Government of **Western Australia**
Department of **Water and Environmental Regulation**

Mapping dust plumes at Mandogalup using a LiDAR

Report of air quality monitoring conducted between1 December 2017 and 31 March 2018

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January 2019

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Preface

This report provides an analysis of data obtained from a short-term air quality monitoring campaign in Mandogalup, a locality in the southern Perth metropolitan area. The campaign monitored particle levels arising from sources in and around Mandogalup. Conventional monitoring methods for particles with an equivalent aerodynamic diameter smaller than 10 micrometres (µm) (PM_{10}), such as tapered element oscillating microbalance (TEOM) and beta attenuation monitor (BAM) were used, as well as a Light Detection And Ranging (LiDAR) instrument. This analysis covers a four-month period from December 2017 to March 2018.

The objective of this project was to determine the origins and movement of dust contributing to impacts experienced in and around Mandogalup over the 2017–18 summer by using a Windcube® 200S LiDAR instrument installed atop a tower.

Summary

This report summarises an air quality study conducted in Mandogalup between December 2017 and March 2018 using a number of air monitors designed to detect particles[1] within the atmosphere.

The area is dominated by the Alcoa of Australia Limited (Alcoa) Residue Disposal Area (RDA) to the west while agricultural activities and sand and limestone quarrying also operate in the area.

This study used a LiDAR supplemented with an air-monitoring network (compliant with Australian Standards) to identify dust sources in the area. Major findings of this study are:

- Major contributors to overall dust levels in the area include the Alcoa RDA, sand and other quarries, roads, truck movements, agricultural activities and industrial activity in the Kwinana industrial area.
- The levels of PM_{10} dust at the Central and Norkett sites over the study period seem to be somewhat comparable to other locations in Perth and semi-rural areas in the wider Perth metropolitan area.
- Amenity impacts were unable to be assessed, except to note that the levels of total suspended particles (TSP – larger particles) seem to decrease with distance from the RDA.

During the study period, industrial and agricultural activity both contributed to elevated dust levels in Mandogalup but did not cause an exceedance of the National Environment Protection (Ambient Air Quality) Measure (NEPM) standard for PM_{10}.

TSP concentrations did not exceed the applicable Environmental Protection (Kwinana) (Atmospheric Wastes) Regulations 1992 (EPR) standard of 90 μg/m^3 averaged over 24 hours but exceeded the EPR TSP limit of 1000 μg/m^3 averaged over 15 minutes at two locations on 17 December 2017. Directional and pictorial analysis of these events indicates that it is unlikely the RDA was a major source of the exceedance.

[1] Particles encompass airborne dust from both human-made and natural sources, which generally produce a coarse or larger sized particle, and combustion, which produces exhaust or smoke with a fine or smaller particle size.

1 Background

In June 2017, the Environmental Protection Authority (EPA) provided the Minister for Environment with a section 16(e) advice titled '*Consideration of potential health and amenity impacts of dust in determining the size of a buffer for urban development in the Mandogalup area'.*

This advice was requested by the previous government to assist in the consideration of establishing legislation to control urban (residential) and other sensitive land uses in the vicinity of the Kwinana industrial area (particularly close to Alcoa's RDA).

Key findings in the advice included:

- The eastern area of Mandogalup is located sufficiently far away from the RDA, and outside the predominant wind field that generates dust from the RDA, that there is negligible health risk and low likelihood of unreasonable amenity impacts in this area from RDA dust.
- Air quality does not appear to meet the revised NEPM goal for air quality in the north and north-east Mandogalup area under the current or planned future RDA operation. Dust events from the RDA may cause occasional amenity impacts in the area under current and future operations.

The EPA advised further investigation was required to determine the sources of dust contributing to the exceedances of the NEPM goal in the north and north-east.

In December 2017, in response to the EPA's advice, the Department of Water and Environmental Regulation (DWER) commenced a four-month study focusing on potential sources of dust impacting air quality in the north and north-eastern Mandogalup area. The study was conducted over the summer months starting on 1 December 2017 and ending on 31 March 2018.

A variety of monitoring equipment and technologies was used, including particle monitors, deposition gauges and a Light Detection And Ranging instrument (LiDAR).

A publicly accessible webpage displaying real-time results operated for the duration of the study; it is no longer active as the study has been completed.

Figure 1 Mandogalup study area. The 4-kilometre radius green semicircle is centred on the LiDAR location atop a scaffold and represents the approximate coverage of the LiDAR beam. Monitoring sites are marked as are the nominal areas indicated by the EPA. A view south from the top of the tower is included at the bottom of the figure

2 Measurement instruments

As part of this project Australian Standard compliant beta attenuation monitors (BAM) and tapered element oscillating microbalance (TEOM) instruments were used to measure PM_{10} concentrations and assist in the calibration of the LiDAR. The instruments were installed:

- 3.4 kilometres south of the LiDAR site (fire station)
- 1.9 kilometres south of the LiDAR site (Norkett Rd)
- 2 kilometres south of the LiDAR site (Central)
- 1.4 kilometres south-west of the LiDAR site (Mandogalup Rd).

DWER's Windcube® 200S LiDAR was also installed, and operated by Ecotech Pty Ltd on behalf of DWER, on a tower erected at Wattleup Road for the study period.

LiDAR is a well-established technology developed in the 1960s. One of its first uses was by the US National Centre for Atmospheric Research to measure cloud height.

The LiDAR instrument sends out thousands of light pulses per second and measures the amount of time it takes for each pulse to bounce back after being reflected from a distant object. As light moves at a constant speed of 0.3 metres per nanosecond, the LiDAR instrument can precisely calculate the distance between itself and a target.

By repeating this in quick succession and rotating through 360 degrees, the instrument essentially measures the backscattering (reflection intensity) of light from any particles in the atmosphere and is able to give a qualitative measure of these particles, which are dispersed in the air. A measurement is taken of the average backscatter of particles within the length of the light beam, as recorded at every 20-metre interval along the beam.

For this project, the Windcube® 200S LiDAR was erected on a tower and set to perform continuous semicircular scans from east (90 degrees) through south (180 degrees) to west (270 degrees), with each scan completed every five minutes.

The LiDAR output provided a reading of backscatter intensities (or relative particle concentrations) at each point within a semicircular area centred on the LiDAR and extending out up to 4 kilometres for each compass degree. The radial (or going out from the centre) resolution was 20 metres.

Each of these points is termed a gate-degree, with a gate defined as the resolution available along the laser extending out from the LiDAR. As the semicircular resolution is a one degree sweep of the LiDAR beam, each gate-degree encompasses a 20 metre x 1 degree area.

Thus, the LiDAR provides a mechanism whereby a virtual particle measure can be obtained at each of the available points within that disc, making up more than 34,000 measurements of backscatter intensities every five minutes within the total observational space of 25 square kilometres.

The LiDAR's positioning on the tower allowed a largely unimpeded view of the surrounding landscape with some hard targets (e.g. one large tree due south and transmission towers) within the landscape obscuring some of the LiDAR beam. These are seen on some of the LiDAR plots as sections extending outwards where there is no backscatter return due to obstruction.

Data were collected on a five-minute cycle where the LiDAR scanned over a semicircle (180 degrees). During each scan, the LiDAR beam passed over each of the four particle monitors installed in the region. The information provided by the real-time feed from those instruments was used to calibrate the LiDAR to correct for atmospheric conditions. Further use of this facility of the LiDAR is still under investigation and may be the subject of future reports. For this report, all PM_{10} concentrations used will be those obtained from the standard particle monitors installed as part of the Mandogalup particle network. LiDAR backscatter data are used for determining particle pathway and source allocation.

3 Potential dust sources

Alcoa operates the Kwinana Alumina Refinery located close to Cockburn Sound, about 26 kilometres south of the Perth central business district (CBD). The refinery was established in the early 1960s to process bauxite mined from company leases in the Darling Range. The two components of the Kwinana Alcoa operations are refinery processing and disposal of residue from bauxite processing.

The current RDA is located in an area bounded by Anketell Road (south), Abercrombie/Postans Road (west), Mandogalup Road (east) and the Western Power grid high-voltage power line track (north).

A number of quarries and sand pits also operate in the area. These include the Mandogalup Sand Pit located 500 metres south of the LiDAR and three quarries located 2.8 kilometres west, 3.3 kilometres west-southwest and 5 kilometres south-west of the LiDAR.

The locality also has a mixture of land uses that include agricultural pursuits, such as market gardens and hobby farms.

While Mandogalup Road, running generally north to south, is the major access path into and out of the area, there are a number of minor roads, both paved and unpaved, that are heavily trafficked by motor vehicles, trucks and agricultural vehicles.

4 Particle data analysis

The EPR provide a 24-hour averaged ambient air quality standard for total suspended particulates (TSP) of 90 µg/m^3 with a limit, which is never to be exceeded, of 150 µg/m^3 for areas within a large part of the study region. The EPR also provide a short-term 15-minute concentration average for TSP of 1000 µg/m^3, which applies throughout the whole area of the Environmental Protection (Kwinana) (Atmospheric Wastes) Policy 1999 (Kwinana EPP). The EPR does not provide any standards or limits for PM_{10}. For this report, PM_{10} standards will be those provided within the NEPM of 50 µg/m^3 averaged over one day.

TSP is a measure of particles with an equivalent aerodynamic diameter (EAD) of less than 50 µm. The definition of EAD is the diameter of a spherical particle of density 1000 kg/m^3, which is the density of water, and which exhibits the same aerodynamic behaviour as the particle in question. As the name implies, PM_{10} are the particles with an EAD of 10 µm. PM_{10} particles are respirable (can be inhaled) and hence may affect health. They can also have a major effect on visibility because of their light scattering properties. While small particles may affect both health and visibility, larger particles are a source of nuisance as they tend to deposit on and soil property.

Monitoring performed within the study area found that during the study period, particle concentrations did not exceed either the 24-hour PM_{10} NEPM standard of 50 µg/m^3 or the 24-hour TSP standard for the Kwinana EPP Area C of 90 µg/m^3. The highest concentrations recorded at each site are shown in Table 1, compared with two PM_{10} particle monitors operating in metropolitan Perth over the same monitoring period (at Caversham in the Swan Valley and South Lake, 7.5 kilometres north of the LiDAR).

Table 1 Highest concentration measured at each site during the study period

Site	Daily TSP (% data recovery)	15 min TSP	Daily PM_{10} (% data recovery)
	(µg/m^3)	(µg/m^3)	(µg/m^3)
Mandogalup	72 (98.2%)	1145 (17/12 12:40 am)	46 (98.1%)
Norkett	56 (98.0%)	1069 (17/12 11:50 am)	36 (98.1%)
Central	86 (92.6%)	N/A*	39 (92.8%)
Firestation	82 (84.2%)	N/A*	34 (85.6%)
Caversham	N/A	N/A	34.5 (99.1%)
South Lake	N/A	N/A	41 (99.3%)

* BAM data was collected as clock hours; therefore, 15-minute averages are unavailable.

The 15-minute averaged TSP concentration limit specified within the EPR was exceeded once at both the Mandogalup and Norkett monitoring sites on 17 December 2017. Fifteen-minute averages are unavailable from Central or Firestation, as these sites had BAMs that only provide hourly averages. The maximum hourly concentration recorded on 17 December 2017 at Central was 137 µg/m^3 and at

Firestation was 77 µg/m³. A report on this and a number of additional periods of elevated particle concentrations is presented in Appendix A.

A cumulative frequency of one-hour averaged concentrations was produced by summing the number of hours when each concentration was exceeded. Figure 2 shows cumulative frequency graphs for the four particle monitoring sites for the study period. Also included are the cumulative frequency plots for two PM_{10} particle monitors operating in metropolitan Perth (Caversham and South Lake) over the same monitoring period. The plot has lognormal axes to better display features of interest at the higher concentrations.

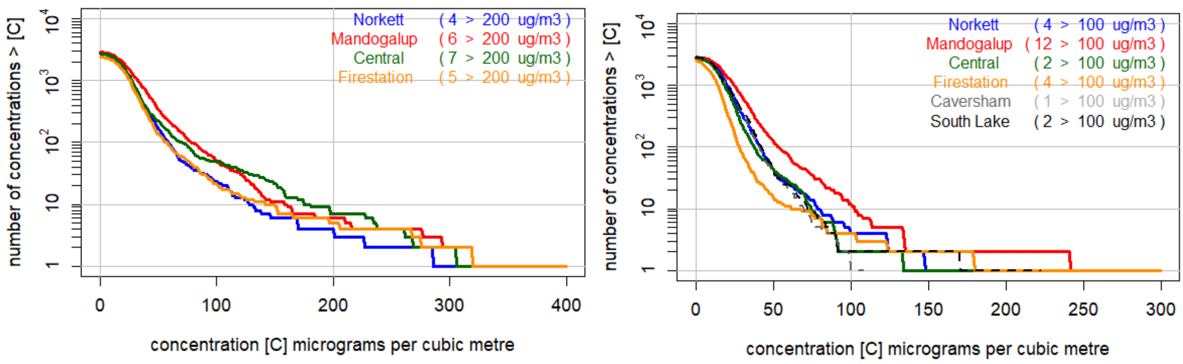


Figure 2 Cumulative frequency plot for one-hour averaged TSP (left) and PM_{10} (right) over the study period

Notations in the upper right quadrant of Figure 2 indicate the number of times the hourly averaged TSP concentration exceeded 200 µg/m³ and PM_{10} concentration exceeded 100 µg/m³ during the monitoring period. These particular concentrations have been chosen to illustrate the number of moderately high, but relatively short-term, events that occurred during the study. Neither the 200 µg/m³ nor 100 µg/m³ hourly concentrations relate to a published standard. All events occurred on days when the NEPM 24-hour PM_{10} standard was not exceeded.

The right-hand side of Figure 2 includes two additional sites, Caversham and South Lake, which monitor PM_{10} particles within the Perth metropolitan region. Caversham is located in a semi-rural area 14 kilometres north-east of the Perth CBD in the Swan Valley – a grape-growing region next to the Perth foothills. The region mainly comprises low-density housing and vineyards. The site is 800 metres north-east of a large brickworks. South Lake is a metropolitan site, 17 kilometres south of Perth with moderate to high-density housing. The site is 1.6 kilometres west of the Kwinana Freeway, a main north–south arterial road carrying about 87,000 vehicles daily and is 4 kilometres north-east of the northern border of the Kwinana industrial area. TSP is not monitored at either of these sites.

The PM_{10} cumulative frequency plot shows that over the study period, Norkett and Central most resemble the levels recorded at the metropolitan sites of Caversham and South Lake.

The Mandogalup site stands out from the other sites in having the highest number of times each PM_{10} concentration was recorded over the full range of concentrations.

The cumulative frequency analysis of TSP concentrations is slightly more complex, with the number of TSP concentrations up to 100 µg /m³ recorded at Mandogalup higher than all other sites. Above 100 µg/m^3, the Central site was higher than most other sites.

While the Norkett and Central sites were similar for hourly averaged PM_{10}, the TSP diverged markedly with the Central site, greatly exceeding the Norkett site for the number of hourly concentrations greater than 50 µg/m^3. The Central site was located about 250 metres from the eastern boundary of the RDA. The Norkett site was another 400 metres further east. Figure 3 shows a comparison of the difference in one-hour averaged particle concentrations between Central ($[C]_{Central}$) and Norkett ($[C]_{Norkett}$) over the study period.

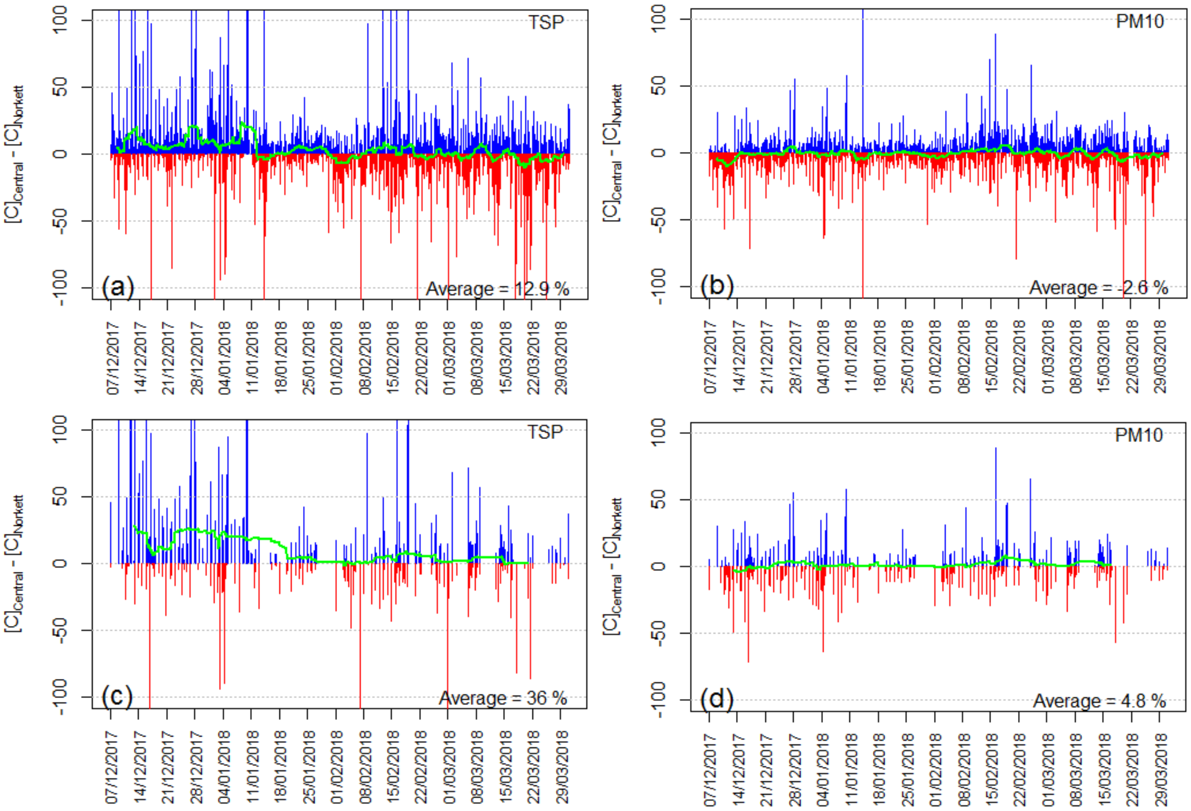


Figure 3 Comparison of the difference in one-hour averaged particle concentrations between Central and Norkett over the study period (blue represents when $[C]_{Central} > [C]_{Norkett}$ while red represents when $[C]_{Central} < [C]_{Norkett}$)

Figure 3 demonstrates the change in particle sizes affecting each site. The upper half of Figure 3 shows that for all wind directions, Central's PM_{10} was around 2.6 per cent lower than Norkett's, while the difference in TSP particle concentration was more marked with Central's TSP around 12.9 per cent higher overall than Norkett. The lower half of Figure 3 shows similarly calculated plots but was restricted to times when the wind direction was between 210 and 300 degrees. This arc of influence, as measured from Norkett, takes in the RDA. The wind direction data used in this analysis was taken from the DWER meteorological site installed at the top of the RDA. Winds on the RDA were within this arc of influence for 24 per cent of the study period. Portion (c) of Figure 3 shows a higher difference in TSP particle concentration, with Central's TSP around 36 per cent higher than Norkett.

