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

Mapping dust plumes at Port Hedland using a LiDAR

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Preface

This report provides an analysis of data obtained from a short term air quality monitoring campaign in Port Hedland, in the Pilbara region of Western Australia. The campaign monitored particle levels arising from sources in and around Port Hedland, including the various port operations. 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 five month period from February 2017 to June 2017.

The objective of this project was to determine the origins and movement of dust contributing to impacts experienced in and around Port Hedland by using a Windcube® 200S LiDAR instrument installed atop a tower located in the town for a period of five months over the 2017 autumn/winter period. Additionally, the former Department of Environment Regulation (DER) sought to assess the suitability of applying LiDAR technology as a general tool in assessing dust pathways and impacts on local communities. The former DER, Department of Water and the Office of the Environmental Protection Authority were amalgamated to form the Department of Water and Environmental Regulation (DWER) on 1 July 2017.

Summary

This report summarises an air quality study conducted in Port Hedland between February and June 2017 using a number of monitors designed to detect particles[1] within the atmosphere.

As there are number of large export facilities near the town, each with a possibility of contributing to the overall dust levels, it has been difficult to determine a single specific cause or a major contributor to any dust event utilising only the existing monitoring network. This study sought to use a LiDAR to supplement the monitoring network and to identify dust sources in the area.

Major findings of this study are:

- During the study period, there were three PM_{10} exceedances of the 70 micrograms per cubic metre ($\mu g/m^3$) 24-hour PM_{10} guideline at the Harbour monitoring site, two exceedances at both the Richardson and Kingsmill sites and one exceedance recorded at Taplin Street. There was also one exceedance at the Bureau of Meteorology (BoM) background site.
- PM_{10} concentrations generally decreased as the distance from the port area increased.
- The ratio profile of particles with an equivalent aerodynamic diameter smaller than 2.5 µm ($PM_{2.5}$) to PM_{10} indicates that the majority of dust was not due to combustion but was coarser in nature, indicating dust lift-off from wind or mechanical processes.
- The *National Environment Protection (Ambient Air Quality) Measure* (NEPM) PM_{10} annual average standard of $25\mu g/m^3$ was exceeded at Taplin Street every year from 2011 to 2016 with 2017 likely to also exceed the annual standard.
- Directional analysis indicated that the majority of particle loading to all town sites originated from a southerly direction.
- There was a high correlation between the LiDAR backscatter and the concentrations determined by the particle monitors, which provided a measure of confidence that the LiDAR was providing a valid representation of atmospheric particle loading.

[1] Particles encompass airborne dust from both man-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

Port Hedland is a small town with a population of approximately 4000[b] located in the Pilbara region of northern Western Australia around 1300 km north of Perth.[1] The township is approximately one kilometre wide, five kilometres long, on an east-west orientated narrow strip located between the BHP Billiton Limited Iron Ore (BHP) processing and loading facility at Nelson Point and the ocean.

Rainfall occurs mostly during summer months from cyclones and thunderstorms, with tropical cloud bands during the May-June period making up the remainder.

The existing Port Hedland port infrastructure is one of the largest export ports, by tonnage, in Australia. Key industries currently using the port to export product are BHP, Fortescue Metals Group Limited (FMG), Roy Hill, Pilbara Ports Authority (PPA) and Dampier Salt. Of these, BHP and FMG are the only exporters with tonnage exceeding 100 million tonnes per annum (Mtpa).

Table 1: Major Port of Port Hedland operators

Operator	Material	Scale of Operation
BHP	Iron ore	Allocated capacity 270Mtpa Four berths at Nelson Point Four berths at Finucane Island
FMG	Iron ore	Allocated capacity 175Mtpa Five berths at Anderson Point
Roy Hill	Iron ore	Allocated capacity 55Mtpa Two berths at South West Creek
PPA (Utah Point Facility)	Iron ore, manganese ore	Allocated capacity 21.35Mtpa Single berth at Utah Point
Dampier Salt	Salt	Allocated capacity 75,000 tonnes per day Utilises single berth (Berth 3)
PPA (Eastern Operations)	Copper concentrate	Throughput approximately 500,000 tonnes per annum - Two berths in Port Hedland (Berth 1 and 2)

As the town is close to a number of large iron ore exporting facilities, it is subjected to periods where the PM_{10} dust levels exceed the NEPM standard of 50µg/m^3 (24-hour average).

Particle emissions to air and their associated impacts are important issues for the community, industry and government. Port Hedland is affected by fugitive iron ore and other mineral dusts as a consequence of shipping operations. The town is also within a semi-arid climate which, together with natural events such as bushfires, is conducive to generally higher dust levels. The region is characterised by low and variable rainfall levels, cyclonic activity and consistently high temperatures.

Particle concentrations in Port Hedland vary depending on the proximity to handling operations, port activities and the weather. To assist in addressing the issues surrounding particle concentrations, the WA Government established the Port

[b] Does not include South Hedland.

Hedland Dust Management Taskforce (Taskforce) in May 2009. The objective of this Taskforce, which is comprised of representatives from Local and State Government, industry and service providers, is to provide effective dust management strategies within Port Hedland.

In 2010, the Taskforce released the Port Hedland Air Quality and Noise Management Plan. Acknowledging that 24-hour average PM_{10} levels regularly exceeded the NEPM standard, the Taskforce established an alternative interim 24-hour PM_{10} guideline of 70µg/m^3 pending the completion of a Health Risk Assessment.

The Health Risk Assessment, released by the Western Australian (WA) Department of Health (DoH) in 2016, supports the interim 24-hour PM_{10} guideline of 70µg/m^3 in residential areas of Port Hedland with an allowance of ten exceedances annually to account for adverse meteorology and/or region-wide particle events (e.g. fires).[2]

Owing to the small population of the area, there is negligible difference in estimated health effects between a criterion based on 70µg/m^3 and the NEPM criterion of 50µg/m^3. DoH has recommended that the WA Government adopt the NEPM criterion for PM_{10} for Port Hedland if the population increases over time and the composition of particles in the airshed changes to include more combustion derived particles.[2]

It is important to note that the10 allowable exceedances for the PM_{10} interim guideline was introduced to account for the impact of natural events such as, bushfires and dust storms rather than applying to urban and industrial air pollution.

Port Hedland however continues to have significant ambient air quality management challenges, including the fact that dust generated by operations in and around the port has pushed ambient dust levels in residential areas in Port Hedland above the NEPM PM_{10} standard as well as the interim 24-hour PM_{10} guideline of 70µg/m^3. The nature of monitoring using conventional methods means that attribution of the source of these high particle levels is unclear, being one or a combination of port operations, local dust sources, regional events or some other unknown factors.

Figure 1 *Port Hedland with major operators BHP, FMG, PPA and Roy Hill outlined. The 5km radius white circle is centred on the LiDAR location atop the Town Centre Viewing tower (inset) and represents the approximate coverage of the LiDAR beam. Allocated loading berths are numbered.*

2 Measurement Instruments

As part of this project, the following Australian Standard compliant instruments to measure PM_{10} concentrations and assist in the calibration of the LiDAR were installed:

- a PM_{10} monitor 2.2 kilometres (km) NNW of the LiDAR site at the Northern tip of Finucane Island.
- a PM_{10} monitor located 5 km SW of the LiDAR site on Redbank road.
- a PM_{10} monitor located 4 km E of the LiDAR site adjacent to the Council Offices.

A Windcube® 200S LiDAR was also installed and operated by Ecotech Pty Ltd on behalf of DWER in the Town Centre lookout tower for a five-month period.

LiDAR is a well-established technology developed in the 1960s. One of its first uses was by the United States 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 light beam length as recorded at every 20 metre interval along the beam.

For this project, the Windcube® 200S LiDAR was erected on the Town Centre Viewing tower,and set to perform continuous circular scans with each scan completed every 10 minutes. The ideal measurement range for the 200S is from 0.1 km up to six kilometres. In practice, a measurement range of around five kilometres is generally achieved.

The LiDAR output provided a reading of backscatter intensities (or relative particle concentrations) at each point within a disc centred on the LiDAR extending out up to 6km for each compass degree. The radial (or going out from the centre) resolution is 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 circular resolution is one degree sweep of the LiDAR beam, each gate-degree encompasses a 20 metres x 1 degree area. One can therefore conclude that the LiDAR provides a mechanism whereby, a virtual particle measure can be obtained at each of the available points within that disc making up over 105,000 measurements of backscatter intensities every 10 minutes within the total observational space.

The LiDAR's positioning on the tower allowed a largely unimpeded view of the surrounding landscape with some hard targets (e.g. buildings) 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 the obstruction.

Data were collected on a 10 minute cycle where the LiDAR scanned a full 360 degrees. During each scan, the LiDAR beam passed over each of the three 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 used within the Port Hedland particle network. LiDAR backscatter data are used for determination of particle pathway and source allocation.

3 Potential dust sources

The action of wind can exacerbate the generation of dust from activities such as ore mining, handling, processing and transport.

Wind generated dust from uncontrolled static stockpiles can occur when the wind speed exceeds a “threshold” velocity (nominally around 4m/s or 14km/hr). The amount of dust generated is highly dependent upon this wind speed, below which little or no dust is suspended. Above this wind speed, the vertical flux of particles smaller than 10µm in diameter generally becomes proportional to the cube of the horizontal wind speed.

Material handing processes, such as grinding operations, transfer points, stacking, reclaiming and ship loading, and vehicular movement over unsealed or dust laden surfaces can suspend dust. Dust generated from these processes has a different wind speed dependency to that from uncontrolled static stockpiles and is also dependent on the moisture properties of the material being transferred, the particle size distribution of the material, drop heights and the dust management measures and emission controls in place for the sources.

For natural sources of wind-blown dust, the soil particle size distribution, apparent roughness of the site, vegetation cover, presence of a crust on the soil, and presence of non-erodible elements (e.g., large stones) are parameters which can be used to estimate the potential for suspension.

There are a number of potential natural and industrial dust sources within the region. Many of these sources were detected by the LiDAR at one time or another and were observed contributing to the general dust levels in Port Hedland. Appendices A, B and C provide some analysis of selected events that best demonstrate these contributory dust sources.

BHP

BHP port operations consist of processing, stockpiling and ship loading facilities at Nelson Point and Finucane Island, located on opposite sides of the Port Hedland Harbour. A generalised description of the ore handling route includes receiving of ore railed from various mines, processing of the ore to meet customer specifications, stockpiling and reclaiming and ship loading into vessels. Depending on the source of the ore and required specification, ore processing may involve crushing, screening and/or beneficiation prior to stockpiling. The infrastructure at Nelson Point differs from Finucane Island to cater for different ore and product types.

The infrastructure at Nelson Point comprises:

- Three ore unloading car dumpers;
- A lump re-screening plant;
- Two tertiary crushing and screening plants;
- Two ore handling and stockpile yards (North and South Yards);
- Two ship loading facilities; and
- General administrative and maintenance facilities.

The infrastructure at Finucane Island comprises:

- Single ore unloading facility and associated rail loop;

- Secondary and tertiary crushing plants;
- Primary and tertiary screening plants;
- Ore handling and stockpile facility;
- Two ship loading facilities; and
- Associated maintenance and administration facilities.

FMG

FMG mines and exports ore from its operations in the Pilbara region through Port Hedland. FMG's Herb Elliott Port Facilities based at Anderson Point, Port Hedland, consist of car dumping, stockpiling, reclaiming and ship loading facilities.

The port infrastructure consists of three inload and three outload circuits (with five ship-loading berths). The inload circuits unload the ore from the trains and stack it onto blended stockpiles. The outload circuits reclaim the iron ore from the stockpiles and verify the quality via two robotic sample plants before loading the ore onto ships. There are a total of 30 separate stockpiles catering for various FMG products.

Emission sources (activities) identified are:

- Stockpile stacking
- Stockpile reclaiming
- Transfer stations
- Ore conveyors
- Wind erosion or windblown dust (from stockpiles, open or cleared areas, unsealed roads)
- Ship loading.

PPA

PPA owns and operates four berths in the inner harbour, i.e. No.1 Berth (PH1), No.2 Berth (PH2), and No.3 Berth (PH3) at Nelson Point and No.4 Berth (PH4) at the Utah Point Berth Facility (UPBF). The bulk storage and loading facility at Utah Point was designed as a multi-user facility. All material is brought in by road trains from surrounding mines. The UPBF consists of 15 stockpile stacking areas with respective truck unloading hoppers (or bunkers) and stackers. Reclaiming on site is conducted by front end loader into central dump pockets with the ore then directed to the single ship loader.

Emission sources identified are:

- Truck unloading
- Stockpile stacking
- Stockpile reclaiming (front end loader operation)
- Dump hoppers
- Ore conveyors
- Roads
- Wind erosion or windblown dust (from stockpiles, open or cleared areas, unsealed roads and product accumulated on sealed roads).

Roy Hill

Roy Hill's iron ore port facility at Port Hedland receives, stockpiles, screens and exports iron ore as lump and fines. The stockyard has the capacity to store over 2.3 million tonnes, with ten 230,000 tonne live stockpiles.

Key emission sources are considered to be associated with:

- material transfer by conveyors and transfer stations
- material loading from reclaimers
- material unloading from car dumpers, trucks dumping and stackers
- dust from roads
- lump re-screening plant
- ship loaders
- wind erosion from stockpiles and open areas.

Beaches

Along the north coast of Port Hedland there are sandy beaches with the potential for dust lift off or salt spray. In some cases, these beaches are within 50 metres of the town site.

The spoil bank is the spit of land extending north from the Port Hedland town site. It is composed entirely of dredged shelly sand from the harbour channel and contains beaches on either side of the bank. The 2.7 km long west facing beach is relatively steep and narrow and fronted by generally deeper water, while the 2.9 km long east-facing beach is fronted by low tide sand flats. Sand is accumulating naturally at the eastern base of the beach causing it to extend along the northern beach rock shoreline.

Roads, Rail and Shipping

A number of sealed and unsealed roads crisscross the area with potential for dust generation during periods of high traffic. Trains are used to transport ore to the various port facilities and have the potential to be a dust source.

While not a major contributor, shipping movements (as opposed to ship loading) are also a small contributor to particle levels in the port area.

4 Particle data analysis

There were seven days where the PM_{10} concentration exceeded the 24-hour PM_{10} interim guideline of 70µg/m^3 during the period 1 February 2017 to 30 June 2017. These were 23/02/2017 (BoM), 02/03/2017 (Taplin), 06/03/2017 (Kingsmill), 08/04/2017 (Richardson and Harbour), 03/06/2017 (Kingsmill), 22/06/2017 (Harbour) and 28/06/2017 (Harbour and Richardson). A summary of each of these exceedances is provided in Appendix A, where the particle source and their origins are discussed. Table 2 provides the number of daily averaged concentrations exceeding 50µg/m^3, 65µg/m^3 and 70µg/m^3.

Table 2 Number of daily averaged concentrations exceeding specified concentrations

Site	Number of daily concentrations greater than			Study Period Average (µg/m^3)
	50µg/m^3 (NEPM)	65µg/m^3 (93rd %ile)	70µg/m^3 (Interim Guideline)	
Harbour	22	3	3	36.9
Richardson Street	34	10	2	36.9
Kingsmill Street	12	4	2	32.7
Hospital	3	0	0	21.5
Taplin Street	5	1	1	30.0
Neptune	0	0	0	20.2
BoM	2	1	1	19.8
Yule	0	0	0	15.3

The 24-hour PM_{10} interim guideline exceedance at the BoM site on 23/02/2017 was caused by a brief local event of unknown cause lasting one or two hours. The remaining days recorded low concentrations at the background sites of Yule and BoM. This combined with wind movements indicates that all other exceedances were caused by industry activity.

Figure 2 displays the number of days where the 24-hour averaged PM_{10} concentrations exceeded a nominated concentration during the period 1 February 2017 to 30 June 2017. As a general observation, it indicates that during the period of monitoring, the number of exceedances and the overall PM_{10} average generally decreases the further east one moves away from the port operations. Additionally, the previous five years of averaged data has also been included in Figure 2. In terms of an overall five month average, these concentrations indicate that during the months of the study, the average PM_{10} concentrations at Harbour, Kingsmill and Hospital were the lowest since 2012, while the other sites of Richardson Street, Taplin Street and Neptune experienced a typical year.

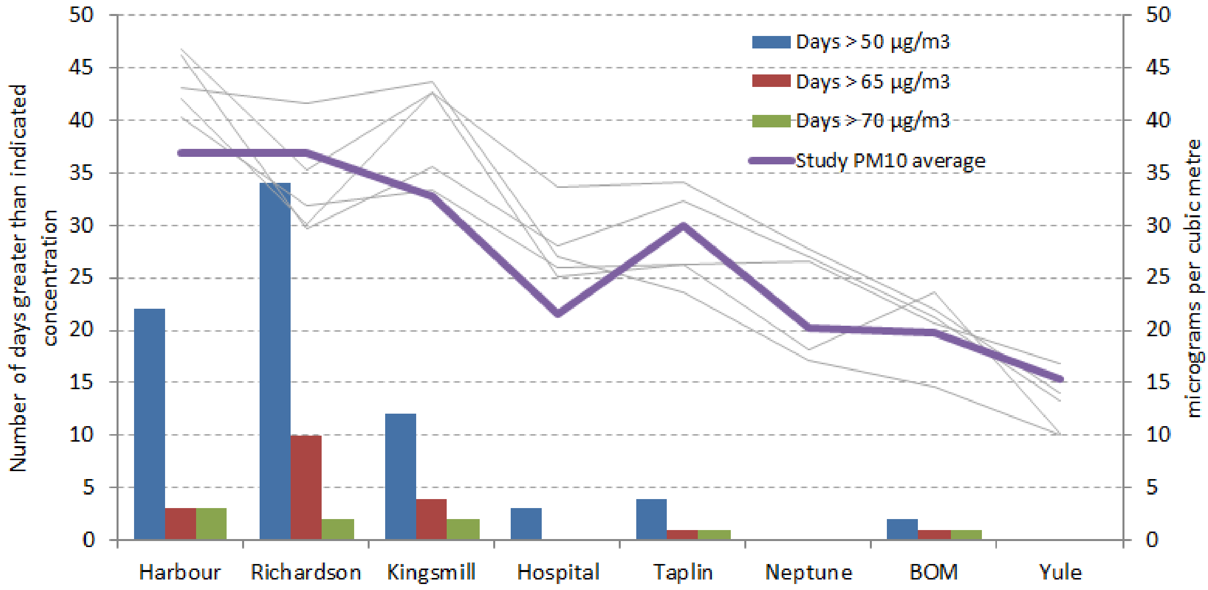


Figure 2 The number of days where the 24-hour PM_{10} average exceeded the nominated concentration and the PM_{10} study average for various PHIC sites during 1 February 2017 to 30 June 2017. Grey lines are study period averages for previous years 2012 through to 2016.

The locations of the five Port Hedland Industry Council (PHIC) sites and the LiDAR within Port Hedland are shown in Figure 3. The sites are owned and operated by the various industry operations within the region with PHIC operating Richardson Street, Kingsmill and Taplin Street while BHP operates the Harbour and Hospital sites. The Neptune site, which is also run by PHIC, is located within the town but at the eastern end of Port Hedland. Two sites are nominally termed background sites given their distance from Port Hedland. These are the PHIC site at Yule, 10 kilometres south south-west of Port Hedland, and the BoM site which is 8 kilometres south east of Port Hedland.

Figure 3 Location of PHIC monitoring sites within the township of Port Hedland.

While the majority of the PHIC sites measure the PM_{10} particle fraction, Taplin Street site also measures $PM_{2.5}$. The ratio of $PM_{2.5}$ to PM_{10} is of interest, given the focus on $PM_{2.5}$ in relation to health effects. In urban areas such as Perth, the annual average ratio of $PM_{2.5}$ to PM_{10} is typically 0.5 to 0.6. At DWER's Duncraig air quality monitoring station (suburban Perth) where PM_{10} and $PM_{2.5}$ monitors are run side by side, the ratio exceeds 0.8 during high particulate events caused by domestic wood fires in winter or smoke from bushfires or prescribed burns. Smoke will therefore tend to produce a larger portion of fine particles giving rise to $PM_{2.5}$:PM_{10} ratios of greater than 0.6 while general dust lift-off from wind or mechanical processes will produce coarse particles which will in turn have a lower $PM_{2.5}$:PM_{10} ratio. Figure 4 shows histograms of the $PM_{2.5}$:PM_{10} ratios calculated from 10 minute averaged data collected at Taplin Street between 2011 and 2016 and, for comparative purposes, a residential site in Perth during the same period. The data threshold was set at 50µg/m^3 for Taplin Street and 25µg/m^3 at Duncraig to remove some of the background concentrations and better display the PM ratios when particle concentrations were elevated above these thresholds.

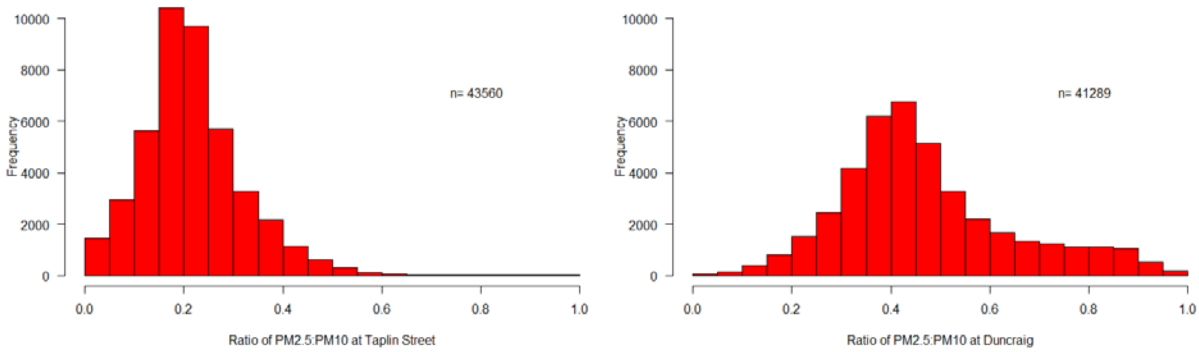


Figure 4 Histogram showing the $PM_{2.5}$:PM_{10} ratios for 10 minute averaged data from Taplin Street (left) and Duncraig, a suburb of Perth (right).

Figure 4 indicates that at Taplin Street, the peak frequency for the $PM_{2.5}$:PM_{10} ratio occurs at around 0.2 when PM_{10} concentrations are greater than 50µg/m^3. After reaching this peak, the ratio falls quickly indicating that the particles causing elevated concentrations are predominantly coarse and suggest dust from mechanical action rather than from smoke or fine dust. The profile from Duncraig shows a $PM_{2.5}$:PM_{10} ratio peak at around 0.4 and a histogram tail that persists from 0.6 to 0.9. This suggests that particles from smoke or other combustion products are a major contributor to particle levels.

There were no exceedances of the NEPM daily $PM_{2.5}$ standard of 25µg/m^3 at Taplin Street over the study period.

In February 2016, the NEPM was varied by the National Environment Protection Council to, among other things:

- provide for a PM_{10} annual standard of 25µg/m^3;
- create two standards for $PM_{2.5}$ of 25µg/m^3 averaged over 24 hours and 8µg/m^3 averaged over one year;

An annual average for each year at all sites where PM_{10} and $PM_{2.5}$ was being monitored has been compiled in Table 3.

Table 3 Annual averages for a selection of sites in Port Hedland and surrounds

Year	PM_{10} particles					$PM_{2.5}$ particles				
	RI	HO	TA	BO	YU	RI	HO	TA	BO	YU
2011	N/A	28.9	39.2	N/A	26.6	N/A	N/A	8.8	N/A	5.6
2012	43.2	34.8	36.7	27.9	21.8	6.3	N/A	7.5	N/A	5.0
2013	36.9	31.6	33.6	26.3	22.9	5.6	8.8	6.2	9.1	6.6
2014	42.7	38.4	38.6	27.1	18.9	8.6	10.6	9.5	7.4	8.7
2015	36.1	31.3	33.1	25.3	22.1	8.3	10.1	12.0	7.2	7.4
2016	36.7	29.9	31.5	N/A	15.0	5.2	N/A	11.4	N/A	4.1

The annual average NEPM standard for PM_{10} of 25µg/m^3 has been exceeded at all sites in all years except for Yule. While $PM_{2.5}$ annual concentrations are above the NEPM annual standard of 8µg/m^3 at most sites, these concentrations are only marginally higher than those measured in Perth.

5 Weather and meteorology

As the LiDAR is dependent on the backscatter of light on atmospheric particles to determine relative dust concentrations, rainfall has the potential to be misinterpreted as particles in the atmosphere. The Bureau of Meteorology (BoM) maintains a weather station at the Port Hedland Airport located 8 kilometres south-southwest of Port Hedland that provides rainfall and weather observations. Figure 5 summarises the weather data obtained from BoM for February 2017 to June 2017. The full record of BoM daily weather observations is provided in Appendix D.

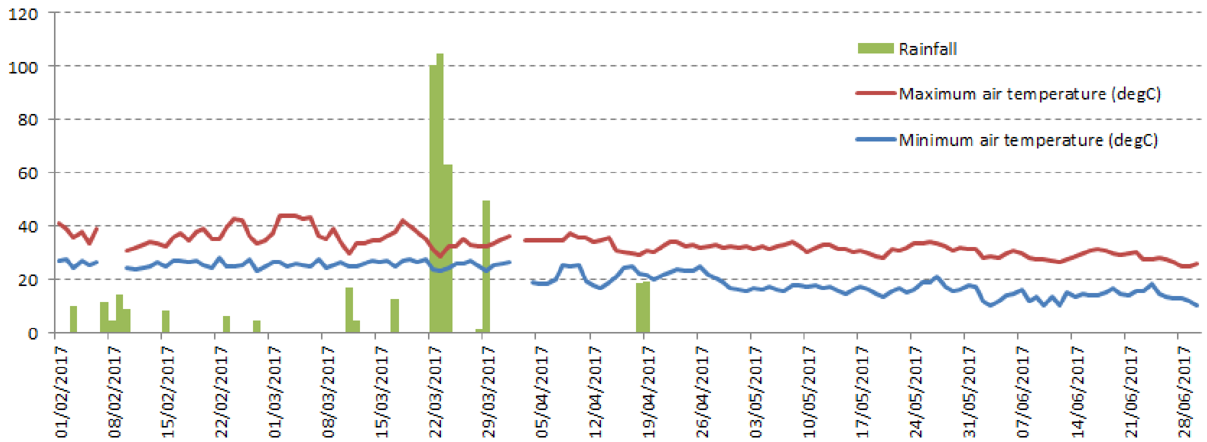


Figure 5 Port Hedland weather data including daily rainfall (green) and maximum (red) and minimum (blue) temperature. (Sourced from http://www.bom.gov.au/climate/dwo/201703/html/IDCJDW6113.201703.shtml)

During the period of the study from 01/02/2017 to 30/06/2017, rainfall was recorded at the BoM weather station on a number of days.

Figure 6 shows the percentage occurrence of a particular wind speed and wind direction throughout the period of the study divided into day time and night time. The meteorological data were sourced from PHIC monitoring sites. Each wind speed and direction segment of the plot shows the percentage contribution of that segment to the complete dataset. Wind speed is in metres per second and extends radially out from the centre of the plot. The different colours represent the percentage occurrence of that particular wind speed and direction within the whole dataset.

