Ozone pollution episode Summer 2017/18

Ozone episode analysis: 19 and 22 January 2018

This report describes in detail the conditions responsible for the summer ozone episode during 19-22 January 2018. Ground-level ozone is a secondary air pollutant which is not emitted in significant amounts but formed in the atmosphere from photochemical reactions between a complex mixture of gases. Elevated ozone concentrations are often not related directly to proximity to emission sources, but to several factors such as temperature, cloud cover, synoptic meteorology and local-scale wind conditions, and the distribution and strength of emission sources (industry and motor vehicles) of ozone precursors. As demonstrated in this analysis, variations in these factors may lead to distinctive ozone profiles on different days during an ozone episode.

Meteorological conditions in Sydney across the four days between 19 and 22 January were similar. Ozone exceedances of national standards, however, were observed only on Friday (19 January) and Monday (22 January), and not during the weekend (20 and 21 January). Observation of nitrogen oxide (NO_X) gases, a major precursor to ozone formation in urban areas, were found to be higher on the exceedance days. These higher NO_X concentrations were observed across the Sydney Basin[1] in the early morning, and in the western regions of Sydney during the afternoon, concurrent with the ozone exceedances.

The differences in the NO_X concentrations were due primarily to differences in emissions between weekdays and weekends, specifically the impact of increased vehicle emissions during weekday morning hours. An additional factor was a bushfire in the Royal National Park on the southern outskirts of Sydney. The increased NO_X concentrations in western Sydney during Monday 22 January led to increased ozone concentrations, more than would be expected from regular emissions alone.

Event description

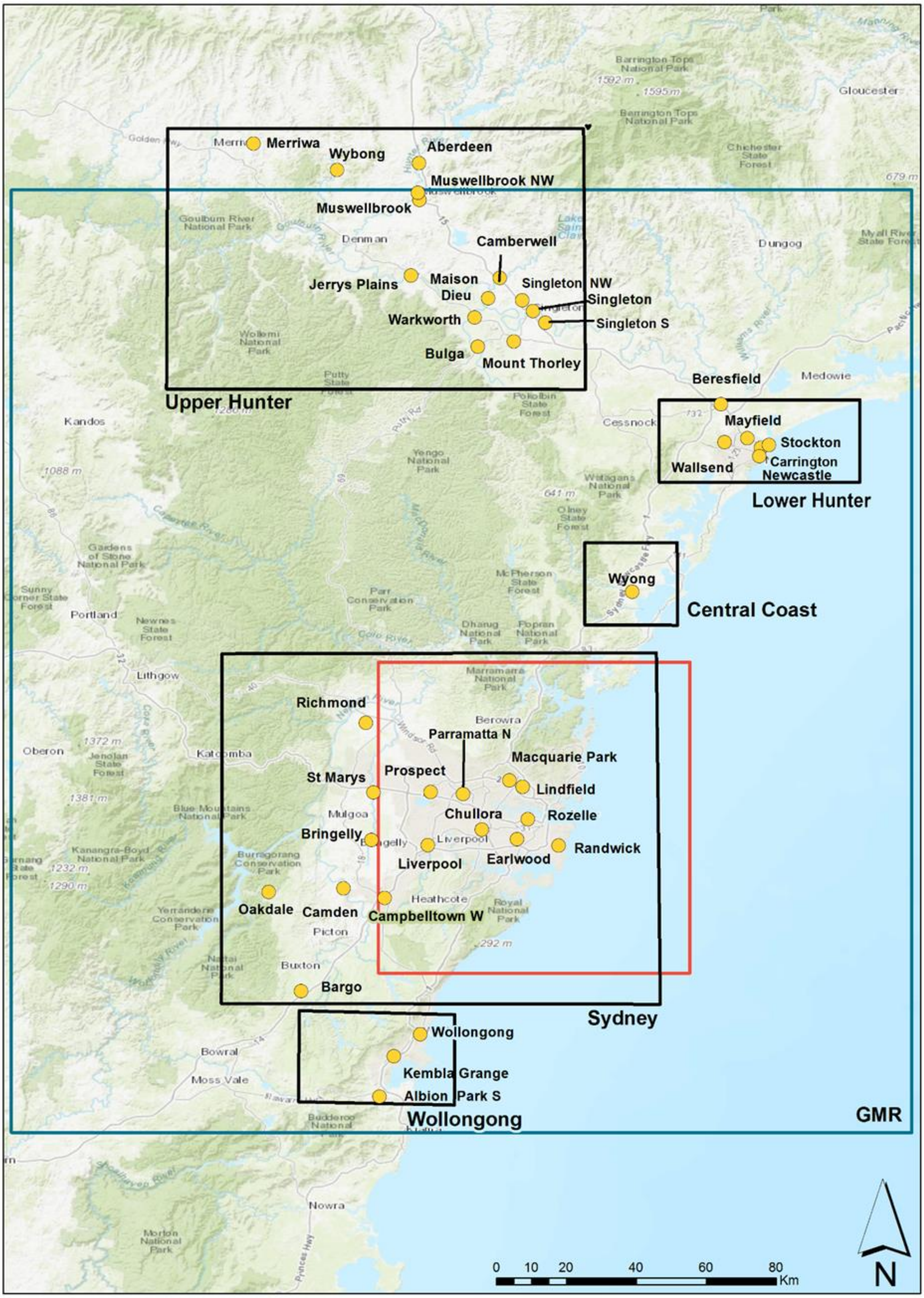
During 2018, ozone was monitored continuously at 23 stations in the NSW Greater Metropolitan Region (GMR), including six stations in Sydney East, six in Sydney South-west, four in Sydney North-west, three in the Lower Hunter, one on the Central Coast and three in the Illawarra (Figure 1).