The particle concentration difference seemed to be higher during December and early January, as seen by tracing the green line in the early portion of Figure 3(c), falling to similar levels as that shown by the PM_{10} trace on Figure 3(d) for the remainder of the period. To help explain this, Table 2 shows the average wind speed for different periods recorded within the 210 degree and 300 degree arc of influence, as measured from the Norkett site. For periods when the Central site TSP was higher than Norkett during December and early January (the December and part of January portion of Figure 3(c)), the average wind speed was around 7.4 metres per second. For all other periods and conditions, the average wind speed was more than 20 per cent lower.

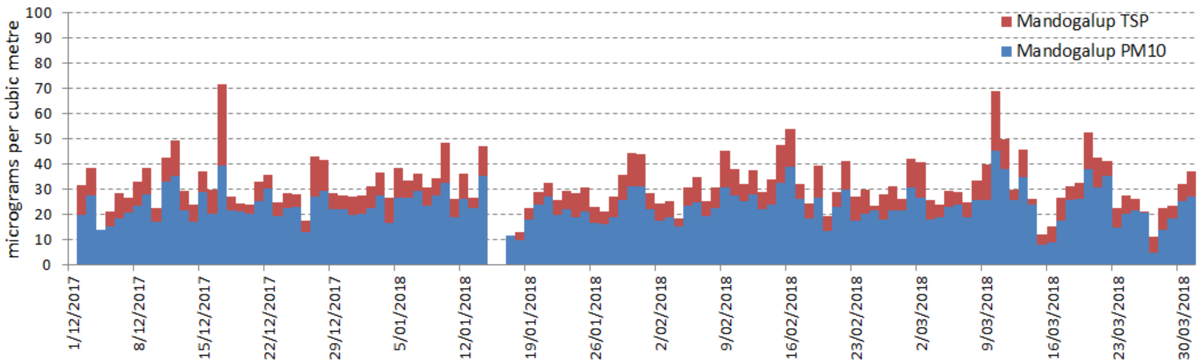
The high wind speed during December and early January could explain the difference in TSP concentrations between Central and Norkett. These higher wind speeds are conducive to the lift-off of larger sized particles from denuded ground. Heavier particles do not travel as far as lighter particles. Figure 8 shows the frequency occurrence of a particular wind speed and wind direction throughout the study period divided into daytime and nighttime. From the figure, it can be seen that the wind speeds recorded at the Norkett site, which is on the leeward side of the RDA, are much less than those recorded at the DWER meteorological site located at the top of the RDA. This reduction in wind speed causes larger fallout of the bigger dust particles and hence may cause a measurable difference in TSP concentrations at the two spatially close sites that are in an approximate line with the RDA.

Table 2 Average wind speed within the 210 degree and 300 degree arc of influence

Condition	Average wind speeds (m/s)	
	01/12/2017 to 14/01/2018	15/01/2018 to 31/03/2018
Central TSP > Norkett TSP	7.4	5.9
Central TSP < Norkett TSP	5.8	5.0

As PM_{10} particles tend to remain in suspension for a longer period due to their much smaller size, only a small difference in PM_{10} measurements at these two sites was expected and observed.

Daily (midnight to midnight) averages were calculated to enable comparisons with the NEPM standard. These have been displayed in Figure 4 for the complete monitoring period. Averages were calculated in accordance with the NEPM convention requiring no less than 75 per cent valid data for that day's average to be calculated. On no day was the NEPM PM_{10} standard of 50 µg/m^3 averaged over one day exceeded during the monitoring period.



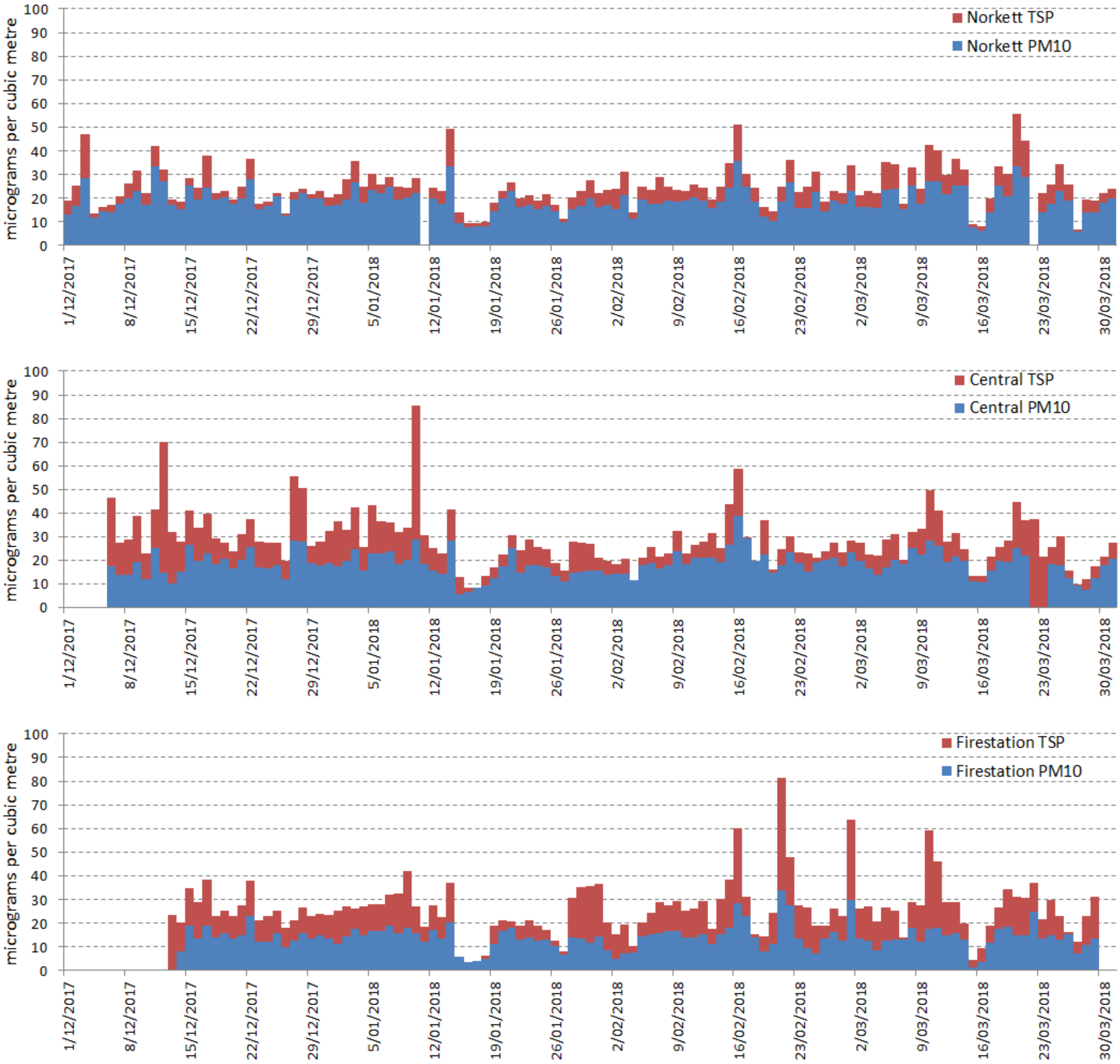


Figure 4 Daily TSP and PM_{10} averages for the four study sites

The ratio of PM_{10} to TSP is of interest, given the focus on PM_{10} in relation to health effects. In areas such as the Perth CBD, where both PM_{10} and TSP high volume samplers were run between 1994 and 2006, the median ratio of PM_{10} to TSP was 0.46.

The PM_{10} to TSP ratio depends on the source of the particulate matter. When the source is a chemical or combustion process, the ratio of PM_{10} to TSP is generally greater than 0.5 (i.e. PM_{10} makes up greater than 50 per cent of the TSP). However, when the source is a physical process (e.g. dust generated by soil handling or road-generated vehicular dust), the ratio of PM_{10} to TSP is generally less than 0.5 (i.e. PM_{10} makes up less than 50 per cent of the TSP). Smoke will tend to produce a larger portion of fine particles, giving rise to higher PM_{10} to TSP ratios, while general dust lift-off from wind or mechanical processes will tend to produce coarse particles that will in turn have a lower PM_{10} to TSP ratio.

Figure 5 shows histograms of the PM_{10} to TSP ratios calculated from one-hour averaged data collected at the study sites.

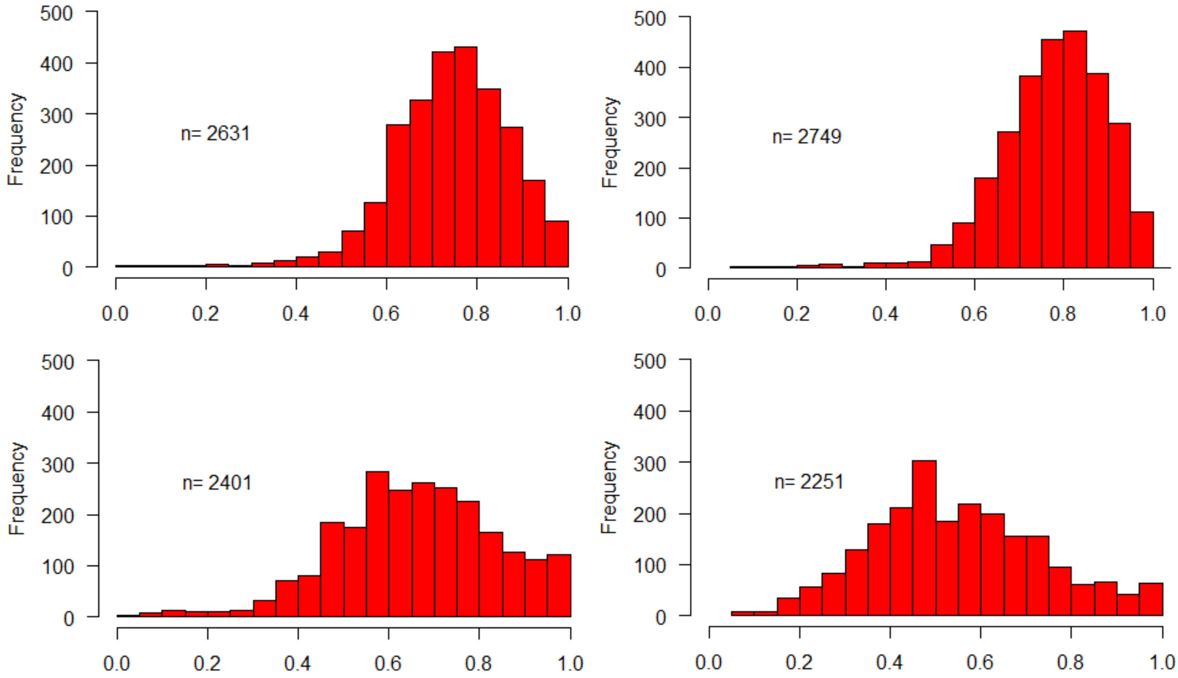


Figure 5 Frequency plot of the ratio of one-hour averaged PM_{10} to TSP for Mandogalup (top left), Norkett (top right), Central (bottom left) and Firestation (bottom right)

Figure 5 indicates that at Mandogalup and Norkett, the peak ratios of PM_{10} to TSP occur between 0.7 and 0.8, indicating that the majority of the TSP is made up of particles less than 10 µm EAD, with a smaller amount between 10 µm and 50 µm. The profiles from Central and Firestation show a more flattened histogram with a PM_{10} to TSP ratio peak between 0.4 and 0.5. Considering the well-established equivalency of monitoring methods, this suggests that the coarse fraction is a large contributor to particle levels in these locations.

An assessment can also be made of how the PM_{10} particle levels for the Mandogalup sites compare with two sites in the DWER metropolitan network. Figure 6 displays a profile plot of all PM_{10} data obtained throughout the study period, represented as percentiles for each hour of the day. The red line represents the 99th percentile, which means it shows the concentration below which 99 per cent of all the concentrations fall for that hour and is about equal to the 2nd highest hourly concentration. The 95th percentile (green) is around the 6th highest. The 75th percentile (purple) is around the 30th highest and the 50th percentile (blue) is the median value, which is the middle of the dataset at around the 60th highest.

The 100th percentile plot, which represents the maximum concentrations, has not been shown in Figure 6 as these are discussed in Appendix 1 and the purpose of the profile plot is to observe and compare the mid to lower levels to see how similar or different the concentration patterns are between each site throughout the day.

The plots show a typical trend of particle levels rising in the morning between 6am and 8am, likely due to increased traffic followed by a broader hump during the middle of the day. Another peak is observed during evening peak hour.

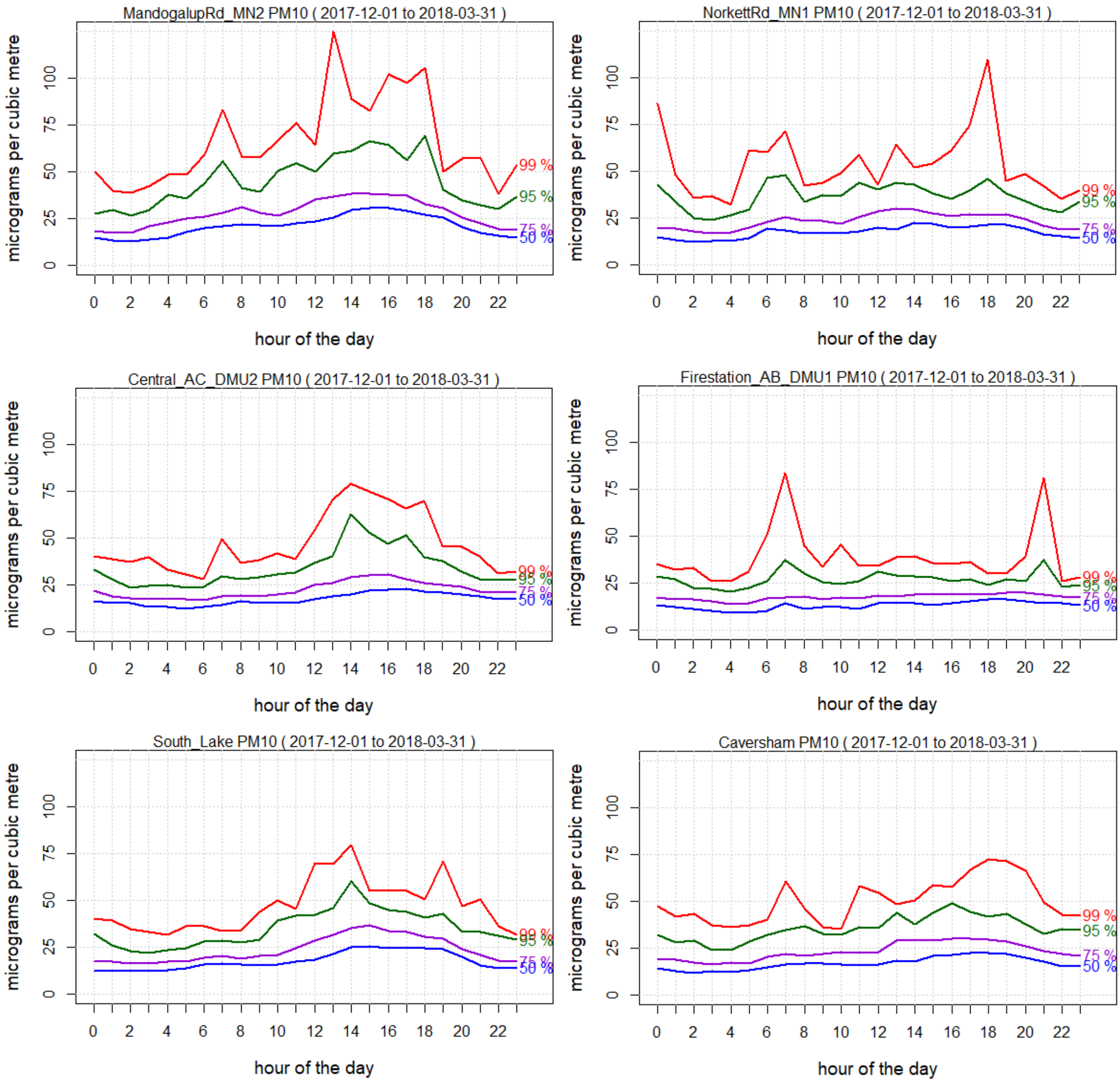


Figure 6 Profile plot of one-hour averaged PM_{10} for Mandogalup (top left), Norkett (top right), Central (mid left) and Firestation (mid right), South Lake (bottom left) and Caversham (bottom right)

A general observation of the data as shown in these plots indicates that the 75th and 50th percentile plots at Norkett and Central are somewhat similar to each other and to South Lake and Caversham. On the other hand, the Firestation site has a flatter profile and is less influenced by anthropogenic activities. The Mandogalup site, with its proximity to agricultural activities, is slightly higher in particle concentration than the others.