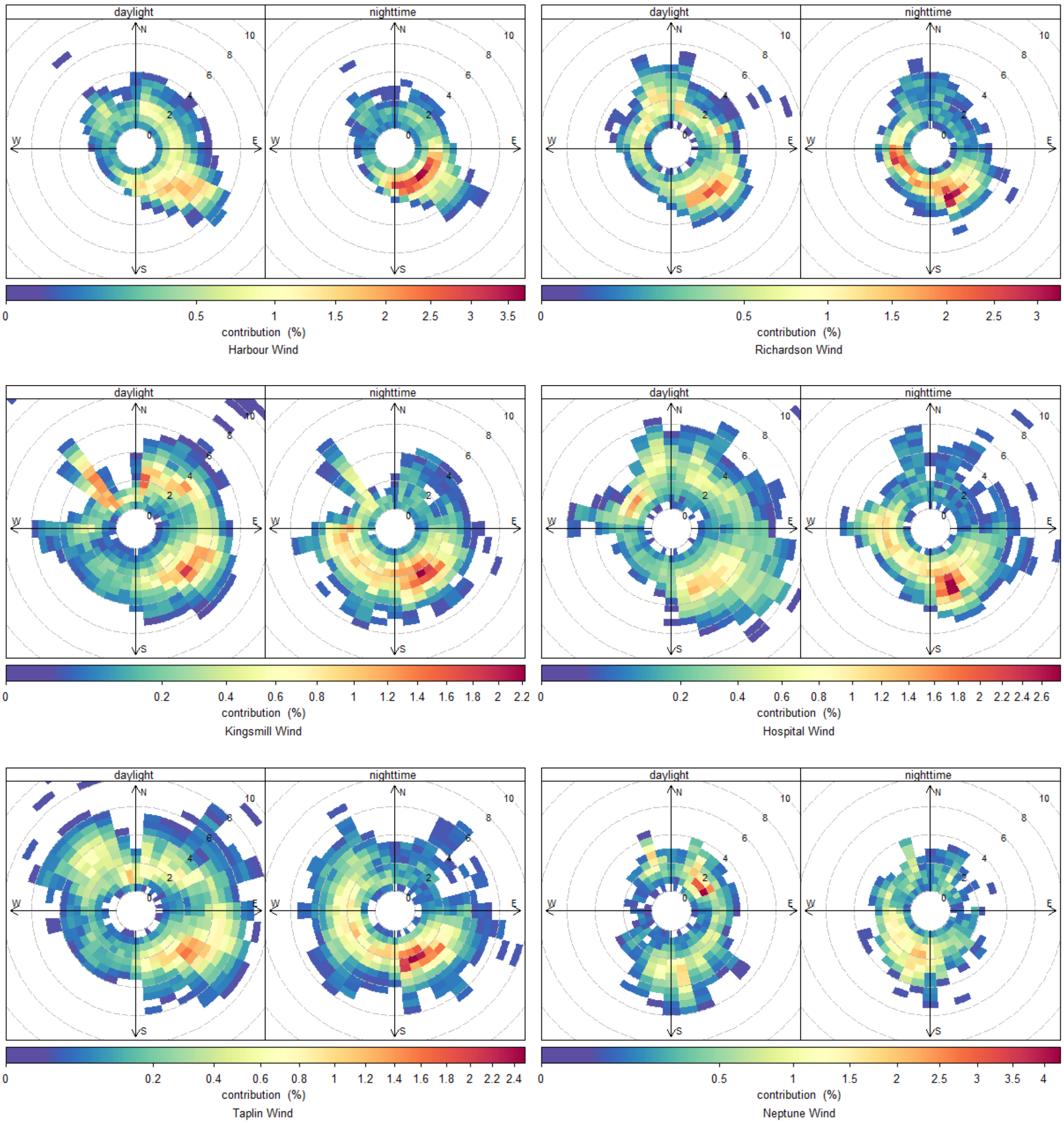


Figure 6 Polar frequency plots of wind speed and direction during the period of the study for six sites within the township of Port Hedland.

Notable from Figure 6 is the similarity of the percentage occurrences of wind directions for the sites west of Neptune with small differences between the day time profiles which are dominated by south south-east winds and night time profiles which have a similar profile with more westerly components. In most cases, for a sizeable portion of the study period, the wind arriving at each monitoring site has come from a predominantly south south-easterly direction.

Figure 7 is a plot of each pair of wind speed and wind direction data for sites within Port Hedland for the period of the study.

The plots compare data from the Nelson Point meteorological tower with the other Port Hedland sites.

While the correlation coefficients[c] for wind directions between Nelson Point Met and the sites of Richardson Street, Kingsmill, Hospital and Taplin Street were large at 0.82, 0.77, 0.75 and 0.80 respectively, Harbour and Neptune were moderate or small at 0.28 and 0.03 respectively. Low correlations are most likely due to surrounding buildings or trees funnelling winds into various directions.

These high correlation coefficients confirm the validity of the wind analysis performed within this report using wind data obtained from Nelson Point, Richardson Street, Kingsmill, Hospital and Taplin Street.

[c] A correlation coefficient is a normalised measurement of how two variables are linearly related. Correlation coefficients can vary from +1.0 to -1.0. A positive correlation indicates the extent to which those variables increase or decrease together; a negative correlation indicates the extent to which one variable increases as the other decreases. A zero correlation indicates there is no correlation between the variables. A perfect correlation (either +1.0 or -1.0) is one where the data, when compared, will have a perfect one-to-one relationship, that is, they will lie in a perfectly straight line with no deviations. Convention has it that, anything with a correlation of greater than 0.5 is considered large or high, 0.5-0.3 is seen as moderate while 0.3-0.1 is small or low.

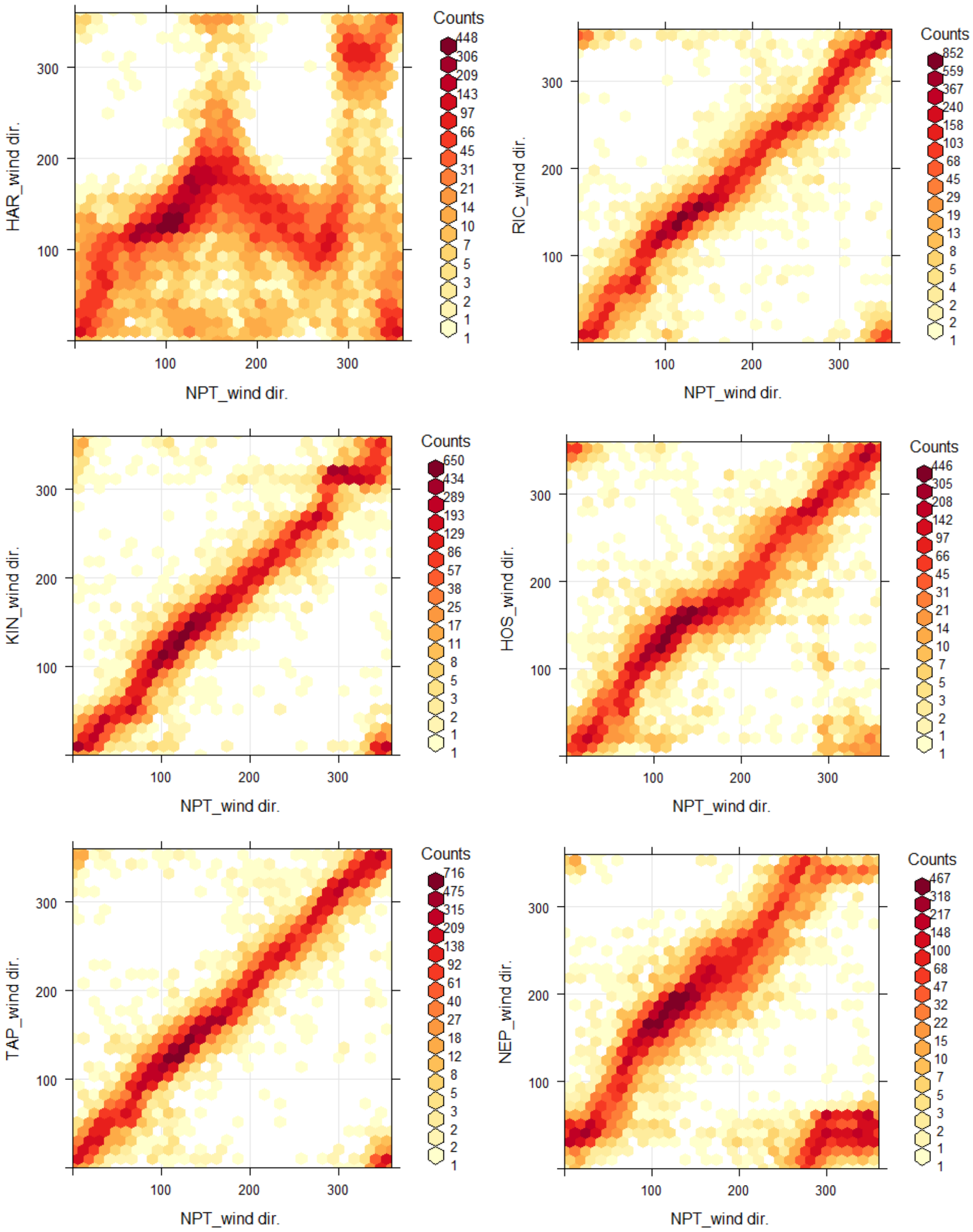


Figure 7 *Scatter plots showing the relationship between corresponding measurements of wind direction between Nelson Point Met tower (10 metres) and Harbour (top left), Richardson Street (top right), Kingsmill (centre left), Hospital (centre right), Taplin Street (bottom left) and Neptune (bottom right).*

6 Directional analysis

Figure 8 shows PM_{10} concentrations weighted by their frequency of occurrence and their contribution to overall loading within each wind direction and wind speed pair for day time and night time.

The meteorological data were sourced from PHIC monitoring sites. Each wind speed segment of the plot spans 1 metre per second radially out from the centre of the plot and direction segment spans 10 degrees. Each segment is colour coded to show the percentage contribution of that segment to the complete dataset.

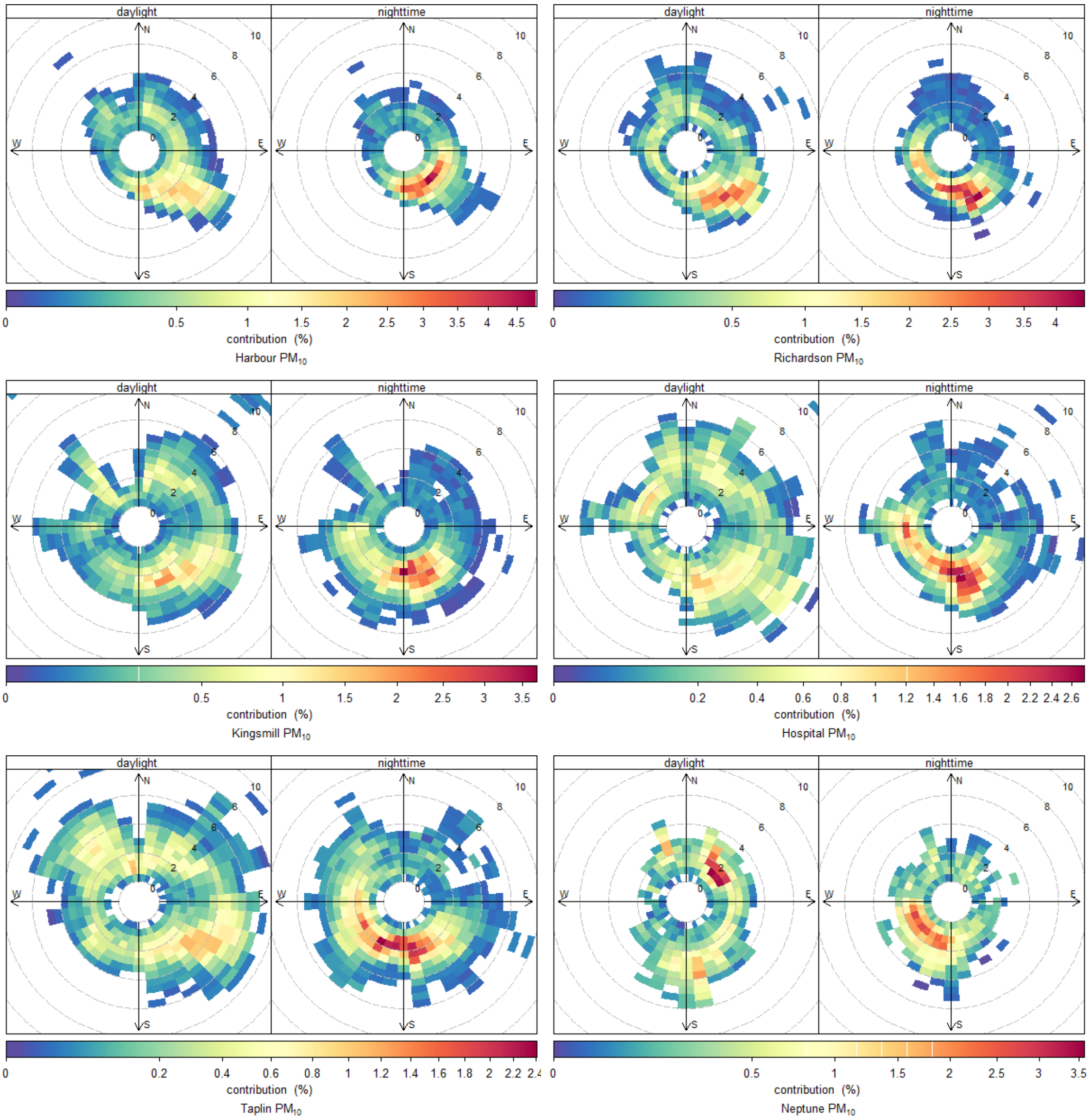


Figure 8 Polar frequency plots of PM_{10} particles, wind speed and direction during the period of the study for six sites within the township of Port Hedland.

The plots in Figure 8 have been ordered left to right and top to bottom to display each site in order, as one proceeds in an easterly direction from the harbour entrance.

Figure 9 overlays the night-time frequency plots over each site. Additionally, arcs encompassing the major portion of the PM load are shaded.

Figure 9 Port Hedland sites overlayed with the night time polar frequency plots of PM_{10} particles, with arcs showing the likely origin of the majority of the PM_{10}.

Within the night time plots displayed in Figure 9, as one travels further east, there is a general clockwise movement of the PM_{10} contribution (shown by the reddish portion of the polar plots).

The shaded arcs in Figure 9, suggest that the main dust sources are located in areas south of each monitoring site. The extents of the arcs were assessed from the red shaded areas within each of the polar frequency plots. This provides a good approximation of the likely location of the PM loading arriving at that location overnight.

7 LiDAR assessment

As part of this study, the LiDAR was to be evaluated as a tool for assessing the sources and pathways of dust contributing to impacts experienced in the Port Hedland community.

The LiDAR provides a mechanism which effectively places a virtual particle monitor at each of the available points within the LIDAR's observational space, recording backscatter intensities every 10 minutes. To assess how the LiDAR performed, a check can be made comparing the LiDAR's backscatter signal for a particular location where a standard particle monitor exists.

The LiDAR data were analysed to find all periods where a backscatter signal exists coinciding with the distance and compass heading associated with the four BAM monitors located at North Finucane Island, Taplin Street, Richardson Street and Harbour. Table 3 shows the distance and headings to these four air quality monitoring sites.

Table 3 Distance and heading of four sites from the LiDAR tower

Site	Distance in metres	Compass heading from LiDAR tower in degrees from North
North Finucane Island (NFI)	2120m	326^{o} (or -34.0^{o})
Taplin Street (TAP)	2440m	82.9^{o}
Richardson Street (RIC)	280m	34.9^{o}
Harbour (HAR)	260m	286^{o} (or -74.0^{o})

Figure 10 plots an overlay of the LiDAR backscatter signal (shown as scaled LiDAR Beta in the plots) over the BAM signal for each of the four sites listed in Table 3. The plot shows how the LiDAR backscattering signal follows the BAM signal over the selected week at these locations. Note that the vertical axis in Figure 10 shows units relating to the particle data (blue), while the LiDAR Beta trace (red) is dimensionless and has been scaled to enable comparison.

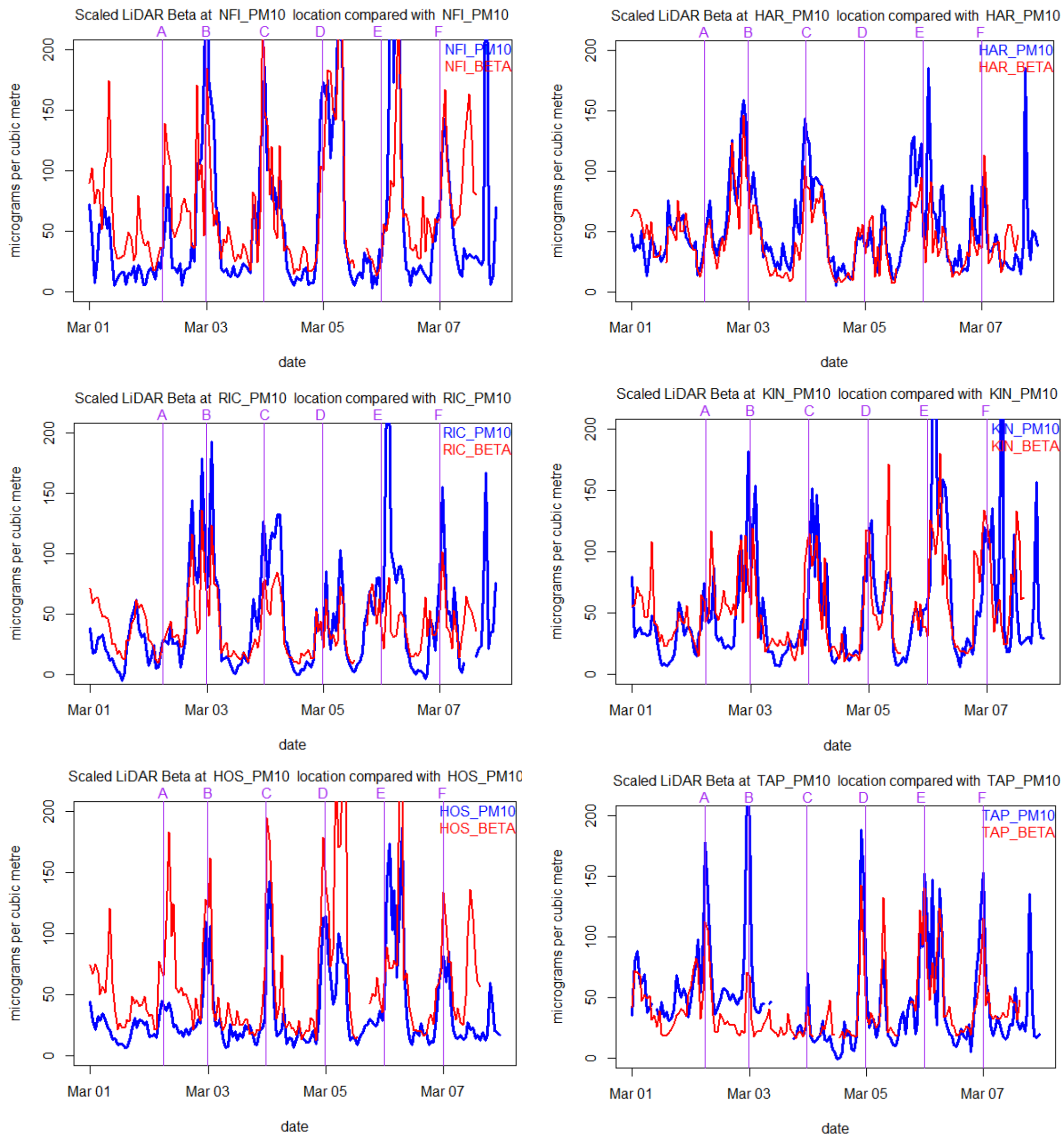


Figure 10 Comparing signals from the LiDAR with particle monitors located at North Finucane Island (top left), Harbour (top right), Richardson Street (centre left), Kingsmill (centre right) and Hospital (bottom left) and Taplin Street (bottom right).

The LiDAR and BAM signals in Figure 10 match reasonably well, with correlations between the LiDAR and the standard monitors ranging from 0.55 to 0.77. There are however some issues which combined to reduce the correlation coefficient. These are:

- Height: The LiDAR was installed on a scaffold on top of a tower located in the west end of Port Hedland which gave it a scanning height of 25 metres. With the LiDAR elevation set to zero degrees, the beam passed over the monitoring sites at a height of approximately 25 metres (depending on the actual height of the monitoring stations). The difference in height between the LiDAR beam and the ground-level location of the BAM would cause a difference between the recorded levels as concentrations at ground levels will likely differ from those at 25 metres.

- Particle size: The LiDAR beam measures backscatter from all particles within each 20 metre gate of the beam extending outwards from the LiDAR. The BAMs however are fitted with a size selective inlet which 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 BAM to be recorded.
- Averaging period: While the BAMs 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 10 minutes, pausing only one second to scan each compass degree. This means that the LiDAR's beam only spends one second every 10 minutes at an azimuth which overshoots the BAM's location providing only six one second readings every hour to provide a one hour average.
- Area: BAMs collect particle data at one point which is two or three metres above ground level. This position is considered to be 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 a cylindrical area extending 50 metres in length and approximately 35 metres in diameter.
- Timestamp: When comparing the LiDAR scan data with standard particle monitoring technologies, the method used for averaging becomes very important. The time which is allocated to the BAM particle data is timestamped at the end of the sampling period while the data collected by the LiDAR are allocated a timestamp which is the start of the sampling period. For example the data used to compile the 1am hourly BAM average uses data collected from midnight through to 1am while the LiDAR average for 1am uses data from 1am to 2am. If compared, there will clearly be a one hour offset to the two data sets. To reconcile these differences, the timestamp of the BAM's data has been adjusted one hour to ensure the times for both LiDAR and BAMs are correct and reflect the same monitoring periods.

Further confirmation of the good match between the LiDAR and the PM_{10} BAM can be seen in Figure 11 where the LiDAR scan for each vertical line shown in Figure 10 is presented. The figures each show a 10 minute scan from the LiDAR which show that in a majority of cases, the LiDAR scan mirrors that indicated from the BAMs.

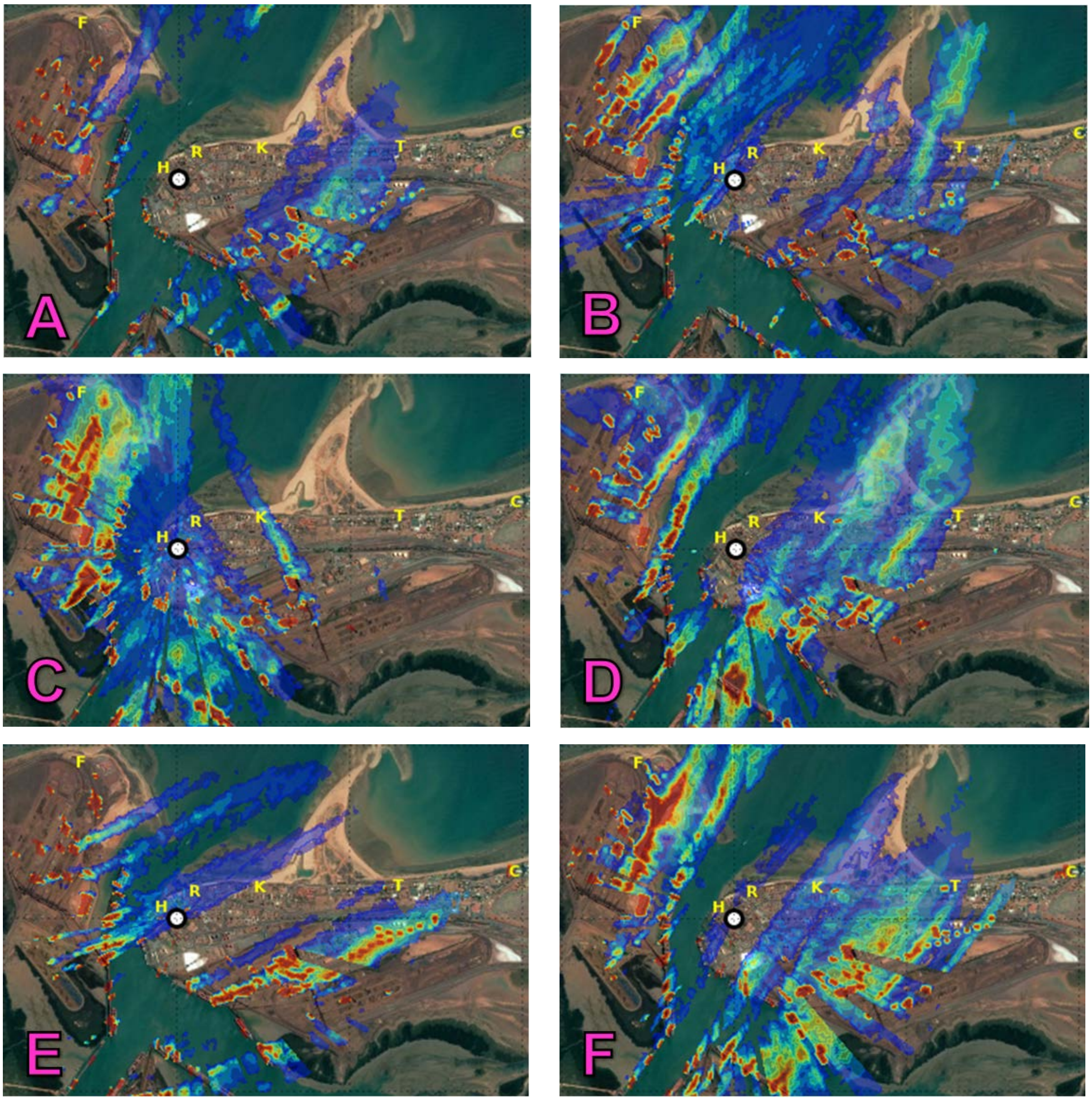


Figure 11 LiDAR images. The images are marked with large violet letters A to F which mark those images related to the vertical markers on Figure 10. The smaller yellow lettering shows the locations of various PM_{10} monitoring sites (F=North Finucane Island, H=Harbour, R=Richardson Street and T=Taplin Street).

Periods of low PM_{10} concentrations as indicated by the BAMs were experienced at midday on 3rd and 4th March 2017 as is evident from the graphs in Figure 10. Figure 12 shows the LiDAR record for those periods showing that no plumes were recorded by the LiDAR at any of the PM_{10} monitoring stations at that time.

Figure 12 LiDAR image at midday on 3 March 2017 (left) and 4 March 2017 (right) with little or no PM_{10} activity recorded on either BAMs or LiDAR

Appendix B contain information on specific events where two or more sites recorded PM_{10} concentrations greater than 200µg/m^3 averaged over one clock hour on the same day during the campaign. Choosing a PM_{10} concentration greater than 200µg/m^3 was done to limit the number of short-term events investigated.

