Sydney Basin and are more common in the west and south-west.
- The spatial extents vary from season to season, i.e. there are large differences among the years shown.
- While bushfire activity can contribute significantly to ozone exceedence days, the 2000–01 season shows that widespread, numerous exceedences can occur without a bushfire influence.
- The west and south-west are the areas of the Sydney region most often exposed to ozone concentrations above the Air NEPM standards. However, as the severe seasons of 1997–98 and 2000-01 demonstrate, practically all parts of the region can experience ozone concentrations above the Air NEPM standards at some time.

8.6 Seasonal analysis and bushfires

In most circumstances air quality data are presented using annual calendar-year summaries. There are several reasons for this, such as the familiarity of viewing data that way and that Air NEPM standards are based on calendar-year reporting. However, because exceedences of the ozone standards occur throughout the warmer months only, peaking in December and January, a seasonal analysis can provide more useful information. A comparison of seasonal and calendar-year ozone concentration is presented for 1-hour ozone (Figure 8.6a & b) and 4-hour ozone (Figure 8.6c & d). These figures also indicate the impact that bushfires have on ozone exceedences in the GMR.

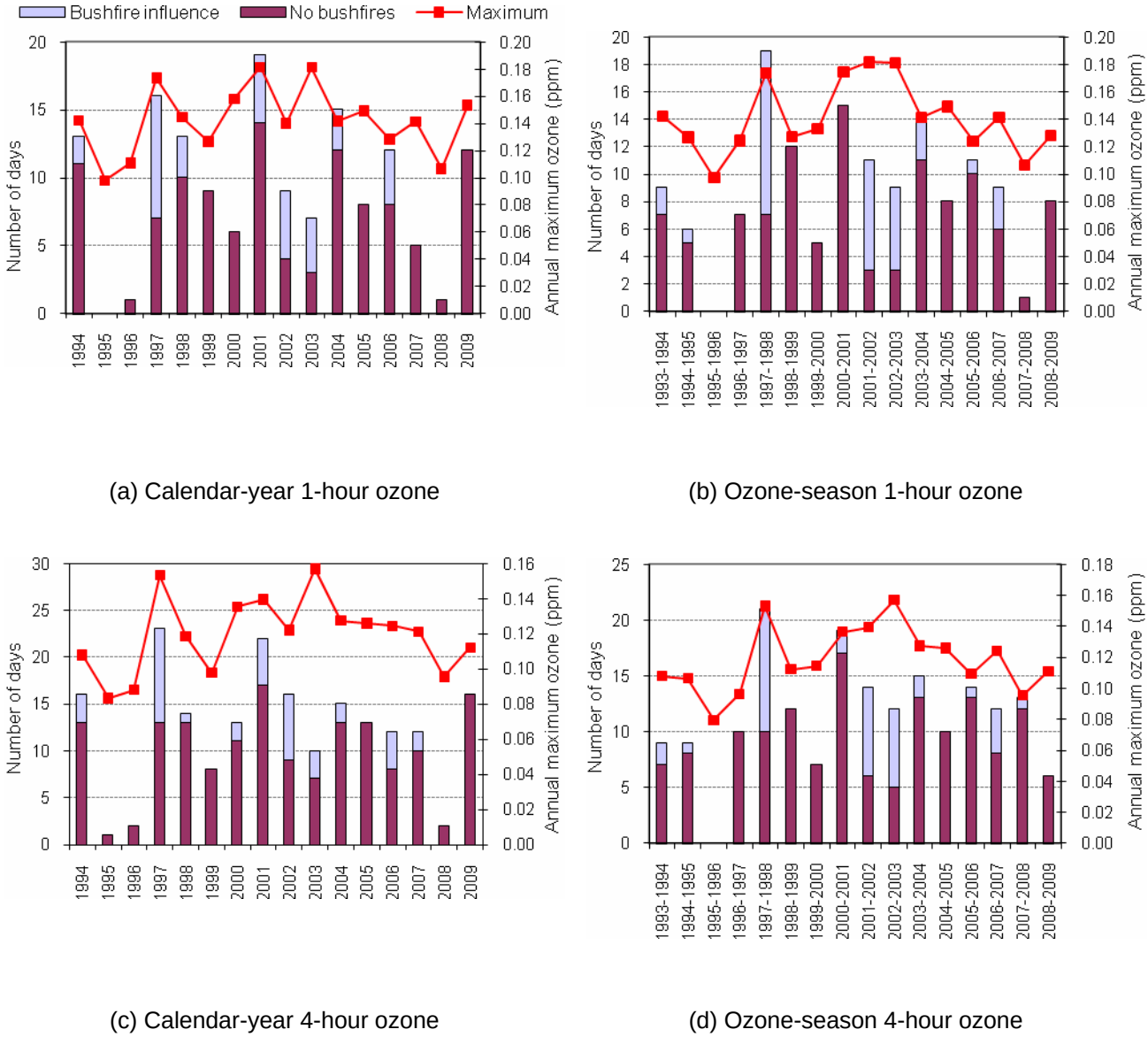
Bushfires are a potentially significant source of ozone precursors (particularly VOCs) and can significantly contribute to ozone exceedences. For example, Sydney bushfires at the end of 2001 contributed to five of the 19 exceedences of the 1-hour ozone standard in 2001 and two of the nine exceedences in 2002.