5 Weather and meteorology

The Bureau of Meteorology (BoM) maintains a weather station at Jandakot Airport (8 kilometres north-northeast of the LiDAR) that provides rainfall and weather observations. Figure 7 summarises the weather data obtained from BoM for December 2017 to March 2018. The full record of BoM daily weather observations is provided in Appendix B.

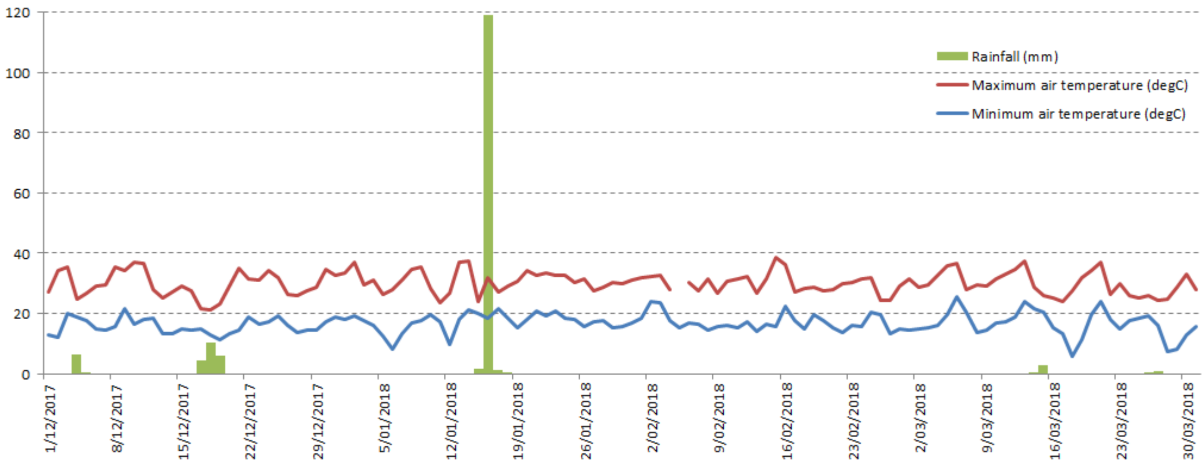


Figure 7 Jandakot weather data including daily rainfall (green) and maximum (red) and minimum (blue) temperature. (Sourced on 17/05/2018 from http://www.bom.gov.au/wa/?ref=hdr)

During the study period, rainfall was recorded at the BoM weather station on a number of days. A major rainfall event occurred on 16/01/2018 with 119 millimetres of rain recorded at the Jandakot BoM site.

BoM records from Jandakot show that rainfall was 153mm over the study period. When the exceptional one-day rainfall event of 119mm in January 2018 is removed, the total rainfall for the study period is reduced to 34.0mm. The median rainfall for the same months December to March during the 36 year period 1972 to 2018 is 22.1mm.

2013 to 2018 historical winds from the DWER Wattleup site were found to be similar to those recorded during the study period. Air temperatures recorded at Wattleup over the same period were found to be slightly lower than those recorded during the study period.

Figure 8 shows the frequency occurrence of a particular wind speed and wind direction throughout the study period divided into daytime and nighttime. The meteorological data were sourced from the Mandogalup, Norkett, Wattleup and RDA meteorological monitoring sites. The meteorological equipment at both the Mandogalup and Norkett sites was installed 3 metres above ground level. The RDA meteorological site was about 4 metres above ground level while the Wattleup instruments were 10 metres above ground level.

Each wind speed and direction segment of the plot shows the number of times when a particular wind speed and direction occurred. Wind speed is in metres per second and extends radially out from the centre of the plot. The different colours represent the number of times that particular wind speed and direction occurred within the whole dataset.

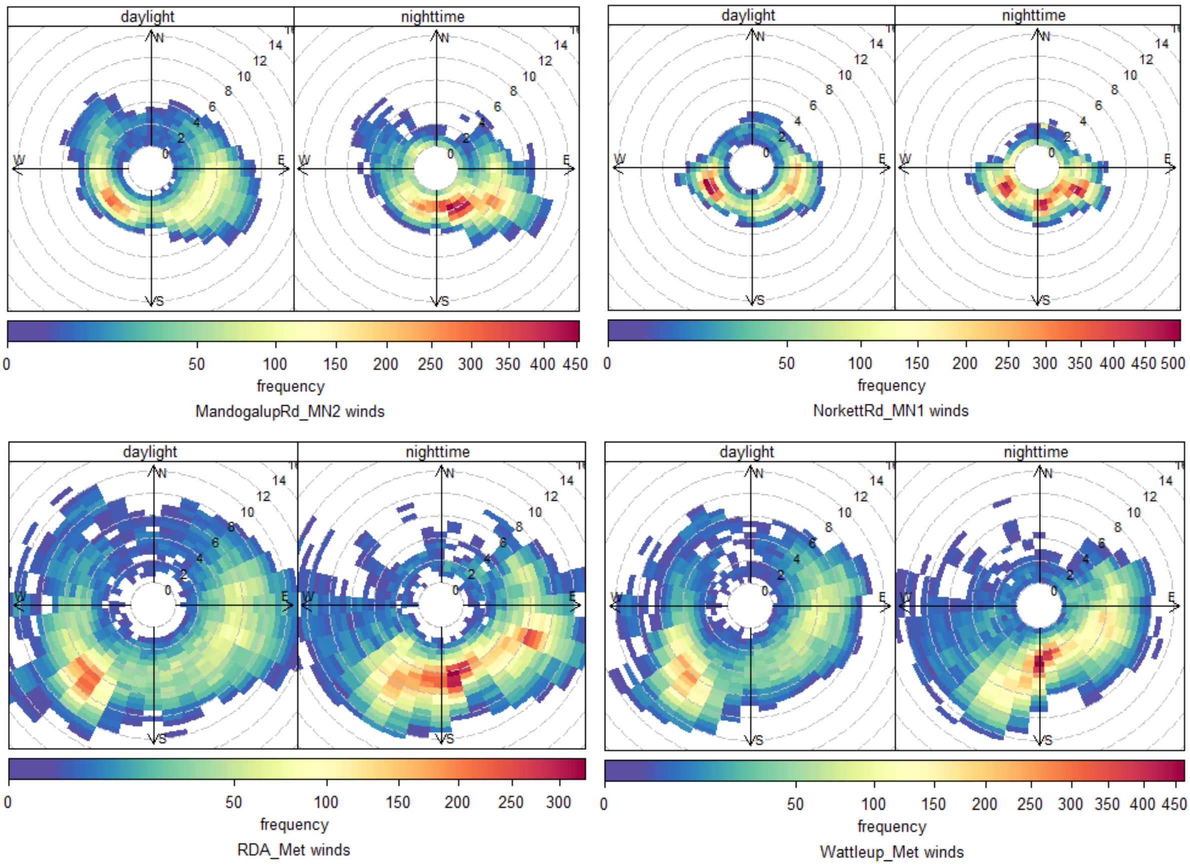


Figure 8 Polar frequency plots of daylight and nighttime wind speed and direction during the study period for the four meteorological sites within the study area

Notable from Figure 8 is the difference in the magnitude of the wind speeds from the RDA meteorological site and Wattleup as compared to the other two sites, which were in a more sheltered location. The overall wind directions for the RDA site and Mandogalup site are similar over the study period, albeit with the RDA showing a much higher overall wind speed. The Norkett Road meteorological site was hampered by trees, which causes overall lower wind speeds recorded at that site when compared to the other two sites.

Figure 9 is a plot of each pair of wind speed and wind direction data for sites within the study area. The plots compare five-minute averaged data from the DWER meteorological tower on top of the RDA with the other three meteorological sites at Mandogalup, Norkett and Wattleup.

While the correlation coefficients for wind directions between the RDA meteorological site and the sites of Mandogalup and Norkett were large (at around 0.7), the wind speeds for Mandogalup and Norkett were reduced at each site by a factor of 0.7 and 0.3, respectively. The Wattleup site closely follows the RDA meteorological site in both wind speed and direction. This is likely due to the open aspect of the Wattleup site.

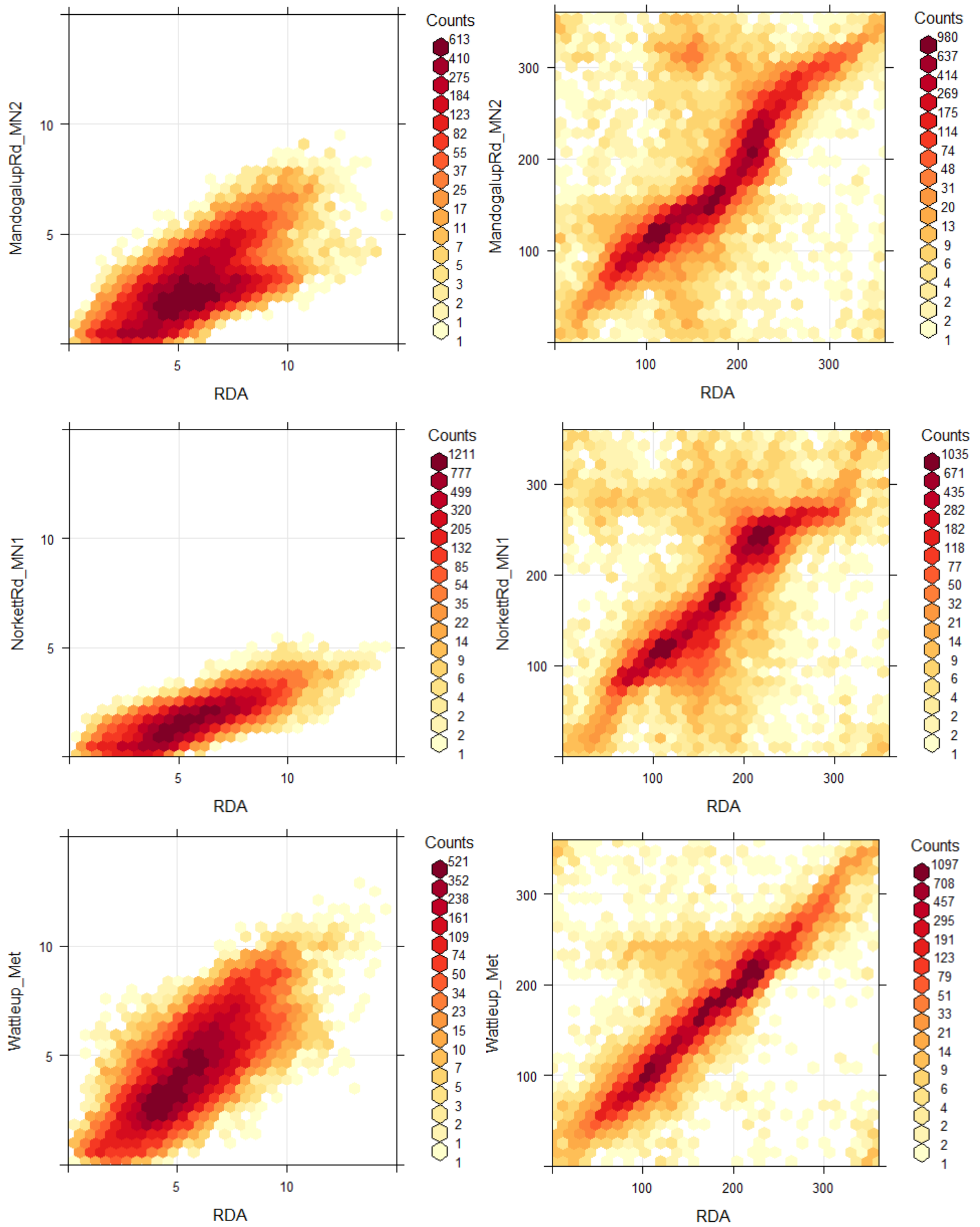


Figure 9 Scatter plots showing the relationship between corresponding measurements of wind speed (left) and wind direction (right) between the RDA meteorological tower and Mandogalup (top), Norkett (centre) and Wattleup (bottom)

As this report concentrates mainly on the direction from where the dust originates, a large wind speed correlation is not considered vital to perform the directional analysis.

6 Directional analysis

Figure 10 shows PM10 and TSP concentrations weighted by their frequency of occurrence and their contribution to overall loading within each wind direction and wind speed pair for daytime and nighttime. Each wind speed segment of the plot spans one metre per second radially out from the centre of the plot and the direction segment spans 10 degrees. Each segment is colour coded to show the percentage contribution of that segment to the complete dataset.

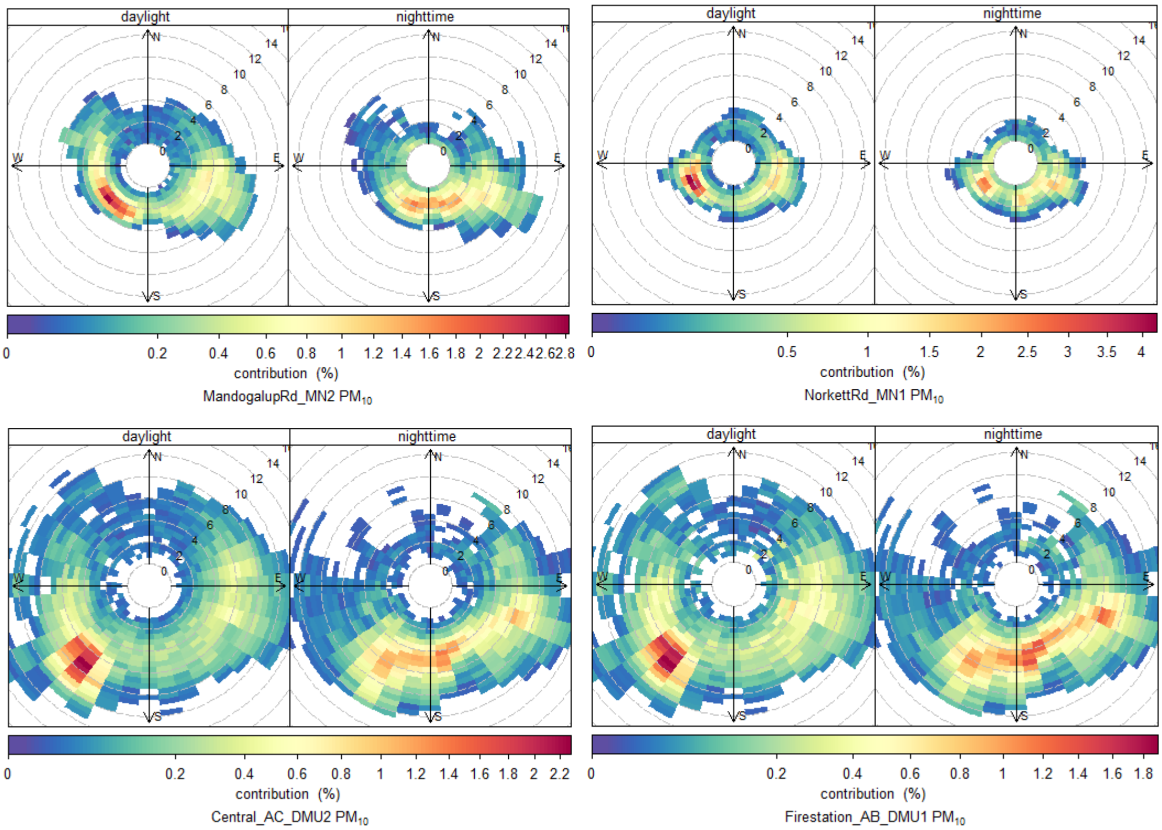


Figure 10 Weighted mean polar frequency plots of PM_{10} particles during the study period for Mandogalup (top left), Norkett (top right), Central (bottom left) and Firestation (bottom right)

The Mandogalup and Norkett plots used the meteorological data collected at those sites to generate the frequency plot. As the Central and Firestation sites did not have meteorological instruments, RDA meteorological data was used to produce the plots relating to these two sites in Figure 10.

Figure 11 overlays the daylight frequency plots over the Mandogalup, Norkett and Firestation sites.

Figure 11 Mandogalup sites overlayed with the daylight (left) and nighttime (right) polar frequency plots for PM_{10} particles

Figure 11 shows a general tighter arc during daylight. That is, the bulk of the particle load originated from a smaller arc wind direction during the day than at night where the directions where particles arrive at the site are more distributed.

Please note that the scales used to represent the weighted means are different, as can be seen in Figure 10.

Figure 12 displays the 90th percentile polar plot for TSP concentrations for all sites overlayed on a map of the region. The scaling for each polar plot has been kept consistent for the image, with the scaling limited to 100 µg/m^3 for display purposes. The wind speed and direction for all four sites has been taken from the DWER site located at the top of the RDA.