Appendix C has information pertaining to additional days where events of interest occurred that demonstrate the ability of the LiDAR to capture dust or smoke plumes within the region. These events, while not exceeding any standard, have been chosen to further display the versatility of the LiDAR by showing different types of particle plumes which are, at times, completely missed by the existing monitoring network using standard equipment.

Examples shown are of dust lift-off or smoke seen on Spoilbank and ship plumes as they enter or leave the harbor. Some plumes can be very long and narrow and pass between established monitoring stations.

The LiDAR has successfully shown its ability to reveal dust sources within a region and display their pathways to sensitive receptors.

8 Conclusions

The study provided valuable information regarding sources and pathways of dust within the area immediately around Port Hedland during a five month period February to June 2017.

The study findings were that:

- During the study period, there were three PM_{10} exceedances of the 70µg/m^3 24-hour PM_{10} guideline at the Harbour monitoring site, two exceedances at both the Richardson and Kingsmill sites and one exceedance recorded at Taplin Street. There was also one exceedance at the BoM background site.
- PM_{10} concentrations generally decreased as the distance from the port area increased.
- The $PM_{2.5}$ to PM_{10} particle ratio profile indicates that the majority of dust was not due to combustion but was coarser in nature indicating dust lift-off from wind or mechanical processes.
- The NEPM PM_{10} annual average standard of 25ug/m^3 was exceeded at Taplin Street every year from 2011 to 2016 with 2017 likely to also exceed the annual standard.
- Directional analysis indicated that the majority of particle loading to all sites originated from a southerly direction.
- There was a high correlation between the LiDAR backscatter and the concentrations determined by the particle monitors which provided a measure of confidence that the LiDAR was providing a valid representation of atmospheric particle loading.

This analysis has not looked at any specific meteorological conditions that give rise to dust plumes from industry operations, however as a general statement, it can be said that industry activity has contributed to elevated dust levels in Port Hedland causing exceedances of the interim standard.

The LiDAR is a valuable tool allowing DWER to track dust plumes across large areas and determine emission sources within and around Port Hedland. 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 when reviewing industry licences and works approvals.

9 Appendices

9.1 Appendix A – PM_{10} 24 hour exceedances

The following pages contain information specific to each site exceeding 70µg/m^3 averaged over one day during the campaign. Each analysis is provided in date order and may include one or more of a wind spiral, concentration table and concentration plots. Where known possible sources are indicated. Included are data related to concentrations of PM_{10} particles reached at a selection of sites in Port Hedland. For the purposes of this study, it is considered that the distance and direction of the BoM and Yule site when compared to the Port Hedland instruments allows these to be used as an indicator of background levels.

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 wind direction changes throughout the day.

Where used within the text, wind direction refers to the direction from where the wind originated. The following short-hand nomenclature used throughout this document:

N – 0 degrees	E – 90 degrees	S – 180 degrees	W – 270 degrees
NNE – 30 degrees	ESE – 120 degrees	SSW – 210 degrees	WNW – 300 degrees
ENE – 60 degrees	SSE – 150 degrees	WSW – 240 degrees	NNW – 330 degrees

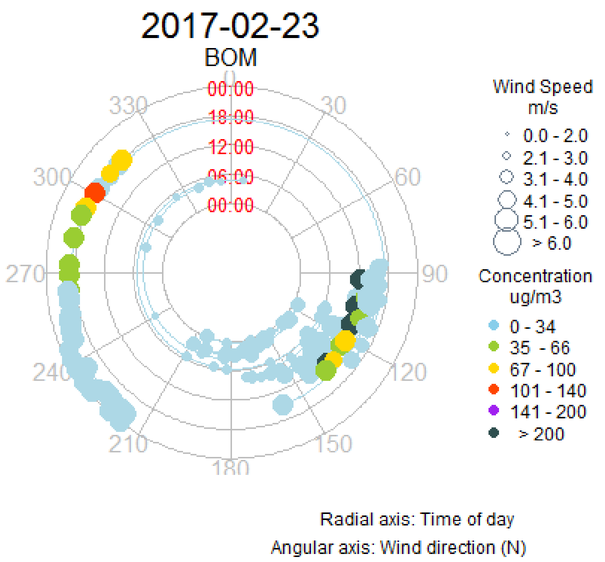
Summary of findings:

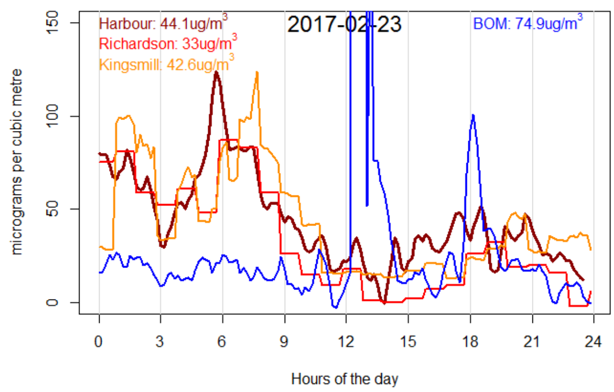
There were seven days where there was at least one exceedance of the 70µg/m^3 PM_{10} daily concentration somewhere in the Port Hedland network, with all but one confined to locations west of Taplin Street.

The majority of these exceedances occurred when winds were from the south or south-east.

One local exceedance occurred on 23/02/2017 at the BoM site with all other sites recording moderate or low PM_{10} concentration during that day.

23 February 2017





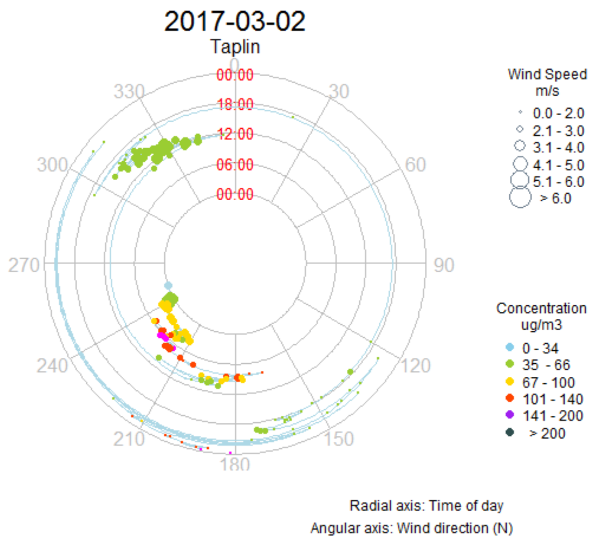
Site concentrations

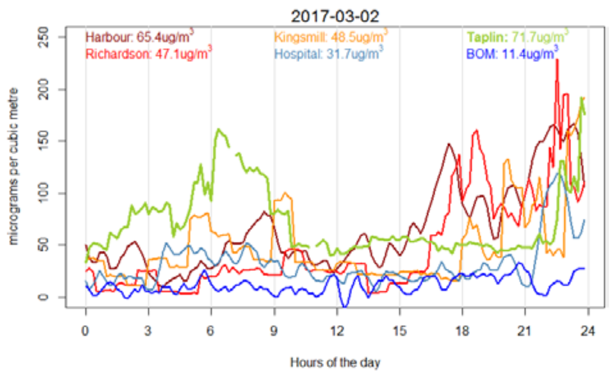
Site	Daily average (µg/m³)
Harbour	44.1
Richardson Street	30.6
Kingsmill Street	39.8
Hospital	31.1
Taplin Street	49.5
Neptune	24.0
BoM	**74.9**
Yule	12.5

Event description

A short-term local event occurred at 1pm at the BoM site with an hourly average of 1300µg/m³ dropping to less than 100µg/m³ either side of that hour. Average wind speed was 6.2ms⁻¹ with winds at 117° or from the ESE. A cause for the high concentration is unknown.

2 March 2017





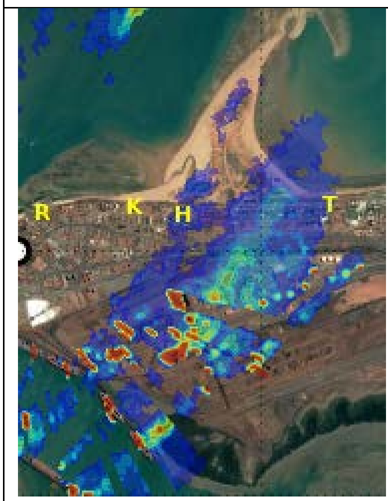
Site concentrations

Site	Daily average (µg/m^3)
Harbour	**68.1**
Richardson Street	49.7
Kingsmill Street	50.3
Hospital	30.0
Taplin Street	**74.4**
Neptune	28.7
BoM	10.9
Yule	7.8

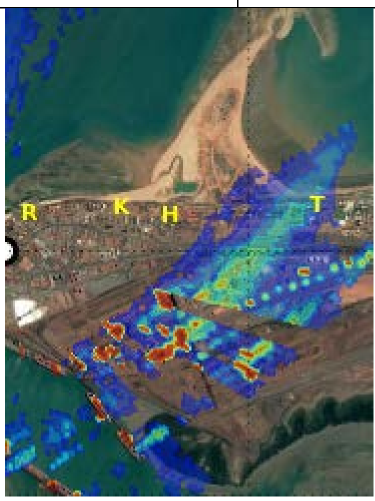
Event description

Winds were from the south west during the morning when the bulk of the particle load was recorded at Taplin Street. The LiDAR shows a plume extending from the south west towards the north east.

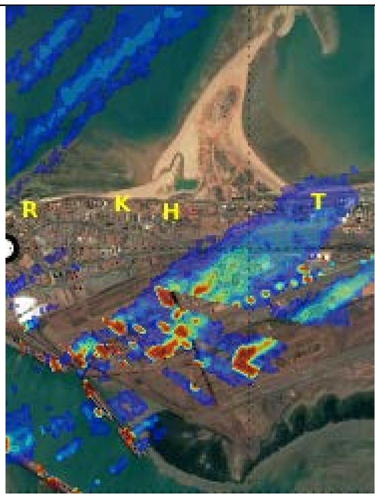
LiDAR images taken at 20 minute intervals from 6:00am on 2 March 2017 are shown below and indicate relative dust levels.



02/03/2017 6:00am

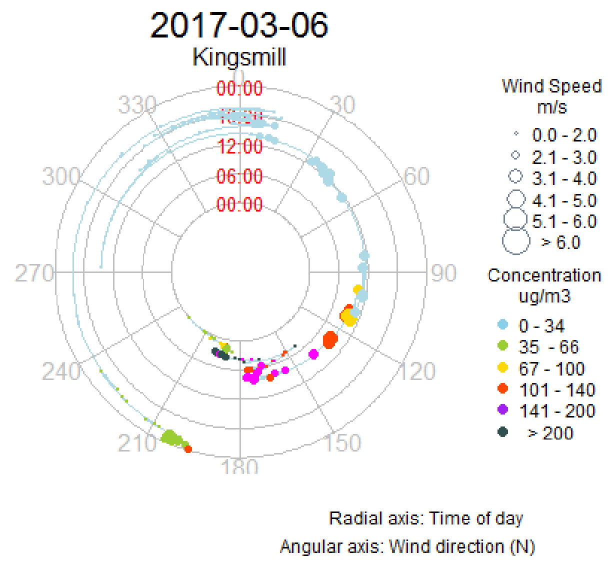


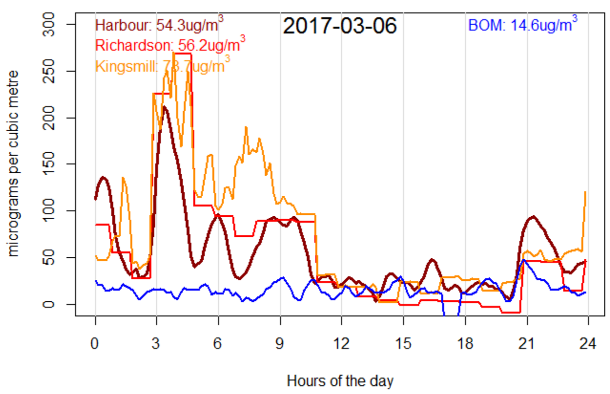
02/03/2017 6:20am



02/03/2017 6:40am

6 March 2017



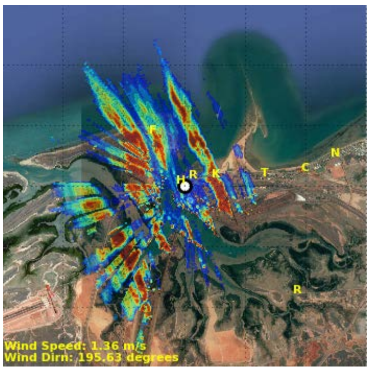


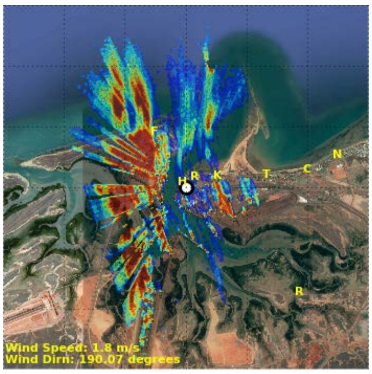
Site concentrations

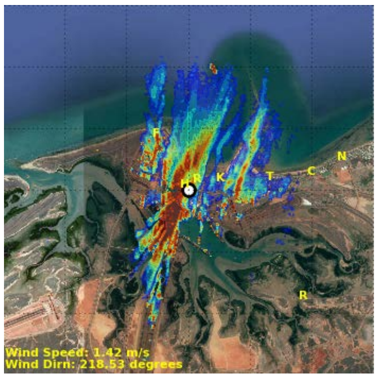
Site	Daily average (µg/m³)
Harbour	**54.3**
Richardson Street	**54.9**
Kingsmill Street	**80.1**
Hospital	58.4
Taplin Street	55.7
Neptune	30.0
BoM	14.6
Yule	10.1

Event description

Generally high PM_{10} concentrations were experienced throughout the west end monitoring stations with prevailing winds averaging around $2ms^{-1}$ from a southerly direction. LiDAR images taken at hourly intervals from 3:30am on 6 March 2017 are shown below and indicate relative dust levels.

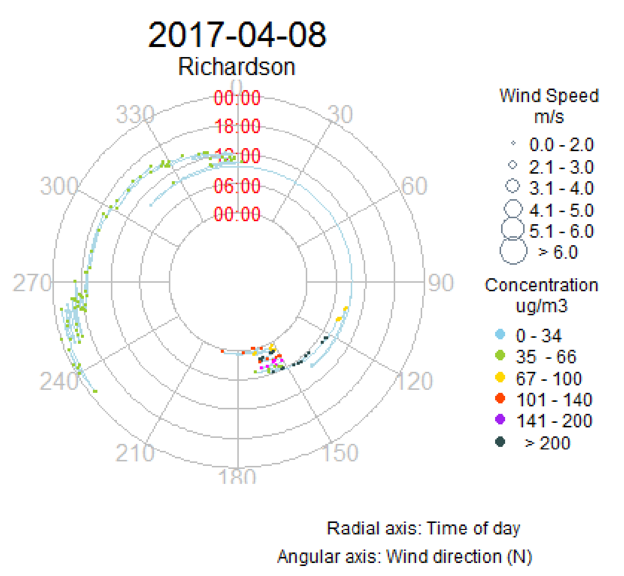


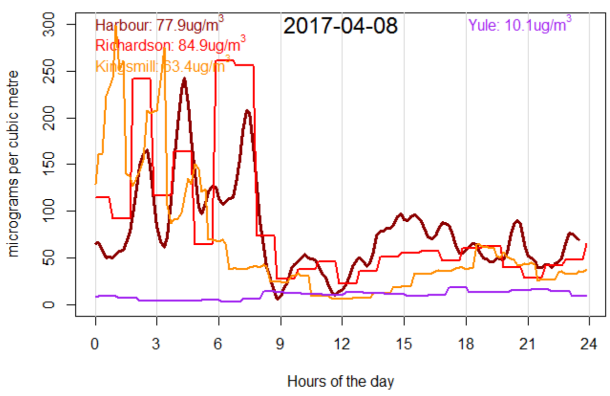




06/03/2017 3:30am 06/03/2017 4:30am 06/03/2017 5:30am

8 April 2017



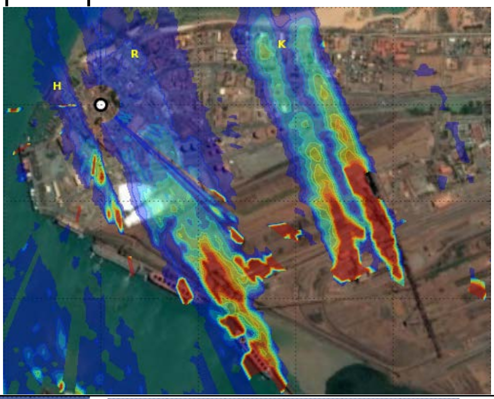


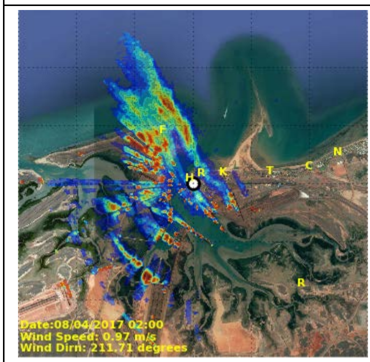
Site concentrations

Site	Daily average (µg/m³)
Harbour	**77.9**
Richardson Street	**83.1**
Kingsmill Street	**54.3**
Hospital	48.3
Taplin Street	38.8
Neptune	25.5
BoM	NA
Yule	10.1

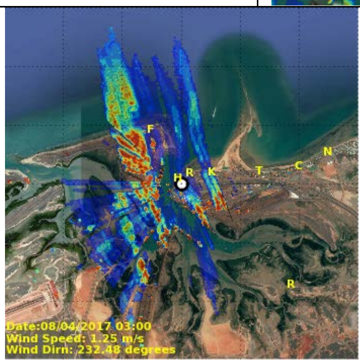
Event description

Wind speeds were low and from the SSE at around 1ms^{-1}. The LiDAR recorded plumes from various locations from the south southwest. These plumes crossed the west end of Port Hedland extending out to sea. The expanded image below shows a close-up of the relevant portions of the port operations at 4am.

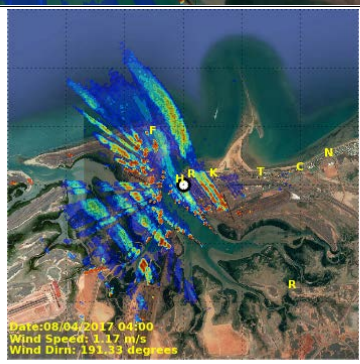




08/04/2017 2am

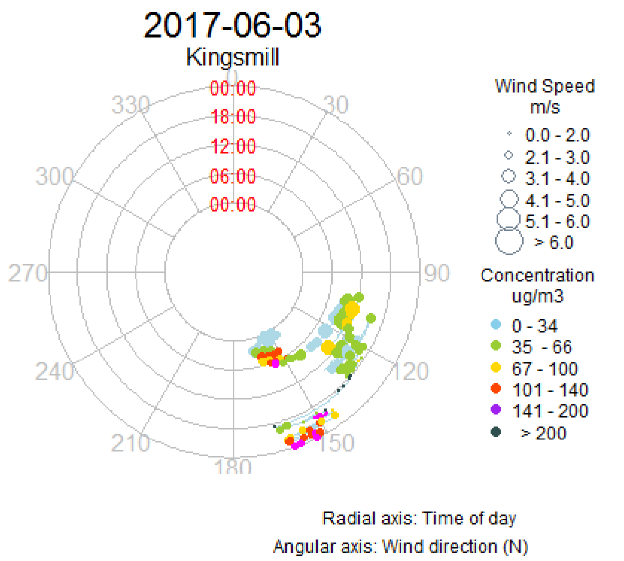


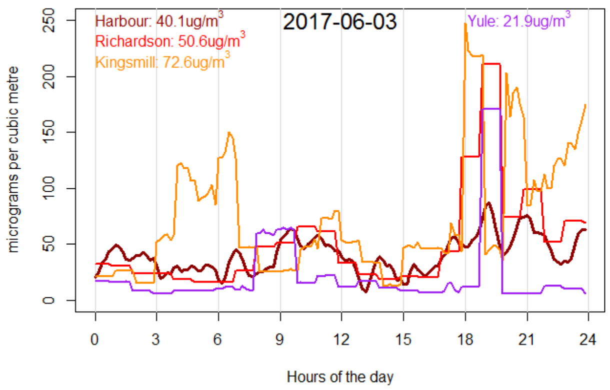
08/04/2017 3am



08/04/2017 4am

3 June 2017





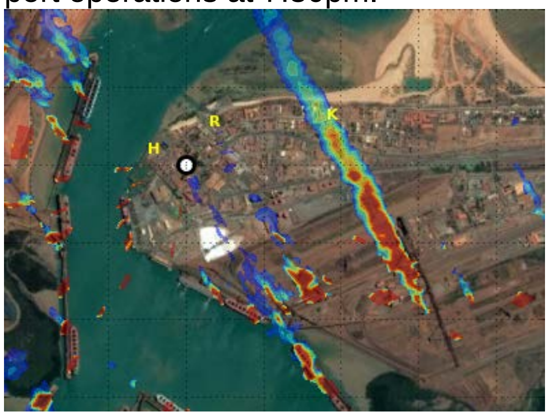
Site concentrations

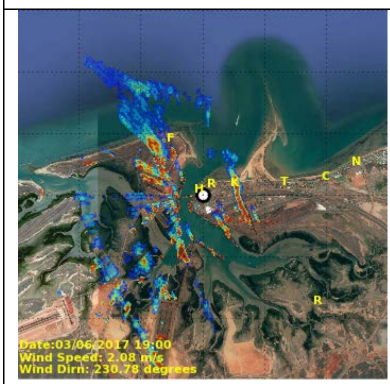
Site	Daily average (µg/m^3)
Harbour	40.1
Richardson Street	**51.9**
Kingsmill Street	**79.2**
Hospital	24.5
Taplin Street	20.8
Neptune	18.7
BoM	23.2
Yule	21.5

Event description

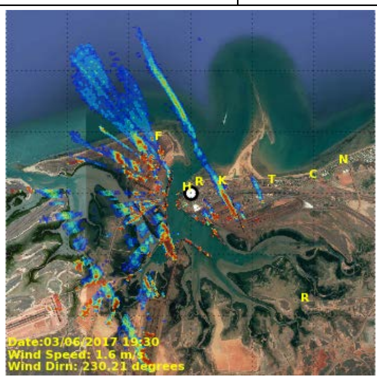
Winds were from the SE at around 2ms^{-1}. Activities from the south created a narrow plume that crossed Kingsmill Street site and extended several kilometres out to sea.

The expanded image below shows a close-up of the relevant portions of the port operations at 7:30pm.

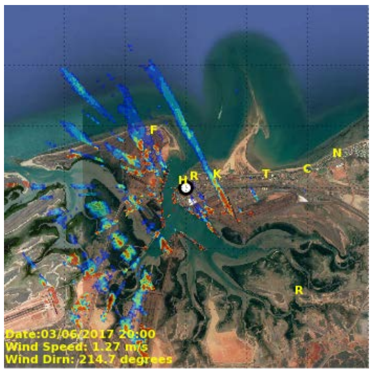




03/06/2017 7pm

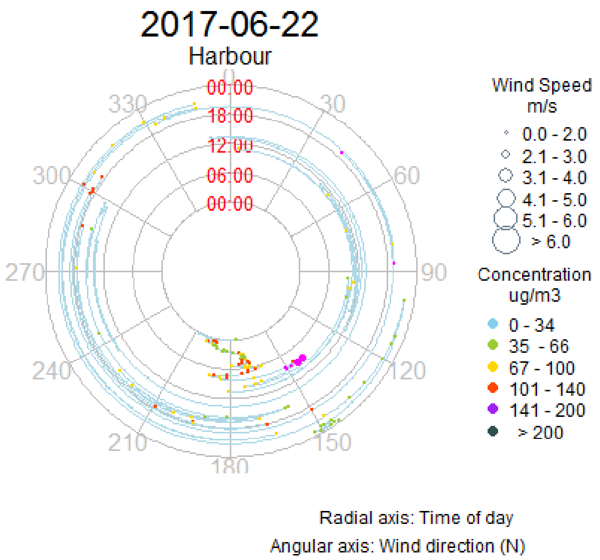


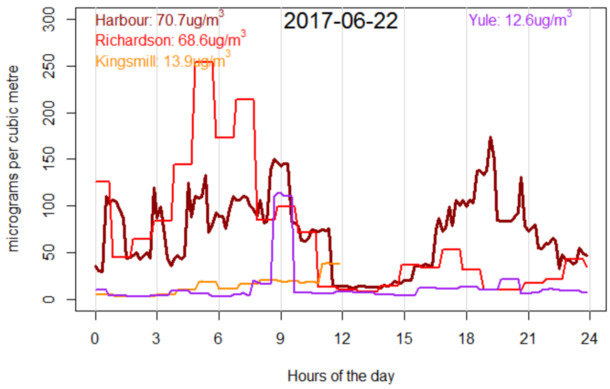
03/06/2017 7:30pm



03/06/2017 8pm

22 June 2017



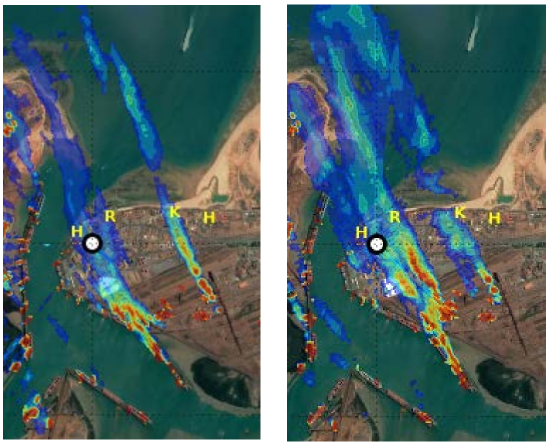


Site concentrations

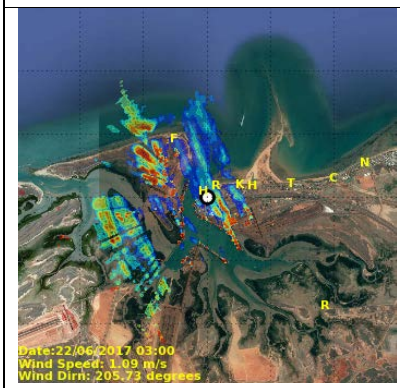
Site	Daily average (µg/m³)
Harbour	**70.7**
Richardson Street	**65.5**
Kingsmill Street	14.2
Hospital	NA
Taplin Street	32.8
Neptune	19.3
BoM	39.7
Yule	12.5

Event description

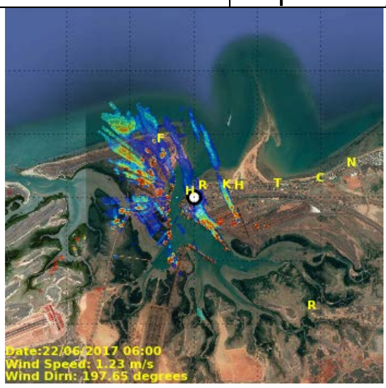
Winds were from the south in the morning up to around 9am. The map indicates the dust originated from the south.