During both 19 and 22 January 2018, ozone levels exceeded both the 1-hour and 4-hour National Environment Protection (Ambient Air Quality) Measure (AAQ NEPM) standards in the south-west and north-west of Sydney. Figure 2 illustrates ozone levels in pphm (parts per hundred million) during the two exceedance days for the ozone 4-hour rolling averages.

Ozone levels recorded above the national standards were similar in magnitude across the exceeding sites: 1-hour ozone was typically in the range 10.1–11.0 pphm, compared to the standard of 10.0 pphm; and the 4-hour ozone was in the range 8.1–9.5 pphm, compared to the standard of 8.0 pphm. Table 1 identifies sites in the NSW GMR which exceeded the 1-hour or 4-hour ozone standard on each of the two days, the maximum ozone concentration recorded, and the hour (as Australian Eastern Standard Time, AEST) during which the maximum was recorded.

The ozone event on 19 January was less extensive than on 22 January, with only four sites in Sydney South-west exceeding either the 4-hour ozone standard, or both the 4-hour and 1-hour ozone standards (Bringelly, Camden, Campbelltown West and Oakdale). On 22 January, the ozone event was more widespread, with eight sites exceeding either the 4-hour ozone standard, or both the 4-hour and 1-hour standards. This included five of the six Sydney South-west stations (Bargo, Bringelly, Camden, Campbelltown West, Liverpool) and three of the four Sydney North-west stations (Parramatta North, St Marys and Prospect).

[1] Sydney Basin: low-lying drainage basin of rivers and streams between the Blue Mountains in the west and the coast in the east



Note: Red frame indicates Greater Sydney air quality forecasting region

Figure 1 **Air quality monitoring stations in the NSW Greater Metropolitan Region (GMR)**

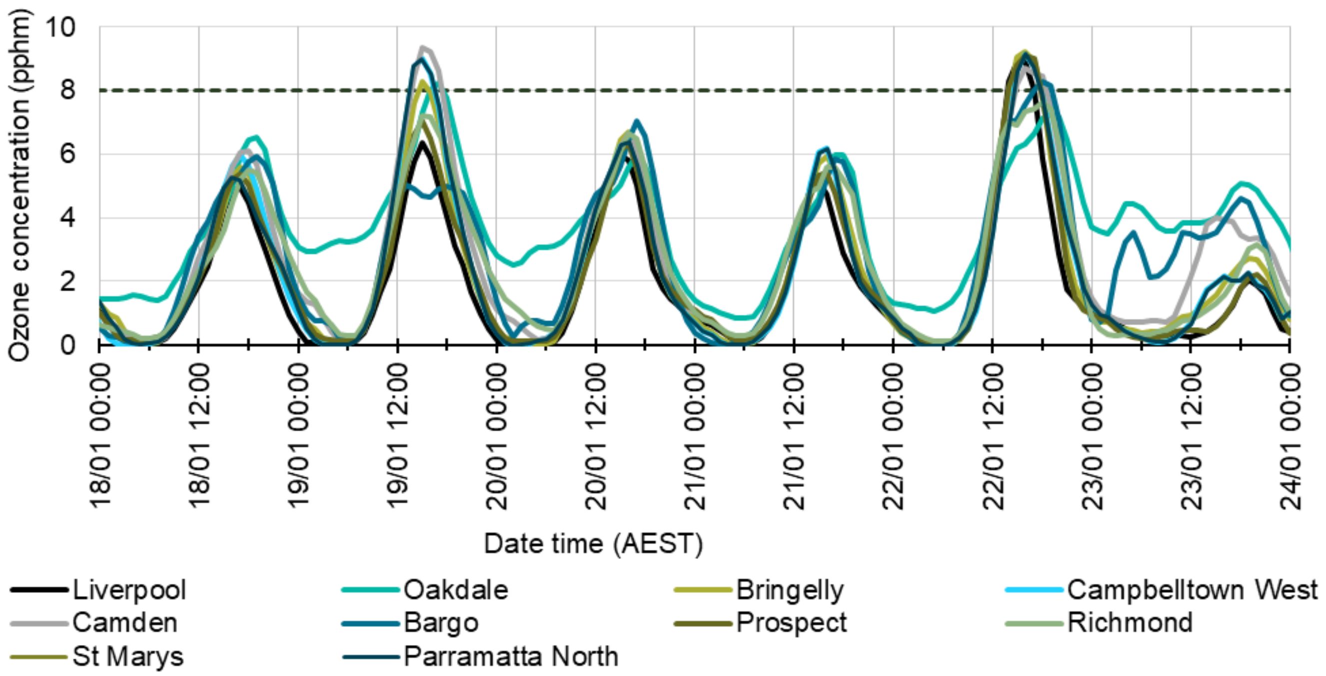


Figure 2 **Ozone 4-hour average concentrations at western Sydney stations, compared to the national standard of 8 pphm (dotted line), during 18–23 January 2018**

