Inhalable Particulate ($PM_{2.5}$) Regional Monitoring Programme Report 2016-2020

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Executive summary

Section 35 of the Resource Management Act (RMA) requires local authorities to undertake monitoring of the region's environment, including land, air, and fresh and marine water quality. The inhalable particulate component of the State of Environment Monitoring (SEM) programme for air quality in Taranaki was initiated by the Taranaki Regional Council in the 1999-2000 monitoring year, with subsequent monitoring occurring on a periodic basis up to 2010 in various representative locations, reflective of the overall low level of anthropogenic sources and high air quality in the region.

This report describes the monitoring programme implemented by the Council to assess the quality of the ambient air in the New Plymouth CBD throughout the period 2016-2020, and the results of that work. While this is the fifth inhalable particulate monitoring programme undertaken in the Taranaki region, and fourth within the New Plymouth CBD, it is the first continuous and extended monitoring programme for $PM_{2.5}$ (particulate matter less than 2.5 microns across) undertaken in the region. The decision was made by the Council to monitor for $PM_{2.5}$ in lieu of PM_{10}, in anticipation that the next revision of the National Environmental Standards for Air Quality will include $PM_{2.5}$, since such data is more meaningful for evaluating public health risk than the current PM_{10} standard.

The monitoring programme entailed the sampling of air using a Beta Attenuated Monitor (BAM) equipped with a $PM_{2.5}$ size selective inlet, sited at Central School, New Plymouth. Continuous sampling was conducted for over the period February 2016 – April 2020. The Council also undertook analysis of filters used during the monitoring, to further investigate the likely origins of suspended particulate matter collected during the sample period.

Following MfE ambient air quality categories, applied to World Health Organisation (WHO) $PM_{2.5}$ thresholds, the monitoring showed that 96% of daily mean $PM_{2.5}$ concentrations fell into the Ministry's 'excellent' or 'good' air quality categories, while all days monitored met the 'acceptable' category. There were no exceedances of WHO's daily mean threshold, with the maximum individual daily mean recorded over the entire dataset being 14 $\mu g/m^3$. An annual mean of 4 $\mu g/m^3$ was recorded for each full year of the monitoring period, or 40% of the threshold of 10 $\mu g/m^3$ set by WHO.

Both filter analysis, and a comparison of monitoring results with meteorological conditions, indicate that marine aerosols are the major source of $PM_{2.5}$ in the region. Emissions from domestic fires used for heating are also a major contributor to concentrations of $PM_{2.5}$ levels during winter months in some localities, with levels being exacerbated by atmospheric conditions on calm evenings. The elevated levels of $PM_{2.5}$ recorded during colder winter months result in a clear seasonality in the overall dataset.

The monitoring showed that $PM_{2.5}$ concentrations are higher in the presence of moderate to strong prevailing onshore winds, with sea-salts prevalent on the analysed filters in such conditions. These findings agree with previous inhalable particulate surveys undertaken in New Plymouth, which found marine aerosols to be a major source of particulate matter in the region.

Long-term trend analysis undertaken on the monitored data shows no evidence that overall $PM_{2.5}$ concentrations in the region are either increasing or decreasing.

An analysis of $PM_{2.5}$ levels throughout the Covid-19 lockdown in March-April 2020 shows no evidence for a decrease in $PM_{2.5}$ levels due to a decrease in anthropogenic sources such as traffic. It is hard to reach firm conclusions on this, however, due to the low concentrations of $PM_{2.5}$ being analysed, and the short period of the lockdown sampled.

Overall, these results, and all regional monitoring to date, show that Taranaki has very clean air, and on a regional basis there are no significant pressures upon the quality of air as a resource. Recommendations for future monitoring and investigations are listed in Section 7.

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1 Introduction

1.1 General

The *Resource Management Act 1991* (RMA) established new requirements for local authorities to undertake environmental monitoring. Section 35 of the RMA requires local authorities to monitor, among other things, the state of the environment of their region or district, to the extent that is appropriate to enable them to effectively carry out their functions under the Act.