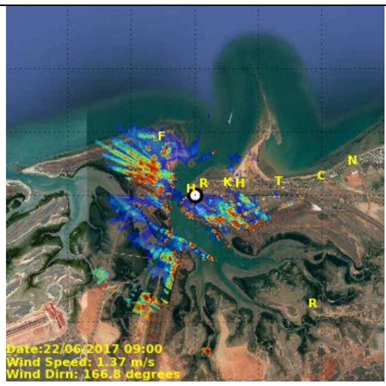
22/06/2017 3am and 6am (partial & expanded)



22/06/2017 3am

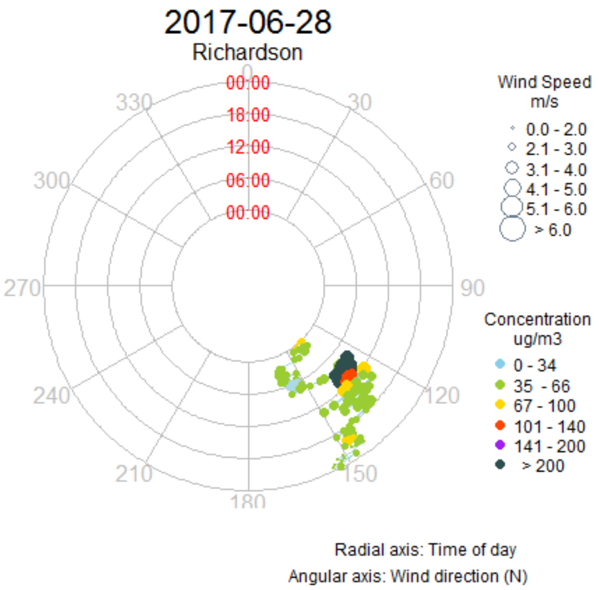


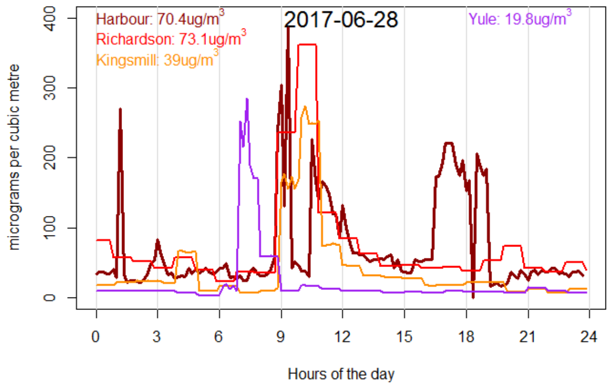
22/06/2017 6am



22/06/2017 9am

28 June 2017



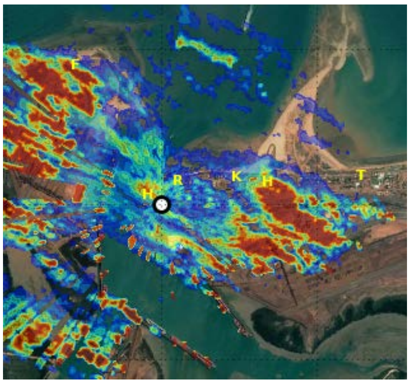


Site concentrations

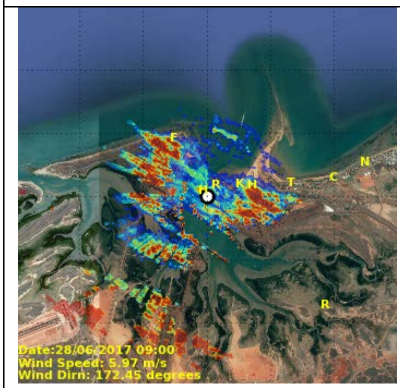
Site	Daily average (µg/m³)
Harbour	**70.9**
Richardson Street	**71.6**
Kingsmill Street	39.5
Hospital	28.5
Taplin Street	28.2
Neptune	17.4
BoM	NA
Yule	20.0

Event description

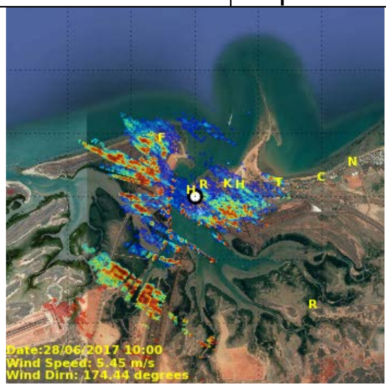
Winds were from the south east with high particle concentrations experienced at several sites in Port Hedland between 9am and 11am. The expanded 9am image below shows dust emanating from various centres however the impact to Port Hedland seems to originate from the south west.



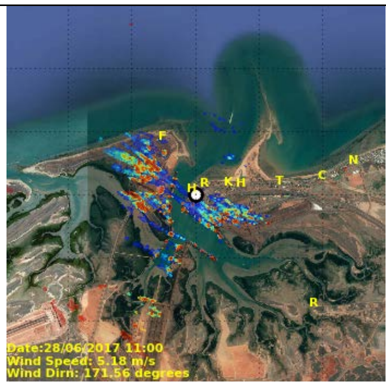
28/06/2017 9am (partial and expanded)



28/06/2017 9am



28/06/2017 10am



28/06/2017 11am

9.2 Appendix B — PM_{10} one hour concentrations greater than 200µg/m^3

During the campaign, the following pages contain information on specific events where two or more sites recorded PM_{10} concentrations greater than 200µg/m^3 averaged over one clock hour on the same day. Choosing a PM_{10} concentration greater than 200µg/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. Where known, possible sources are indicated. Included are data related to concentrations of PM_{10} particles reached at a selection of sites in Port Hedland. For the purposes of this study, it is considered that the distance and direction of the BoM and Yule sites when compared to the Port Hedland instruments allows these to be used as an indicator of background levels.

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 wind direction changes throughout the day.

Where used within the text, wind direction refers to the direction from where the wind originated. The following short-hand nomenclature used throughout this document:

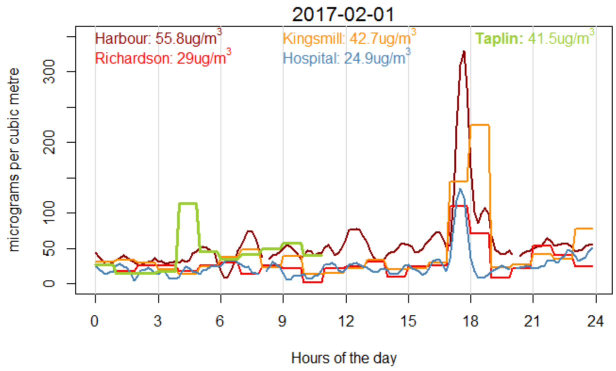
N – 0 degrees	E – 90 degrees	S – 180 degrees	W – 270 degrees
NNE – 30 degrees	ESE – 120 degrees	SSW – 210 degrees	WNW – 300 degrees
ENE – 60 degrees	SSE – 150 degrees	WSW – 240 degrees	NNW – 330 degrees

Time is represented using the 24 hour clock method where 1am is represented by 01:00 and 11pm is represented as 23:00.

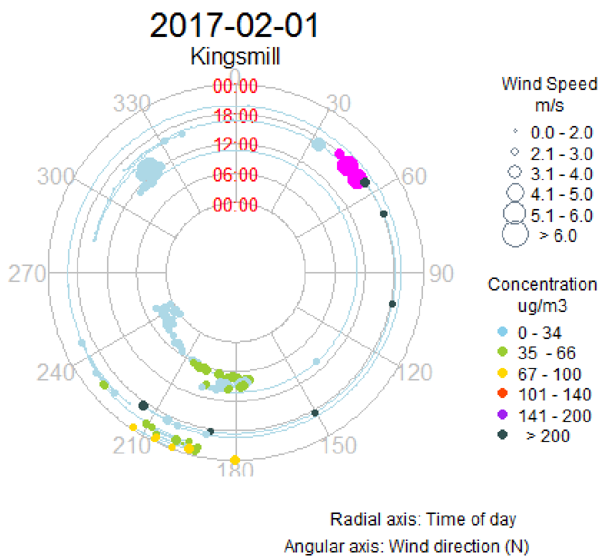
The PM_{10} concentration plot used in the site concentration tables represent PM_{10} concentrations as presented by industry in their various data files.

Summary of findings:
Between 01/02/2017 and 30/06/2017, there were 57 one-hour averaged PM_{10} concentrations greater than 200µg/m^3 recorded at two or more sites on the same day within Port Hedland. Five of these were recorded at Taplin Street, one at Neptune, with the remainder recorded at sites west of Taplin Street.
For 19 days during the study, two or more town sites exceeded 200µg/m^3 averaged over one hour on the same day.
These events mainly occurred when winds were from a southerly direction.

1 February 2017



60 minute averaged PM_{10} concentrations



Wind speed and direction

Site concentrations

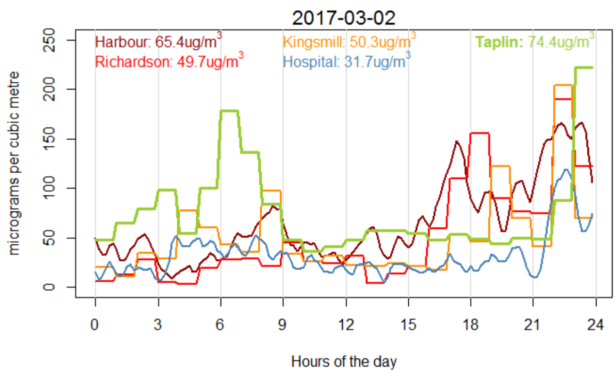
Site	Maximum hourly average ($\mu g/m^3$)
Harbour	219.9
Richardson Street	109.0
Kingsmill Street	224.0
Hospital	95.8
Taplin Street	114.0
Neptune	68.0
BoM	104.1
Yule	N/A

Event description

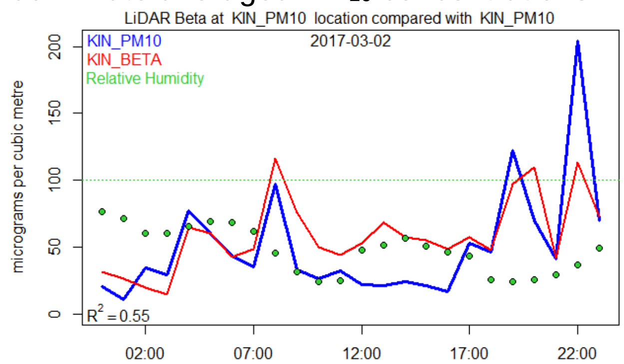
Winds were highly variable during this event spanning from the north east through to the south west. A large portion of the particle load seemed to be from the north east at around 18:00 or 6pm.

The LiDAR was not operational on this day.

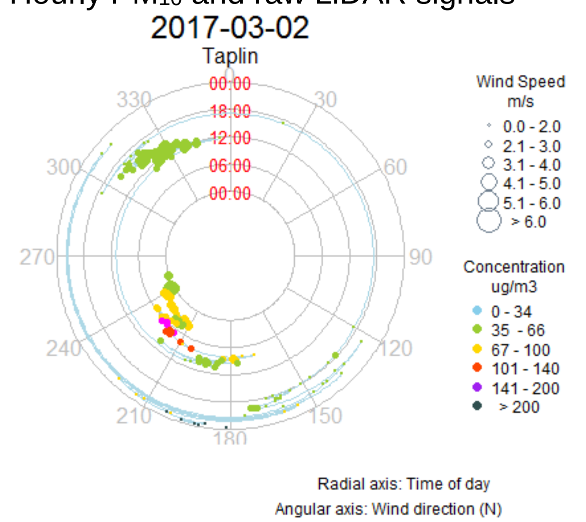
2 March 2017



60 minute averaged PM_{10} concentrations



Hourly PM_{10} and raw LiDAR signals



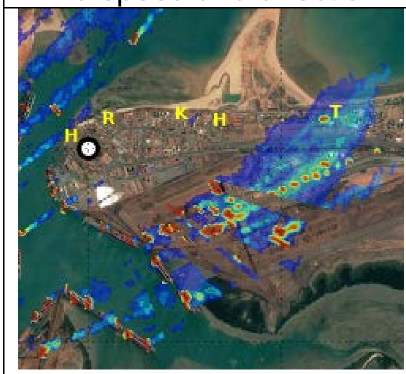
Wind speed and direction

Site concentrations

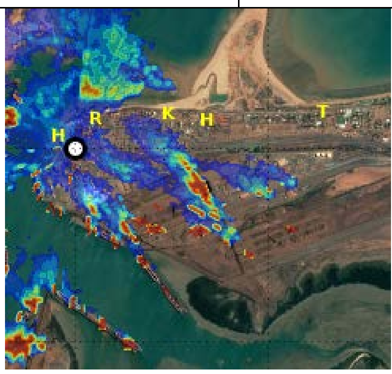
Site	Maximum hourly average (µg/m^3)
Harbour	158.3
Richardson Street	190.0
Kingsmill Street	204.0
Hospital	111.0
Taplin Street	222.0
Neptune	55.0
BoM	25.8
Yule	15.0

Event description

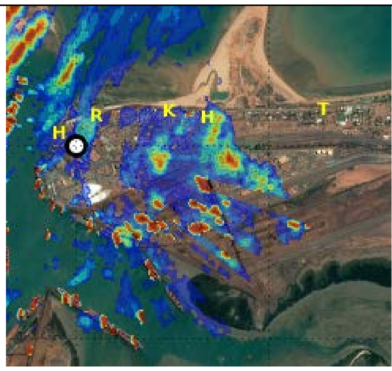
Morning winds were from the south west. In the early afternoon these turned northwest with southerly dominating through to late evening. Humidity levels remained low at below 50% in the evening.



02/03/2017 06:30

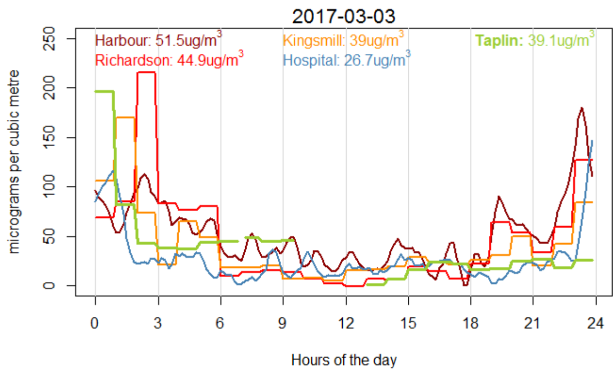


02/03/2017 22:00

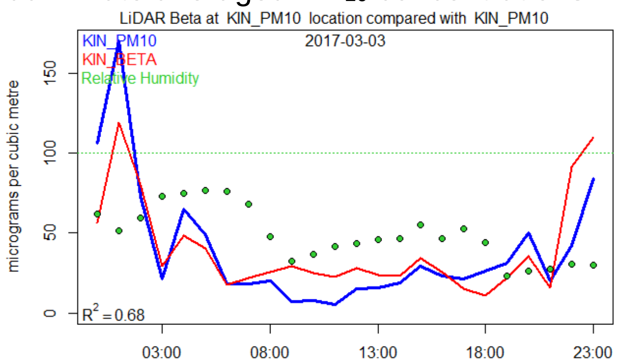


02/03/2017 23:00

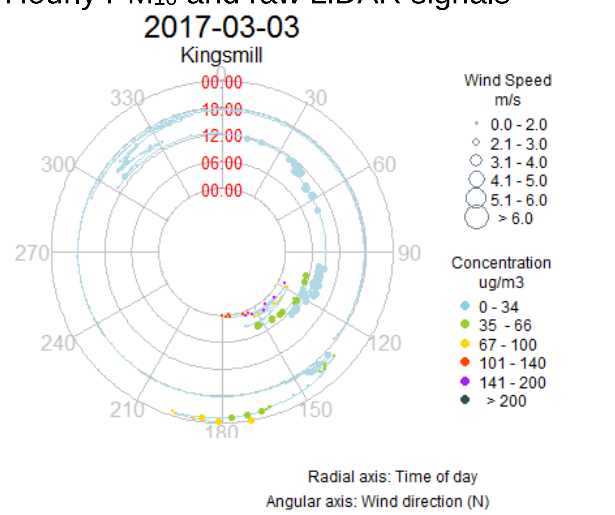
3 March 2017



60 minute averaged PM_{10} concentrations



Hourly PM_{10} and raw LiDAR signals



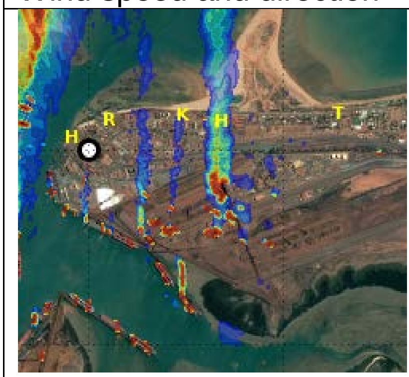
Wind speed and direction

Site concentrations

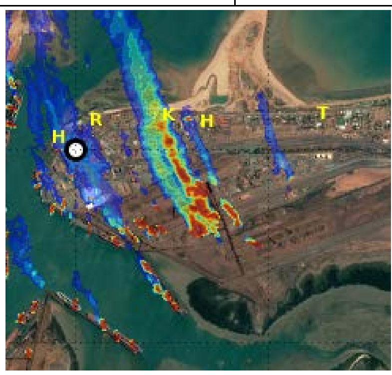
Site	Maximum hourly average ($\mu g/m^3$)
Harbour	148.9
Richardson Street	215.0
Kingsmill Street	170.0
Hospital	101.9
Taplin Street	196.0
Neptune	224.0
BoM	50.4
Yule	20.0

Event description

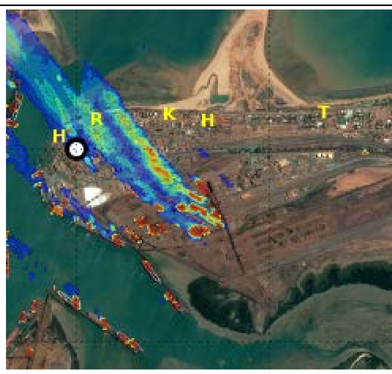
Early morning winds were from the south to the south east. Late evening winds were also from the south. The bulk of the particle load during this day originated from these directions.



03/03/2017 01:00

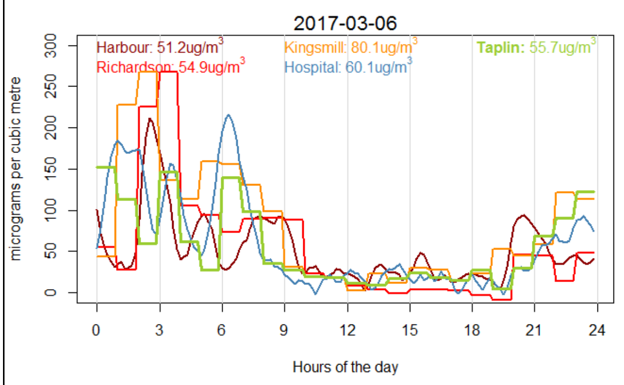


02/03/2017 02:00

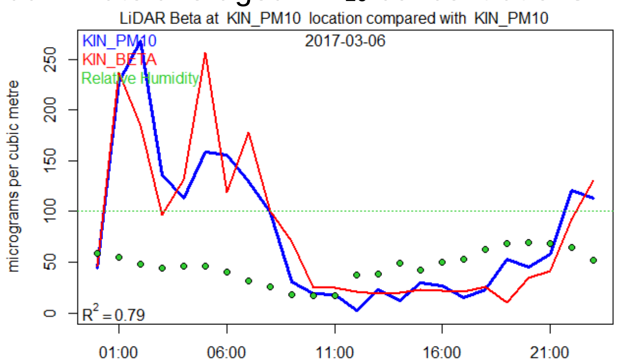


02/03/2017 02:30

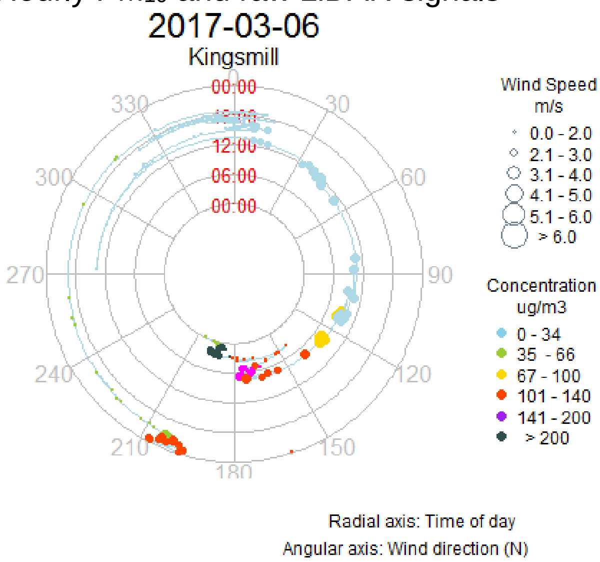
6 March 2017



60 minute averaged PM_{10} concentrations



Hourly PM_{10} and raw LiDAR signals



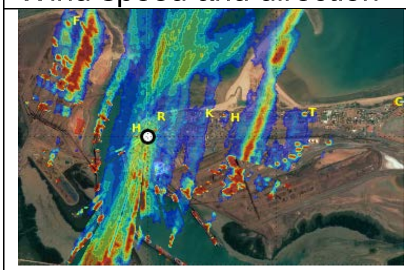
Wind speed and direction

Site concentrations

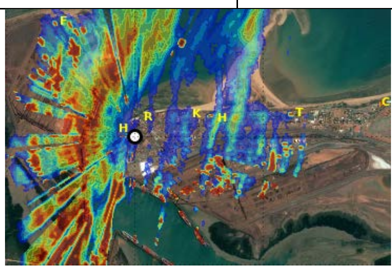
Site	Maximum hourly average (µg/m^3)
Harbour	171.5
Richardson Street	268.0
Kingsmill Street	268.0
Hospital	196.1
Taplin Street	152.0
Neptune	88.0
BoM	36.2
Yule	27.2

Event description

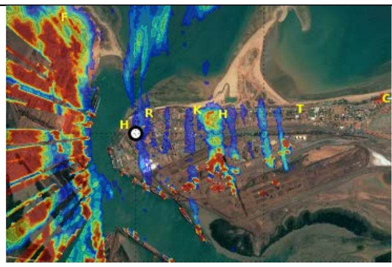
Early morning winds from SSW swinging anti-clockwise to SSE to about 7am resulted in particle levels increasing in all west end sites including Taplin Street.
Humidity levels remained somewhat low at below 50% with no rain recorded at the BoM site.
LiDAR images show the majority of the dust impacting the west end of Port Hedland originates from the south.



06/03/2017 03:00

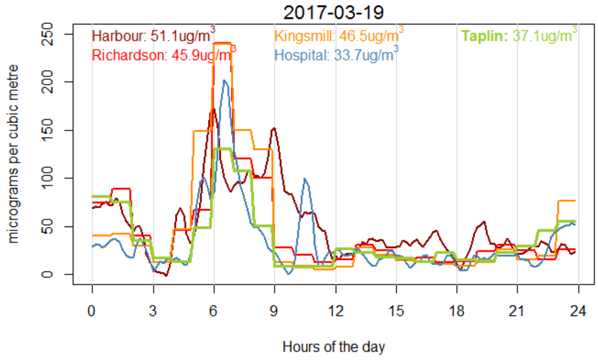


06/03/2017 03:40

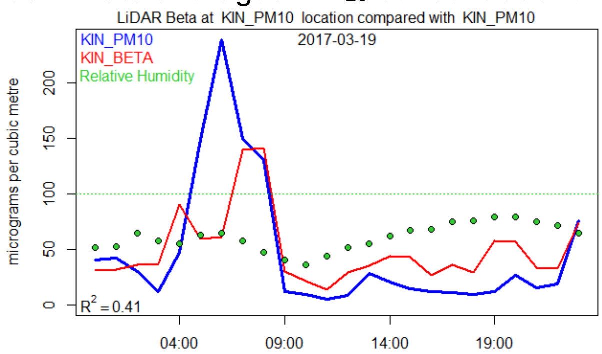


06/03/2017 04:20

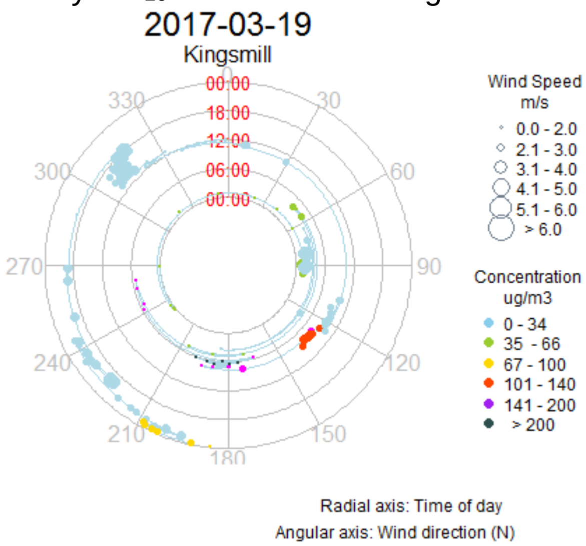
19 March 2017



60 minute averaged PM10 concentrations



Hourly PM10 and raw LiDAR signals



Wind speed and direction

Site concentrations

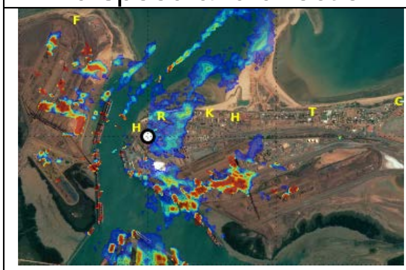
Site	Maximum hourly average (µg/m³)
Harbour	120.3
Richardson Street	240.0
Kingsmill Street	239.0
Hospital	158.3
Taplin Street	131.0
Neptune	74.0
BoM	145.4
Yule	23.7

Event description

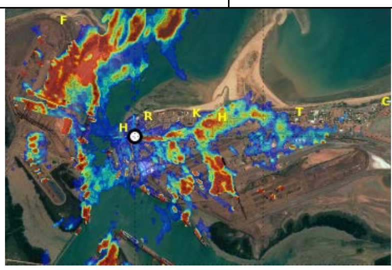
Morning winds were southerly for the majority of the high concentrations causing high PM10 levels at all sites in the west end including Taplin Street. Humidity levels remained moderate at around 60% or less with 0.1mm rain recorded at the BoM site.

Plumes originated from the south and southwest.

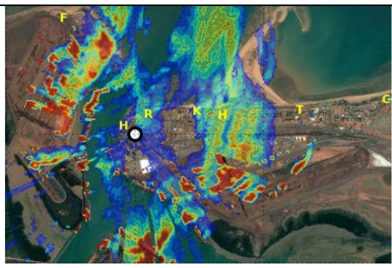
Note the plume from two ships at 6:10ampm with the plumes tending to track the path of the vessels.