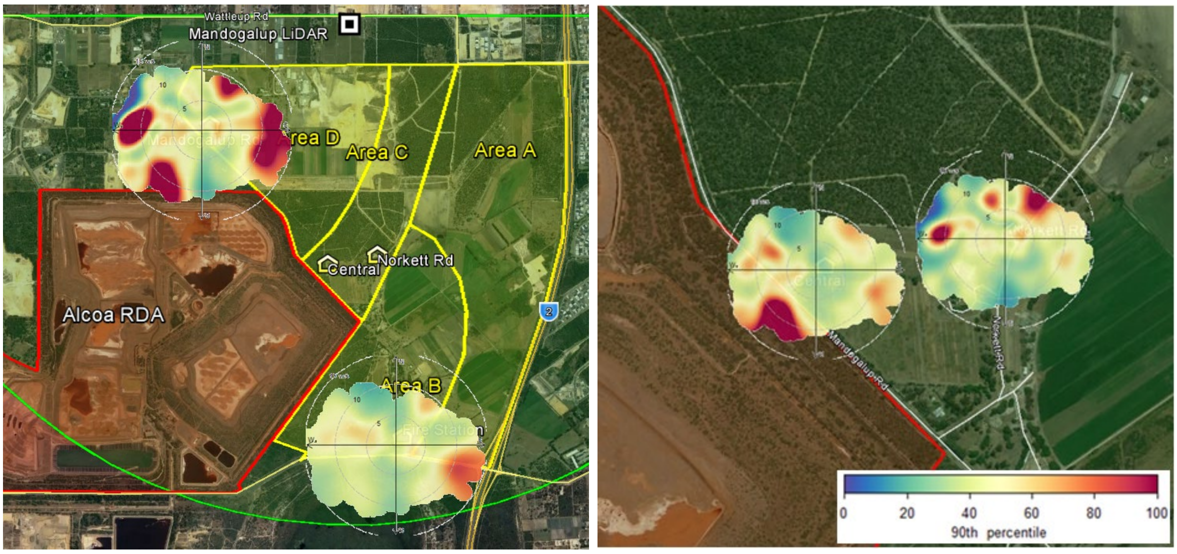


Figure 12 Mandogalup sites overlayed with the 90th percentile polar plots for TSP particles for Mandogalup and Firestation (left) with a close-up of Central and Norkett (right)

The various red-coloured nodes on each of the polar plots in Figure 12 represent about the top 20 per cent of readings for that particular wind speed and direction. The Mandogalup site shows high concentrations of TSP originating from a range of combinations of wind speed and direction, while at the Firestation site a moderate amount comes from the east with a smaller portion from the west and north-northeast. Norkett shows high TSP originating from the west and north for certain wind speed/direction combinations, while for Central it is more from the south-west and westerly directions.

7 LiDAR assessment of dust

As part of this study, the LiDAR was used as a tool for assessing both sources and pathways of dust contributing to impacts experienced in the Mandogalup study area.

The LiDAR provides a mechanism that effectively places a virtual particle monitor at each of the available points within the LiDAR's observational space, recording backscatter intensities every five minutes.

To check LiDAR performance, a test was made comparing the LiDAR's backscatter signal returned from above the location where a standard particle monitor exists. Table 3 lists the distance and headings from the LiDAR tower to these four air quality monitoring sites.

Table 3 Distance and heading from LiDAR to air quality monitoring sites

Site	Distance from LiDAR in metres	Compass heading from LiDAR tower in degrees from north	Height in metres below LiDAR beam set at one degree elevation
Mandogalup	1,442	232	60
Norkett	1,944	174	60
Central	2,025	185	60
Firestation	3,420	173	90

Figure 13 plots an overlay of the LiDAR backscatter signal (shown as scaled LiDAR Beta in the plots) over the particle monitor signal for each of the four sites listed in Table 3. The plot shows how the LiDAR backscattering signal follows the particle monitor signal over the selected week at these locations. Note that the vertical axis in Figure 13 shows comparative units only to assist in comparing the two sets of data.

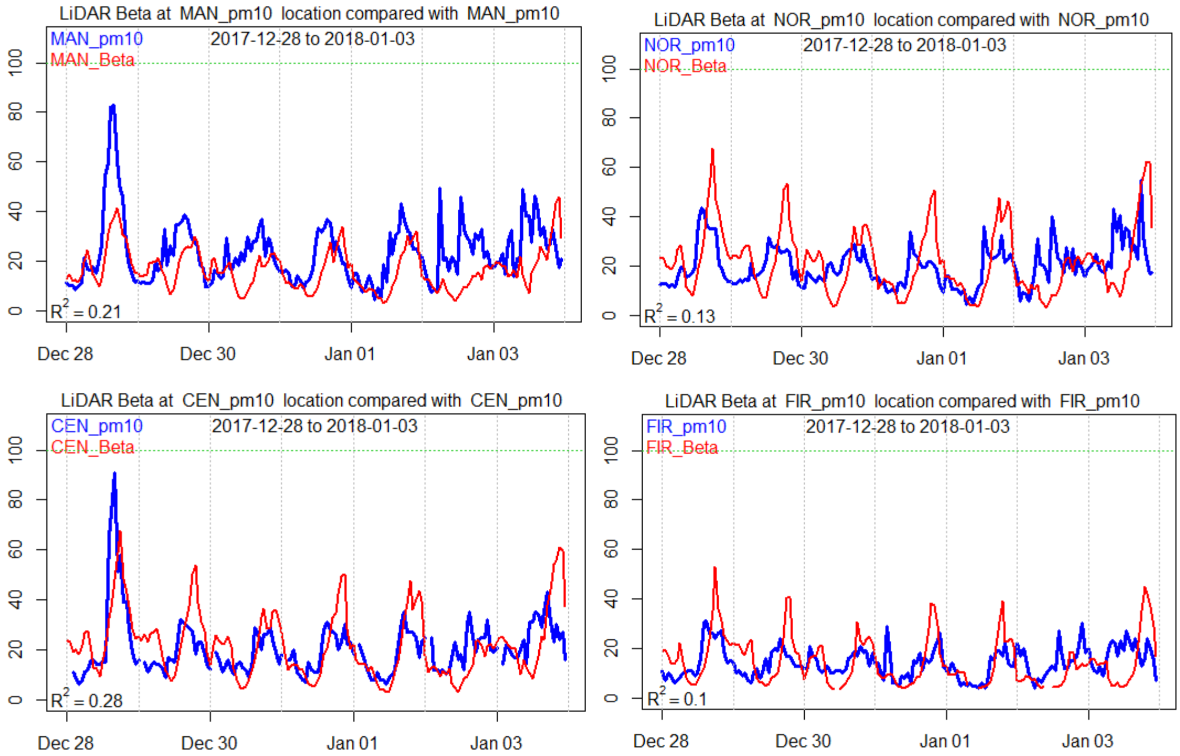


Figure 13 Comparing signals from the LiDAR with particle monitors located at Mandogalup (top left), Norkett (top right), Central (bottom left) and Firestation (bottom right)

A visual comparison of the LiDAR and signals from the standard monitors in Figure 13 show there are similarities in the traces, with the peaks and troughs matching reasonably well. There are, however, some issues that combined to reduce the 'goodness of fit' between the different instruments. These are:

- **Sampling height:** The LiDAR was installed 10 metres above ground level on a scaffold located off Wattleup Road. With the LiDAR elevation constrained to one degree owing to ground-level obstructions, the beam passed over the monitoring sites at the heights detailed in Table 3. The difference in height between the LiDAR beam and the ground-level location of the particle monitors would cause a difference between the recorded levels, as concentrations at ground levels will likely differ from those at significant elevation.
- **Particle size:** The LiDAR beam measures backscatter from all particles within each 20 metre gate of the beam extending outwards from the LiDAR. The particle monitors are fitted with a size-selective inlet that only allows particles with an aerodynamic equivalent diameter of less than 10 micrometres (PM_{10}) to pass into the instrument to be measured. This size-selective head is designed to specifically exclude all particles greater than PM_{10} from entering the particle monitor to be recorded.
- **Averaging period:** While the particle monitors record continuous PM_{10} concentrations, which are then averaged over one clock hour, the LiDAR performs circular sweeps of the observational space recording backscatter intensities once every five minutes, pausing only one second to scan each compass degree. This means that the LiDAR's beam only spends one second every five minutes at an

azimuth that overshoots the BAM's location, providing only 12 one-second readings every hour to provide a one-hour average.

- **Sampling area:** Particle monitors collect particle data at one point, which is fixed and located two or three metres above ground level. This position is considered representative of the concentration of a pollutant within the immediate vicinity of the monitoring site. It is, however, possible for pollutants to be in a narrow plume which, while passing close to an air quality monitor, may not be captured by that monitor. The LiDAR beam measures backscatter from all particles within each 20-metre gate of the beam, extending outwards from the LiDAR. While these gates are electronically set to 20 metres, each gate is programmed to overlap the adjacent gates, providing an effective 50-metre resolution for each gate. At a distance of 2000 metres, the LiDAR is providing an average backscatter from particles within an area extending 50 metres in length and about 35 metres in width.
- **Timestamp:** When comparing the LiDAR scan data with standard particle monitoring technologies, the method used for averaging becomes very important. The time that is allocated to the particle monitor data is timestamped at the end of the sampling period while the data collected by the LiDAR are allocated a timestamp that is the start of the sampling period. These have been adjusted to reflect the same monitoring periods.

The LiDAR has been successfully used in the past to clearly show particle source and pathway. For this study, the overall particle concentrations experienced in the region, while about 5 per cent higher than at other Perth metropolitan monitoring sites, are much lower than previous LiDAR studies in other locations reported by DWER.

Figure 14 shows the summed LiDAR signal filtered through a median-distance filter that removes unwanted artefacts. The totalling of all five-minute LiDAR scans provides an indication of potential sources of particles. This type of analysis only indicates sources of dust in the area and does not show the pathway of dust or ambient levels.

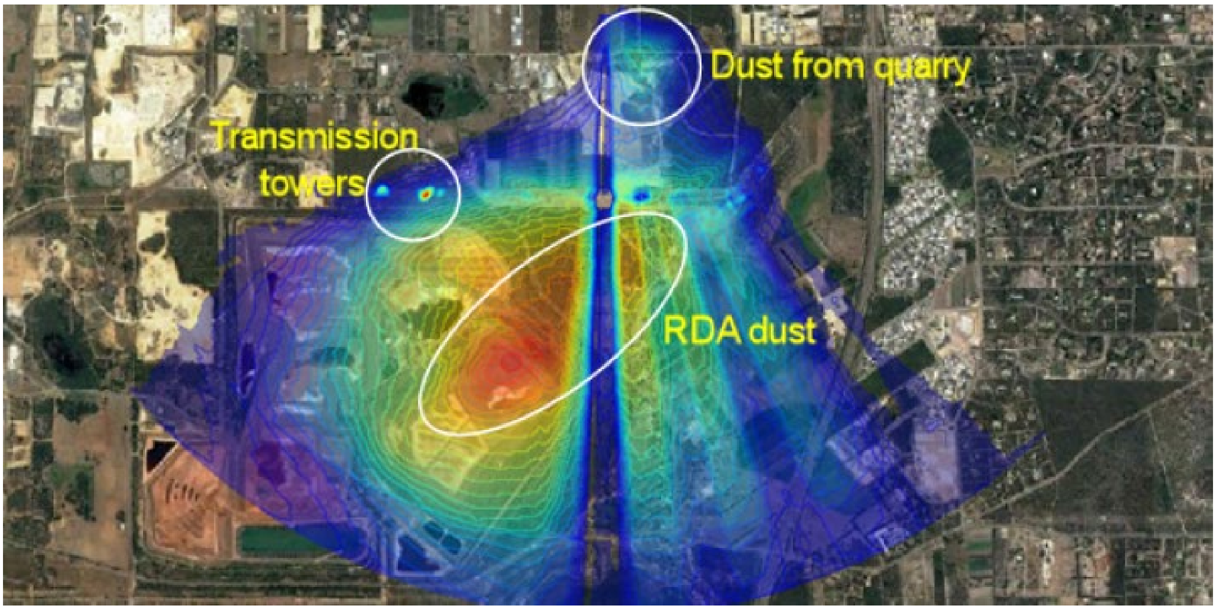


Figure 14 Summed LiDAR signal with particle sources and hard objects located by LiDAR. The map colours, although representative of relative dust levels, do not represent actual concentrations.

Shadows and hard targets from various objects at times obscure the beam. These objects can be seen in the lowest image of Figure 1, namely the tree located in the centre of the image and various transmission lines in the path of the beam.

Highlighted on Figure 14 are areas that show some elevated LiDAR signals. These are in the eastern portion of the RDA with a small node extending to the north-east. Additionally, the quarry located slightly east of south from the LiDAR also shows an increase in LiDAR signal. Note that this type of analysis only shows dust that intersects the path of the LiDAR beam which, in some cases, may be significantly elevated above the ground, and consequently should not be taken as the extent of dust but only as an indication of dust sources.

8 Conclusions

The study provided valuable information regarding dust levels in and around Mandogalup during the four-month period from 1 December 2017 to 31 March 2018.

The study findings were that:

- Major contributors to overall dust levels in the area include the Alcoa RDA, sand and other quarries, roads, truck movements, agricultural activities and industrial activity in the Kwinana industrial area.
- The levels of PM_{10} dust at the Central and Norkett sites over the study period seem to be somewhat comparable to other locations in Perth and semi-rural areas in the wider Perth metropolitan area.
- Amenity impacts were unable to be assessed, except to note that TSP (larger particles) levels seem to decrease with distance from the RDA.

This analysis has not examined any specific meteorological conditions that give rise to dust plumes from industry operations. However, as a general statement, it can be said that during the study period, industrial and agricultural activity contributed to elevated dust levels in Mandogalup but did not cause an exceedance of the NEPM standard for PM_{10}.

TSP concentrations exceeded the EPR TSP limit of 1000 $\mu g/m^3$ averaged over 15 minutes at two locations on 17 December 2017. Directional and pictorial analysis indicates that it is unlikely the RDA was a major source of the exceedance. The applicable EPR standard for TSP of 90 $\mu g/m^3$ averaged over 24 hours was not exceeded.

The LiDAR is a valuable tool allowing DWER to track dust plumes across large areas and determine major emission sources. It has become a useful tool for DWER to assess dust sources impacting local communities and to measure the effectiveness of dust mitigation measures. Results from LiDAR studies will contribute to decision-making under Part V of the *Environmental Protection Act 1986*.

Appendices

Appendix A — PM_{10} one-hour concentrations greater than 100 µg/m^3

The following pages contain information on specific events during the campaign where two or more sites recorded PM_{10} concentrations greater than 100 µg/m^3 averaged over one clock hour on the same day. Choosing a PM_{10} concentration greater than 100 µg/m^3 has no basis other than to limit the number of short-term events investigated. Each analysis is provided in date order and may include one or more of a wind spiral, concentration table and concentration plots. Included are data related to concentrations of PM_{10} particles reached at a selection of sites in Mandogalup. Wind spirals are a representation of wind data recorded throughout the day. The wind speeds are represented by the size of the marker, while PM_{10} concentrations are represented by the colour of the marker.

The radial axis of each wind spiral represents the time of day extending out from the centre, while the angular axis represents the direction from where winds were arriving when recorded by the meteorological instrument. Wind spirals are a visual representation useful to demonstrate the way that wind direction changes throughout the day.

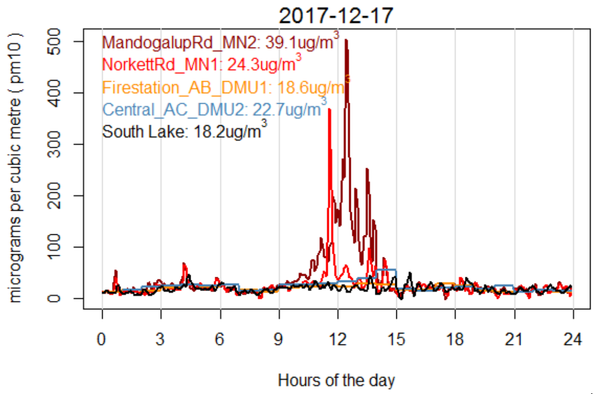
As Central and Firestation did not have meteorological instrumentation installed, the wind information was obtained from the DWER meteorological station located on the top of the RDA.

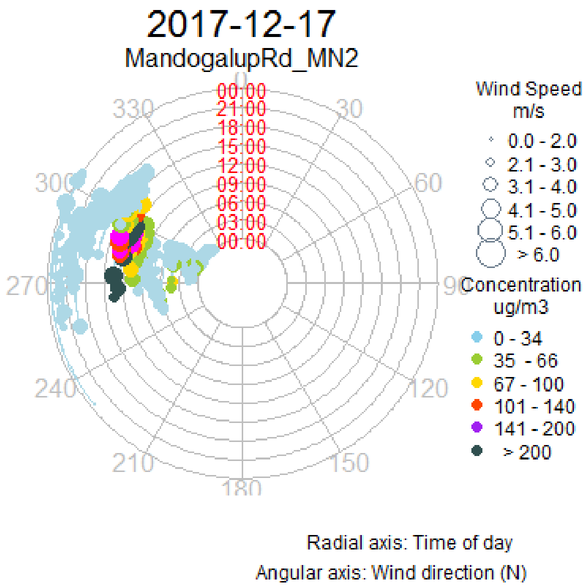
Where used within the text, wind direction refers to the direction from where the wind originated.