During the period 18–23 January, no sites in Sydney East exceeded the ozone standards, with Macquarie Park recording a 4-hour average of just 8.0 pphm at 16:00 on 22 January 2018[2]. Observed ozone concentrations in the Lower Hunter, Illawarra and Central Coast were also considerably lower than those observed in western Sydney. Ozone exceedances observed during this period occurred only in the western Sydney regions, and not in any coastal locations in the GMR. Due to the greater exposure to onshore sea breezes at coastal locations, ozone and its precursors (e.g. emissions of NO_X from motor vehicles) were transported further inland towards western Sydney, where levels tend to build up under prevailing calmer conditions.

Table 1 **Time (AEST) and concentration (pphm) of maximum ozone levels recorded over national standards, on 19 and 22 January 2018**

Region	Site	19 January		22 January	
		1-hour Ozone	4-hour Ozone	1-hour Ozone	4-hour Ozone
Sydney SW	Bargo				18:00, 8.3
Sydney SW	Bringelly		15:00, 8.3	15:00, 11.0	16:00, 9.2
Sydney SW	Camden	14:00, 10.9	15:00, 9.4		16:00, 8.7
Sydney SW	Campbelltown West	14:00, 11.0	15:00, 9.0	15:00, 11.0	16:00, 9.1
Sydney SW	Oakdale		17:00, 8.2		
Sydney SW	Liverpool			14:00, 11.1	16:00, 8.9
Sydney NW	Parramatta North			13:00, 10.2	16:00, 9.3
Sydney NW	Prospect			14:00, 10.5	16:00, 9.1
Sydney NW	St Marys			16:00, 10.5	17:00, 9.4

Note: SW – South-west, NW – North-west

[2] The AAQ NEPM defines an exceedance as an averaged value that exceeds the standard to the last significant figure, which for ozone is 0.1 pphm.

Episode analysis

This analysis describes how variability in the meteorological conditions and emissions between days with similarly high temperatures led to differences in ozone concentrations during 18–22 January.

Meteorological conditions

Synoptic weather charts for 18–23 January in Figure 3 show that during this period, a high-pressure system was located off the NSW coast, over the Tasman Sea. This system led to light morning winds and high temperatures within the Sydney Basin, and north-easterly afternoon sea breezes driven by the Tasman high-pressure system. These conditions have been found to be conducive to high ozone episodes and exceedances in Sydney during summer months[3]. Temperatures peaked on 22 January when maximums up to 41 °C were observed in western Sydney. By 23 January, conditions eased when a low-pressure trough brought cooler conditions to eastern New South Wales.