19/03/2017 06:10

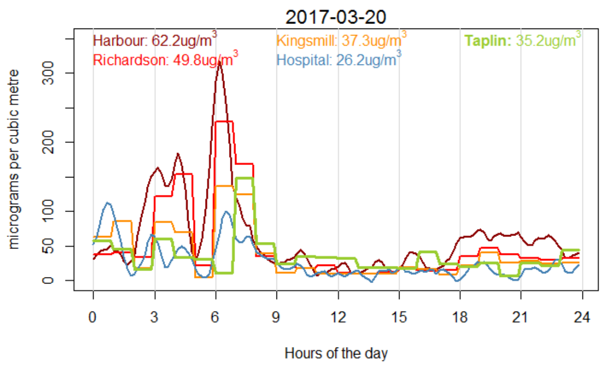


19/03/2017 06:40

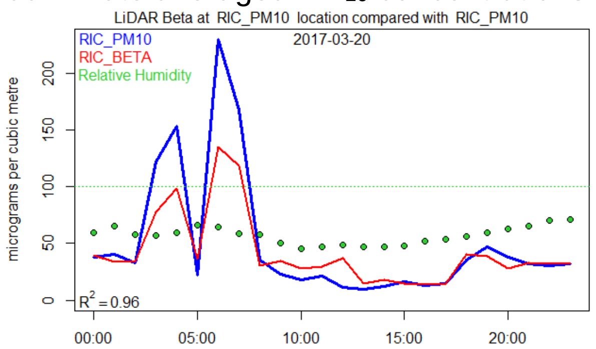


19/03/2017 07:00

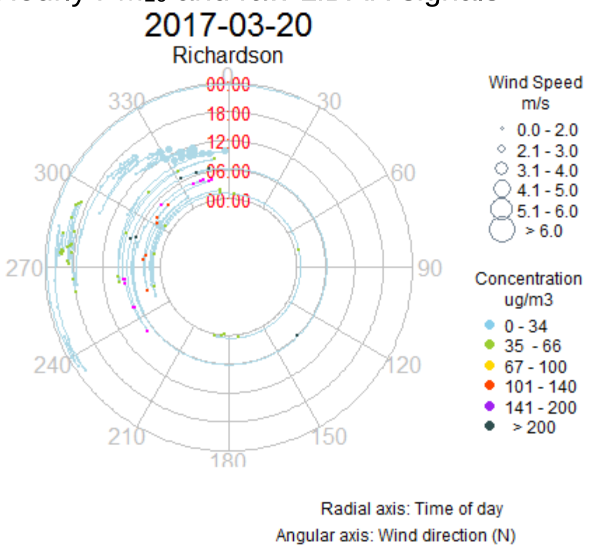
20 March 2017



60 minute averaged PM_{10} concentrations



Hourly PM_{10} and raw LiDAR signals



Wind speed and direction

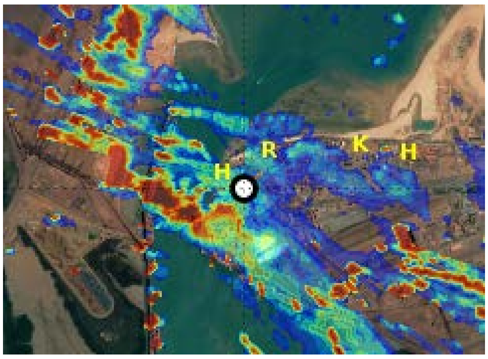
Site concentrations

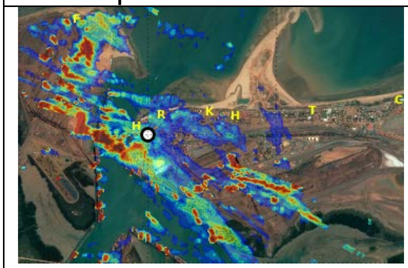
Site	Maximum hourly average (µg/m³)
Harbour	250.0
Richardson Street	230.0
Kingsmill Street	136.0
Hospital	88.0
Taplin Street	148.0
Neptune	45.0
BoM	71.0
Yule	21.5

Event description

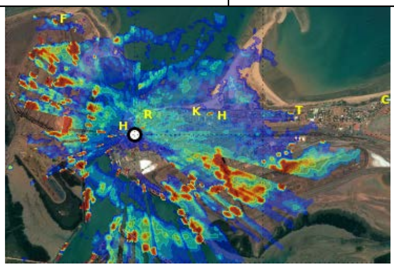
Morning winds varied from west to north. The LiDAR shows dust from the west impacting Port Hedland Humidity levels remained moderate at around 60% or less with no rain recorded at the BoM site.

A plume from the east can be clearly seen in the expanded image of the LiDAR at 6:30am below.

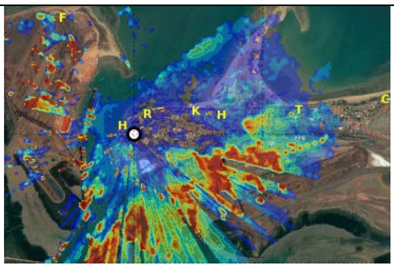




20/03/2017 6:30

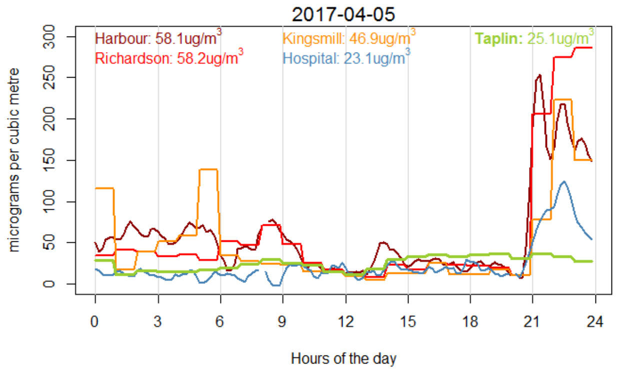


20/03/2017 07:00

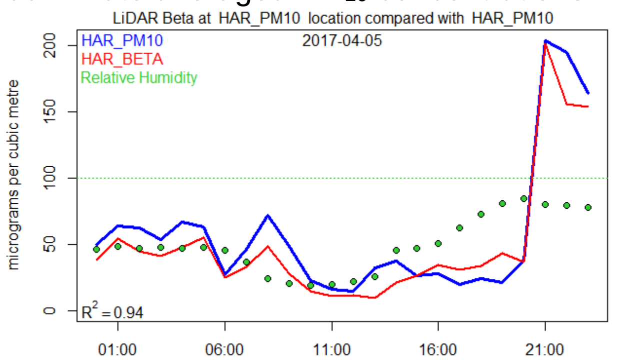


20/03/2017 07:30

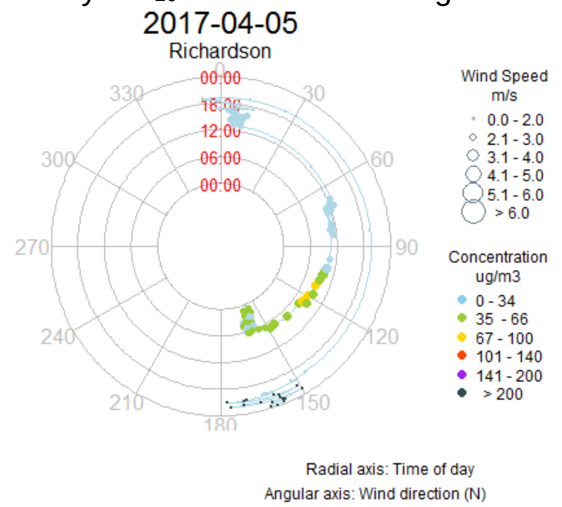
5 April 2017



60 minute averaged PM10 concentrations



Hourly PM10 and raw LiDAR signals



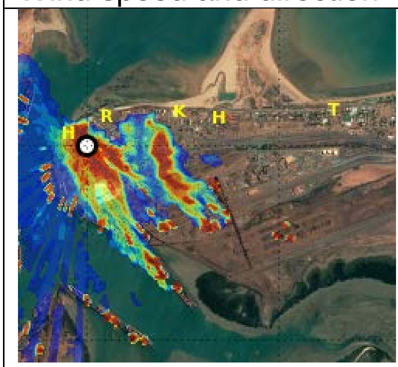
Wind speed and direction

Site concentrations

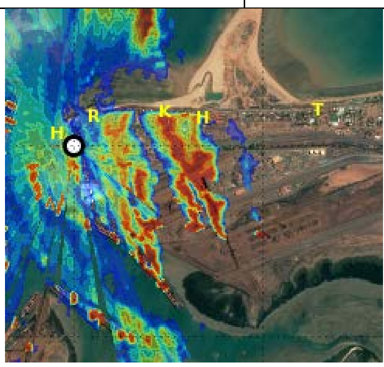
Site	Maximum hourly average ($\mu g/m^3$)
Harbour	203.7
Richardson Street	286.0
Kingsmill Street	223.0
Hospital	111.0
Taplin Street	37.0
Neptune	28.0
BoM	N/A
Yule	18.5

Event description

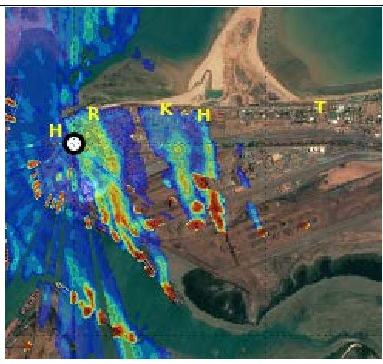
During the late evening, when the concentration of PM10 was elevated, winds were from the south-southeast. Humidity levels were high during this period.



05/04/2017 21:20

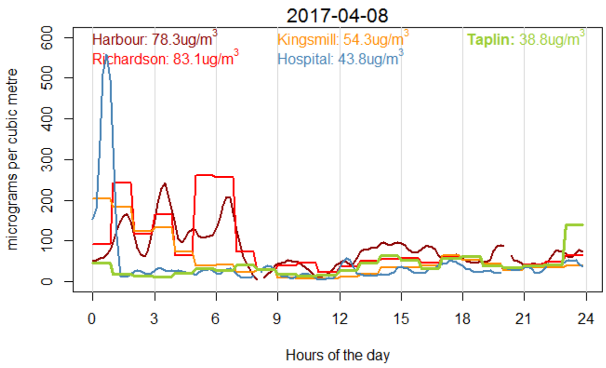


05/04/2017 22:20

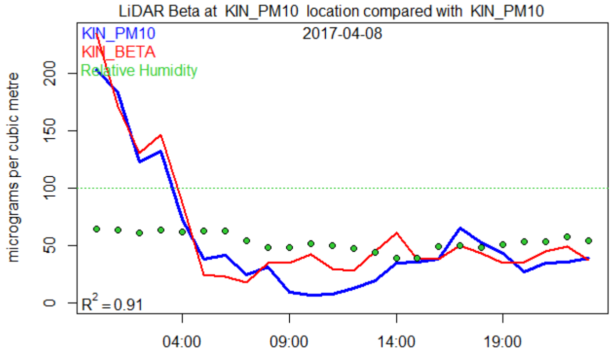


05/04/2017 23:20

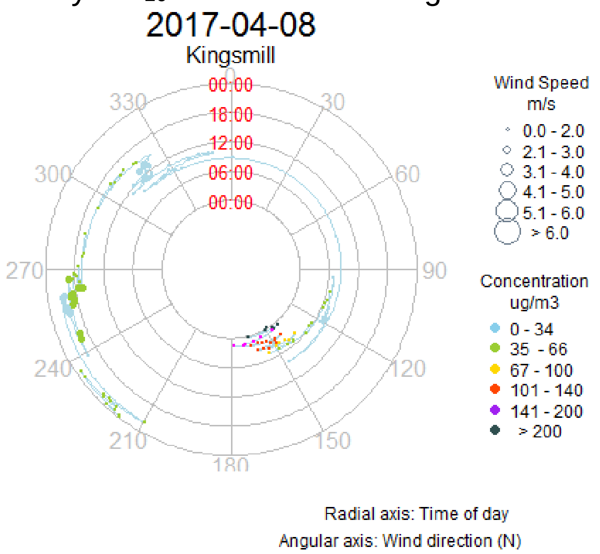
8 April 2017



60 minute averaged PM10 concentrations



Hourly PM10 and raw LiDAR signals



Wind speed and direction

Site concentrations

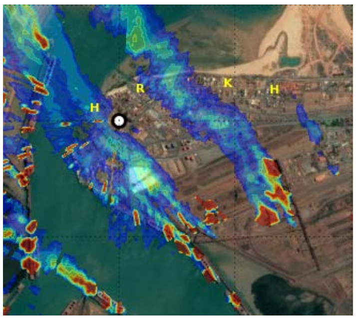
Site	Maximum hourly average (µg/m³)
Harbour	201.4
Richardson Street	261.0
Kingsmill Street	203.0
Hospital	373.6
Taplin Street	140.0
Neptune	87.0
BoM	N/A
Yule	15.7

Event description

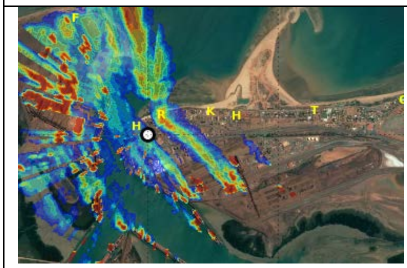
Winds remained south- south east in the early morning. The LiDAR shows dust from Nelson Point impacting Port Hedland

Humidity levels remained moderate at around 60% or less with no rain recorded at the BoM site.

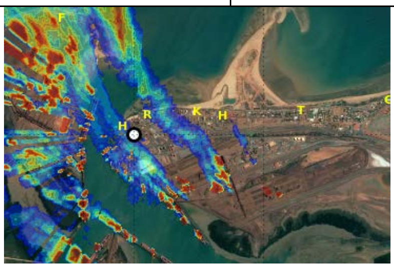
Plumes can be seen originating from the south . It is noticeable here that the plume is narrow, passing between Richardson Street and Kingsmill.



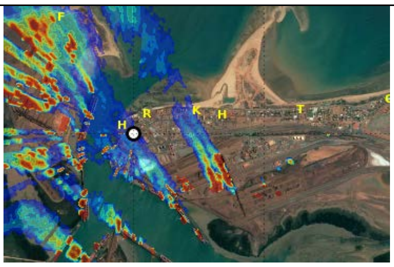
08/04/2017 02:00 (expanded)



08/04/2017 01:50

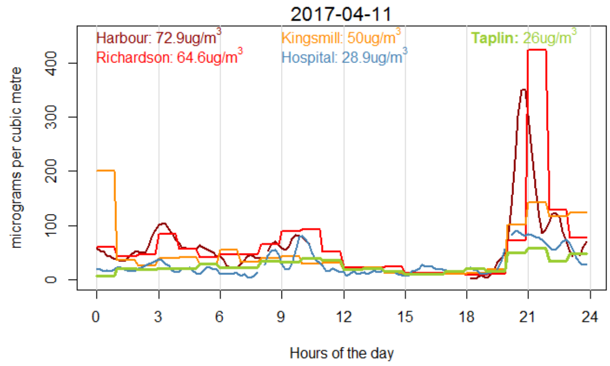


08/04/2017 02:00

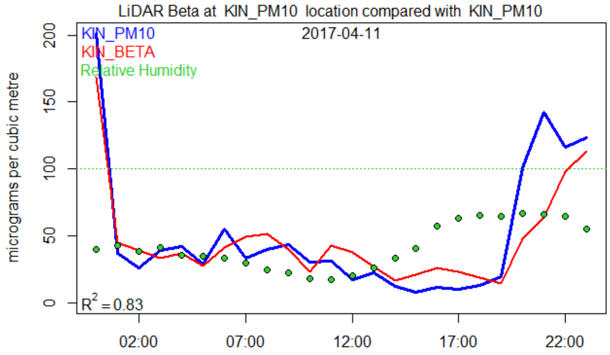


08/04/2017 02:10

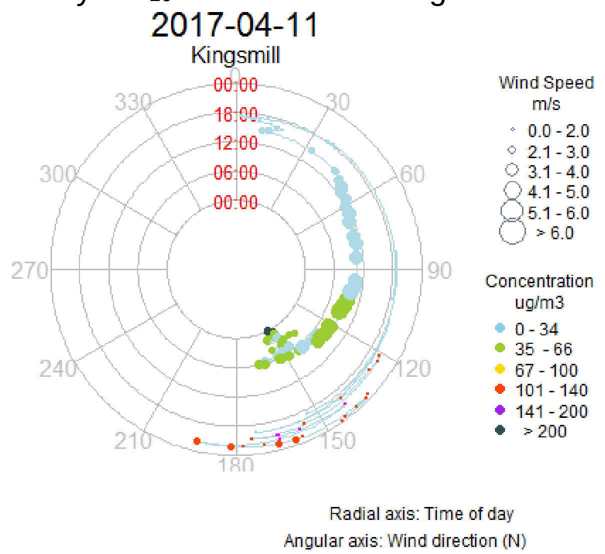
11 April 2017



60 minute averaged PM_{10} concentrations



Hourly PM_{10} and raw LiDAR signals



Wind speed and direction

Site concentrations

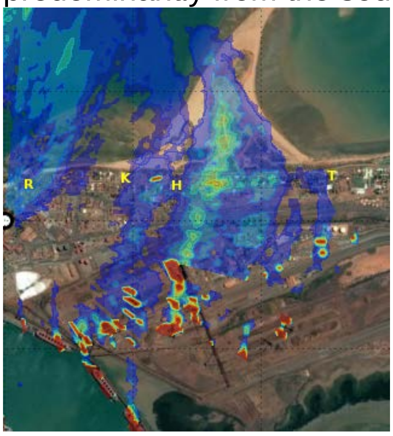
Site	Maximum hourly average ($\mu g/m^3$)
Harbour	238.4
Richardson Street	423.0
Kingsmill Street	201.0
Hospital	85.3
Taplin Street	59.0
Neptune	35.0
BoM	20.8
Yule	16.2

Event description

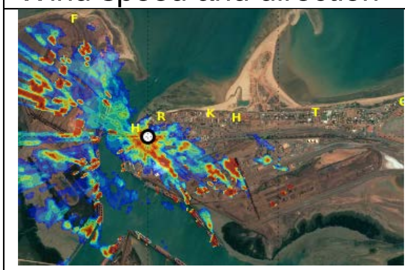
Winds were south-south east in the late evening. The LiDAR shows dust from the south impacting Port Hedland extending up through the Spoilbank.

Humidity levels remained moderate at around 60% or less with no rain recorded at the BoM site.

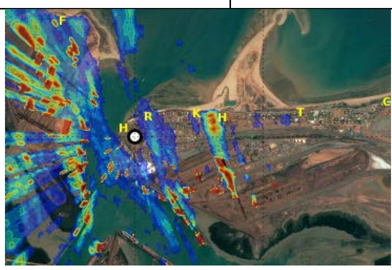
The plume seems to originate predominantly from the south.



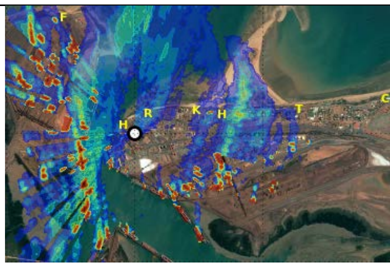
11/04/2017 23:00 (expanded)



11/04/2017 21:30

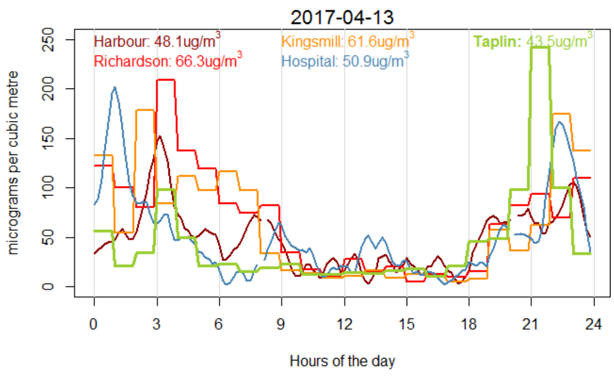


11/04/2017 22:00

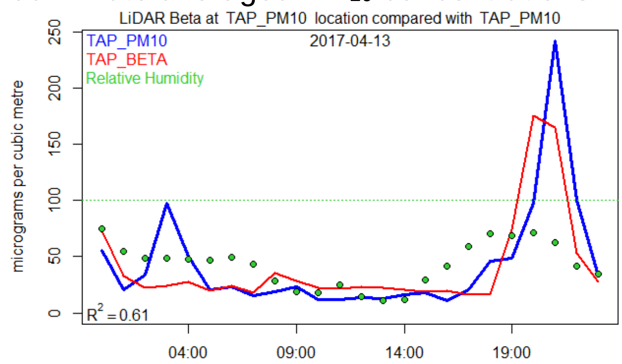


11/04/2017 23:00

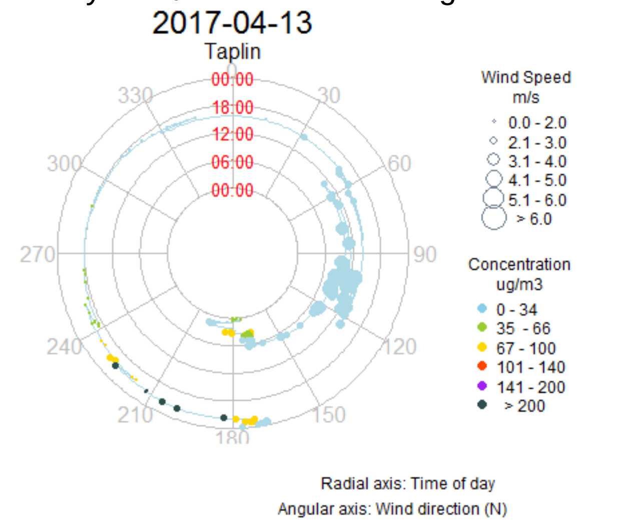
13 April 2017



60 minute averaged PM10 concentrations



Hourly PM10 and raw LiDAR signals



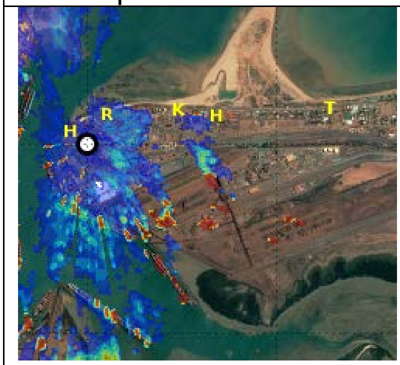
Wind speed and direction

Site concentrations

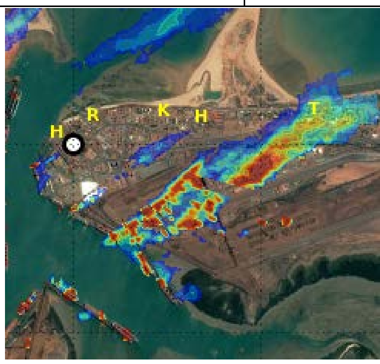
Site	Maximum hourly average ($\mu g/m^3$)
Harbour	125.6
Richardson Street	209.0
Kingsmill Street	178.0
Hospital	154.0
Taplin Street	242.0
Neptune	99.0
BoM	29.0
Yule	17.5

Event description

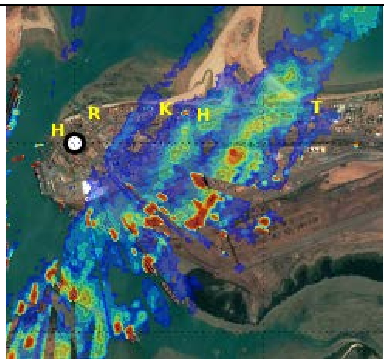
High concentrations in the evening coincide with winds from the south through to the south west.



13/04/2017 03:10

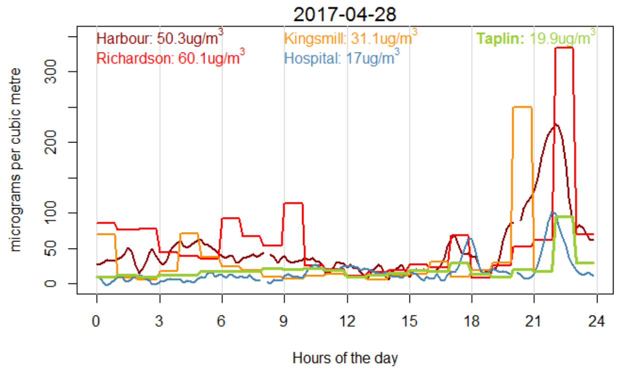


13/04/2017 21:00

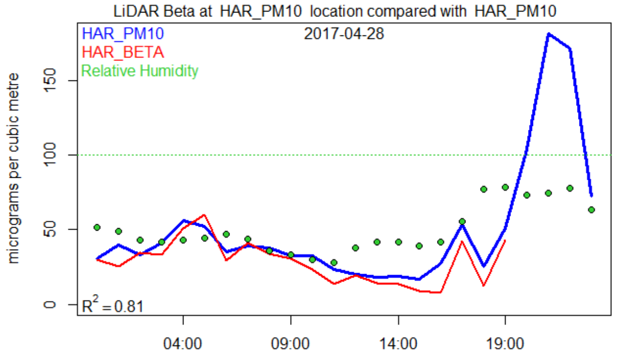


13/04/2017 22:00

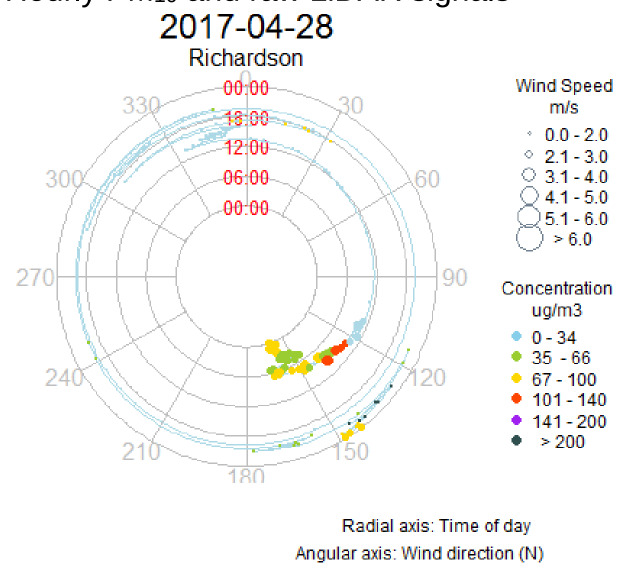
28 April 2017



60 minute averaged PM_{10} concentrations



Hourly PM_{10} and raw LiDAR signals



Wind speed and direction

Site concentrations

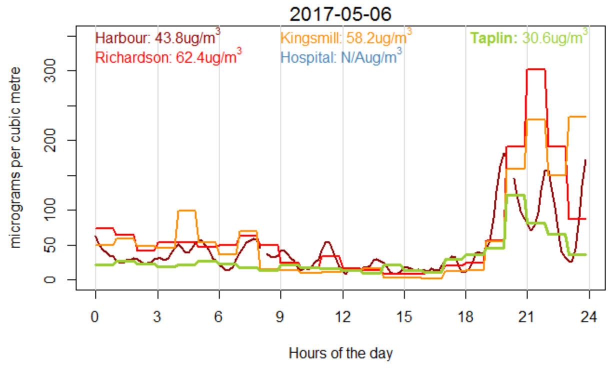
Site	Maximum hourly average (µg/m³)
Harbour	181.3
Richardson Street	334.0
Kingsmill Street	249.0
Hospital	61.1
Taplin Street	95.0
Neptune	26.0
BoM	36.8
Yule	18.8

Event description

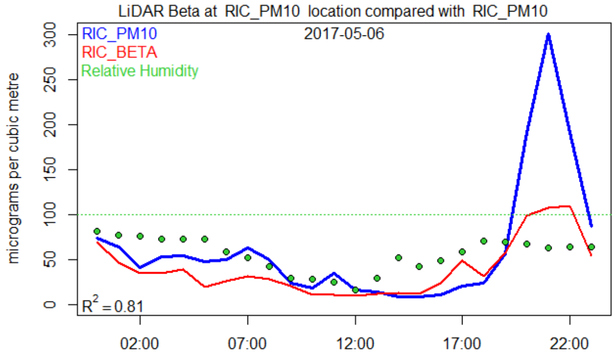
High concentrations in the evening coincide with winds from the southeast through to the south.