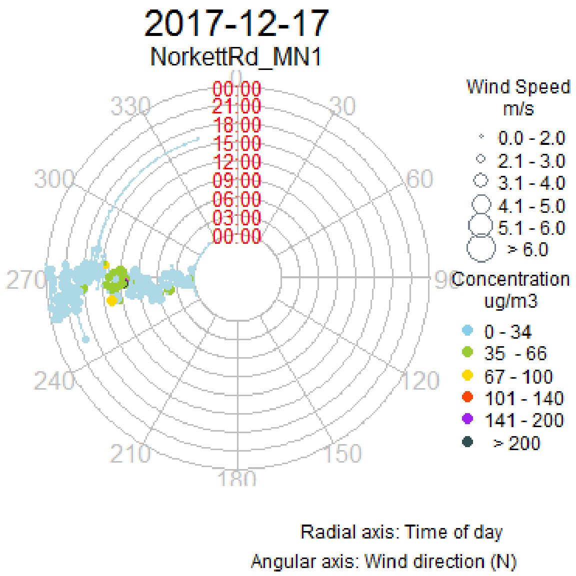
Where available, the percentage of PM_{10} within the TSP is presented for times when five-minute averaged PM_{10} at a particular site was greater than 100 µg/m^3. When PM_{10} makes up greater than 50 per cent of the TSP (ratio is greater than 0.5), the source is likely a chemical or combustion process. When the ratio of PM_{10} to TSP is generally less than 0.5, the source is likely a physical process, such as dust generated by soil handling or road-generated vehicular dust. Smoke will tend to produce a larger portion of fine particles giving rise to higher PM_{10} to TSP ratios, while general dust lift-off from wind or mechanical processes will tend to produce coarse particles that will in turn have a lower PM_{10} to TSP ratio.

On the wind spiral plots, time is represented using the 24-hour clock method where 1am is represented by 01:00 and 11pm is represented by 23:00.

17 December 2017





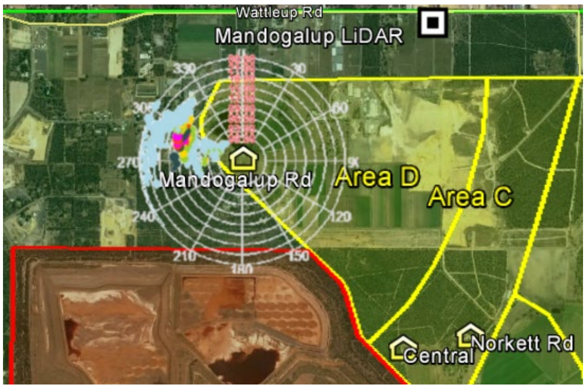


Maximum one clock-hour averaged concentrations

Site	PM_{10}	TSP
Mandogalup	241.4	567.9
Norkett	99.5	340.5
Central	54	137
Firestation	28	77
South Lake	26.3	N/A

Event description

Winds were westerly during the period where high particle concentrations were recorded at the Mandogalup site. This direction excludes the RDA as a source of the particles.



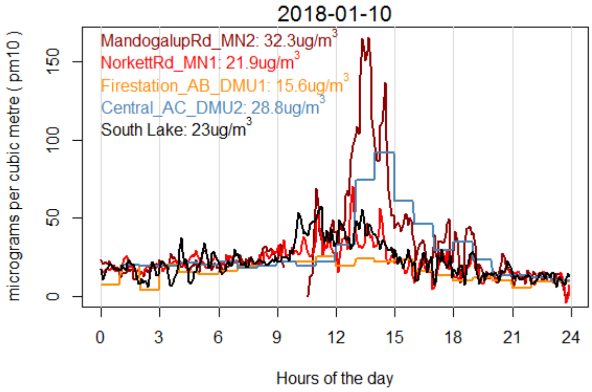
Wind spiral for 17/12/2017 overlayed at the Mandogalup site

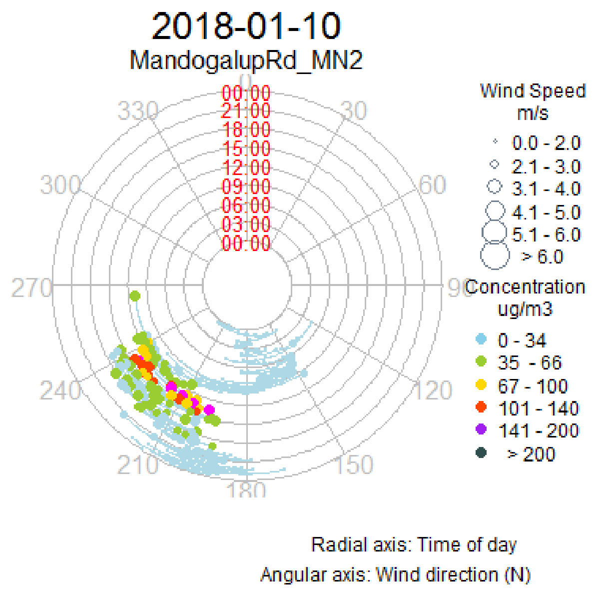
High particle concentrations at the Norkett site were caused by high winds combined with ride-on mower activity near the monitoring station.

Picture taken at the Norkett site on 17/12/2017 at 11:26:43am

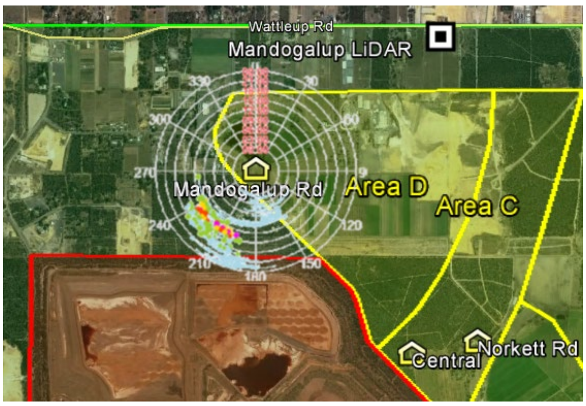
The cause is a local event

10 January 2018





The ratio of PM_{10} to TSP for times when 5-minute averaged PM_{10} at Mandogalup was greater than 100 µg/m^3 is 63 per cent.



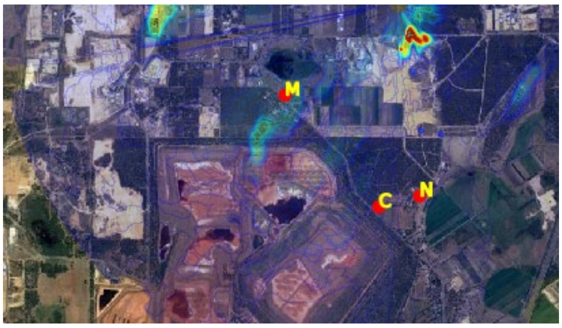
Wind spiral for 10/01/2018 overlayed at the Mandogalup site

Maximum one clock-hour averaged concentrations

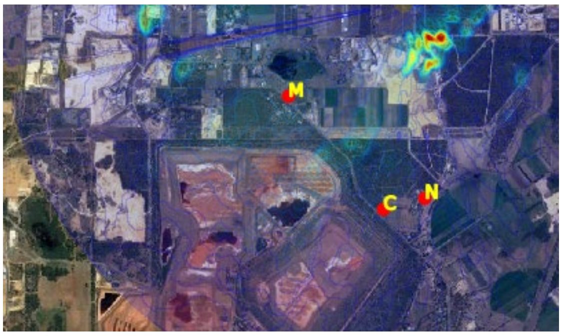
Site	PM_{10}	TSP
Mandogalup	134.5	215.7
Norkett	38.8	55.8
Central	92	269
Firestation	25	53
South Lake	45.6	N/A

Event description

The LiDAR record of backscatter shows some plumes arising from quarries located to the north of the RDA and north-east of the RDA. A LiDAR signal was also detected at the RDA. Winds were from the south-west for most of the afternoon.



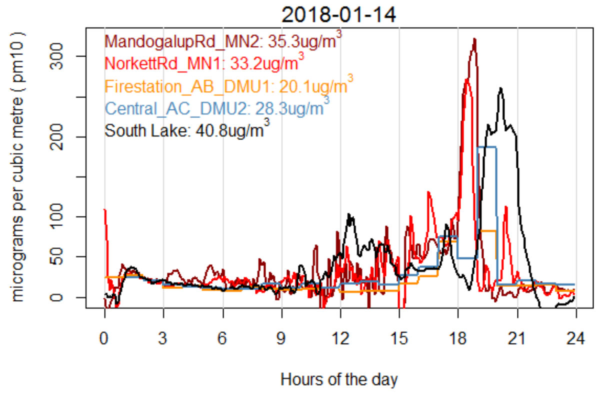
LiDAR record on 10/01/2018 at 1:30pm

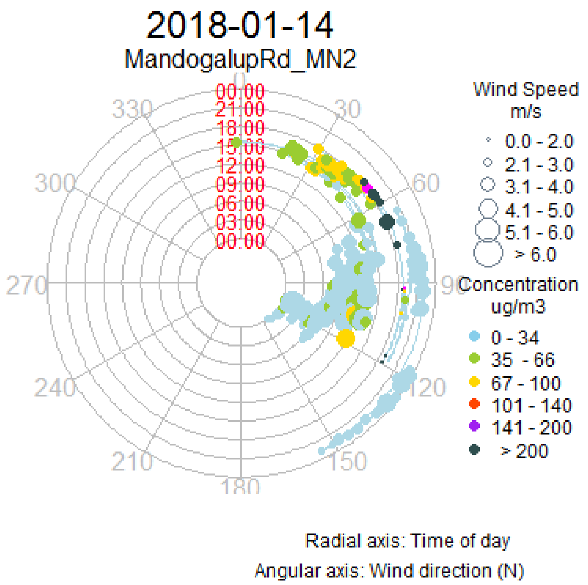


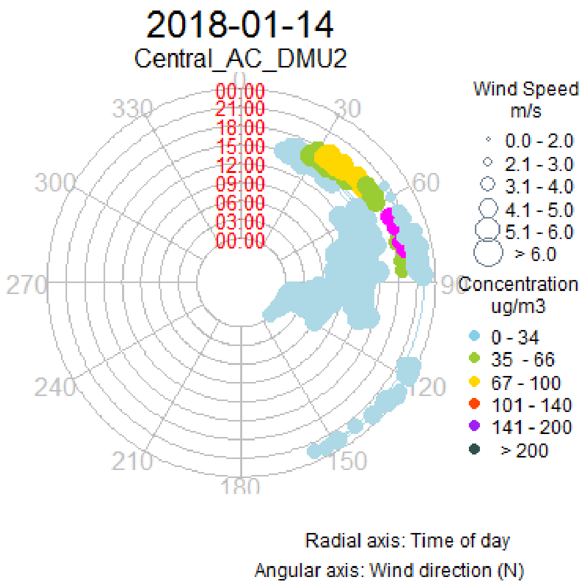
LiDAR record on 10/01/2018 at 2:30pm

The cause is possible RDA dust.

14 January 2018







The ratio of PM_{10} to TSP for times when five- minute averaged PM_{10} at Mandogalup was greater than 100 µg/m^3 is 87 per cent.

Maximum one clock-hour averaged concentrations

Site	PM_{10}	TSP
Mandogalup	253.8	293.9
Norkett	185.9	226.1
Central	186	238
Firestation	82	133
South Lake	222.9	N/A

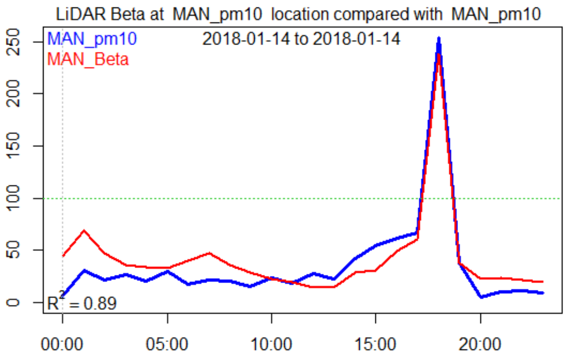
Event description

Smoke from fires in Mundaring caused elevated particle levels south of the Perth CBD.

The satellite image shows smoke generally impacting southern metropolitan areas.

Terra/MODIS satellite image showing Mundaring fire plume

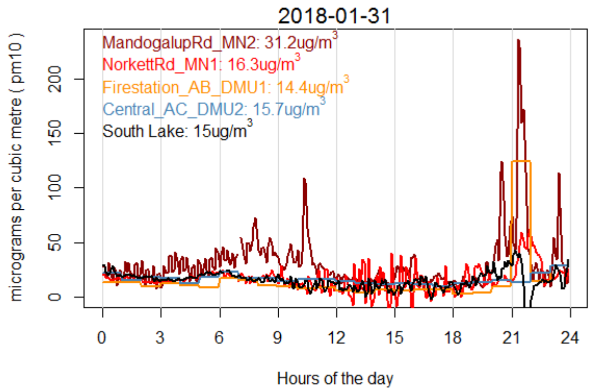
The LiDAR and Mandogalup PM_{10} traces compared favourably for this day.

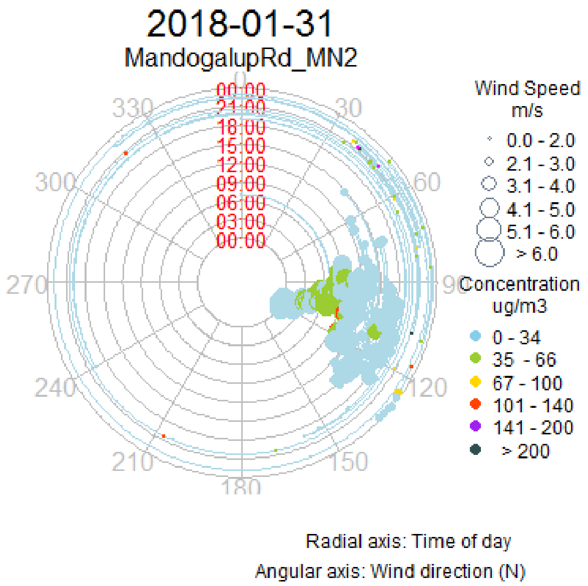


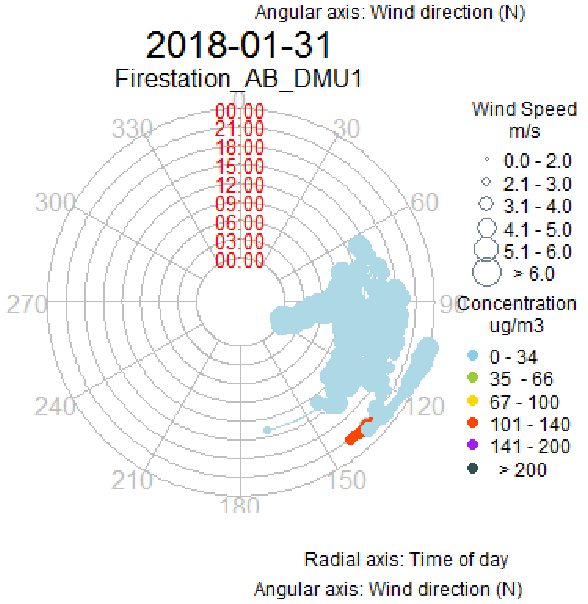
Comparing Beta data recorded by the LiDAR with PM_{10} data recorded at Mandogalup (timeoffset=0, mult=2E8).

The cause is smoke from bushfires.

31 January 2018







The ratio of PM$_{10}$ to TSP for times when five-minute averaged PM$_{10}$ at Mandogalup was greater than 100 μg/m^3 is 68 per cent.

Maximum one clock-hour averaged concentrations

Site	PM$_{10}$	TSP
Mandogalup	112.4	184.2
Norkett	39.8	53.1
Central	28	38
Firestation	124	197
South Lake	25.2	N/A

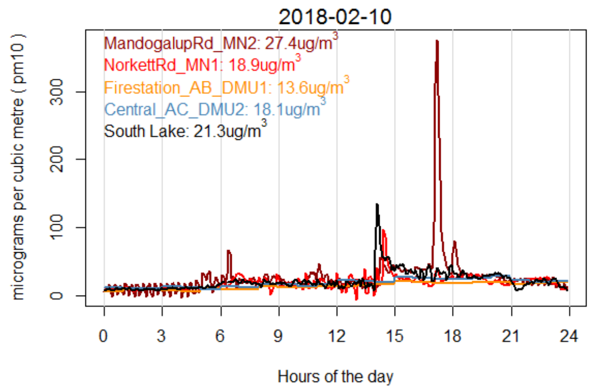
Event description

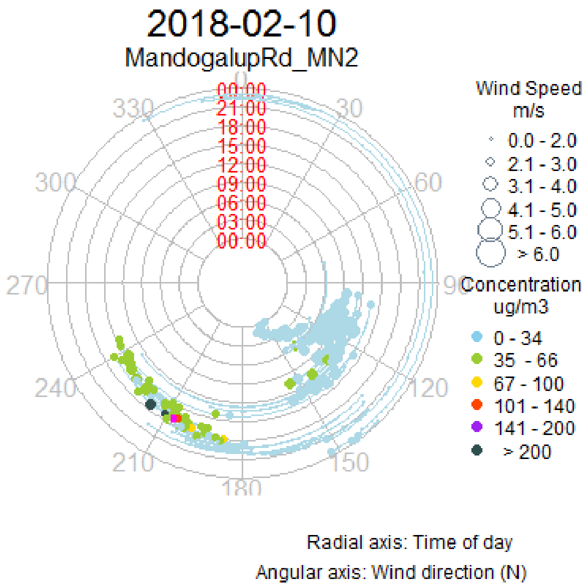
Winds were easterly during the period where high particle concentrations were recorded at the Mandogalup site. This direction excludes the RDA as a source of the particles. There is possible fugitive quarry emission; however, a similar sized event occurred at Firestation at the same time.

Wind spiral for 31/01/2018 overlayed at the Mandogalup site

The cause is unknown.

10 February 2018





The ratio of PM_{10} to TSP for times when five-minute averaged PM_{10} at Mandogalup was greater than 100 μg/m^3 is 63 per cent.