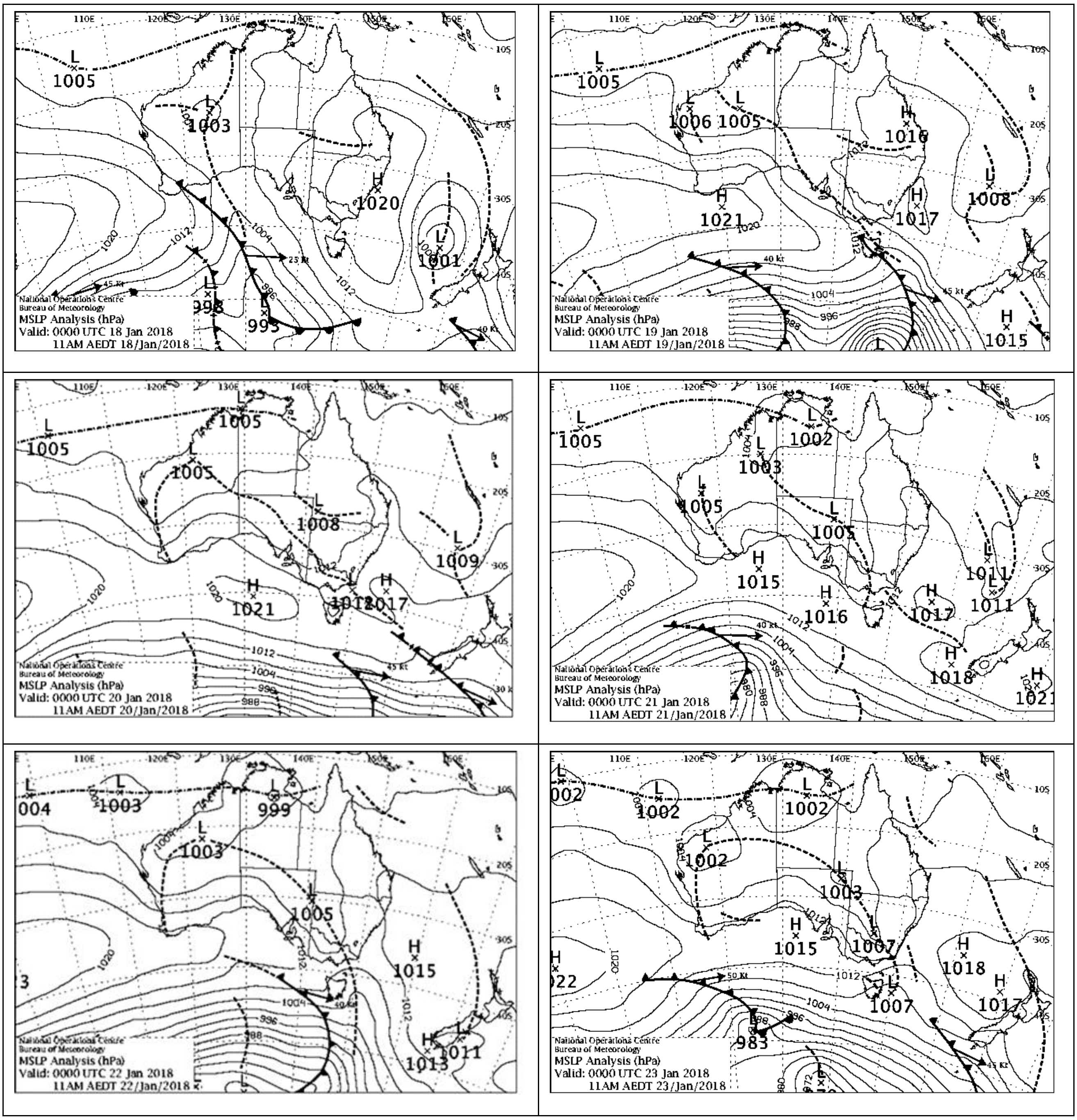


Figure 3 **Synoptic charts for 10:00 AEST (11:00 AEDT) during 18–23 January 2018.**

[3] Jiang et al 2016, Visualising the relationships between synoptic circulation type and air quality in Sydney, a subtropical coastal-basin environment, International Journal of Climatology. Published online in Wiley Online Library

Ozone chemistry

The conditions leading to typical high ozone events in New South Wales have been summarised in the NSW State of Knowledge: Ozone report[4]. This will not be replicated in detail here, except to reference briefly the importance of photochemical interactions between gaseous ozone (O_3), nitrogen oxides and other volatile organic compounds (VOCs).

Nitrogen oxides (NO_X) refer to the combination of two distinct species: nitric oxide (NO) and nitrogen dioxide (NO_2). Direct atmospheric emissions of NO_X within the NSW GMR are predominantly anthropogenic (e.g. motor vehicle emissions) and comprised mostly of NO. This is converted by rapid atmospheric reaction with available O_3 to produce NO_2, as well and molecular oxygen (O_2). Therefore, NO_X concentrations as NO_2 tend to build up downwind of transport corridors during and following morning and afternoon traffic peaks, when highest NO levels occur at the emission source. During the day, degeneration of NO_2 can occur through photolysis under the effect of ultra-violet light, leading to the formation of NO and O_3. Further, under high solar radiation and high temperatures, NO can react directly with other ozone precursors such as VOCs, resulting in ozone formation later in the day.

Due to the rapid reaction of NO and O_3, high ozone concentrations usually occur only when NO concentrations are low, but where NO_2 is still present. This means that the highest ozone concentrations do not occur typically at the NO_X emission point, but downwind if other conditions allow. Where NO and NO_2 concentrations are low, ozone concentrations are typically at background levels which are well below the standards.

Detailed analysis

Ozone concentrations vary both spatially and temporally. Local meteorology and concentrations of ozone precursors recorded each day are important in understanding the location of ozone exceedances, and the magnitude of ozone formation and associated photochemical pollution.

Figure 4 shows the daily maximum 1-hour averages for ozone and temperature at six Sydney stations: Earlwood in Sydney East; Parramatta North and St Marys in Sydney North-west; and Liverpool, Campbelltown West and Camden in Sydney South-west.

Figure 4 also shows the maximum 1-hour NO_X concentration between 12:00 and 19:00 AEST. This time period was selected to focus on the period when daily maximum ozone concentrations typically occur. During these hours of the day, the proportion of NO_2 in total NO_X is high and temperatures are elevated. These are essential conditions that drive photochemical ozone formation.

Day 1, Thursday 18 January 2018

The day was characterised by a pattern of light winds inland in the basin, followed by stronger afternoon sea breezes. The maximum daily temperatures reached between 30 °C and 35 °C in western Sydney. There were no exceedances; the maximum 1-hour average ozone of 8.2 pphm was at Oakdale.

Day 2, Friday 19 January 2018

The second highest ozone levels during the event period (18–22 January 2018) were recorded on this day, following calm morning conditions, with wind speeds below 1 m/s between 0:00 and 6:00 AEST at most sites. Temperatures during this period ranged between 11 °C and 17 °C at around 4:00 AEST. During the morning commute times, between 5:00 and 7:00 AEST, maximum 1-hour NO_X in the range 7.0–8.5 pphm were observed at the four sites in Sydney located closest to major roadways: Liverpool, Parramatta North, Earlwood and Rozelle.

Later in the morning, strong northerly winds prevailed off the coast (Figure 5, top panel). These strong northerlies blocked the weak inland north-westerly winds and resulted in increases in ozone along the coastal Sydney region. At around 13:00 AEST, winds changed from north to north-easterly at the coast, but the inland parts of the Sydney Basin were still calm. As the inland temperature increased, the onshore sea breeze moved into the Sydney Basin. Higher NO_2 concentration levels accumulated around the front of this breeze.