It is important to recognise that while bushfire events can have an impact on ozone pollution in Sydney, even without bushfires, emissions from human activities are sufficient to cause regular, widespread exceedences of the Air NEPM standards. Many of the weather conditions resulting in high bushfire danger are also conducive to the formation of photochemical smog and elevated concentrations of ozone.

This seasonal versus calendar-year analysis reveals some subtle, yet important, information:

- The low-ozone season of 1995–96, which was a relatively cool and wet summer, is clearly displayed in the seasonal analysis. However, in the calendar-year analysis, the single low season of 1995–96 is misleadingly shown as two low years (1995 and 1996).
- The extreme season of 1997–98, which included some severe fire events, is more clearly illustrated in the seasonal analysis.

- The calendar-year analysis identifies that 2001 was significantly influenced by bushfire events. However, the seasonal analysis shows that although the 2000-01 season was a severe ozone season there was little bushfire activity then, whereas the 2001-02 season had many days impacted by bushfires.



(a) Calendar-year 1-hour ozone

(b) Ozone-season 1-hour ozone

(c) Calendar-year 4-hour ozone

(d) Ozone-season 4-hour ozone

Figure 8.6: Bushfire influence on Sydney region ozone data (1-hour and 4-hour concentrations) by calendar year (1994 to 2009) and ozone season (1993–94 to 2008–09)

8.7 Trends in background ozone

Duc and Azzi (2009) have examined the trend in background ozone concentration, defining 'background ozone' as ozone occurring without photochemical production. They determined that no photochemical production is occurring if nitrogen dioxide concentration is zero for two consecutive hours. This led to using ambient ozone concentrations overnight, from 7 pm to 8 am.

Their analysis shows there is a clear upward trend in the period 1998 to 2005 for nearly all monitoring sites in Sydney. Figure 8.7 shows this trend for one site in western Sydney. An

upward trend in surface ozone concentration has also been reported for the United States (Jaffe and Ray 2007) and Europe (Simmonds *et al.* 2004). Jaffe and Ray suggest increasing global emissions as one possible explanation for these observed trends. An upward trend in background ozone increases the difficulty for a single jurisdiction to take effective action to meet its air quality standards.

Duc and Azzi also found this statistic varies within the Sydney Basin, being lowest at sites in the south-west, slightly higher at sites in the north-west and highest for sites in the east of the region. The median concentrations varied from 15 to 21 ppb.