Maximum one clock-hour averaged concentrations

Site	PM_{10}	TSP
Mandogalup	135.0	210.6
Norkett	41.1	50.8
Central	28	39
Firestation	21	40
South Lake	65.3	N/A

Event description

A high short-term event was experienced at the Mandogalup site with five-minute averages ranging from 107 μg/m^3 at 5pm to 376 μg/m^3 at 5:10 and 94 μg/m^3 at 5:25pm.

The LiDAR trace shows a short-term plume in the local vicinity of Mandogalup site, indicating local activity in the area.

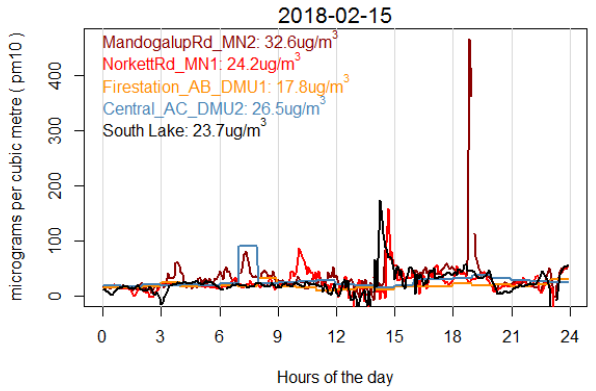
LiDAR record on 10/02/2018 at 4:50pm

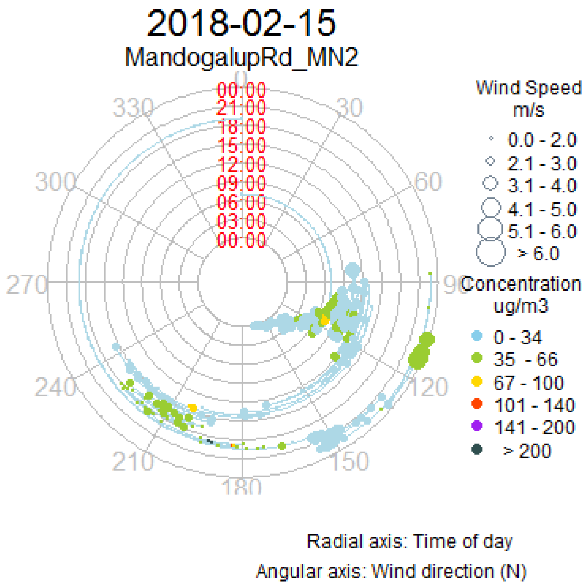
LiDAR record on 10/02/2018 at 4:55pm

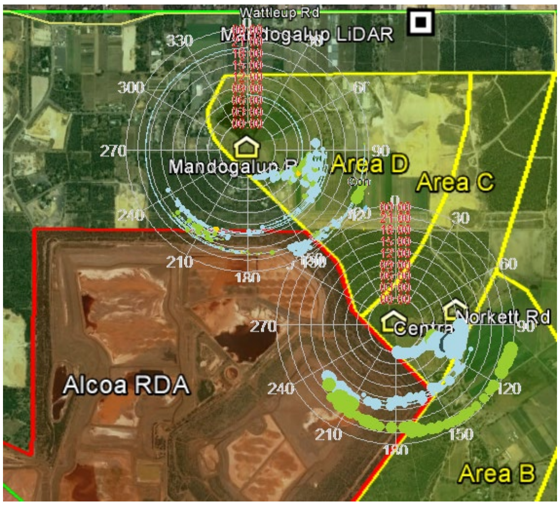
LiDAR record on 10/02/2018 at 5:00pm. No further traces were evident through to 6pm.

No RDA activity was detected by LiDAR. The cause is due to a local event.

15 February 2018







The ratio of PM_{10} to TSP for times when five-minute averaged PM_{10} at Mandogalup was greater than 100 µg/m^3 is 78 per cent.

Maximum one clock-hour averaged concentrations

Site	PM_{10}	TSP
Mandogalup	107.9	140.8
Norkett	56.1	97.3
Central	90	352
Firestation	31	102
South Lake	87.6	N/A

Event description

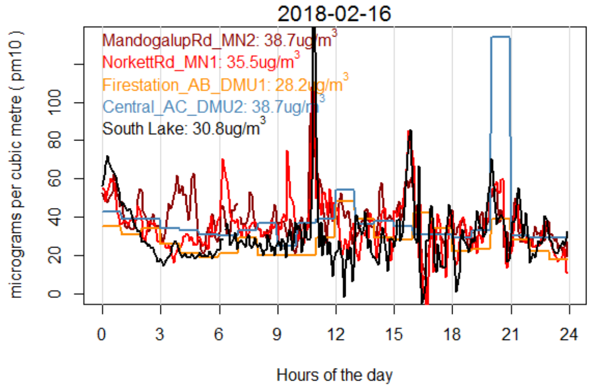
The maximum at Mandogalup occurred around 7pm while that at Central occurred around 7am. Winds were from the east-southeast in the morning and south-southwest in the evening.

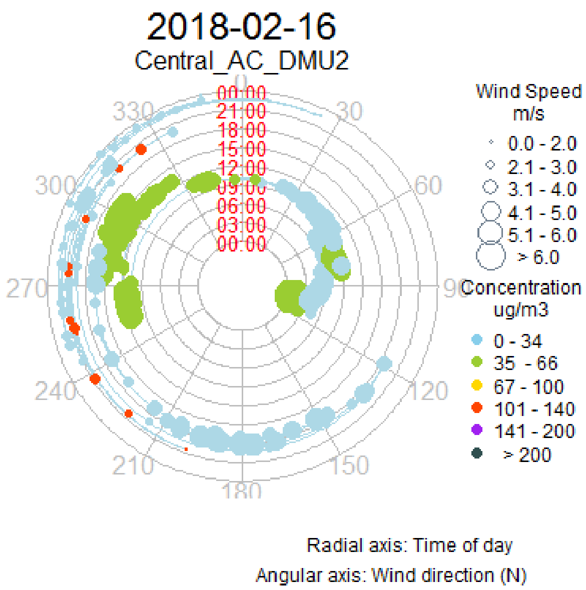
The majority of the particle load came from the east and south-east.

LiDAR traces show no activity on the RDA in the evening.

The cause is unknown.

16 February 2018





The ratio of PM_{10} to TSP for times when one-hour averaged PM_{10} at Central was greater than 100 µg/m^3 is 57 per cent.

Maximum one clock-hour averaged concentrations

Site	PM_{10}	TSP
Mandogalup	52.0	84.4
Norkett	56.9	80.5
Central	134	235
Firestation	48	151
South Lake	61.8	N/A

Event description

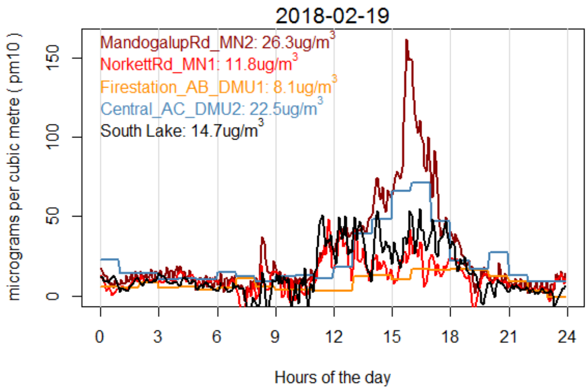
The Central BAM particle monitor only provided hourly averages; therefore, the short-term (5 minute) concentration, which almost certainly would have been higher, could have occurred at any time between 8pm and 9pm. Winds ranged from 220º to 320º throughout the hour.

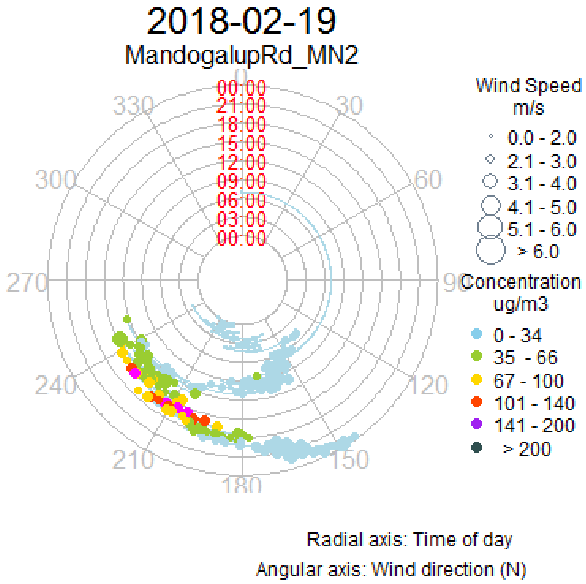
The source of the particles seems to be in the direction of the RDA.

LiDAR traces show no activity on the RDA during that period.

The cause is possible local source or RDA dust.

19 February 2018





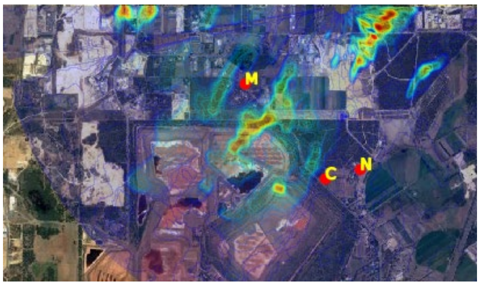
The ratio of PM_{10} to TSP for times when five-minute averaged PM_{10} at Mandogalup was greater than 100 μg/m^3 is 62 per cent.

Maximum one clock-hour averaged concentrations

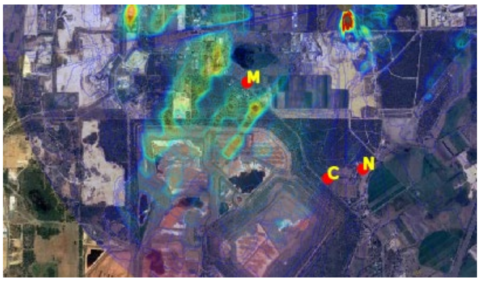
Site	PM_{10}	TSP
Mandogalup	104.7	165.4
Norkett	27.4	38.2
Central	71	146
Firestation	17	40
South Lake	39.1	N/A

Event description

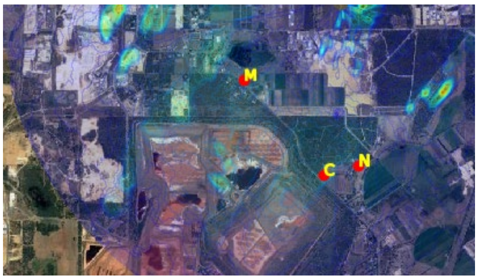
Winds from the south-west caused some dust lift-off in mid to late afternoon.



LiDAR record on 19/02/2018 at 3:40pm



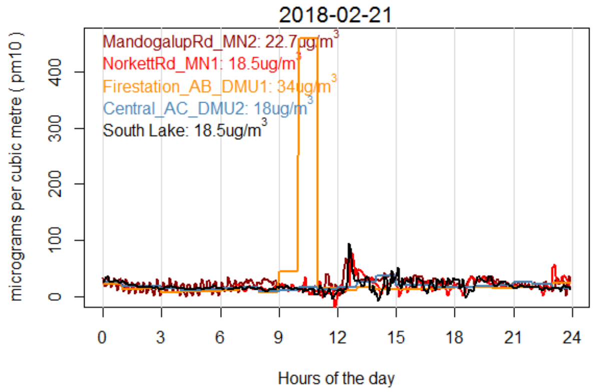
LiDAR record on 19/02/2018 at 4pm

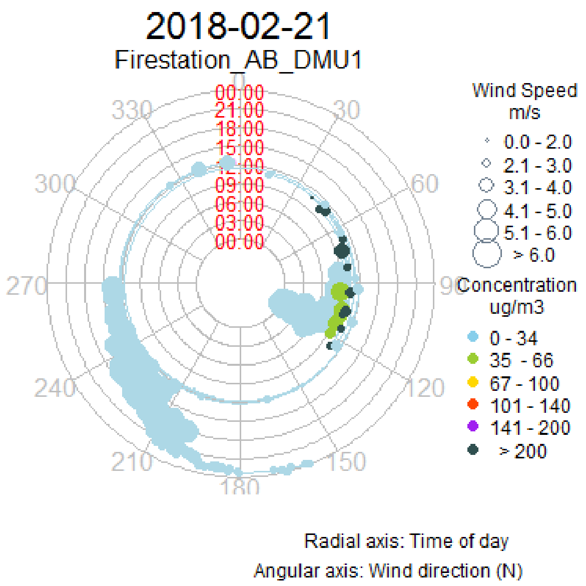


LiDAR record on 19/02/2018 at 4pm

The cause is likely due to RDA dust.

21 February 2018





The ratio of PM_{10} to TSP for times when one-hour averaged PM_{10} at Firestation was greater than 100 µg/m^3 is 48 per cent.

Maximum one clock-hour averaged concentrations

Site	PM_{10}	TSP
Mandogalup	39.3	43.1
Norkett	35.8	51.8
Central	37	69
Firestation	459	958
South Lake	31.7	N/A

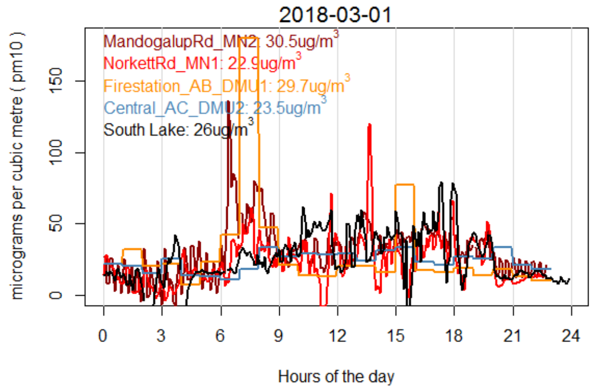
Event description

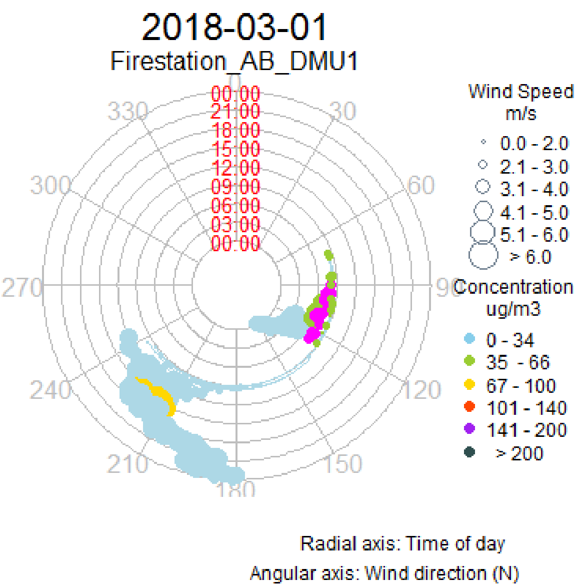
Residents reported that at the time of this event, Pioneer Park, located adjacent to the Firestation site, was being mowed by ride-on mowers.

This observation is consistent with the wind direction at the time of the high concentrations, which were between the north-east through to south-east.

The cause was mowing in a local park.

1 March 2018





The ratio of PM_{10} to TSP for times when one-hour averaged PM_{10} at Firestation was greater than 100 μg/m^3 is 56 per cent.

Maximum one clock-hour averaged concentrations

Site	PM_{10}	TSP
Mandogalup	63.5	101
Norkett	52.5	146.4
Central	33	42
Firestation	180	320
South Lake	49.6	N/A

Event description

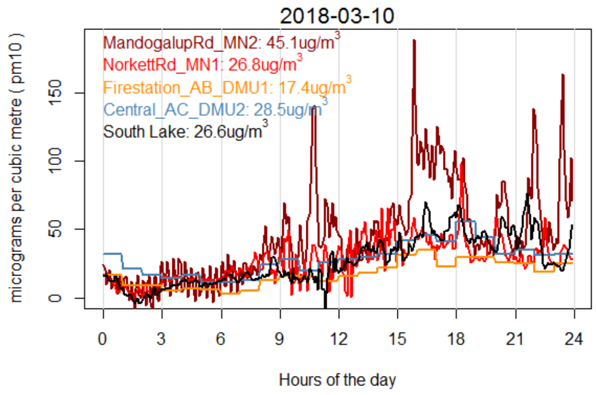
The high concentrations at the Firestation site occurred between 6am and 7am. During this period, winds at the top of the RDA were from the east through to the east–southeast.

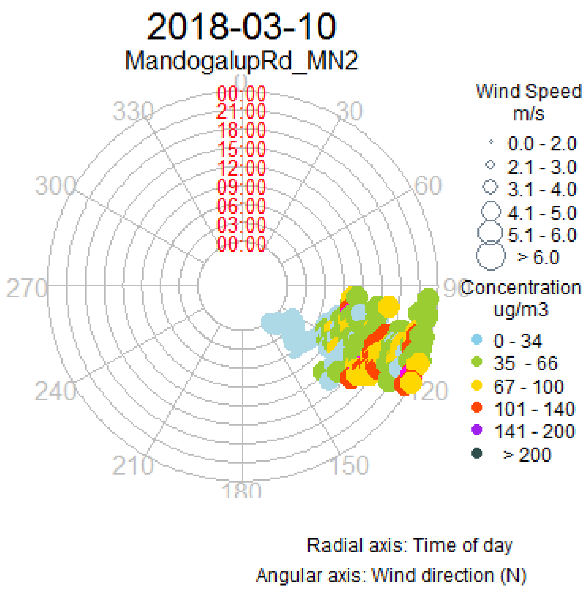
Firestation only provided one-hour averaged data so it is likely that elevated particle levels occurred within a short timeframe within that one-hour period.

This event was most likely a short-term event occurring reasonably close to the monitoring site.

The cause is unknown.

10 March 2018





The ratio of PM10 to TSP for times when five-minute averaged PM10 at Mandogalup was greater than 100 µg/m^3 is 66 per cent.