As this wind-transported air mass moved further into the south-west and north-west, the subsequent concentrations of NO_X (mainly NO_2) increased in the atmosphere, causing ozone levels to spike above the national standards in these areas. The ozone peak was greater and endured longer, the further west

[4] Department of Environment, Climate Change and Water NSW 2010, State of Knowledge: Ozone

into Sydney the breeze moved (Figure 5, bottom panel). A maximum hourly concentration of 10.9 pphm was observed at Camden at 14:00 AEST. By 16:00 AEST, the sea-breeze had moved into the south-west and north-west of Sydney Basin, reducing ozone levels in all but the outer west of the basin.

Day 3, Saturday 20 January 2018

The morning NO_X concentrations between 5:00 and 8:00 AEST at Earlwood (Sydney East) and Parramatta North (Sydney North-west) were about 2 pphm lower than observed on the previous day. As the conditions were still during these hours, lower traffic volumes on a Saturday were the likely reason for lower NO_X, which was still mostly comprised of NO. However, NO_X concentrations at Liverpool (Sydney South-west) were equivalent to those on 19 January.

Meteorology on this day was very similar to 19 January, with afternoon maximum temperatures between 34 and 39° C across the city. The lower NO_X concentration in the morning at most locations was also reflected in lower NO_X concentrations in the afternoon in the west (Figure 4, bottom panel). Wind speeds in the basin were higher than the previous day, peaking at 7 m/s at Bringelly at 16:00 AEST, with slightly better ventilation conditions (hence a reduced ozone build-up effect) compared to 19 January, resulting in a maximum 1-hour ozone of 8.4 pphm recorded at Bringelly (Sydney South-west) at 16:00 AEST.

Day 4, Sunday 21 January 2018

The morning NO_X levels were lowest on this day. Unlike Saturday, when only some stations had reduced NO_X concentrations compared to Friday, all stations in Sydney recorded lower NO_X levels on Sunday. Maximum 1-hour ozone concentrations measured 1.8 and 4 pphm at Parramatta North (Sydney North-west) and Liverpool (Sydney South-west), respectively. This was due to decreased traffic volumes on Sunday morning compared to weekday or Saturday mornings (transport being the major NO_X emission source in Sydney), resulting in much lower NO_X in the afternoon in both the east and the west of Sydney (Figure 4, bottom panel). Temperatures were high, reaching between 35 and 37 °C in the west, although they were 1–2 °C cooler than the previous two days (Figure 4, middle panel). The maximum ozone concentration was 7.5 pphm at the Oakdale station in far south-west of Sydney at 16:00 AEST.

Day 5, Monday 22 January 2018

This day recorded the most intensive ozone episode and the most extensive spread of high ozone levels in the western Sydney region during the event period (19–22 January). Conditions were like those on 19 January when ozone standards were first exceeded. While both 19 and 22 January had high morning NO_X from the morning peak traffic, one difference for this day was that a bushfire had started on 20 January[5] in the Royal National Park, south of the city. Prevailing winds on 22 January dispersed bushfire smoke from the National Park into the Sydney Basin, particularly the south-western area. This was evident from the reduced visibility in Sydney South-west on this day (Figure 6).

The bushfire smoke likely contributed to the much higher NO_X observed in western Sydney (Figure 4, bottom panel), providing additional precursors for afternoon ozone formation and the resulting higher ozone levels (Figure 4, top panel). Like 19 January, calmer conditions with daytime winds below 4 m/s prevailed in western Sydney, allowing ozone levels to build up. A maximum hourly ozone concentration of 11.1 pphm was observed at Liverpool (Sydney South-west) at 16:00 AEST.

Day 6, Tuesday 23 January 2018

On 23 January, there was a southerly change over the Sydney region, bringing an end to the ozone episode. The south-easterly winds hit Sydney during late morning and prevented the formation of the typical pattern of early sea breezes seen during the previous four days. The southerly change, together with enhanced cloud cover, limited maximum temperatures to below 30 °C in north-west Sydney, significantly lower than the previous days (between 36 and 41 °C).

The south-easterly winds moved through western Sydney in the afternoon and smoke from the Royal National Park bushfire was seen across Sydney and impacted visibility. Notably, daytime NO_X levels were the highest recorded during18–23 January (Figure 4, bottom panel). However, a combination of cooler temperatures, overcast conditions (reduced solar radiation) and higher NO concentrations throughout the day (due to direct transport from the bushfire emissions under southerly winds) contributed to suppressed ozone formation. Hence, in contrast to the previous day, a maximum hourly ozone concentration of 5.2 pphm occurred at Bargo (Sydney South-west) at 16:00, while Parramatta North (Sydney North-west) saw a maximum of 2.3 pphm at 16:00 AEST.