To this effect, the Taranaki Regional Council (the Council) has established a suite of state of the environment monitoring (SEM) programmes for the region. These programmes are outlined in the Council's 'State of the Environment Monitoring Procedures Document', which was prepared in 1997. The monitoring programmes are based on the significant resource management issues that were identified in the *Council's Regional Policy Statement for Taranaki (1994)*.

The SEM programmes are made up of a number of individual monitoring activities, many of which are undertaken and managed on an annual basis (from 1 July to 30 June). For these annual monitoring activities, summary reports are produced following the end of each monitoring year (i.e., after 30 June). Where possible, the compliance monitoring of individual consents has been integrated within the SEM programme to save duplication of effort and minimise costs. The purpose of annual SEM reports is to provide a regular summary of regional environmental monitoring activity results for the year, and provide an interpretation of these results, together with an update of trends in the data.

Annual SEM reports act as 'building blocks' towards the preparation of the regional state of the environment report every five years. The Council's first, or baseline, state of the environment report was prepared in 1996 (TRC, 1996), summarising the region's progress in improving environmental quality in Taranaki over the past two decades. The second report (for the period 1995-2000) was published in 2003 (TRC, 2003). Data spanning the ten year period 1995 to 2005 have been used in the preparation of a trend report (TRC, 2006). The third State of the Environment report (for the period 1995 to 2007) was published (TRC, 2009) and included trend reporting and the fourth report (for the 1995 to 2014 period) has been published (TRC, 2015). The provision of appropriate computer software statistical procedures allows regular reporting on trends in the environmental quality over time, in relation to Council's ongoing monitoring activities, now that there has been an accumulation of a comprehensive dataset of sufficient duration to permit a meaningful analysis of trends (i.e. minimum of 10 years).

This report summarises the results for the Inhalable particulate ($PM_{2.5}$) SEM programme over the 2016-2020 monitoring period. This is the first report on the Council's continuous $PM_{2.5}$ monitoring programme, which was initiated in 2016. In total, this is the fifth inhalable particulate monitoring programme undertaken in the Taranaki region, and fourth monitoring run undertaken within the New Plymouth CBD since the inhalable particulate component of the SEM programme was initiated by Taranaki Regional Council in 1999-2000.

1.2 Background

1.2.1 The National Environmental Standard for Fine Particulates

In October 2004, the National Environmental Standards for Air Quality (NES-AQ) were released by the Ministry for the Environment (MfE). The NES is built up of 14 standards, which together aim to set a guaranteed minimum level of health protection for all New Zealanders. One aspect of air quality which is covered by the NES, and forms the focus of this report, is fine particulates, which can pose a health hazard when inhaled into the body.

Particulate matter found in the air can originate from a wide variety of sources, both natural and anthropogenic. In general, the most prevalent anthropogenic sources of particles are emissions from combustion processes, for example: motor vehicle emissions, solid and oil-burning processes (e.g. from industry or power generation), incineration and burning of waste, and domestic wood-fires. Higher concentrations of these particles typically manifest themselves in forms such as smoke, photochemical smog, or haze. Natural sources, such as sea-spray and pollen, also contribute to overall levels.

Air-borne particles vary greatly in size, with the posed health risk increasing with smaller particulate size. The scientific short-hand used to describe small airborne particles is in the form PMn, where 'PM' =Particulate Matter, and 'n' represents the maximum diameter of the particles in question, expressed in microns (millionths of a metre, or µm). While relatively coarse particulate matter of 2.5-10 µm diameter may deposit in the nose, throat and upper airways, finer particulates of less than 2.5 µm can be inhaled deeper into the lungs, where air-blood exchange occurs. Ultrafine particles, of less than 0.1 µm diameter, are smaller enough to transfer into blood vessels and circulate around the body. While coarser particulates settle on the ground relatively quickly, fine and ultrafine particles can remain suspended in the air for extended periods of time. Short term episodes of exposure to PM pollution has been shown to correlate with increased adverse medical outcomes for heart, respiratory and circulation conditions (eg asthma, emphysema, heart attack, strokes); over the longer term, increased concentrations correlate with increased cancer rates and premature death rates as well as chronic effects of the sorts outlined above. Evidence has already emerged from medical studies during the covid-19 pandemic, of a strong correlation between areas of higher concentrations of fine suspended particulate and higher rates of mortality from covid-19 infection.