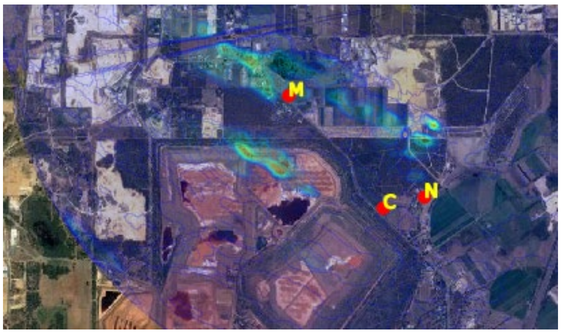
Maximum one clock-hour averaged concentrations

Site	PM_{10}	TSP
Mandogalup	102.6	160.8
Norkett	47.1	75.2
Central	56	97
Firestation	35	122
South Lake	53.5	N/A

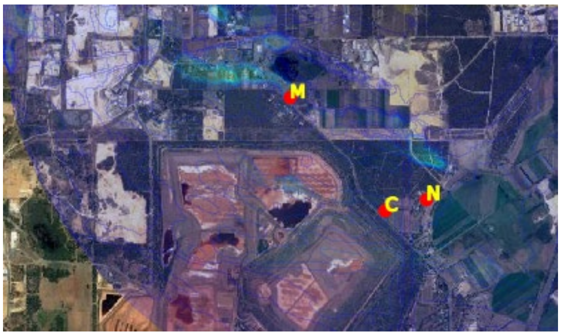
Event description

Generally elevated particle levels can be seen in the afternoon, with somewhat higher concentrations at the Mandogalup site. The winds were from the east-southeast during the day.

Given the similarly elevated base particle level at South Lake, this was likely a low-level regional event with some contribution from agricultural activities at the Mandogalup site.



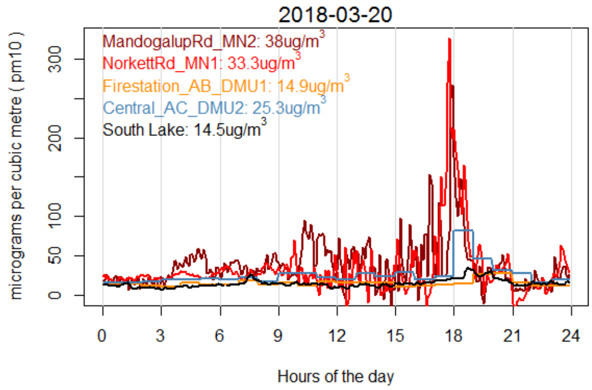
LiDAR record on 10/03/2018 at 4:50pm

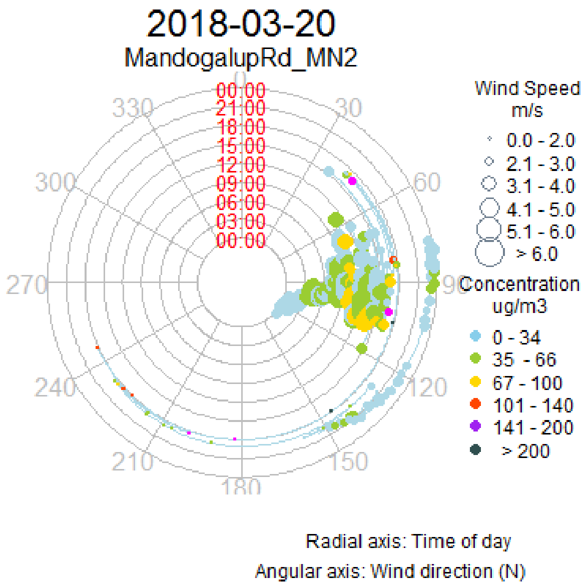


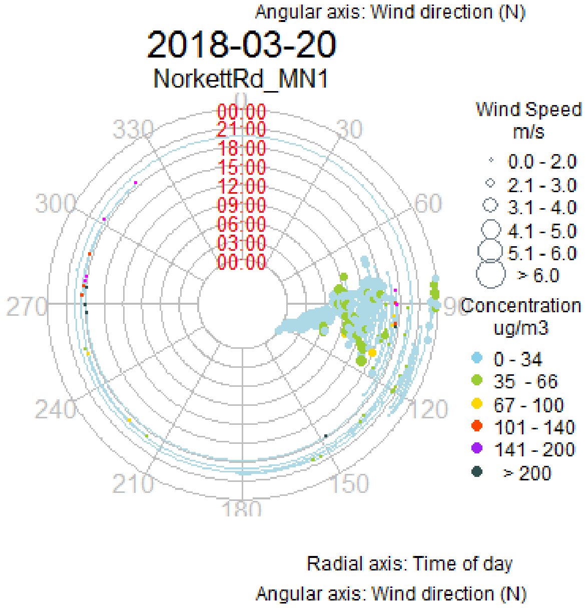
LiDAR record on 10/03/2018 at 5:20pm

The cause is possible dust from agriculture or quarry.

20 March 2018







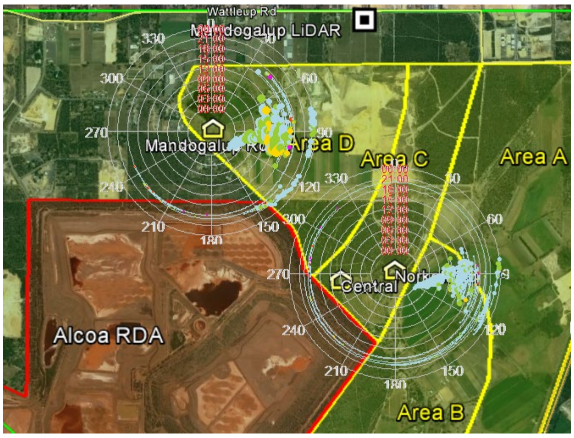
The ratio of PM_{10} to TSP for times when five-minute averaged PM_{10} at Norkett was greater than 100µg/m^3 is 56%.

Maximum one clock-hour averaged concentrations

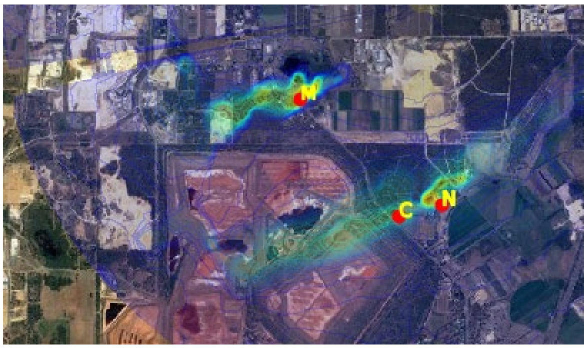
Site	PM_{10}	TSP
Mandogalup	94.4	138.9
Norkett	147.8	285.7
Central	82	198
Firestation	28	54
South Lake	27.1	N/A

Event description

Winds were from the east throughout most of the day. Winds did swing around to the west at around 6pm.



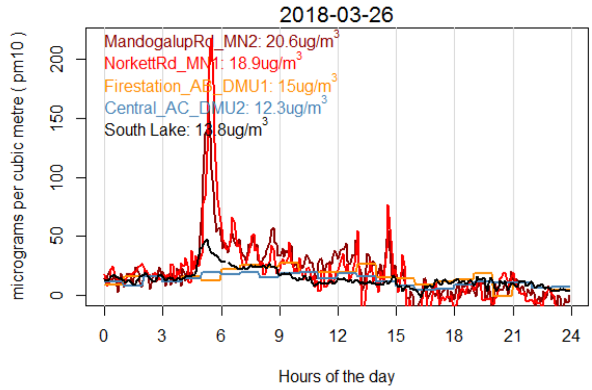
Wind spiral for 20/03/2018 overlayed at the Mandogalup and Norkett site

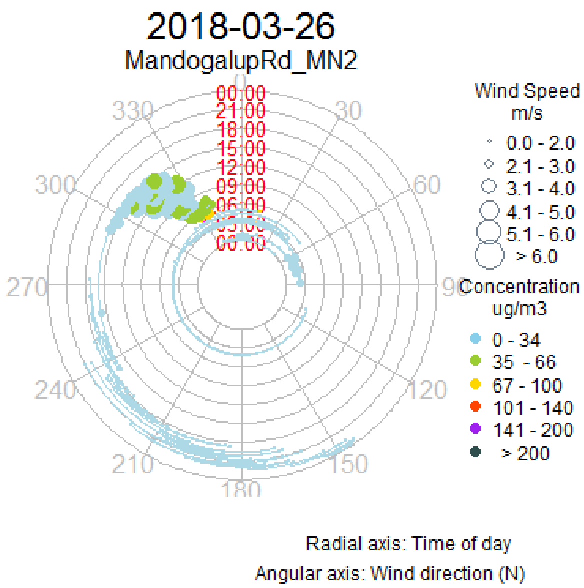


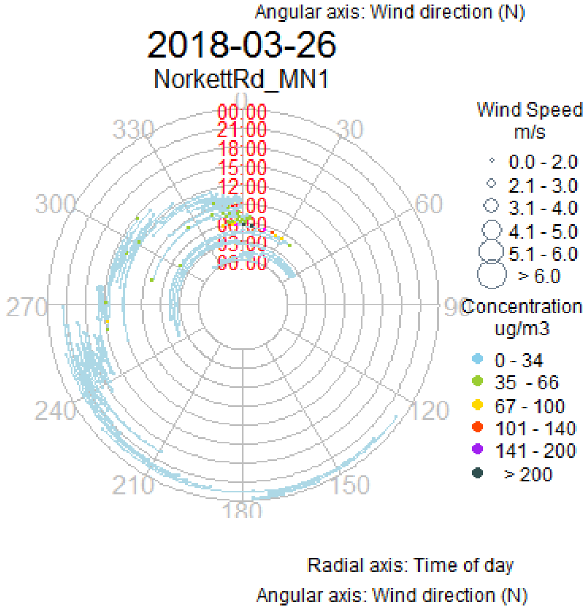
LiDAR record on 20/03/2018 at 6pm

The cause is unknown.

26 March 2018







The ratio of PM10 to TSP for times when five-minute averaged PM10 at Norkett was greater than 100 μg/m^3 is 72 per cent.

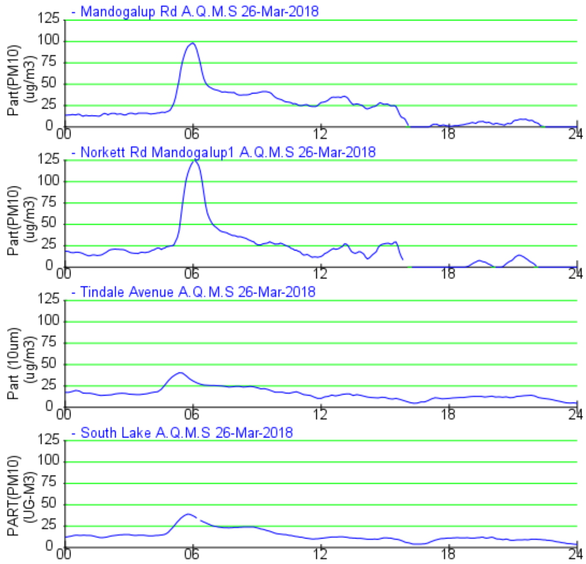
Maximum one clock-hour averaged concentrations

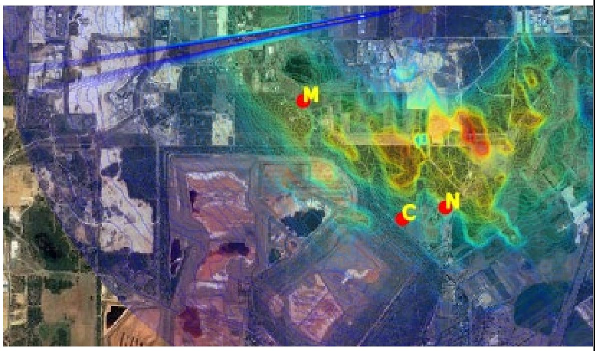
Site	PM10	TSP
Mandogalup	98.3	86.5
Norkett	123.4	169.2
Central	19	27
Firestation	27	38
South Lake	38.1	N/A

Event description

High hourly concentrations were recorded at Mandogalup and Norkett sites in the morning. During this period, the winds were from the northern sector.

PM10 from other metropolitan sites show slightly elevated concentrations at around 6am.





LiDAR record on 26/03/2018 at 5:40am

The cause is possible local smoke moving in a south-southeasterly direction.

Appendix B — Jandakot weather data obtained from the Bureau of Meteorology

December 2017

Date	Day	Temps		Rain	Evap	Sun	Max wind gust			9am						3pm					
		Min	Max				Dir	Spd	Time	Temp	RH	Cld	Dir	Spd	MSLP	mp	RH	Cld	Dir	Spd	MSLP
		°C	°C	mm	mm	hours		km/h	local	°C	%	8th		km/h	hPa	°C	%	8th		km/h	hPa
1/12/2017	Fri	12.9	27.3	0		13.2	E	43	3:15	21	34		E	22	1019.6	25	36		SW	31	1016.5
2/12/2017	Sat	12.2	34.3	0		13.2	E	44	23:31	24.6	30		ENE	20	1017.7	32.8	19		SW	26	1013.9
3/12/2017	Sun	19.8	35.6	0		4.6	NW	52	17:40	29.3	19		ENE	26	1014.5	34.4	12	8	NE	24	1011.8
4/12/2017	Mon	18.8	24.8	6.4		0.9	SSW	24	6:23	19	93	8	SSE	15	1012.8	23.1	70	7	N	9	1009.7
5/12/2017	Tue	17.7	26.9	0.2		12.8	SW	44	13:50	24.6	54	1	SSW	19	1011.9	25.7	62		SSW	31	1010.5
6/12/2017	Wed	14.9	28.9	0		13.2	WSW	50	15:12	21.2	43		SSE	15	1015.5	25.4	43		SW	35	1013.1
7/12/2017	Thu	14.4	29.3	0		13.2	ESE	43	0:37	20.9	46		E	17	1018.7	27.8	33		S	11	1015
8/12/2017	Fri	15.8	35.6	0		12.4	E	50	23:55	24	27		ENE	24	1016.1	33.9	13		ENE	15	1011.9
9/12/2017	Sat	21.4	34.1	0		6	N	52	11:12	29.8	17	7	NE	24	1011.4	26	50	8	SSW	6	1012.7
10/12/2017	Sun	16.5	37	0		13.2	N	44	11:33	31.2	33		NE	17	1012.3	32.8	33	5	WSW	30	1009.9
11/12/2017	Mon	18.1	36.8	0		13.1	WSW	43	15:33	33	25		NNE	15	1009.2	32.4	27		WSW	26	1006.3
12/12/2017	Tue	18.3	28.1	0		11.7	SW	54	15:17	25	64		W	19	1010.7	26	50		SSW	35	1011.2
13/12/2017	Wed	13.4	25.2	0		13.2	WSW	44	14:49	22.3	44	4	S	22	1017.9	24.7	45	1	WSW	35	1015.9
14/12/2017	Thu	13.4	27	0		13.2	WSW	43	14:38	21.6	47		E	13	1018.1	25	45		WSW	33	1014.3
15/12/2017	Fri	14.7	28.9	0		13.4	WSW	41	13:16	24.2	44		ESE	19	1012.5	28.4	47		SSW	26	1009.1
16/12/2017	Sat	14.6	27.7	0		12.6	SW	46	12:58	24.2	48		SW	7	1007.4	22.6	60	1	WSW	35	1006.7
17/12/2017	Sun	14.8	21.6	4.4		5.9	WSW	69	13:36	18.7	63	8	W	35	1004.1	18.7	83	8	WNW	39	1002.8
18/12/2017	Mon	13	21.3	10.4		7.1	WSW	76	11:12	16	86	8	WSW	31	1004.1	20.5	61	8	WSW	43	1006.6
19/12/2017	Tue	11.2	23.3	5.8		13	SW	46	15:27	17.8	51	4	S	28	1016.6	22.3	46		WSW	33	1015.8
20/12/2017	Wed	13.4	28.9	0		13.2	SW	39	14:10	21.2	46		ENE	15	1019.7	27	45		SW	28	1015.8
21/12/2017	Thu	14.6	35	0		13.3	E	35	4:42	28.9	24		ENE	17	1013.1	34.4	13		WSW	22	1010.2
22/12/2017	Fri	18.7	31.3	0		13.1	WSW	35	15:32	27	38		SSW	7	1008.5	30.3	30		WSW	28	1007.8
23/12/2017	Sat	16.6	30.9	0		13.2	ESE	44	23:45	22.6	45		ESE	20	1012.7	29.4	38		WSW	26	1010.1
24/12/2017	Sun	17.4	34.3	0		13.2	ESE	48	0:25	24.7	39		ESE	26	1013.3	31.9	30		W	26	1009.3
25/12/2017	Mon	19.2	31.8	0		13.3	SW	39	15:37	27.5	36		E	9	1008.4	30.2	28		WSW	28	1007.2
26/12/2017	Tue	16	26.4	0		13.2	WSW	44	14:48	22	61	2	SSW	19	1011.7	24.5	46		WSW	33	1010.2
27/12/2017	Wed	13.5	25.8	0		12.3	SW	52	13:26	21.2	47	6	S	19	1013.7	24.4	38		SW	37	1010.6
28/12/2017	Thu	14.3	27.4	0		13.2	SSW	48	16:36	21.3	47		SSE	17	1015	26.2	44		SW	33	1012.1
29/12/2017	Fri	14.4	28.8	0		13.1	SW	46	16:30	21.7	54		SSE	19	1016.7	27.7	75		SW	30	1013.2
30/12/2017	Sat	17.1	34.7	0		13.2	ESE	43	6:33	25	41		E	17	1014.1	32.5	40	1	SW	28	1010.4
31/12/2017	Sun	18.9	32.8	0		13.2	SW	44	16:35	25.5	75		S	13	1012.2	30.7	94		SW	31	1009.9