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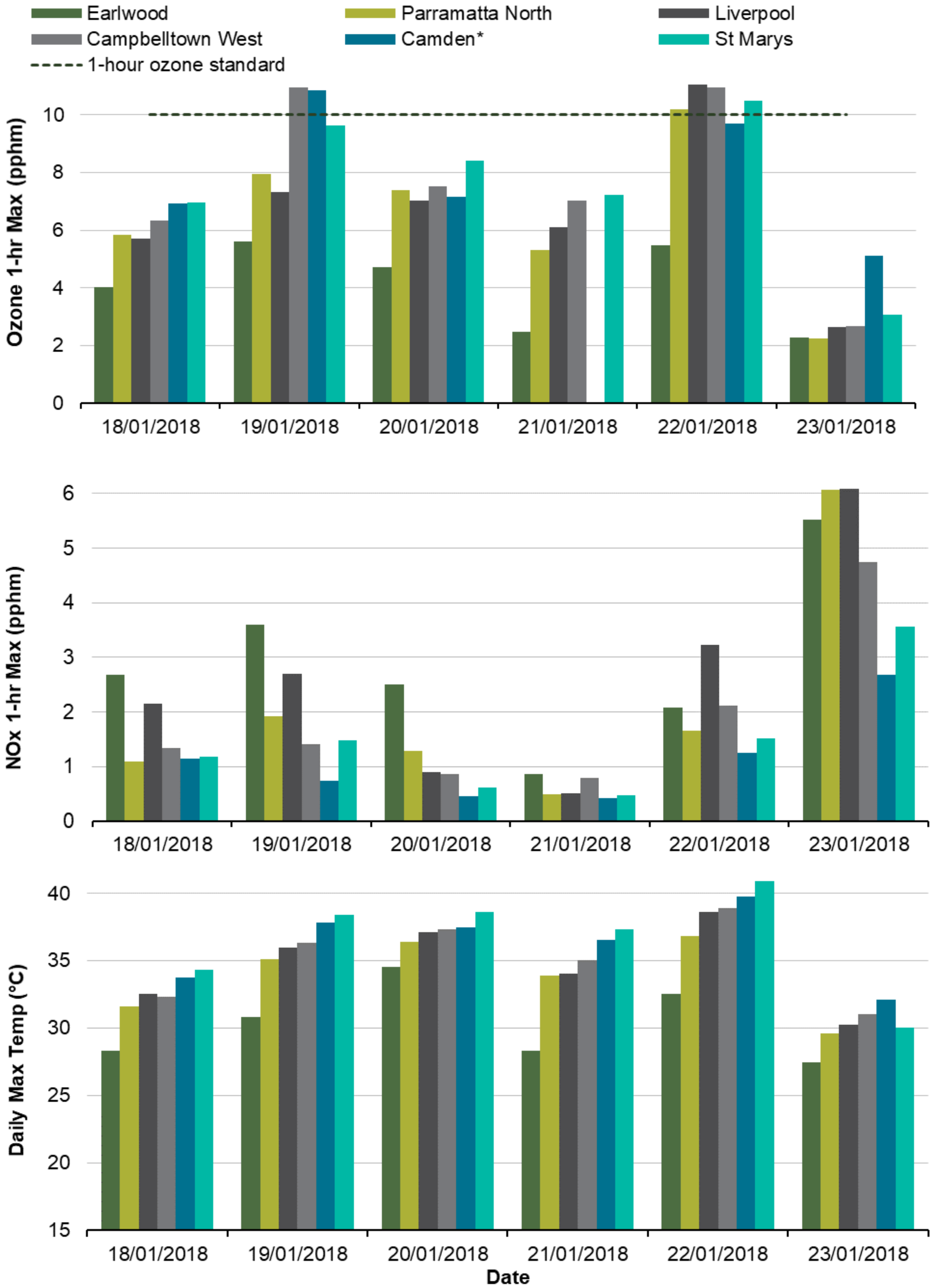
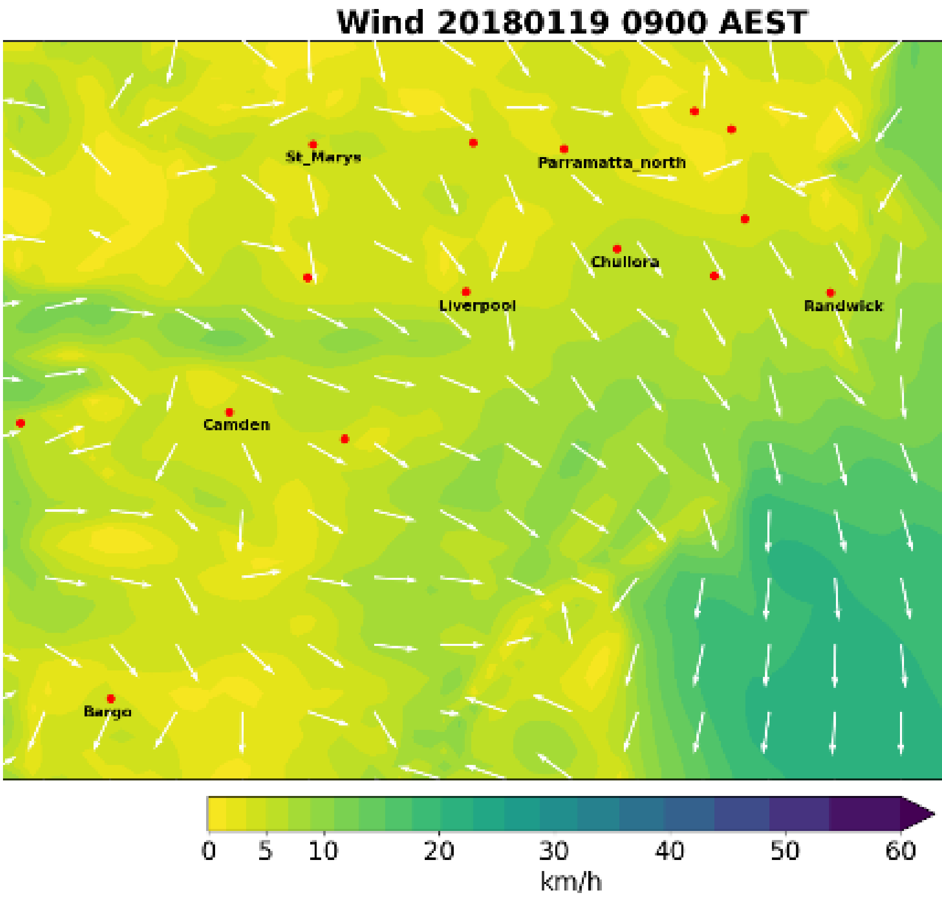
[5] The Royal National Park bushfire burned around 2,000 hectares by the time it was extinguished in mid-February 2018.