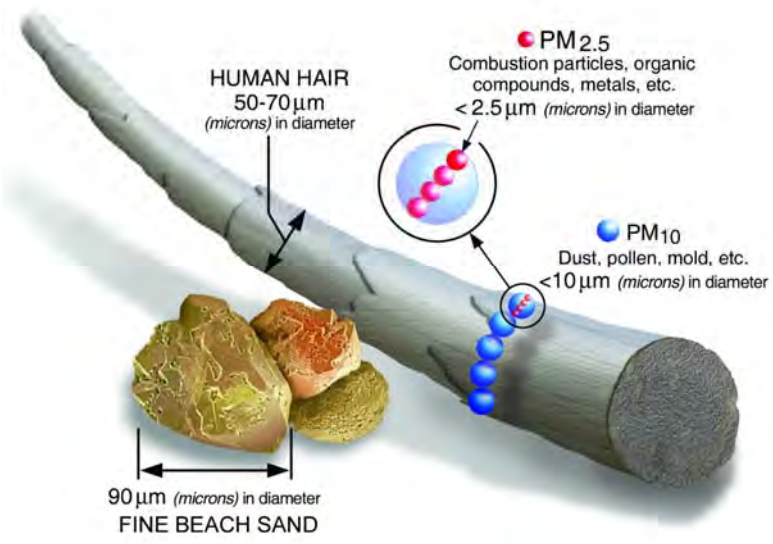

Figure 1 Comparison of PM sizes. Image retrieved from https://www.epa.gov/pm-pollution/particulate-matter-pm-basics June 2020.

In order to avoid such effects, in 2004 the MfE set a NES-AQ for PM_{10} of 50 µg/m^3 (24-hour average), with 1 permissible exceedance per year. In addition, the National Ambient Air Quality guideline for PM_{10} is an annual average of 20 µg/m^3 or less. Previous monitoring by Taranaki Regional Council has focused on PM_{10} levels, in line with the NES-AQ. However, even by 2004 the science had already advanced well beyond the setting of standards that were based on PM_{10} measurements. It was widely recognised that the critical fractions of particulate matter for the protection of human health were those that were even smaller- $PM_{2.5}$ or below. With evidence growing for the increased health hazards posed by even smaller particulates, there is a growing push for monitoring of $PM_{2.5}$. A decision was thus made by the Council to set up a continuous monitoring programme for $PM_{2.5}$ in anticipation that the next revision of the NES-AQ will include $PM_{2.5}$ and that in any case such data is more meaningful for evaluating public health risk in the region.

While there are currently no national standards for $PM_{2.5}$, the World Health Organization (WHO) guidelines can be used for assessing the significance of $PM_{2.5}$ monitoring results (MfE, 2020). These are given in Table 1, along with permissible exceedances per year.

Table 1 WHO guidelines for $PM_{2.5}$ monitoring

Threshold concentration ($\mu g/m^3$)	Averaging Period	Permissible Exceedances (per year)
25	24-hours	3
10	Annual	NA

1.2.2 Previous monitoring of inhalable particulates by the Council

To date, Taranaki is one of two New Zealand regions that have never exceeded national air quality standards. As a result of this, the region has never been required to create a 'gazetted airshed' in response to air quality issues, and ongoing National Environment Standard monitoring is not mandatory in Taranaki, as it is in other parts of New Zealand with air quality issues. Regardless of this, the Council has continued regional air quality monitoring, in order to confirm and demonstrate that the region does not generally experience issues with air quality. With air discharges from industry and agriculture well regulated and no widespread change in the nature of regional emissions, there are no significant pressures on air quality in the region.