LiDAR data is unavailable for the period of interest.

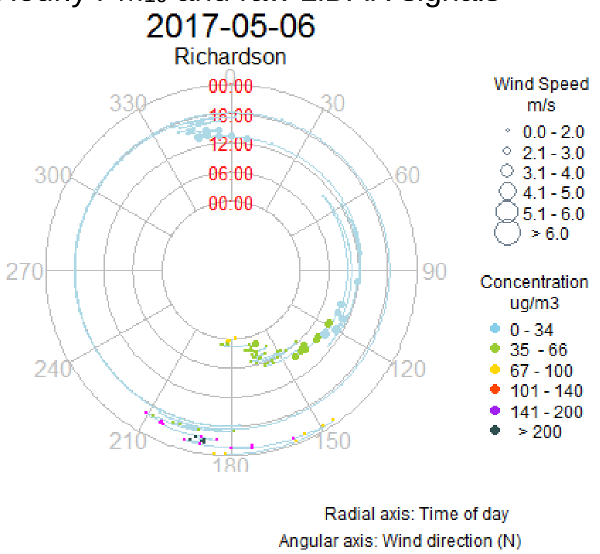
6 May 2017



60 minute averaged PM10 concentrations



Hourly PM10 and raw LiDAR signals



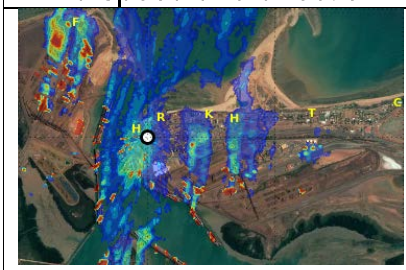
Wind speed and direction

Site concentrations

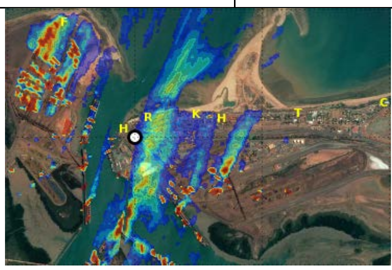
Site	Maximum hourly average (µg/m³)
Harbour	126.5
Richardson Street	301.0
Kingsmill Street	233.0
Hospital	N/A
Taplin Street	122.0
Neptune	51.0
BoM	20.6
Yule	74.0

Event description

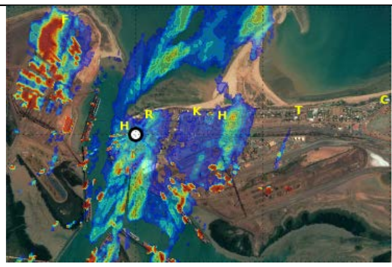
Winds were south-south west in the late evening. The LiDAR shows dust extending up to the Spoilbank.
In this instance, the raw LiDAR signal was not fully capturing the particle load as did the particle monitors. A number of factors could have caused this and these are more fully explained in the report text.
Humidity levels remained moderate at around 70% or less with no rain recorded at the BoM site.



06/05/2017 20:00

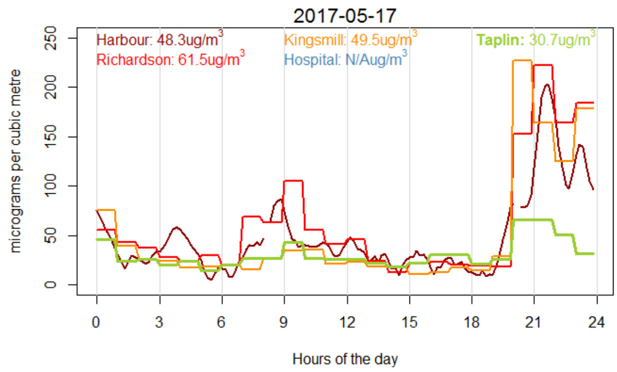


06/05/2017 21:00

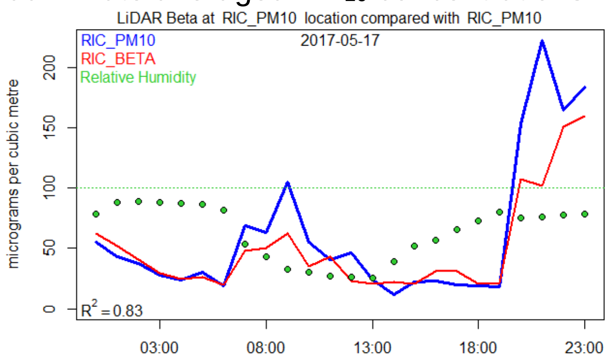


06/05/2017 22:00

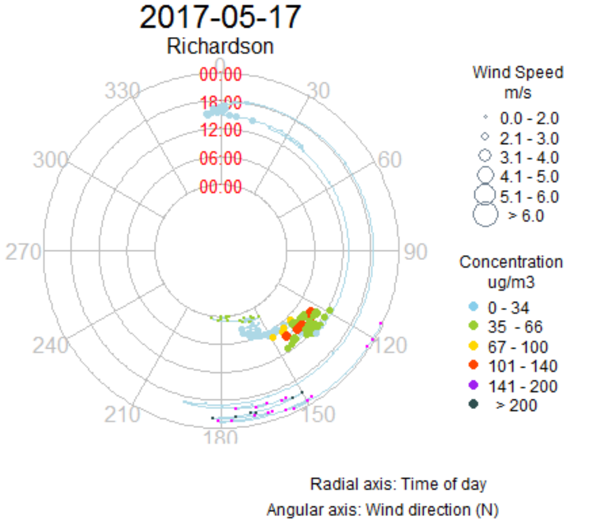
17 May 2017



60 minute averaged PM_{10} concentrations



Hourly PM_{10} and raw LiDAR signals



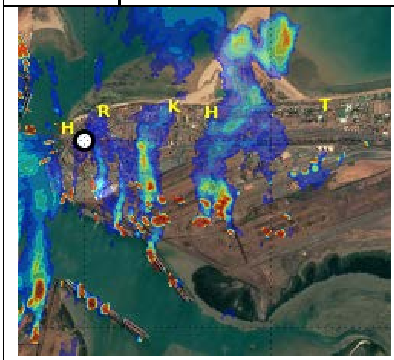
Wind speed and direction

Site concentrations

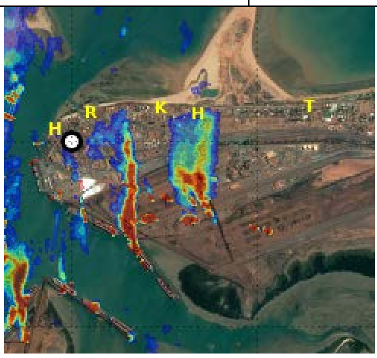
Site	Maximum hourly average (µg/m³)
Harbour	175.9
Richardson Street	222.0
Kingsmill Street	227.0
Hospital	N/A
Taplin Street	66.0
Neptune	46.0
BoM	39.3
Yule	24.2

Event description

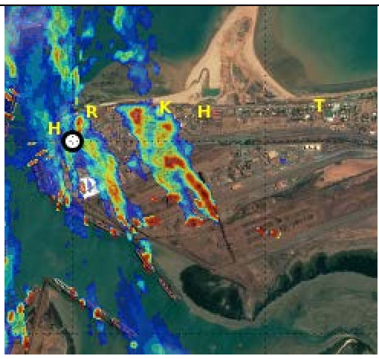
High concentrations in the evening coincide with winds from the south east through to the south.



17/05/2017 20:10

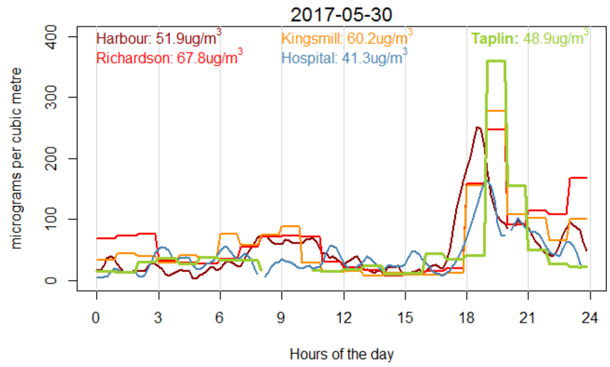


17/05/2017 21:10

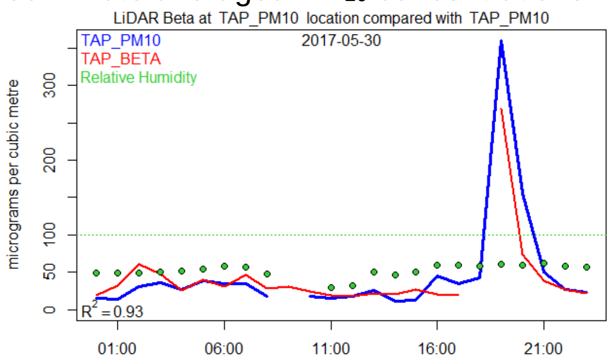


17/05/2017 22:10

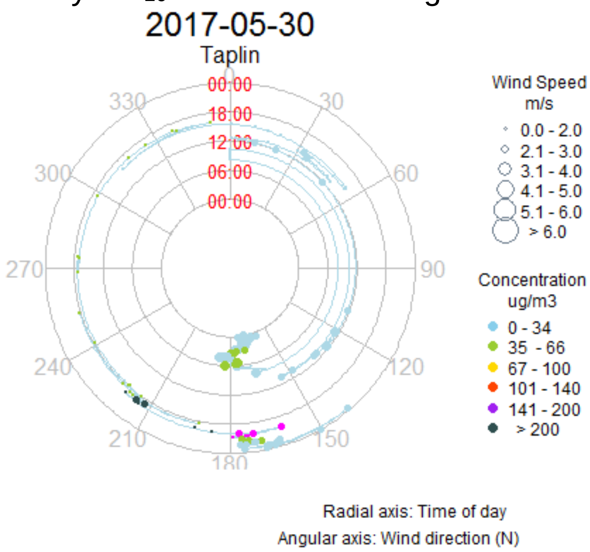
30 May 2017



60 minute averaged PM_{10} concentrations



Hourly PM_{10} and raw LiDAR signals



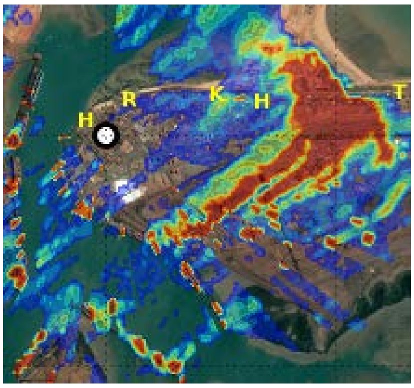
Wind speed and direction

Site concentrations

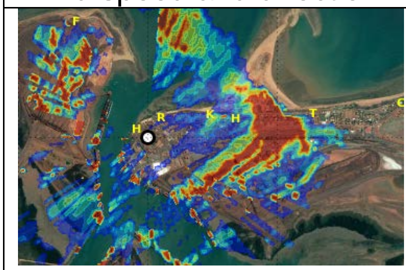
Site	Maximum hourly average (µg/m³)
Harbour	223.1
Richardson Street	247.0
Kingsmill Street	278.0
Hospital	115.9
Taplin Street	360.0
Neptune	107.0
BoM	77.0
Yule	26.0

Event description

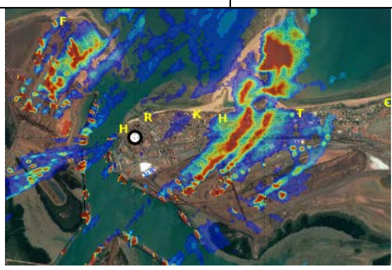
Winds were south west through to south in the late evening. The LiDAR shows dust from the southwest extending up through Spoilbank. Peaks were recorded during late morning and late evening when winds were from the south-south east. Humidity levels remained moderate at around 60% or less with no rain recorded at the BoM site.



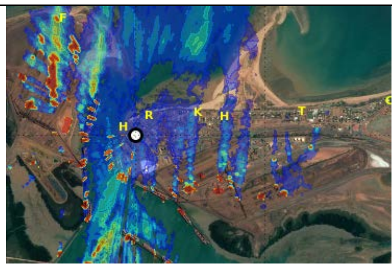
30/05/2017 19:30



30/05/2017 19:30

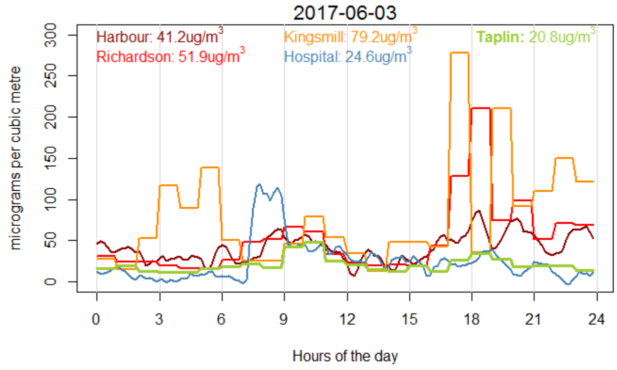


30/05/2017 20:00

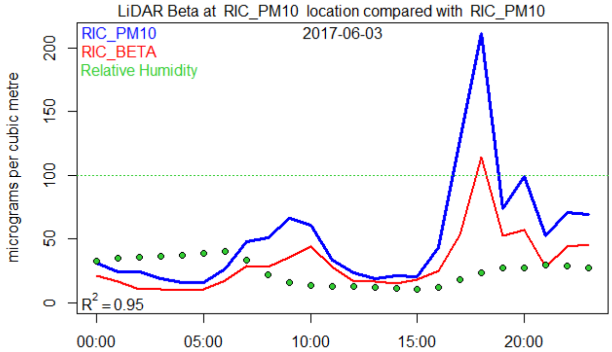


30/05/2017 21:00

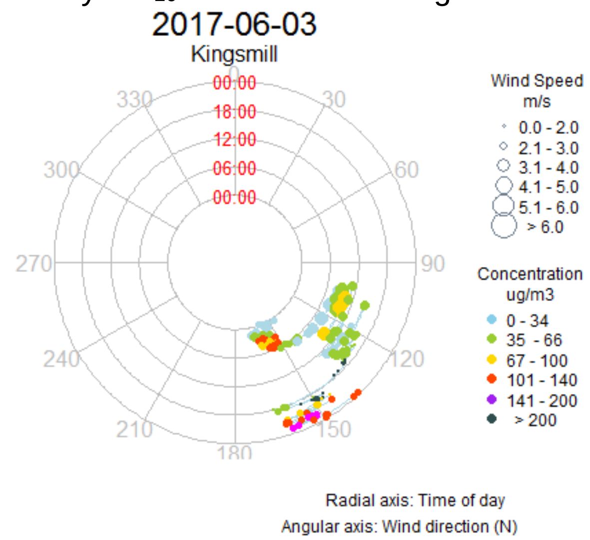
03 June 2017



60 minute averaged PM_{10} concentrations



Hourly PM_{10} and raw LiDAR signals



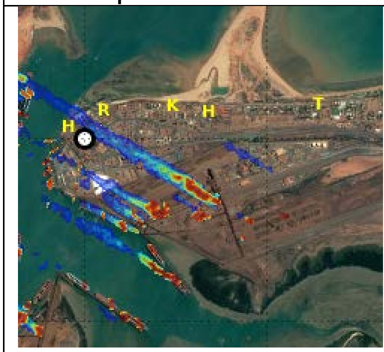
Wind speed and direction

Site concentrations

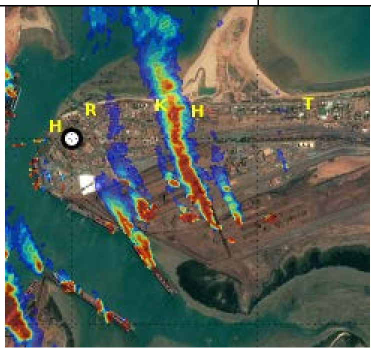
Site	Maximum hourly average (µg/m³)
Harbour	71.8
Richardson Street	211.0
Kingsmill Street	278.0
Hospital	106.4
Taplin Street	48.0
Neptune	38.0
BoM	65.9
Yule	171.0

Event description

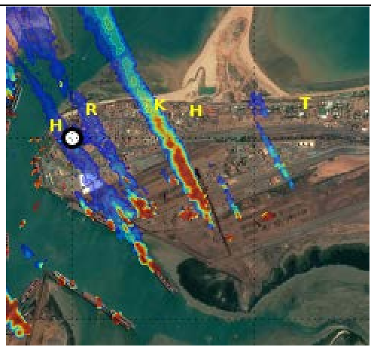
High concentrations in the afternoon coincide with winds from the south east through to the south.



03/06/2017 18:00

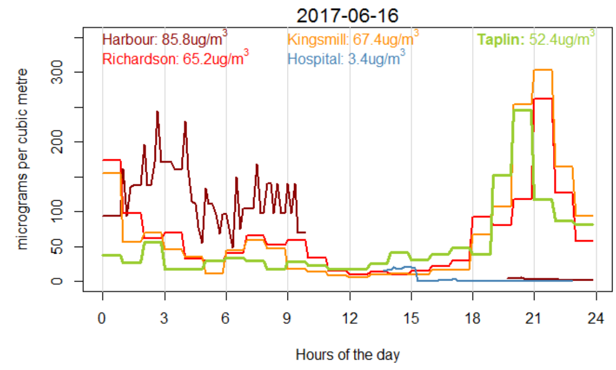


03/06/2017 19:00

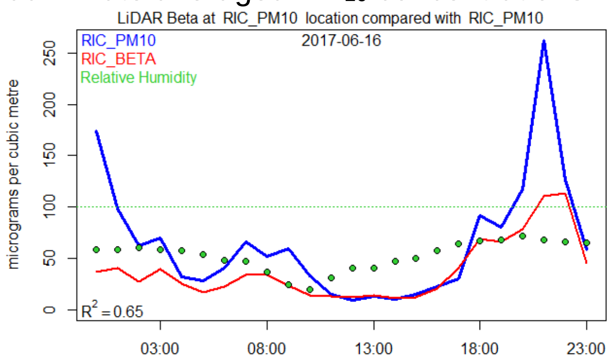


03/06/2017 20:00

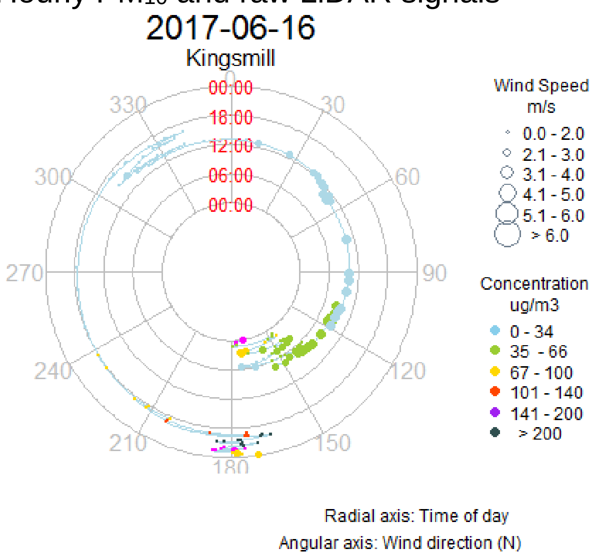
16 June 2017



60 minute averaged PM_{10} concentrations



Hourly PM_{10} and raw LiDAR signals



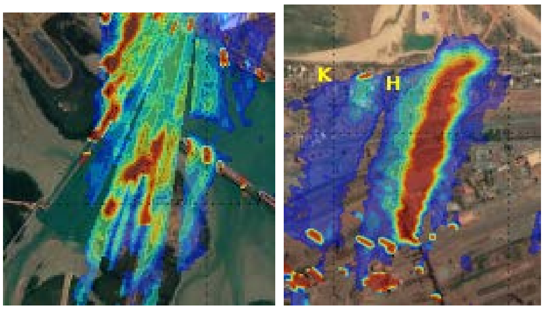
Wind speed and direction

Site concentrations

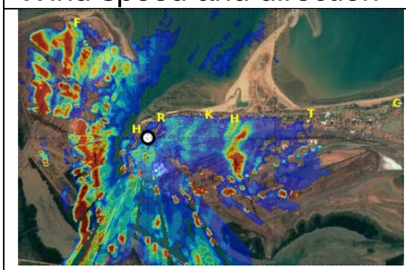
Site	Maximum hourly average (µg/m³)
Harbour	176.3
Richardson Street	262.0
Kingsmill Street	303.0
Hospital	18.5
Taplin Street	245.0
Neptune	104.0
BoM	66.0
Yule	230.0

Event description

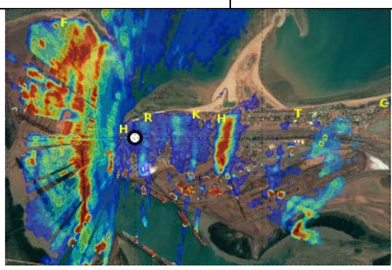
Evening winds were from the south and at that time, dust plumes were also observed from the south. Humidity levels were around 80% or less with no rain recorded at the BoM site.



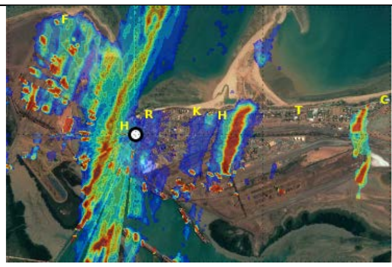
16/06/2017 22:00 (partial and expanded)



16/06/2017 21:00

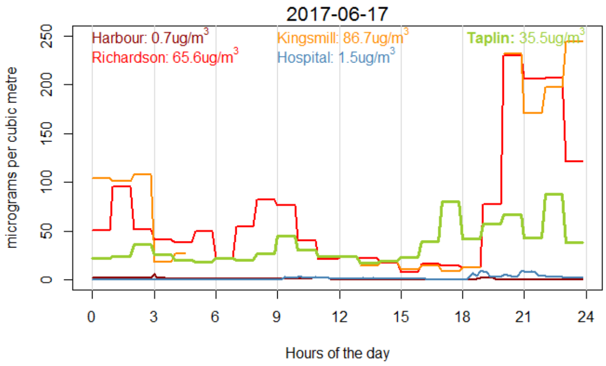


16/06/2017 21:30

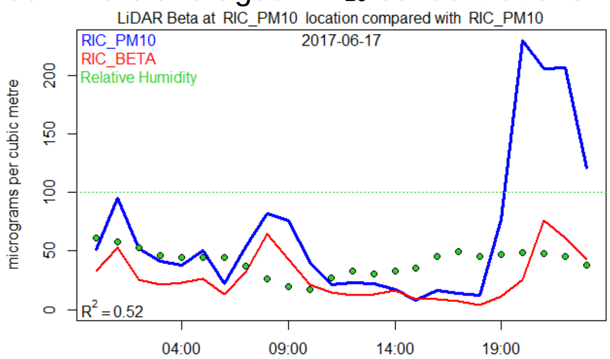


16/06/2017 22:00

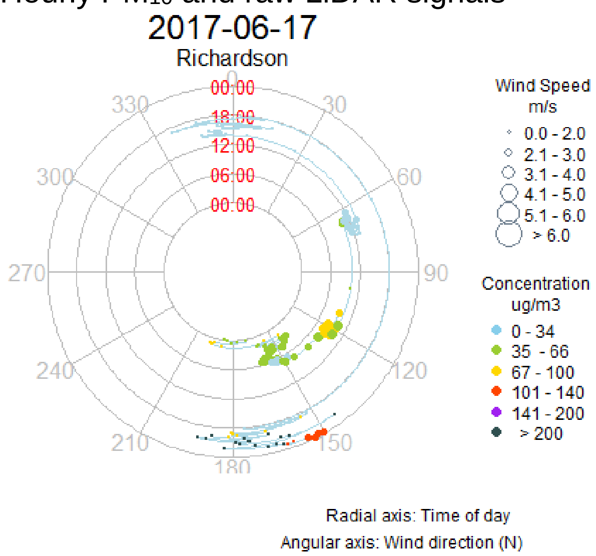
17 June 2017



60 minute averaged PM_{10} concentrations



Hourly PM_{10} and raw LiDAR signals



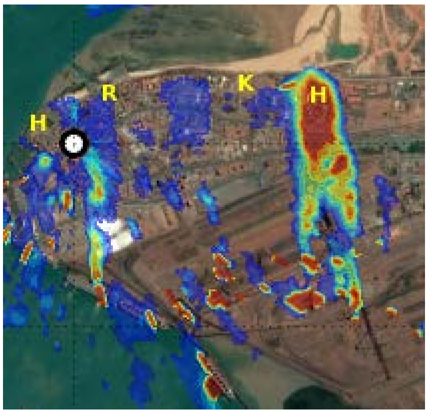
Wind speed and direction

Site concentrations

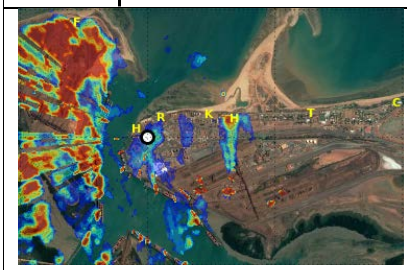
Site	Maximum hourly average (µg/m³)
Harbour	N/A
Richardson Street	230.0
Kingsmill Street	244.0
Hospital	N/A
Taplin Street	88.0
Neptune	33.0
BoM	72.0
Yule	68.5

Event description

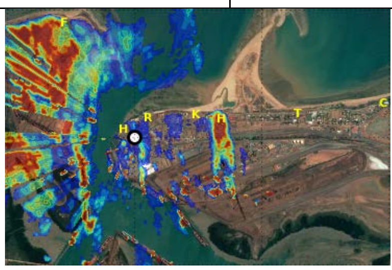
Evening winds were from the south and at that time, dust plumes were also observed from the south. Humidity levels were around 50% or less with no rain recorded at the BoM site.