* Camden ozone data was not available on 21/01/2018 due to power outage

Figure 4 **Daily maximum 1-hour average ozone, total nitrogen oxides (NO_X) and temperature during 12:00 and 19:00 AEST, at six selected stations in Sydney, between 18–23 January 2018**



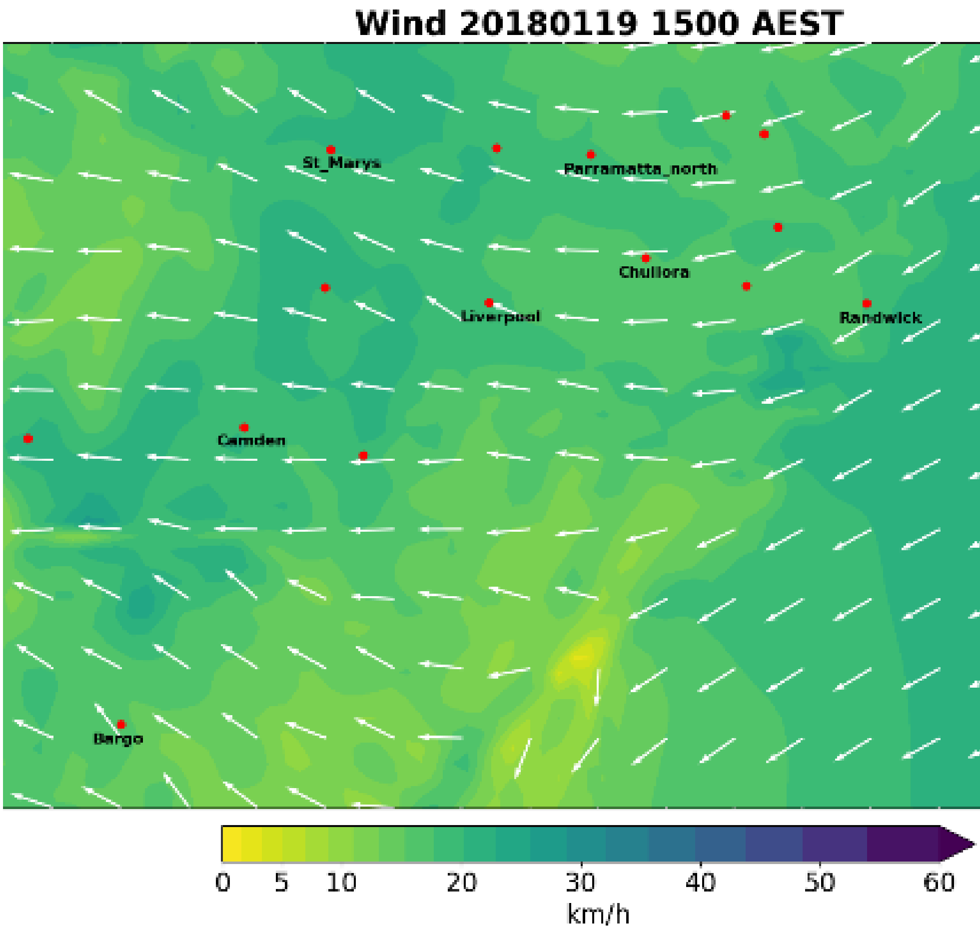


Figure 5 **Wind direction (arrow) and speed (colour scale) fields for Sydney on 19 January 2018, illustrating calm wind conditions at 9:00 AEST (top) and the east to north-easterly sea-breezes at 15:00 AEST (bottom)**