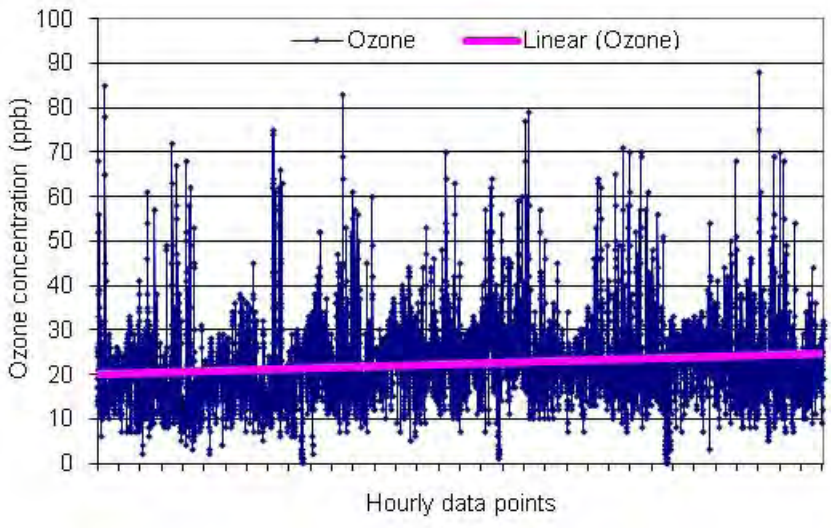


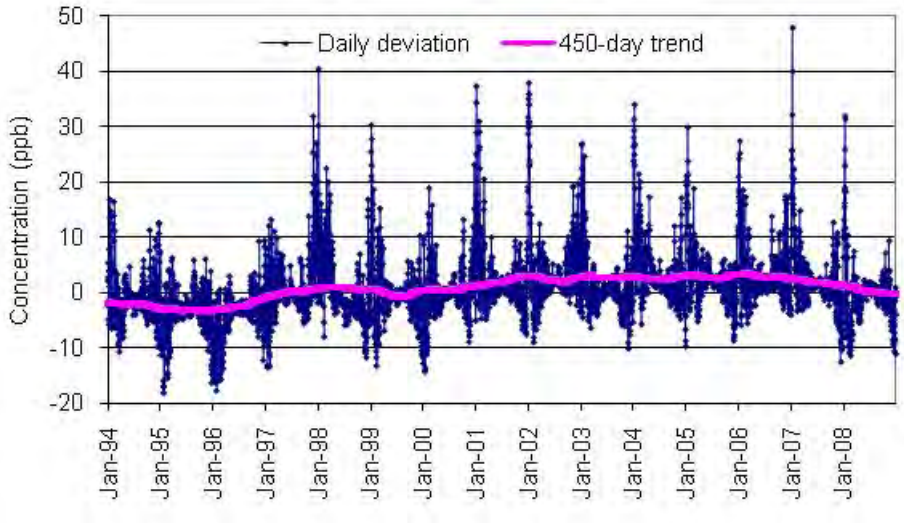
Figure 8.7: Background (no photochemistry) ozone concentrations at St Marys, Sydney

Night-time and early morning concentrations with linear trend,
1 January 1998 to 22 June 2005 (Duc and Azzi 2009)