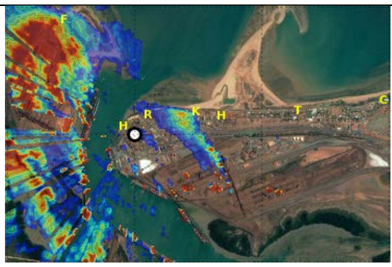
17/06/2017 21:30 (partial and expanded)



17/06/2017 21:00

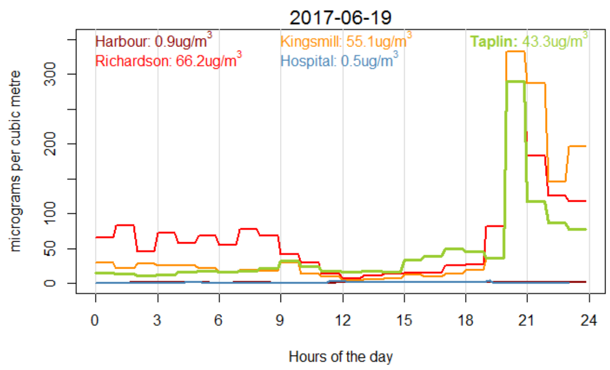


17/06/2017 21:30

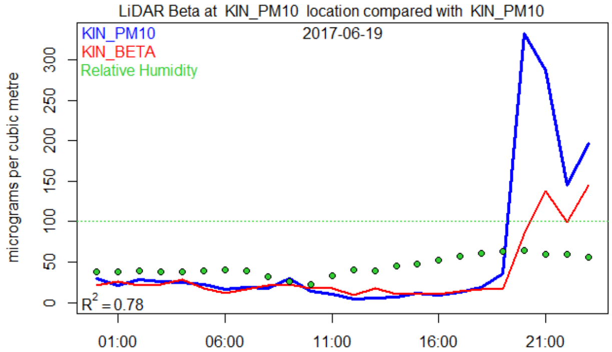


17/06/2017 22: 00

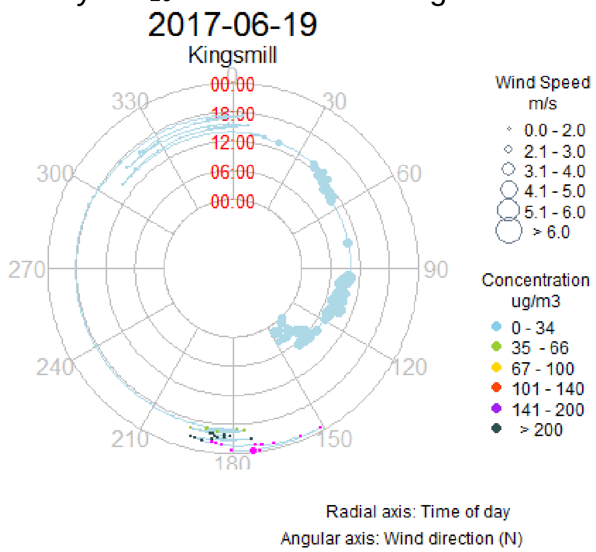
19 June 2017



60 minute averaged PM10 concentrations



Hourly PM10 and raw LiDAR signals.



Wind speed and direction

Site concentrations

Site	Maximum hourly average (µg/m³)
Harbour	N/A
Richardson Street	290.0
Kingsmill Street	332.0
Hospital	N/A
Taplin Street	290.0
Neptune	88.0
BoM	44.5
Yule	203.3

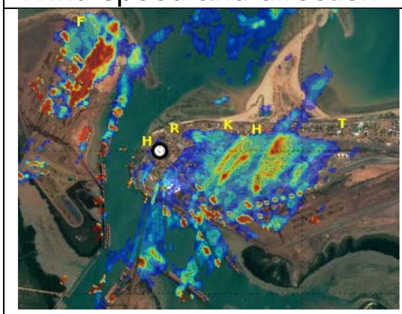
Event description

Evening winds were from the south

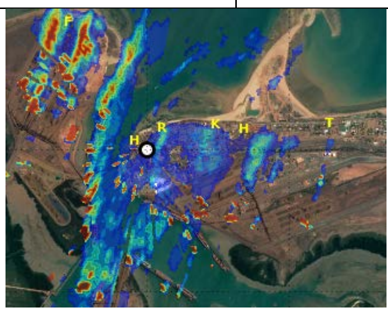
Dust plumes were recorded at a number of sites.

Humidity levels were around 70% or less with no rain recorded at the BoM site.

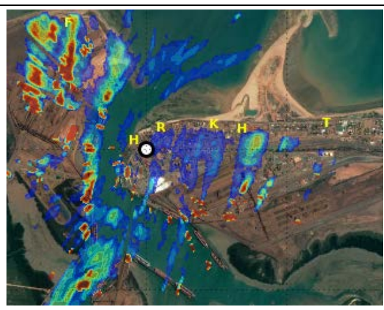
Air temperature at 4pm was 23°C decreasing steadily to 20°C at midnight.



19/06/2017 21:00

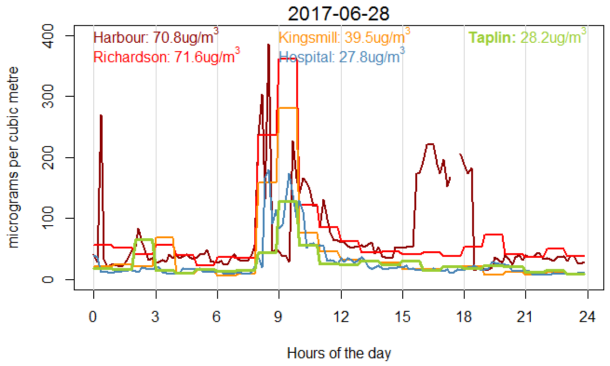


19/06/2017 21:30

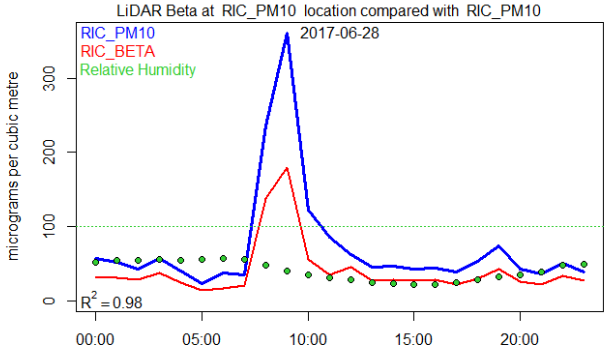


19/06/2017 22: 00

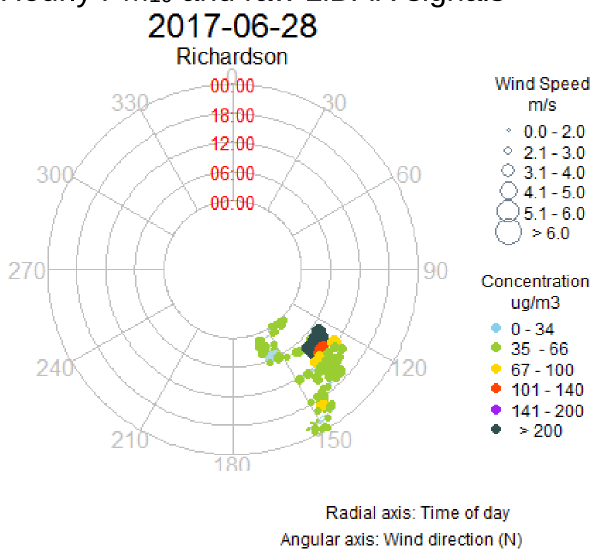
28 June 2017



60 minute averaged PM_{10} concentrations



Hourly PM_{10} and raw LiDAR signals



Wind speed and direction

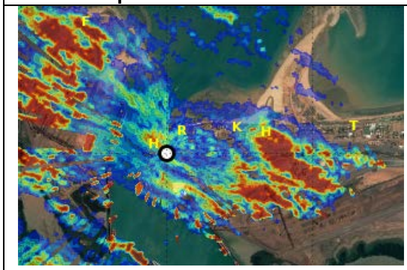
Site concentrations

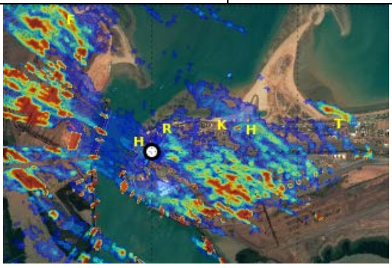
Site	Maximum hourly average ($\mu g/m^3$)
Harbour	203.4
Richardson Street	361.0
Kingsmill Street	280.0
Hospital	121.0
Taplin Street	128.0
Neptune	52.0
BoM	N/A
Yule	187.2

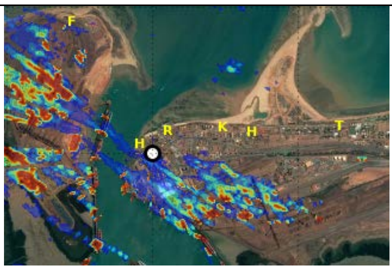
Event description

Winds from the south-east in the middle of the day saw dust impact all air quality sites located within the west end.

Humidity levels were low at less than 50% with no rain recorded at the BoM site.







28/06/2017 09:00am 28/06/2017 10:00am 28/06/2017 11: 00am

9.3 Appendix C — Selected events recorded by the LiDAR

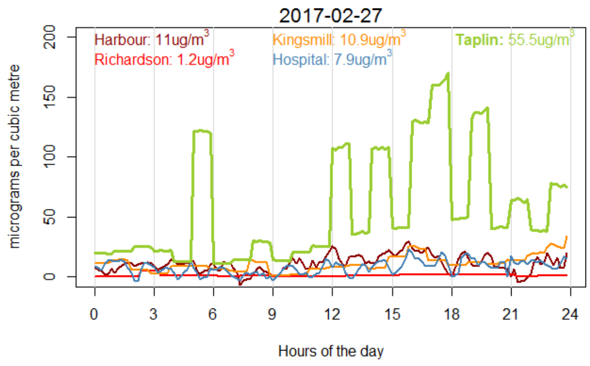
The following pages contain information specific to each site that shows events of interest which may or may not have exceeded any air quality standard. Each analysis is provided in date order and may include one or more of a wind spiral, concentration table and concentration plots. Where known, possible sources are indicated.
Included are data related to concentrations of PM_{10} particles reached at a selection of sites in Port Hedland. For the purposes of this study, it is considered that the distance and direction of the BoM and Yule site when compared to the Port Hedland instruments allows these to be used as an indicator of background levels.
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 wind direction changes throughout the day.
Where used within the text, wind direction refers to the direction from where the wind originated. The following short-hand nomenclature used throughout this document:

N – 0 degrees	E – 90 degrees	S – 180 degrees	W – 270 degrees
NNE – 30 degrees	ESE – 120 degrees	SSW – 210 degrees	WNW – 300 degrees
ENE – 60 degrees	SSE – 150 degrees	WSW – 240 degrees	NNW – 330 degrees

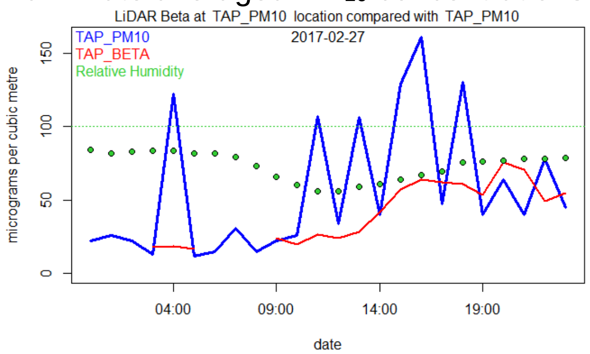
The figures used in the site concentration tables represent PM_{10} concentrations as presented by industry in their various data files.

Summary of findings:
Dust lift-off or smoke can very occasionally be seen on Spoilbank.
Ship plumes are often visible as they enter or leave the harbour
Some plumes can be very long and narrow and pass between established monitoring stations.
Plumes can be seen on the northern end of Finucane Island. These may be one or a combination of dust, sand or salt spray.

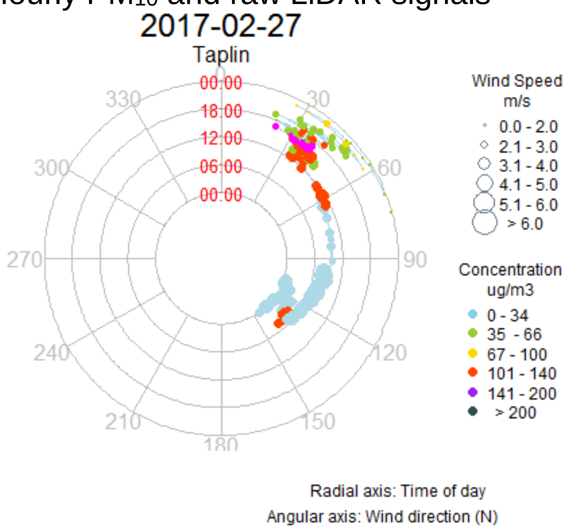
27 February 2017



10 minute averaged PM10 concentrations



Hourly PM10 and raw LiDAR signals



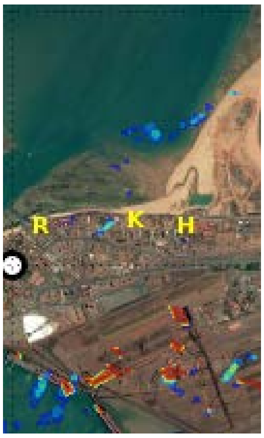
Wind speed and direction

Site concentrations

Site	Maximum hourly average ($\mu g/m^3$)
Harbour	29.5
Richardson Street	5.0
Kingsmill Street	39.0
Hospital	13.8
Taplin Street	161.0
Neptune	41
BoM	86.4
Yule	N/A

Event description

Development of a particle plume on Spoilbank at around 12:20pm with winds coming from the north-north east.



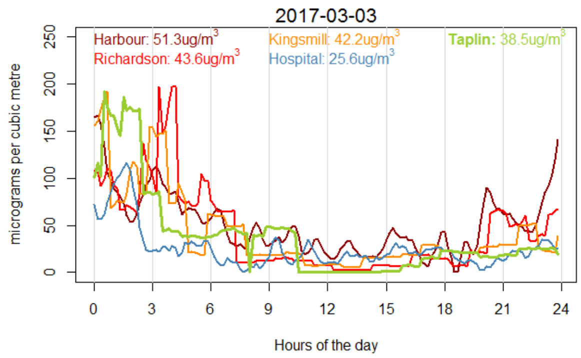
12:20pm

12:30:pm

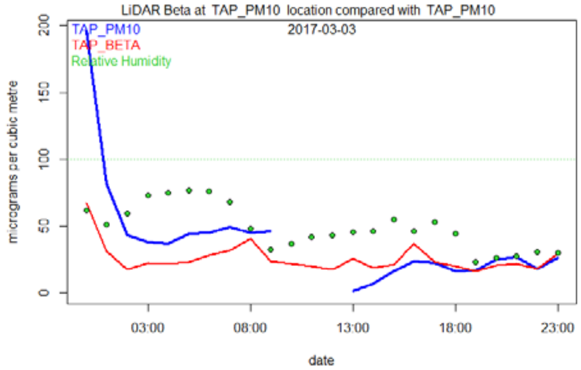
12:40pm

12:50pm

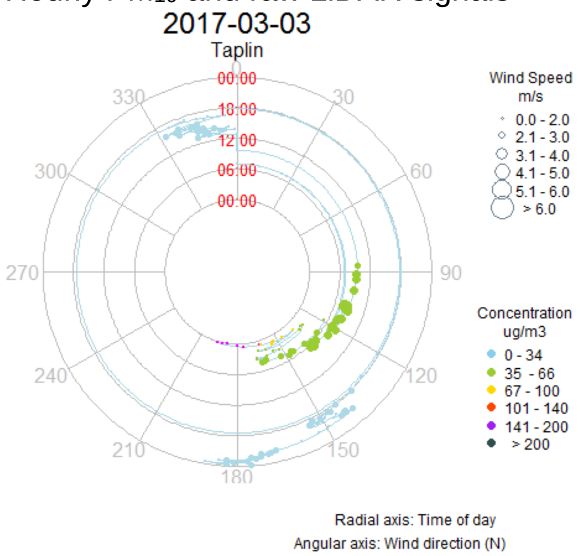
3 March 2017



10 minute averaged PM10 concentrations



Hourly PM10 and raw LiDAR signals



Wind speed and direction

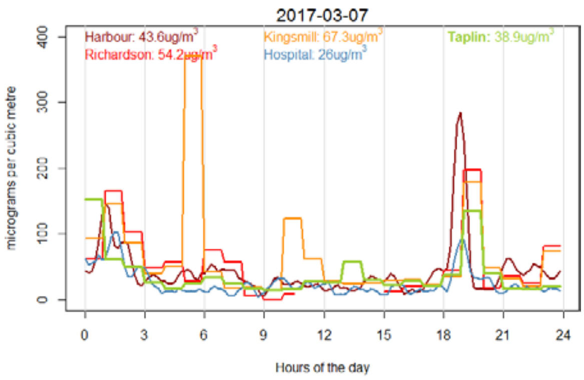
Site concentrations

Site	Maximum hourly average (µg/m³)
Harbour	179.9
Richardson Street	215
Kingsmill Street	170
Hospital	146.8
Taplin Street	196
Neptune	224
BoM	80.8
Yule	20.0

Event description

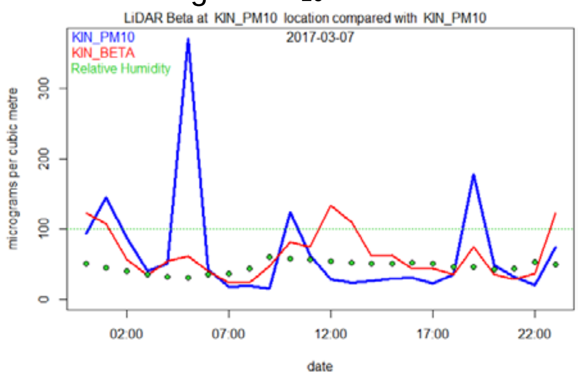
Ship manoeuvring within the harbour at 5:50pm

7 March 2017

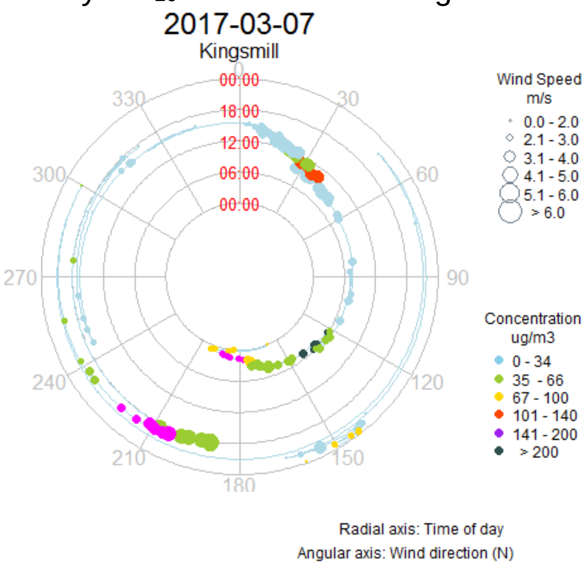


10

minute averaged PM10 concentrations



Hourly PM10 and raw LiDAR signals



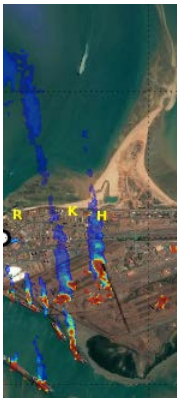
Wind speed and direction

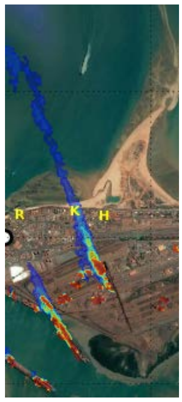
Site concentrations

Site	Maximum hourly average ($\mu g/m^3$)
Harbour	285.6
Richardson Street	197
Kingsmill Street	371
Hospital	103.2
Taplin Street	153
Neptune	72
BoM	75.7
Yule	75

Event description

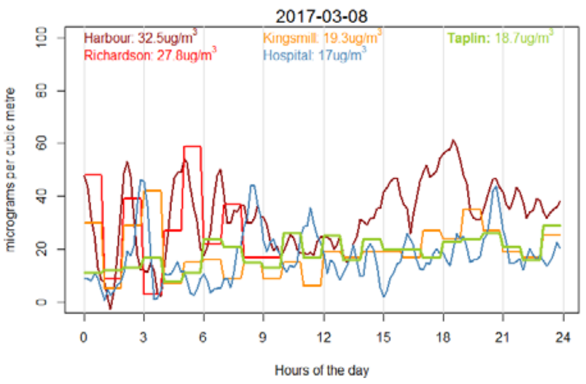
Long narrow plume extending from the centre of Nelson Point, passing between air monitoring sites of Richardson Street and Hospital and continuing past the Spoilbank. The plume remained narrow throughout.



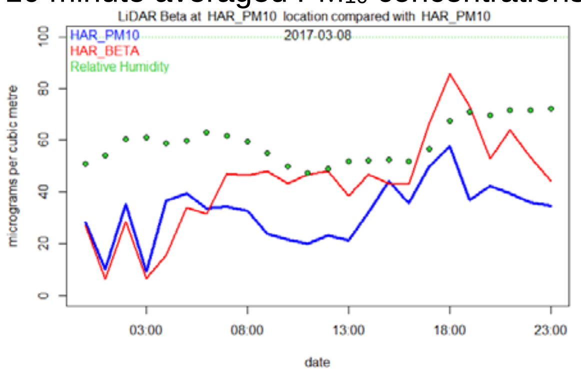


3:20am 4:20am 5:00am

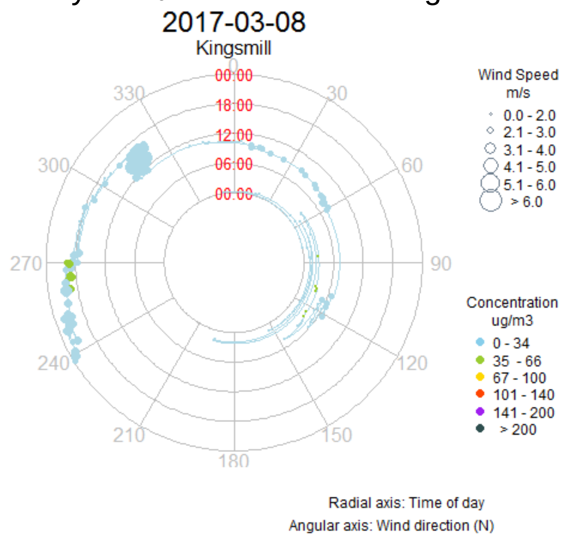
8 March 2017



10 minute averaged PM10 concentrations



Hourly PM10 and raw LiDAR signals



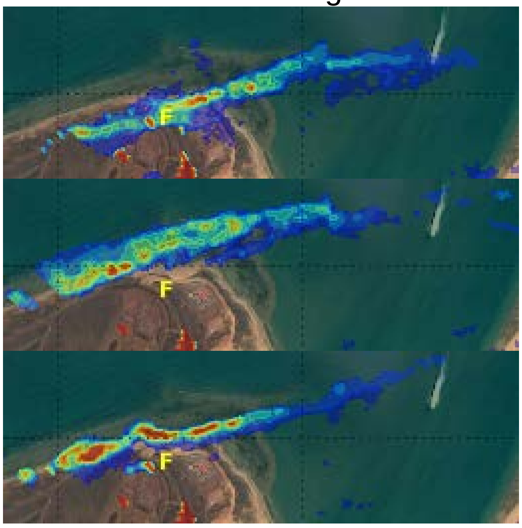
Wind speed and direction

Site concentrations

Site	Maximum hourly average ($\mu g/m^3$)
Harbour	61.5
Richardson Street	59
Kingsmill Street	42
Hospital	46.1
Taplin Street	29
Neptune	56
BoM	47.7
Yule	23

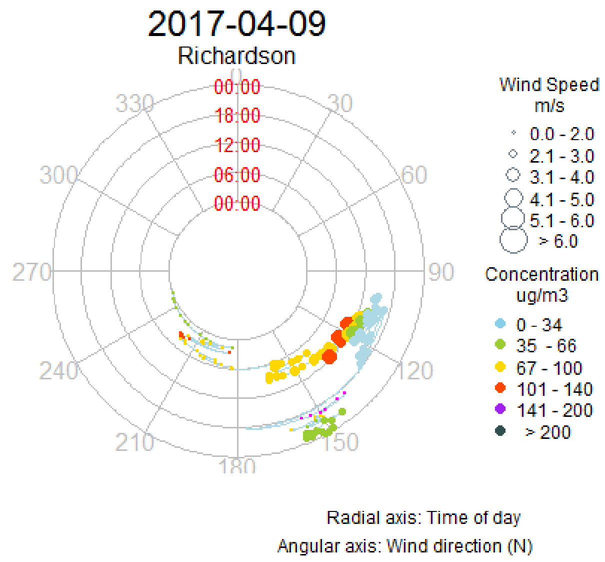
Event description

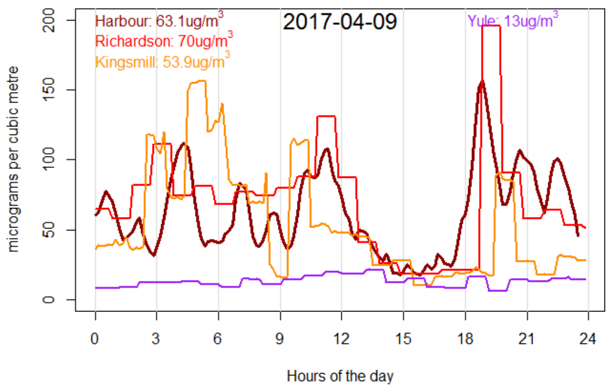
Long narrow plume extending from the north of Finucane Island. The plume remained narrow throughout.



9:50pm (top), 10:10pm (centre) and 10:40pm (bottom)

9 April 2017



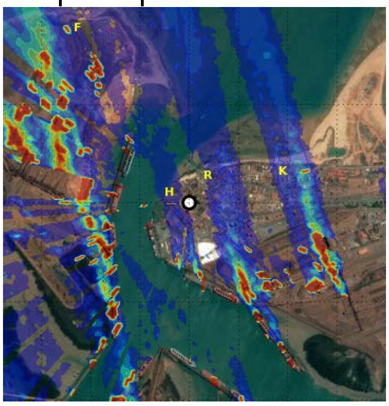


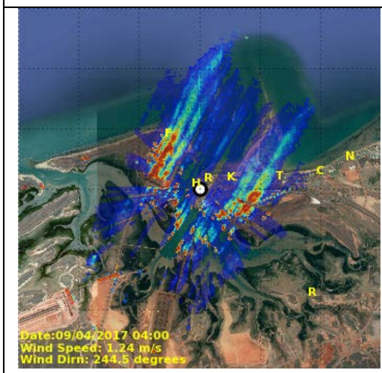
Site concentrations

Site	Daily average (µg/m³)
Harbour	**63.1**
Richardson Street	**69.5**
Kingsmill Street	**53.2**
Hospital	33.3
Taplin Street	42.2
Neptune	20.4
BoM	NA
Yule	13.1

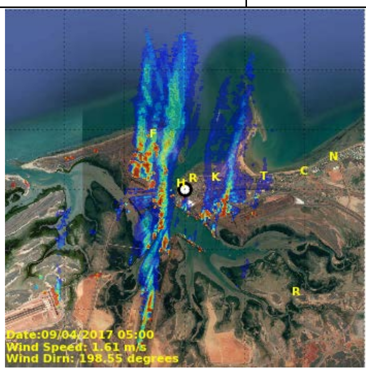
Event description

Wind speeds were from the SSW in the early morning at less than 3ms^{-1}. The LiDAR recorded plumes from various locations from the south. These plumes crossed the west end of Port Hedland extending out to sea. The expanded image below shows a close-up of the relevant portions of the port operations at 6am.