January 2018

Date	Day	Temps		Rain	Evap	Sun	Max wind gust			9am						3pm					
		Min	Max				Dir	Spd	Time	Temp	RH	Cld	Dir	Spd	MSLP	mp	RH	Cld	Dir	Spd	MSLP
		°C	°C	mm	mm	hours		km/h	local	°C	%	8th		km/h	hPa	°C	%	8th		km/h	hPa
1/01/2018	Mon	18	33.3	0		13.2	SSW	46	16:40	25.2	98		SE	19	1013.9	31.6	98		SW	30	1010.6
2/01/2018	Tue	19.1	37.2	0		13.2	ESE	44	2:16	28.6	34		ENE	17	1012	36.8	40		WSW	24	1009.1
3/01/2018	Wed	17.5	29.6	0		13.2	W	37	11:58	28.4	68		WSW	11	1011	28	47		WSW	26	1011.2
4/01/2018	Thu	16.2	30.9	0		13.3	WSW	37	12:41	24.7	38		E	11	1013	30	20		WSW	24	1010.2
5/01/2018	Fri	12.3	26.3	0		10.4	SSW	52	17:33	25.3	40		W	22	1010	22.7	63	8	SW	37	1012
6/01/2018	Sat	8.1	27.8	0		13	WSW	46	14:44	18.7	32		SSE	26	1019.3	24.6	36		WSW	30	1016.2
7/01/2018	Sun	13.4	30.9	0		13.2	SW	50	15:47	22.8	36		ESE	20	1017.8	28.8	34		SW	35	1014.2
8/01/2018	Mon	16.8	34.7	0		13.2	SE	44	6:04	22.7	46		ESE	22	1019.1	33.3	16		SSE	17	1013.1
9/01/2018	Tue	17.7	35.3	0		12.8	ESE	46	0:56	24	42		ESE	26	1013.4	32.8	32		W	22	1008.3
10/01/2018	Wed	19.7	28.5	0		13.2	SW	56	13:19	25.1	47		SSW	17	1007.2	25.1	49		SW	35	1006.8
11/01/2018	Thu	17.3	23.5	0		12.7	WSW	65	14:24	20.7	48	3	SW	33	1010.7	22.3	40	2	SW	37	1011.5
12/01/2018	Fri	9.6	26.7	0		13.1	WSW	48	14:57	20.7	42		S	24	1017.5	24.1	46		WSW	37	1013.4
13/01/2018	Sat	17.9	37.1	0		13.1	ENE	39	14:21	26.4	40		E	22	1014.9	35.8	16		SE	15	1010.7
14/01/2018	Sun	21.1	37.6	0		6.7	E	46	1:53	30.8	28		E	22	1013.4	35.2	23	8	NE	24	1010.5
15/01/2018	Mon	20.1	24.1	1.6		0	E	57	10:44	20.2	79	8	ENE	26	1013.9	20	92	7	ENE	30	1011.1
16/01/2018	Tue	18.3	32	119		8.3	ESE	50	1:50	24	69	4	ENE	19	1006	27.7	64	8	NW	30	1004.2
17/01/2018	Wed	21.7	27.1	1.2		1.5	SSW	37	23:23	23.1	96	8	NW	9	1005	24.7	78	8	SW	22	1005
18/01/2018	Thu	18.4	29	0.2		7.4	SSE	39	7:53	21.2	64	8	S	24	1013	27.4	39	2	SSE	13	1012
19/01/2018	Fri	15.2	30.5	0		13.2	ESE	41	3:10	20.8	48		E	22	1017	29	28		ESE	22	1012.1
20/01/2018	Sat	18.2	34.1	0		13.1	ESE	39	6:46	25.7	45		ESE	22	1010.4	32.9	38		WSW	26	1006.8
21/01/2018	Sun	20.8	32.5	0		13.2	SE	41	22:02	27	55		S	11	1009.2	31.6	44		SW	28	1008
22/01/2018	Mon	19.2	33.5	0		12.9	ESE	44	0:03	23.9	57		ESE	22	1012.5	33.3	39		S	17	1008.3
23/01/2018	Tue	20.9	32.7	0		13	ESE	39	22:58	25.4	56	1	ESE	17	1009.5	31.3	40	1	WSW	28	1006.5
24/01/2018	Wed	18.5	32.5	0		13	ESE	52	3:13	24.5	59		ESE	20	1008.8	31.8	39		SW	31	1004.3
25/01/2018	Thu	17.9	30.3	0		13.3	SW	41	14:07	24.1	55		ESE	15	1007.5	28.5	44		SW	28	1004.9
26/01/2018	Fri	15.8	31.3	0		13.1	WSW	39	13:48	24	53		S	17	1006.3	29.1	44		WSW	26	1002.9
27/01/2018	Sat	17.3	27.6	0		12.8	SW	48	16:36	23.4	64	1	S	26	1005.1	26.4	50		SW	28	1004.4
28/01/2018	Sun	17.6	28.6	0		12.7	SE	57	22:58	21.3	54	5	SE	28	1011.2	27.3	30		S	24	1009.2
29/01/2018	Mon	15.1	30.4	0		12.9	ESE	63	0:01	21.1	37		E	31	1016.2	29.4	20		E	31	1012.2
30/01/2018	Tue	15.7	29.8	0		12.8	ESE	69	11:06	20.6	38		E	33	1017.4	28.5	19		ESE	28	1012.4
31/01/2018	Wed	16.7	30.9	0		12.7	ESE	56	0:16	22	40		E	30	1014.5	30.3	22		SE	19	1009.2

February 2018

Date	Day	Temps		Rain	Evap	Sun	Max wind gust			9am						3pm					
		Min	Max				Dir	Spd	Time	Temp	RH	Cld	Dir	Spd	MSLP	mp	RH	Cld	Dir	Spd	MSLP
		°C	°C	mm	mm	hours		km/h	local	°C	%	8^{th}		km/h	hPa	°C	%	8^{th}		km/h	hPa
1/02/2018	Thu	18.4	31.7	0		12.1	ENE	41	22:48	24	46		ENE	28	1011.1	30.7	30	1	SE	17	1006.7
2/02/2018	Fri	23.8	32.3	0		6.2	ENE	44	2:27	25.8	46	8	NE	28	1008	30.6	32	8	SE	20	1005.2
3/02/2018	Sat	23.7	32.8	0		10.1	WNW	39	14:33	26.4	48	8	NE	22	1006.4	28.4	50	4	W	26	1005.9
4/02/2018	Sun	17.7	28	0		12.6	WSW	43	16:45	23.8	61	3	SW	15	1013.9	26.2	45		WSW	30	1013.2
5/02/2018	Mon	15.2		0		12				23.9	52		S	6	1015.4	28.5		4	WSW	19	1012.8
6/02/2018	Tue	17	30.2			12.4	SW	52	16:22	21.8	71	7	S	17	1013.9	27.6	49		SW	33	1010.6
7/02/2018	Wed	16.5	27.6	0		2.2	SSW	35	0:25	20.6	62	8	SSE	22	1015.1	26.5	48	7	SE	22	1012.4
8/02/2018	Thu	14.6	31.5	0		10.9	ESE	39	9:03	23	51		E	19	1014.6	30.1	43	1	NNW	9	1010.4
9/02/2018	Fri	15.8	26.6	0		12.5	SW	50	12:24	23.1	56		SSW	22	1012.3	25.1	51		SW	33	1012.9
10/02/2018	Sat	16.2	30.7	0		12.5	SW	43	16:12	21.5	53		ESE	24	1017.6	28.3	43		WSW	33	1013.2
11/02/2018	Sun	15.1	31.6	0		12.5	SSW	44	16:14	23.2	47		ESE	13	1013.9	30.3	43		WSW	28	1010.6
12/02/2018	Mon	17.1	32.3	0		12.4	SW	43	15:55	23.8	45		ESE	26	1013.3	30.6	37		SW	30	1009.9
13/02/2018	Tue	13.9	26.6	0		12.3	S	44	7:40	20	63	8	S	30	1015.2	25.4	49		SW	31	1013.8
14/02/2018	Wed	16.5	31.3	0		12.5	WSW	37	14:38	23.3	54		E	17	1017.7	29.6	42		SW	28	1014.6
15/02/2018	Thu	15.5	38.6	0		12.4	E	41	6:22	25.5	46		ESE	30	1015.9	36.9	17		SSW	13	1011.7
16/02/2018	Fri	22.2	36.1	0		8	E	48	2:27	30.8	35		ENE	17	1006.8	27.9	40	8	W	22	1007.4
17/02/2018	Sat	17.7	27.1	0		11.1	WNW	31	13:28	22.8	69	7	W	4	1007	25.5	57		W	19	1005.3
18/02/2018	Sun	14.9	28.4	0		10.1	WSW	41	15:14	24	75	3	ESE	4	1006.2	25.9	65	3	WSW	26	1005.5
19/02/2018	Mon	19.7	28.6	0		10.8	SW	57	15:46	22.8	64	1	SW	20	1009.4	27.3	55		SW	39	1007.4
20/02/2018	Tue	17.5	27.7	0		10.6	ESE	50	22:45	20.2	65	8	ESE	28	1014.6	26.2	45	3	SSE	24	1011.3
21/02/2018	Wed	15.1	27.9	0		12.2	ESE	44	0:31	21.4	56		ENE	15	1010.8	26.9	43		WSW	30	1007.2
22/02/2018	Thu	13.7	29.8	0		12.1	W	35	14:20	24.8	64		NNW	6	1008.6	25.9	60		WSW	26	1007.6
23/02/2018	Fri	16.2	30.4	0		11.8	SSE	48	20:24	24.2	64	1	S	22	1012.3	29.2	40	2	SSE	20	1011.1
24/02/2018	Sat	15.6	31.6	0		11.9	ESE	54	6:29	20.8	45		ESE	33	1018.2	30.7	28	4	E	22	1013
25/02/2018	Sun	20.4	31.7	0		9.6	WNW	50	10:49	26.5	60	8	NNE	24	1008.4	29.7	57	4	WNW	19	1005.4
26/02/2018	Mon	19.4	24.3	0		3.3	SW	48	18:44	21.7	70	8	SSW	24	1007.9	23.1	46		WSW	35	1007.6
27/02/2018	Tue	13.4	24.2	0		12	WSW	46	14:06	18	50	1	S	19	1018	22.3	43		SW	31	1016.3
28/02/2018	Wed	14.9	29.1	0		12.1	W	46	15:17	21.4	48		E	20	1019.3	28.5	37		ESE	15	1014.5

March 2018

Date	Day	Temps		Rain	Evap	Sun	Max wind gust			9am						3pm					
		Min	Max				Dir	Spd	Time	Temp	RH	Cld	Dir	Spd	MSLP	mp	RH	Cld	Dir	Spd	MSLP
		°C	°C	mm	mm	hours		km/h	local	°C	%	8^{th}		km/h	hPa	°C	%	8^{th}		km/h	hPa
1/03/2018	Thu	14.4	31.5	0		11.7	SW	37	15:13	24.8	47		E	6	1012.6	29.9	35		SW	28	1010.2
2/03/2018	Fri	14.8	28.7	0		11.7	SW	50	15:19	20.5	63		SSE	20	1014.7	25.8	48		SW	35	1012.5
3/03/2018	Sat	15.2	29.6	0		11.9	SE	48	0:16	20.5	49		ESE	30	1018	28.5	26		SE	19	1014.4
4/03/2018	Sun	16.2	32.8	0		11.8	ESE	46	0:46	21.8	52		E	20	1017.4	31	29		ENE	19	1014.3
5/03/2018	Mon	19.7	35.9	0		11.8	E	52	1:35	25.8	45		ENE	22	1015.8	34.1	31		NNE	6	1011.9
6/03/2018	Tue	25.6	36.5	0		11.1	NNE	44	10:11	30.3	41		NE	26	1013.8	31.9	42		WNW	28	1012.1
7/03/2018	Wed	20.3	28.1	0		7.9	WSW	35	13:31	22.9	78	8	WSW	13	1015.8	26.9	58		SW	24	1013.5
8/03/2018	Thu	13.5	29.6	0		11.2	WSW	30	14:37	21.8	75		SSW	6	1015	27.8	54		WSW	22	1012.8
9/03/2018	Fri	14.6	29	0		11.2	SSE	50	22:59	22	72		S	17	1017.4	27.4	52		SW	30	1015.4
10/03/2018	Sat	16.7	31.6	0		11.6	E	65	23:44	21.4	57		ESE	33	1023.1	31.2	31		ESE	33	1020
11/03/2018	Sun	17.2	33.2	0		11.2	E	65	2:20	21.9	51		E	33	1025.3	32.5	29		E	24	1021.5
12/03/2018	Mon	19	34.6	0		11.2	E	54	1:07	23.8	54		ENE	22	1024	33.8	31		ENE	20	1019.1
13/03/2018	Tue	23.8	37.6	0		10	ENE	41	2:33	28.1	43	4	ENE	22	1018.3	36.9	27	7	S	19	1013.9
14/03/2018	Wed	21.4	28.6	0.4		2.6	SSW	41	4:37	21.4	89	8	SE	17	1014.5	27.6	67	8	SW	15	1012.5
15/03/2018	Thu	20.3	26.1	2.6		8.2	SW	39	16:29	21.1	92	8	SW	19	1013.9	24.5	64	3	WSW	24	1012.9
16/03/2018	Fri	15.4	25.2	0		8.3	WSW	39	15:22	20.7	71	2	ESE	13	1016.3	23.6	54	3	SW	28	1013.9
17/03/2018	Sat	13.3	23.8	0		8.4	SW	48	9:22	22	49	4	SW	30	1017.5	21.8	55	8	SW	33	1018.2
18/03/2018	Sun	5.7	27.6	0		11	W	37	14:56	17.2	53		ENE	17	1024.6	26.5	40		W	20	1020.5
19/03/2018	Mon	11.2	31.7	0		10.5	ESE	39	6:27	22.2	51		E	13	1022.6	31.1	27		ESE	15	1019.2
20/03/2018	Tue	19.7	34.1	0		8.9	ENE	44	23:28	23.9	51		ENE	28	1019.8	33.6	23		ENE	22	1013.9
21/03/2018	Wed	24	37.1	0		10.1	NNE	43	10:18	29.7	33		NE	24	1010.3	36.2	23		W	22	1006
22/03/2018	Thu	18.1	26.3	0		7.5	W	31	13:53	22.5	84	8	W	15	1009.4	24.6	72	6	WSW	20	1009.8
23/03/2018	Fri	15	29.8	0		6.8	E	39	23:30	20.5	72		SSE	13	1016.4	29	37	8	E	9	1013.3
24/03/2018	Sat	17.7	25.9	0		1.7	ESE	48	3:45	19.2	59	8	ESE	20	1017.5	25	44	8	SE	28	1015.2
25/03/2018	Sun	18.5	25.1	0		0.3	ESE	56	6:44	19.1	64	7	E	7	1015.4	24.6	47	8	NNE	7	1012.2
26/03/2018	Mon	19.1	25.8	0.2		0.1	NNW	48	7:23	23.6	88	8	NNW	30	1008.6	23.1	96	8	NW	30	1007
27/03/2018	Tue	15.9	24.2	0.6		10.7	SW	37	15:58	19.9	64		SE	15	1016.3	23.2	48	1	SSW	20	1015.2
28/03/2018	Wed	7.4	24.7	0		10.8	SW	39	14:01	19.4	61		E	7	1021	23.7	45		SSW	22	1019.1
29/03/2018	Thu	8.3	28.7	0		10.9	SW	33	15:19	19.4	68		ESE	13	1022.1	26.8	47		SW	26	1017.6
30/03/2018	Fri	13	32.9	0		10.1	ESE	39	3:47	21.8	60		ESE	30	1014	31.5	38		WSW	22	1009.6
31/03/2018	Sat	15.7	27.9	0		8.6	SW	43	14:37	20.5	71	5	S	20	1015.1	25.8	48		SW	33	1013.3

Daily Weather Observations for Jandakot, Western Australia for May 2018
Prepared at 03:20 UTC on Tuesday 15 May 2018 IDCJDW6056.201805

Most observations from Jandakot Airport.
On most days, Jandakot experiences very similar sunshine readings to those recorded at Perth Airport but the distance apart is such that there will be occasional exceptions. Some cloud observations are from automated equipment; these are somewhat different to those made by a human observer and may not appear every day.

Temperature, humidity, wind, pressure, cloud and rainfall observations are from Jandakot Aero {station 009172}.

Sunshine observations are from Perth Airport {station 009021}.

Shortened forms

BAM	Beta attenuation particle monitor
[C]	Concentration in micrograms per cubic metre
CBD	Central business district
DWER	Department of Water and Environmental Protection
EAD	Equivalent aerodynamic diameter is the diameter of a spherical particle of density 1000 kg/m^3, which is the density of water, and which exhibits the same aerodynamic behaviour as the particle in question
EPA	Environmental Protection Authority
EPR	Environmental Protection (Kwinana) (Atmospheric Wastes) Regulations 1992
Kwinana EPP	Environmental Protection (Kwinana) (Atmospheric Wastes) Policy 1999
LiDAR	Light detection and ranging
NEPM	National Environment Protection (Ambient Air Quality) Measure
PM_{10}	Particles with an equivalent aerodynamic diameter smaller than 10 micrometres
$PM_{2.5}$	Particles with an equivalent aerodynamic diameter smaller than 2.5 micrometres
RDA	Residue drying area
TEOM	Tapered element oscillating microbalance particle monitor
TSP	Total suspended particulates
µm	micrometres or microns (one thousandth of a millimetre)
µg/m^3	micrograms per cubic metre

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