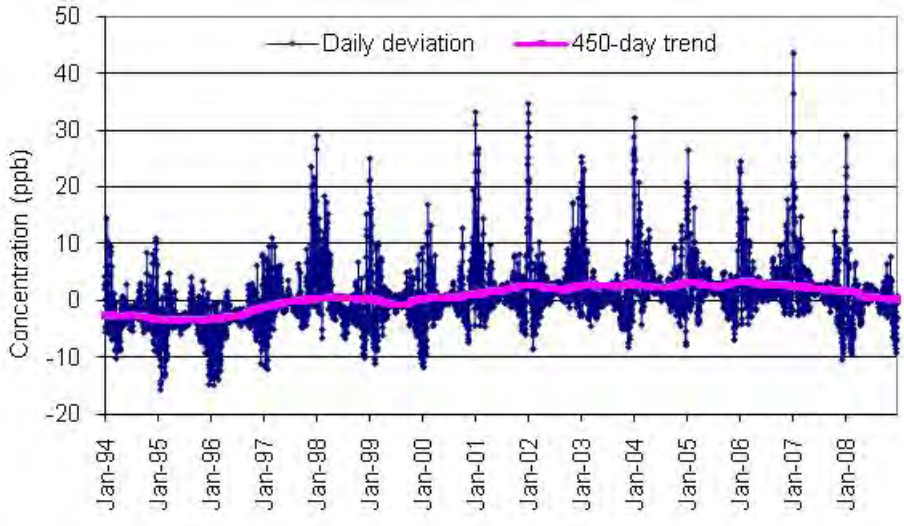
8.8 Long-term ozone trends in Sydney

The ozone monitoring data presented in Section 8.6 show no significant trends in either the numbers of exceedence days per year or in the annual maximum concentrations. Both of these metrics show large variation from year to year. The number of days when ozone standards are exceeded in any given year is strongly dependent on meteorology, which can vary greatly from year to year. For example, the 1995–96 summer was relatively cool and wet, and there were few exceedences of the standards. In contrast, the 1997–98 summer was hot and dry and there were many exceedences of the standards. These conditions also resulted in major bushfires and it is likely additional emissions of VOCs and NO_x from the bushfires contributed to some of the exceedences.

Figure 8.8 shows the results from statistical techniques intended to filter out the meteorological variability and display the underlying trend. The figure shows the maximum daily concentration as a change from the mean, and its 450-day moving average to form a smoothed trend.



(a) Daily maximum 1-hour ozone concentrations



(b) Daily maximum 4-hour ozone concentrations

Figure 8.8: Statistical modelling of the long-range trend in daily maximum average ozone concentrations in the Sydney region (1994–2008)

Note: The pink line is the smoothed long-range trend. It shows change from the mean – positive values indicate concentrations are increasing, negative values that concentrations are decreasing.

These techniques are good at removing the high-frequency signals in the data such as the diurnal and seasonal variations. However, they are limited in their ability to account for the inter-annual variability that occurs as a result of longer term climatic variations such as the El Niño–Southern Oscillation.

Exceedence days are apparent in Figure 8.8 as peaks on the graph. Differences among the seasons are also apparent as differences in the height and number of peaks. The filtered trend shows increasing daily maximum ozone concentration through the 1990s, no trend in the first part of the 2000s and decreasing daily maximum ozone concentration in the past few years. These trends most likely arise from changes to emissions, but some meteorological influence remains, so the link to emissions is only indicative. Note that the trend is shown as the difference from the mean – positive values show concentrations are increasing, negative values show decreasing concentration.

8.9 Ozone monitoring summary

Reducing ground-level ozone pollution in the Sydney and Illawarra regions presents a challenge. Since 1998 there has been no improvement in exceedence statistics in the GMR. Currently both the Air NEPM 1-hour standard and the 4-hour standard for ozone are exceeded regularly during the warmer months of the year. As noted earlier, the number of days when ozone standards are exceeded in any given year is strongly dependent on meteorology, which varies from year to year.

The area within the Sydney region that can at times be exposed to ozone concentrations exceeding the Air NEPM standards is large. The west and south-west of the Sydney region experience concentrations above the standards more frequently than the east and centre.

Bushfire activity influences the severity and frequency of ozone events in the Sydney region, but the impact of bushfires alone does not determine the severity of ozone in a season. Although bushfire events can have an impact on ozone pollution, in Sydney, even without bushfires, emissions from human activities are sufficient to cause regular, widespread exceedences of the standards.

Examination of ozone data trends shows that background (night-time) ozone concentration is increasing, while the decadal trends in daily maximum ozone concentration show increasing concentrations throughout the 1990s, largely stable concentrations to 2007 and then slightly falling concentrations.

8.10 Ozone concentrations in Sydney under climate change

Climate change projections for NSW suggest significant increases in the frequency of drought, increases in the frequency of hot days, and increases in the frequency of high fire risk weather (CSIRO 2007). This has important ramifications for air pollution and health, with ozone pollution events linked to the frequency of hot, sunny days, and the highest particle pollution concentrations linked to the presence of bushfires and dust storms.

In 2008, The Centre for Australian Weather and Climate Research, a partnership between CSIRO and the Bureau of Meteorology, undertook a project to develop and demonstrate a methodology for determining the impact of climate change on ozone concentrations in any location in Australia (Cope *et al.* 2008). Using this methodology, ozone concentrations in Sydney in 20 and 50 years time were modelled to give an insight into the impact of climate change on urban air quality and the possible emissions reduction needed to maintain ozone concentrations below the current Air NEPM standard.