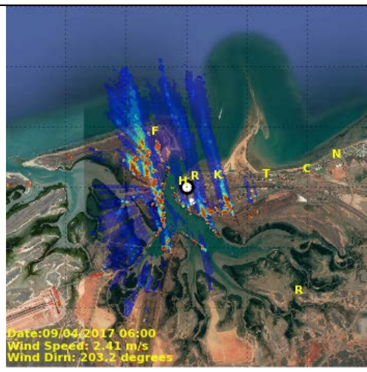




09/04/2017 4am

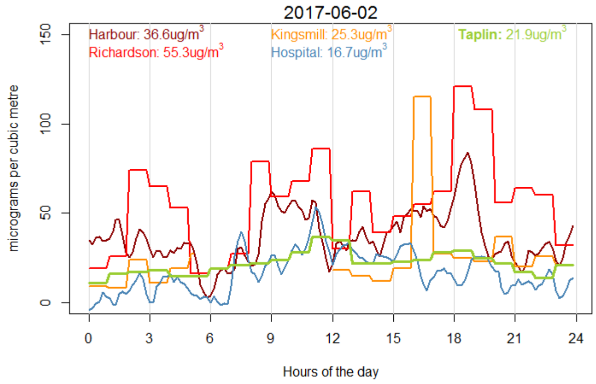


09/04/2017 5am

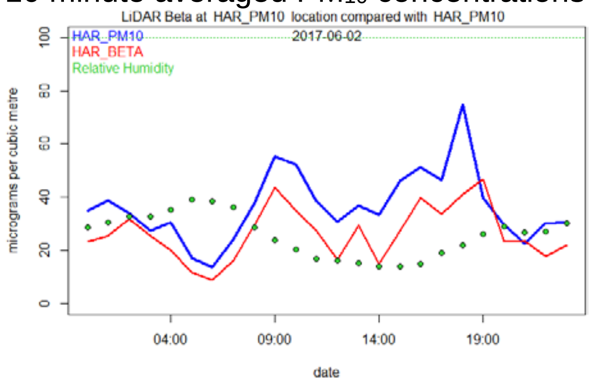


09/04/2017 6am

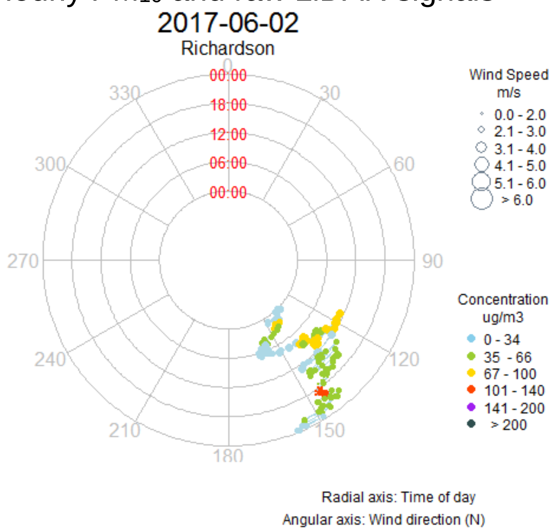
2 June 2017



10 minute averaged PM_{10} concentrations



Hourly PM_{10} and raw LiDAR signals



Wind speed and direction

Site concentrations

Site	Maximum hourly average (µg/m^3)
Harbour	83.8
Richardson Street	121
Kingsmill Street	115
Hospital	53.5
Taplin Street	37
Neptune	38
BoM	75.3
Yule	85

Event description

Long narrow plume extending from the centre of Nelson Point, passing between air monitoring sites of Richardson Street and Kingsmill and continuing past the northern edge of Finucane Island. The plume remained narrow throughout.

02/06/2017 5:30am

9.4 Appendix D— Bureau of Meteorology weather data

Date	Day	Temps		Rain	Evap	Sun	Max wind gust			9:00 AM						3:00 PM					
		Min	Max				Dir	Spd	Time	Temp	RH	Cld	Dir	Spd	MSLP	Temp	RH	Cld	Dir	Spd	MSLP
		°C	°C	mm	mm	hours		km/h	local	°C	%	8th		km/h	hPa	°C	%	8th		km/h	hPa
1/02/2017	We	27.3	41.2	0	10		NE	72	17:59	35	64	5	S	22	1008.5	37.4	59		NW	24	1003.9
2/02/2017	Th	27.6	39.1	0.4	10.8		E	56	8:10	34.6	58	6	ESE	39	1006.8	35.5	57		N	26	1003.7
3/02/2017	Fr	24.4	35.6	10			NE	76	0:27	28.8	84		SSE	30	1006	34.8	60		ESE	24	1001.5
4/02/2017	Sa	27	37.8	0.2			ESE	37	11:19	30.8	80		SSE	19	1004.5	35.5	57		NNE	19	999.9
5/02/2017	Su	25.3	33.7	0			ENE	43	5:05	26.6	96		E	11	1003	31.3	76		WSW	11	998.8
6/02/2017	Mo	26.5	38.9	0	30.2					33.2	67	7	SE	19	1000	35.7	67		N	26	995.8
7/02/2017	Tu			12	10					31.4	49		SE	39							
8/02/2017	We			4.6	2.6																
9/02/2017	Th			14.4	5																
10/02/2017	Fr	24.3	31.1	9.2	3.6		NNW	31	11:31	27.6	97	7	ENE	11	1004.9	29.9	78		NNW	17	1003.1
11/02/2017	Sa	23.8	32.2	0			WNW	35	15:50	28.5	92	1	ESE	7	1008.8	31	72		NW	26	1007.3
12/02/2017	Su	24.2	33.2	0			WNW	41	13:49	28.8	80		SW	20	1010.8	31	73		NW	28	1008.6
13/02/2017	Mo	25.1	34.2	0	21.8		WNW	50	13:46	30.4	72	5	WSW	19	1009.9	33.1	70		WNW	37	1005.7
14/02/2017	Tu	26.6	33.5	0	9.6		NNE	69	14:03	31.8	86	5	WNW	11	1008.5	26.2	100	2	N	22	1009.1
15/02/2017	We	25.2	32.7	8.4	6		NNW	39	13:01	29.8	95	7	NE	13	1010.4	31	86		NNW	22	1007
16/02/2017	Th	26.9	35.8	0	5.6		NW	39	12:35	31.7	90	7	SW	11	1008.5	33.5			NW	28	1004
17/02/2017	Fr	27	37.3	0			ENE	56	12:01	31.8			E	31	1009.6	33.3			NNE	39	1007
18/02/2017	Sa	26.6	34.5	0			N	35	13:47	31			ENE	17	1012.3	32.6			N	24	1009.5
19/02/2017	Su	26.9	38.1	0			ENE	41	11:51	31.9			SSW	11	1011.8	37			N	15	1007.6
20/02/2017	Mo	25.5	38.8	0	31.6		NNE	37	14:31	32.8	38	1	NNE	13	1010.2	36.6			NW	20	1006.2
21/02/2017	Tu	24.3	35.5	0	9.6		NW	41	16:58	30.9	64	1	NNE	9	1010.6	33.3	66		NW	31	1007.2
22/02/2017	We	28.1	35.2	0	10		SSE	63	16:55	31.5	71	3	NW	15	1011.9	34.1			N	22	1008.2
23/02/2017	Th	24.9	39.7	6.4	8.6		E	41	14:34	32.6	60	1	SE	11	1012.9	38.7	24		E	19	1009.3
24/02/2017	Fr	25.2	42.8	0	11.4		ESE	35	10:10	34.4	22	2	SE	20	1012.7	41.6	17		E	17	1008.1
25/02/2017	Sa	25.6	42.2	0			E	48	11:59	36.5			ESE	30	1010.6	37.3			N	28	1007.5
26/02/2017	Su	27.5	36.2	0			ESE	72	20:26	33.1			ENE	26	1009.1	35.2			NE	26	1006.7
27/02/2017	Mo	23.2	33.9	4.6	34.6		E	46	8:28	29.1	67	3	E	31	1011.1	32.7			NNE	24	1009
28/02/2017	Tu	25.1	34.6	0	8		NNW	33	16:13	30.8	62	1	E	13	1010.7	32.5			N	24	1008.8
1/03/2017	We	26.5	37.6	0			NNW	31	14:26	33.3			SSW	11	1011.4	36.3			NW	20	1008
2/03/2017	Th	26.7	44.1	0			E	39	16:50	36.1			S	17	1009.2	41			NNE	13	1005.4
3/03/2017	Fr	25	44.1	0			ENE	48	13:28	36.3			ESE	20	1008.2	39.5			N	20	1004.8
4/03/2017	Sa	26.2	44	0			E	43	11:46	36.8			ESE	30	1008.4	40.3			NNE	26	1005
5/03/2017	Su	25.6	43.1	0			ESE	31	10:26	38.2			SE	19	1008.2	41.8			NNE	19	1004.2
6/03/2017	Mo	25.2	43.3	0			SE	43	9:01	37.5			SE	28	1006.6	40.6			N	20	1003.2
7/03/2017	Tu	27.7	36.1	0	78.8		SSW	52	18:58	34.3	40	5	NE	20	1006.3	34.8	50		N	24	1004.7
8/03/2017	We	24.6	35.5	0	12.8		WNW	37	18:00	31.4	39		NE	15	1009.4	33.9			NW	26	1005.3
9/03/2017	Th	25.6	39.1	0	9		NNE	39	14:13	33.9	46		ESE	15	1007.4	34.4	52		NNE	28	1003.9
10/03/2017	Fr	26.7	34	0	9.6		ENE	48	12:57	30.8	69		NE	13	1008.6	32.3			ENE	24	1007
11/03/2017	Sa	24.8	29.6	17.4			NE	43	8:03	25.6		8	NNE	24	1010.1	26.8			ENE	11	1009
12/03/2017	Su	25.1	33.6	4.8			WSW	43	15:35	29.4			ENE	13	1011.7	32.5			NW	24	1008.8
13/03/2017	Mo	26	33.9	0.2	14		NW	33	13:02	30.1	73	6	SW	9	1011.1	32.6	63		WNW	24	1006.2
14/03/2017	Tu	27	34.6	0	6		N	31	13:23	32	55	6	WSW	13	1010	33.5			NNW	26	1007.4
15/03/2017	We	26.6	35	0	7.6		NNW	26	13:13	32.3	56	6	ESE	7	1009.8	33.2			N	19	1007.6
16/03/2017	Th	27.1	36.3	0	6.6		NNW	33	14:33	31.5	73	5	SW	9	1010.8	34.9	55		NNW	24	1007.4
17/03/2017	Fr	24.9	38	13	10		NNE	46	4:32	27.6	87	7	W	17	1012.1	37.4			SSE	11	1007.4
18/03/2017	Sa	27.2	42.5	0.1			SE	39	8:52	35.2			SE	28	1010.6	42.2			SE	17	1006.1
19/03/2017	Su	27.8	40.2	0.1			E	43	2:32	35.2			SSE	22	1009.3	36.7			N	20	1006
20/03/2017	Mo	26.8	37.8	0	24.2		N	30	11:58	33.1	58	4	NNW	7	1008.6	37.3	41		NNW	17	1004
21/03/2017	Tu	27.7	35.2	0	8.6		E	43	6:16	32.3	55		ENE	17	1007.7	34	54		N	24	1005.1
22/03/2017	We	23.8	31.6	100.2			NE	70	15:12	24.1	100	8	ENE	15	1008.5	31	71		NE	26	1003.5
23/03/2017	Th	23.3	28.9	105			NE	94	12:57	25.3	100	8	ESE	24	1001.3	26	99	8	NNW	54	994.2
24/03/2017	Fr	24.7	32.3	63.2			WNW	39	1:40	28.8	81	7	W	22	1006.3	30.7	72	1	NNW	24	1004.6
25/03/2017	Sa	26	32.7	0			N	26	12:41	29.5	74		SW	9	1008.4	32.3	60		NNW	17	1005.6
26/03/2017	Su	26.2	35.2	0.4			SE	24	10:48	31.1	60		SSE	13	1008.4	34.8	52		NNE	11	1005.7
27/03/2017	Mo	27.2	32.9	0	15.4		NE	76	12:27	31.9	67	3	E	13	1010.8	27.8	80		ESE	13	1009.5
28/03/2017	Tu	25.1	32.6	1.2	3.6		E	48	8:55	29.7	70	3	E	35	1011.4	32.1	68		N	13	1007.6
29/03/2017	We	23.5	32.3	49.8			SSE	56	3:29	27.8	89	7	E	17	1011.4	31.4	71		N	17	1008.6
30/03/2017	Th	25.4	33.6	0	4.6		ESE	41	10:43	27.8	67	4	ESE	28	1014	33.1	54		E	13	1011
31/03/2017	Fr	26	35.1	0			ESE	35	9:16	31.3	46		ESE	20	1014.1	33.5	47		N	13	1011.2
1/04/2017	Sa	26.4	36.3	0			ESE	43	9:21	31.8	50		ESE	26	1013.5	36.1	28		SE	17	1010.3
2/04/2017	Su			0																	
3/04/2017	Mo		34.5	0	28					29	26	0	E	22		33.9	19		E	24	1012.8
4/04/2017	Tu	19.3	34.9	0	8.6		ESE	41	13:40	29.4	25	0	ESE	26	1015.7	34.5	17		ESE	22	1012
5/04/2017	We	18.5	34.8	0	8.2		ESE	46	8:58	29.3	23	0	ESE	31	1012.6	32.3	36		N	20	1009.1
6/04/2017	Th	18.4	34.6	0	9.2		E	33	9:11	29.1	24		ESE	22	1011.2	33	30		N	19	1008
7/04/2017	Fr	20.1	34.9	0	7.2		E	28	11:56	29.8	37	3	SE	7	1012	33.5	29		NNE	9	1009.2
8/04/2017	Sa	25.5	34.9	0						30.4	49		E	6	1012.8	34.2	34		NW	6	1011.2
9/04/2017	Su	25.2	37.5	0												37.4	19		ESE	26	1010.7
10/04/2017	Mo	25.5	36	0	22.4		SE	54	9:06	30.7	24	3	SE	28	1014.1						
11/04/2017	Tu	19.7	35.6	0	11.2		E	54	11:16	30.1	22	1	ESE	35	1013.5	35.4	21		E	22	1010
12/04/2017	We	18	34.4	0	9.4		E	44	11:35	29.9	23	1	ESE	26	1015.1	34	15		SE	19	1011.4
13/04/2017	Th	16.9	34.9	0			E	44	12:07	29.4	22		ESE	26	1015.2	34.6	11		E	20	1011.4
14/04/2017	Fr	18.9	35.9	0			E	46	11:13	30.1	22		ESE	24	1013.6	34.7	25		NE	28	1010.5
15/04/2017	Sa	21.3	30.8	0			E	43	9:23	28.8	43	7	E	26	1013.3	29.8	61	8	NE	22	1010

Date	Day	Temps		Rain	Evap	Sun	Max wind gust			9:00 AM						3:00 PM					
		Min	Max				Dir	Spd	Time	Temp	RH	Cld	Dir	Spd	MSLP	Temp	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
16/04/2017	Su	24.4	30.5	0			ENE	35	10:44	27.3	70	8	ESE	19	1011.9	29.4	71		NNE	28	1008.8
17/04/2017	Mo	24.8	30.1	0			NNE	37	23:07	28.5	68	4	ENE	17	1011.3	25	94	8	SSW	9	1009.2
18/04/2017	Tu	22.5	29.2	18.6	42.6		NNE	43	16:48	27.2	81	5	ENE	19	1010.6	26.1	97	8	E	13	1007.9
19/04/2017	We	21.8	30.8	19.2	2.6		NW	30	15:06	27.4	71	3	WSW	9	1012.4	30.1	53		NW	19	1010.6
20/04/2017	Th	20	30.4	0	4.2		NNW	26	14:04	27.1	73	1	SSE	6	1014.7	29.3	61		NNW	17	1012.3
21/04/2017	Fr	21.9	32.4	0	4.6		NNW	24	16:19	27.2	72		SSW	13	1015.8	31.7	58		NW	15	1011.8
22/04/2017	Sa	22.7	34.4	0			NE	26	13:12	28.9	62	2	SSE	13	1014.8	33.2	49		NNW	17	1011.1
23/04/2017	Su	23.7	34	0			NW	26	14:36	30	58		NNE	7	1014.1	33.1	49		NW	20	1010.9
24/04/2017	Mo	23.6	32.8	0	16.8		NW	30	16:51	28.9	71	2	SE	7	1014.6	31.1	62		NW	19	1011.1
25/04/2017	Tu	23.6	33.3	0			SW	30	8:55	28.9	65		SW	24	1014.6	31.8	49		SSW	17	1012
26/04/2017	We	25.2	32	0			ESE	39	10:57	27	57		ESE	24	1016	30.3	43		ESE	22	1013.2
27/04/2017	Th	21.6	32.8	0			ESE	46	9:36	27.5	31		ESE	28	1017.3	32.1	30		SE	19	1013.8
28/04/2017	Fr	20.8	32.9	0			ESE	39	9:06	27.1	35		ESE	26	1017.2	32.6	29		SE	13	1013.5
29/04/2017	Sa	19.3	32.2	0			E	39	8:59	26.9	32		E	28	1016.3	31.2	23		ESE	13	1013.7
30/04/2017	Su	17	32.3	0			ESE	33	11:52	26.6	28		ESE	19	1017	31.8	18		SSE	20	1013.1
1/05/2017	Mo	16.1	32	0			E	41	9:54	26.5	30		ESE	19	1017.5	31.4	17		ESE	17	1013.9
2/05/2017	Tu	15.8	32.3	0			ESE	50	8:54	26.7	28		ESE	33	1017.5	32.2	19		ESE	19	1014.2
3/05/2017	We	17.1	31.5	0			ESE	50	9:04	25.2	35		ESE	35	1018.6	31.3	22		E	19	1014.5
4/05/2017	Th	16.2	32.5	0			E	48	9:07	27.1	30		E	31	1017.9	30.4	34		NNE	20	1015
5/05/2017	Fr	17.2	31.7	0	9		ESE	33	8:19	27.7	31	0	E	22	1019.5	28.8	41		NNE	24	1016.6
6/05/2017	Sa	16.6	32.7	0			ESE	43	11:38	26.8	32		ESE	20	1020.3	30.9	30		NNE	19	1016.4
7/05/2017	Su	15.6	33.3	0			ESE	43	8:39	27.2	24		ESE	30	1019.9	32.8	19		SE	13	1015.6
8/05/2017	Mo	17.7	34	0	21.2		ESE	39	8:31	28.3	29	1	ESE	28	1017.6	32	33		N	20	1013.5
9/05/2017	Tu	18.1	32.7	0	6.4		E	33	9:15	28.4	32	0	ESE	22	1016.7	29.8	44		NNE	22	1013.7
10/05/2017	We	17.5	30.6	0	6.6		NNE	37	13:40	28.2	35	0	ENE	11	1016.7	28.3	54		NNE	20	1013.5
11/05/2017	Th	17.8	32.1	0	4.6		N	33	12:14	25.7	69	0	E	4	1016.4	28.9	55		NNW	20	1013.2
12/05/2017	Fr	16.7	33	0.2	4.4		S	26	11:31	24	79	0	S	9	1015.1	30.4	45		NNW	19	1011.5
13/05/2017	Sa	17.5	33.1	0			NNW	22	15:27	26.2	59		SSE	9	1014.7	31.8	29		NNW	15	1012.2
14/05/2017	Su	15.6	31.5	0			NNE	31	15:22	27.1	43		ESE	13	1015.4	29.6	35		NNE	20	1012.7
15/05/2017	Mo	14.8	31.4	0	15		N	24	13:11	25.2	44	0	SE	9	1014.3	30.4	22		NNW	17	1011.1
16/05/2017	Tu	16.3	30.4	0	4.2		NNW	30	14:01	23.8	62	0	SW	6	1014	28.9	49		NW	20	1010.8
17/05/2017	We	17.6	31	0	5.2		ESE	43	8:53	25.4	34	0	ESE	31	1014.5	30.8	26		ESE	15	1011.8
18/05/2017	Th	16.4	30.1	0	10.8		ESE	46	8:41	24.4	29	0	ESE	30	1017.8	29.3	24		SE	11	1014.7
19/05/2017	Fr	14.6	28.9	0			E	39	10:28	23.6	33		E	24	1017.7	26.8	33		NNE	17	1013
20/05/2017	Sa	13.4	28.5	0			NNE	24	14:14	21.8	56		NE	7	1014.6	27.7	31		N	17	1010.7
21/05/2017	Su	16	31.3	0			NNW	28	14:06	26.2	55		WSW	17	1012.2	29.6	31		NNW	22	1009.6
22/05/2017	Mo	16.7	31.2	0	22.6		SE	39	8:58	25.5	37	0	SE	22	1016	30.5	29		NNE	13	1012.5
23/05/2017	Tu	15.4	31.9	0	6.2		ESE	48	9:28	25.5	35	0	ESE	30	1017	30.8	34		NNE	17	1013.3
24/05/2017	We	16.4	33.4	0	6.8		ESE	37	9:38	26.2	34	2	ESE	24	1016.6	32.1	27		NNE	19	1012.4
25/05/2017	Th	19.1	33.8	0	6.2		ESE	31	9:13	27.9	32	2	SE	20	1015.8	31.5	39		NNW	15	1012.4
26/05/2017	Fr	19.3	34.4	0	5.4		E	28	12:02	27	44	0	SSE	15	1015.6	33.2	29		N	17	1011.6
27/05/2017	Sa	21	33.7	0			SW	37	0:47	28.3	36		E	13	1014.3	33.1	24		N	15	1011.4
28/05/2017	Su	17.3	32.3	0			ESE	33	10:23	26.3	42		SE	19	1015.9	31.6	28		SE	19	1013.2
29/05/2017	Mo	16	31.1	0	19.4		SE	37	9:28	23.3	49	2	SE	26	1017.8	30.7	25		SE	15	1014.7
30/05/2017	Tu	16.5	31.9	0	7		SSE	30	8:41	23.8	43	3	SSE	20	1018.1	29.9	34		NNE	20	1015.1
31/05/2017	We	18.2	31.7	0	5.8		ENE	50	12:58	26.6	32	1	E	26	1019.1	29.1	41		NNE	30	1017.3
1/06/2017	Th	17.6	31.3	0	8.8		ESE	61	14:21	25	29	0	E	33	1021.9	30.6	16		ESE	33	1017.3
2/06/2017	Fr	11.8	28.2	0	11.2		ESE	44	11:48	22.2	25	1	ESE	28	1022.8	27.5	15		ESE	24	1017.5
3/06/2017	Sa	10.4	29	0			ESE	46	9:12	21.8	18		ESE	28	1021.1	28.4	11		SSE	22	1016.6
4/06/2017	Su	12.1	28.5	0			SE	41	10:51	22.1	18		ESE	26	1019.8	28	13		ESE	20	1015.5
5/06/2017	Mo	14.1	29.9	0			ESE	57	9:01	22.4	23		ESE	41	1018.5	29.7	17		E	26	1014.9
6/06/2017	Tu	14.9	30.7	0	36.8		E	50	9:25	23.2	21	0	E	33	1019.3	28.4	24		N	17	1016
7/06/2017	We	16.1	29.8	0			E	43	11:55	24.1	22		ESE	30	1020.5	26.6	31		NNE	19	1017.2
8/06/2017	Th	12.2	28.2	0			ESE	46	9:15	21.7	15		ESE	31	1021.3	27.8	11		E	17	1017.7
9/06/2017	Fr	13.7	27.7	0			E	52	11:08	21.3	19		ESE	37	1021.9	27.2	10		E	26	1018.2
10/06/2017	Sa	10.5	27.7	0			ESE	50	13:38	20	21		ESE	31	1022.6	23.9	34		NNE	20	1018.7
11/06/2017	Su	13.4	27.1	0			E	54	10:17	19.9	21		E	30	1021.6	23.9	36		N	17	1017.4
12/06/2017	Mo	10.4	26.4	0			E	46	9:37	20.6	20		E	33	1019.5						
13/06/2017	Tu	15.4	27.9	0			E	37	9:22	21.8	22		E	26	1018.8	24.4	43		NNE	22	1016.1
14/06/2017	We	13.6	29	0			ENE	37	11:59	23.4	25		E	26	1019.3	25.6	41		NNE	24	1015.9
15/06/2017	Th	14.8	29.8	0			E	33	10:08	23.1	30		ESE	19	1019.3	26.4	30		N	20	1016.2
16/06/2017	Fr	14	30.7	0			ESE	41	9:35	24.3	26		ESE	22	1018.8	27.5	30		N	19	1015.3
17/06/2017	Sa	14.2	31.4	0			ESE	46	9:13	25.4	20		ESE	30	1019.4	30.9	14		E	28	1016.3
18/06/2017	Su	15.5	31.1	0			E	50	11:39	24.1	29		ESE	31	1019.7	30.6	17		E	30	1015.3
19/06/2017	Mo	16.8	29.7	0			E	44	9:05	23.8	28		ESE	31	1020.2	29	19		SE	17	1015.4
20/06/2017	Tu	14.9	29.5	0			ESE	33	10:02	23.6	27		SE	20	1018	27.4	32		N	19	1014.6
21/06/2017	We	14.1	29.7	0			NNE	24	12:56	23.4	35		SE	15	1017.2	28.6	29		NNE	19	1014
22/06/2017	Th	15.9	30.5	0			NNW	24	16:46	25.1	37		SE	9	1017.2	29.1	33		NNW	17	1013.7
23/06/2017	Fr	16	27.7	0			NNE	24	13:19	25	71		ESE	6	1016	26.1	53		N	15	1012.5
24/06/2017	Sa	18.5	27.6	0			W	26	11:20	23.3	52		WSW	7	1014.5	24.7	52	5	NNW	19	1011.4
25/06/2017	Su	14.5	28.1	0			W	26	12:13	20.2	52	3	WSW	13	1014.7	25.8	41		NW	20	1011.2
26/06/2017	Mo	13.5	27.7	0			SE	39	8:50	20.3	63		SE	28	1016.8	26.5	34		SE	15	1013.9
27/06/2017	Tu	13.2	26.6	0			SE	43	8:28	18.7	58		SE	30	1019.9	26.1	31		SE	19	1015.9
28/06/2017	We	13	25.1	0			SE	57	9:32	17.9	42		ESE	35	1022.3	25	23		SE	24	1018.3
29/06/2017	Th	12.1	24.8	0			ESE	52	8:54	17.4	44		ESE	37	1023.1	24.5	25		SE	26	1017.8
30/06/2017	Fr	10.4	25.9	0			E	35	10:26	18.4	47	7	SE	15	1019.1	24.3	54	1	NNE	19	1014.8

10 References

1. Australian Census 2016 (Australian Bureau of Statistics).

2. "Port Hedland Air Quality Health Risk Assessment for Particulate Matter", January 2016, http://ww2.health.wa.gov.au/Reports-and-publications/Port-Hedland-Health-Risk-Assessment, retrieved 20-12-2017

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