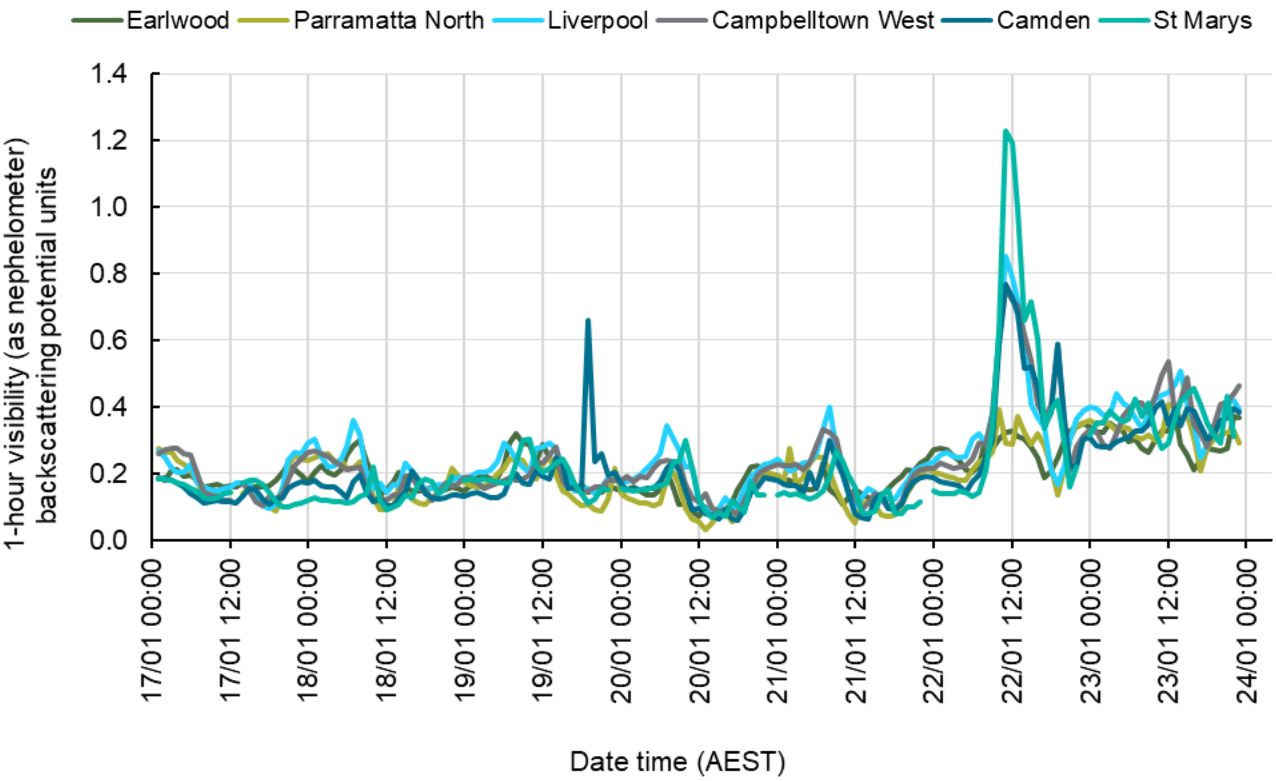


Figure 6 **Visibility measurements at six selected stations in Sydney between 17 and 23 January 2018, illustrating the impact of the Royal National Park bushfire on 22 January**

Summary

This episode analysis highlights the importance of variations in emission sources and meteorological conditions on ozone formation within the Sydney Basin.

The conditions observed during the four days between 19 and 22 January were generally similar in regional and local-scale meteorology, reflected in similar wind speeds and temperatures across the Sydney Basin. The main difference between these four days were related to the NO_X concentrations in the mornings and the subsequent impact on the NO_X concentrations observed at the front of the afternoon sea breezes moving through the Sydney Basin.

A likely contributor to the lower NO_X concentrations observed on 20 and 21 January could be the reduction in morning traffic related emissions during weekends. Lower NO_X concentrations resulted in lower NO_X availability in the afternoon sea breezes, compared to Friday 19 January and Monday 22 January (weekdays).

In addition, other studies suggested that recirculated air can affect NO_X concentrations available for ozone formation[3,4]. When comparing the morning NO_X concentrations in eastern Sydney between Friday 19 January and Monday 22 January: on Friday, the air in eastern Sydney potentially contained a small impact from recirculated precursors (traffic emissions) from previous weekdays. The availability of recirculated precursors was likely lower on Monday. However, a slight increase in NO_X concentrations across central Sydney on Monday, from the Royal National Park bushfire, increased the available NO_X. This contributed to the wider-scale ozone exceedances on Monday 22 January, compared with similar high-temperature days of Saturday and Sunday.

This episode analysis has illustrated how the complex interplays, between NO_X emissions and synoptic and local meteorology, typically influenced photochemical smog in Sydney. The interplays were quite distinct particularly when considering that Tuesday 23 January saw some of the highest daytime NO_X levels but lowest ozone levels during the entire during the episode period. This reflects that while emissions were higher than normal on this day, the southerly wind change, higher cloud cover and temperatures below 30°C suppressed ozone production. The episode demonstrates how variability in temperatures, wind conditions and precursor emissions influenced ozone concentration levels during 18–23 January 2018.

This report was prepared by Dr Stephen White and Dr Upma Dutt, and reviewed by Dr Leanne Graham and Dr Ningbo Jiang

Published by: Department of Planning, Industry and Environment, 59–61 Goulburn Street, Sydney South 1232. Ph: 131 555 Email: info@environment.nsw.gov.au; Web: www.environment.nsw.gov.au
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