Ozone concentrations in the Sydney region were modelled for three 10-year periods 1996–2005, 2021–2030, and 2051–2060. Figure 8.9 shows the impact across the three decades on the spatial distribution of 4-hour ozone exceedence days. While the spatial distribution does not appear to change significantly, the size of the 4-hour ozone exceedence footprint increases across the three decades. This increase in footprint is also predicted for 1-hour exceedence days.

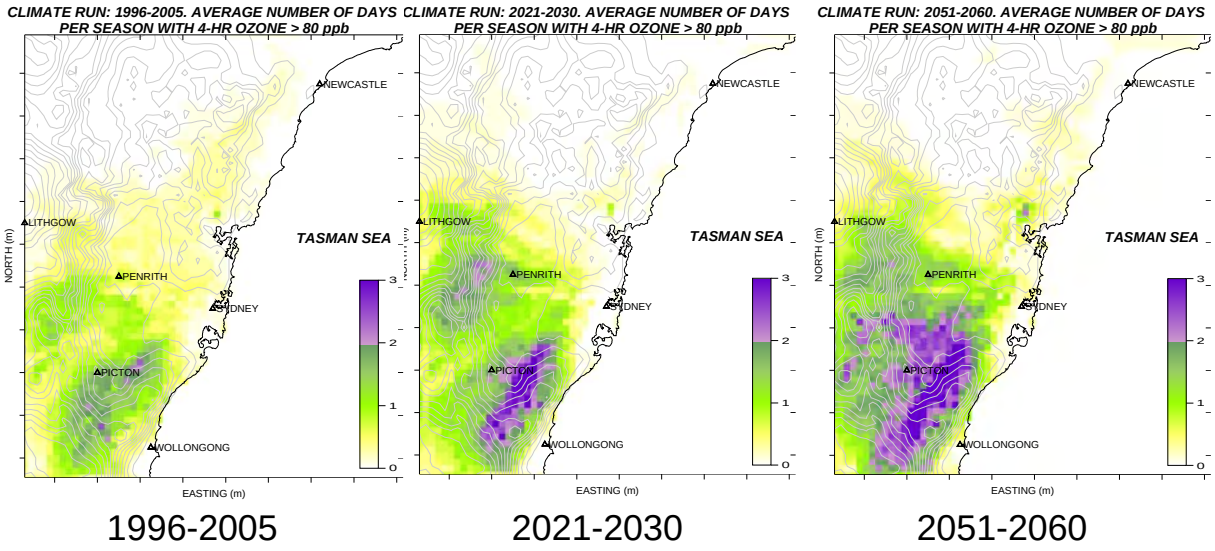


Figure 8.9: Modelled impact of climate change on ozone exceedences – simulated number of days exceeding the 4-hour ozone goal

In the Sydney region, 1-hour exceedence days are predicted to increase by 27% going from the first to the second decade, and to increase by 45% going from the first to the third decade. The average number of exceedences of the 4-hour ozone standard is predicted to increase by 30% and 92% respectively. The most significant single factor responsible for the increase in ozone concentration, and hence this substantial increase in the number of ozone exceedence days, is the predicted increased frequency of hot days.

The modelling also investigated the amount of emission reduction required in order to achieve compliance with the Air NEPM ozone goal within the GMR under predicted climate change conditions for 2051–2060. Emissions were aligned with assumptions used in the Intergovernmental Panel on Climate Change Special Report on Emission Scenarios (www.ipcc.ch/pdf/special-reports/spm/sres-en.pdf). Under these conditions a 40% reduction in precursor emissions from human activities is estimated to reduce peak 1-hour and 4-hour ozone by 17% and 8% respectively. A 70% reduction is estimated to reduce peak 1-hour and 4-hour ozone by 36% and 25% respectively. The results support the finding that the 4-hour ozone standard is more difficult to meet than the 1-hour standard. The results also suggest that an equal reduction strategy for ozone precursors may not be optimal given that emission reductions of even 70% still result in modelled peak ozone concentrations exceeding the Air NEPM standards.

This study is a preliminary investigation into the impact of climate change on air quality in the Sydney region. Nevertheless, it demonstrates that without any changes to current technology, climate change has the potential to increase both peak ozone concentrations and population exposure to elevated ozone concentrations. The increased population exposure comes from increases in the size and duration of elevated ozone concentrations.

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