Since the inception of the inhalable particulate section of TRC's SEM programme in 1999-2000, there have been three inhalable particulate PM_{10} monitoring runs carried out in central New Plymouth; in 2000, 2003 and 2010. In addition, there has been intermittent monitoring of air quality at various sites throughout Taranaki, used in each case to assess the impact of events such as construction work or increased traffic movement. Central New Plymouth has been used as the location for each SEM monitoring run to date, as it represents the largest urban area, with the greatest concentration of industry and traffic, in the region. Sites for monitoring PM_{10} levels have thus been selected in the past as to represent 'worst case scenarios' for air quality, on order to best provide direction with respect to guiding future air quality management programmes.

As ongoing NES monitoring has not been mandatory in Taranaki, sampling periods, protocols and methodologies have varied between previous monitoring runs, and have not always been consistent with those laid out in the 'Good Practice Guide for Air Quality Monitoring and Data Management 2009'. The primary purpose of previous surveys has been to give an indication of the state of the region's air quality, using a screening approach, in order to determine if there is any justification for further investigations using the much more expensive techniques stipulated in the NES. The results of the three SEM runs that have been undertaken in New Plymouth are given in Table 1, and show that New Plymouth has had no significant air quality issues in relation to PM_{10} when compared to the NES guidelines.

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Table 2 Summary of results from previous SEM PM_{10} monitoring runs. (the NES for annual/24-hour average is 20/50 µg/m^3)

Site Identification and Description	Monitoring Period	Average PM_{10} Level (µg/m^3)	Range in Daily Average (µg/m^3)
New Plymouth: TSB Bank, CBD (urban)	January – May 2010	16	5 - 47
New Plymouth: NPDC office, CBD (urban)	May – October 2003	12.0	0.6 - 30.9
New Plymouth, Unichem Pharmacy, Devon-Currie St (Urban)	March – April 2000	9.6	0.7 - 26.0

While the results of these three previous PM_{10} monitoring runs are not directly comparable, due to the different method and protocols employed, some general results are consistent across all runs. Firstly, it is noted that there have been no exceedances of NES for PM_{10} in any of the runs. There are however, significant variations in air quality depending on the prevailing wind direction. Results from all three surveys have indicated that PM_{10} levels are elevated when there is a stable onshore wind, with sea salt spray found to be a major contributing source. In contrast, correlation analysis of the 2003 survey suggested that there was no significant relationship between traffic volumes and PM_{10} concentrations. This is, perhaps, not so surprising given that PM_{10} levels in New Plymouth reflect a coastal environment, which may mask any underlying subtle variation due to relatively moderate traffic levels. However, a move to monitoring $PM_{2.5}$ levels rather than PM_{10} allows a closer examination of whether there is a traffic-related trend, given that the particulate matter resulting from traffic is generally smaller in size than that from sea-spray.

1.2.3 New Plymouth: geographic and meteorological setting

Located on the west coast of the North Island of New Zealand, the Taranaki region has an area of 723,610 square kilometres, and a population of 117,561 (2018 Census). The geography of the region is dominated by a large ring plain which surrounds the conical volcano, Mt Taranaki. The region is bordered to the east by remote hill country, while comparatively small areas of marine terraces and coastal sand country are found in the south and north of the region.

New Plymouth, with a population of around 60,000, is the region's only major city, with other smaller settlements found along the coast and around the ring plain. While the population of Taranaki, and in particular, New Plymouth, is on the increase, the region as a whole remains relatively sparsely populated. The foreshore of New Plymouth is dominated by retail and commercial areas, with residential areas spreading up the rising ground on the inland side of the city.

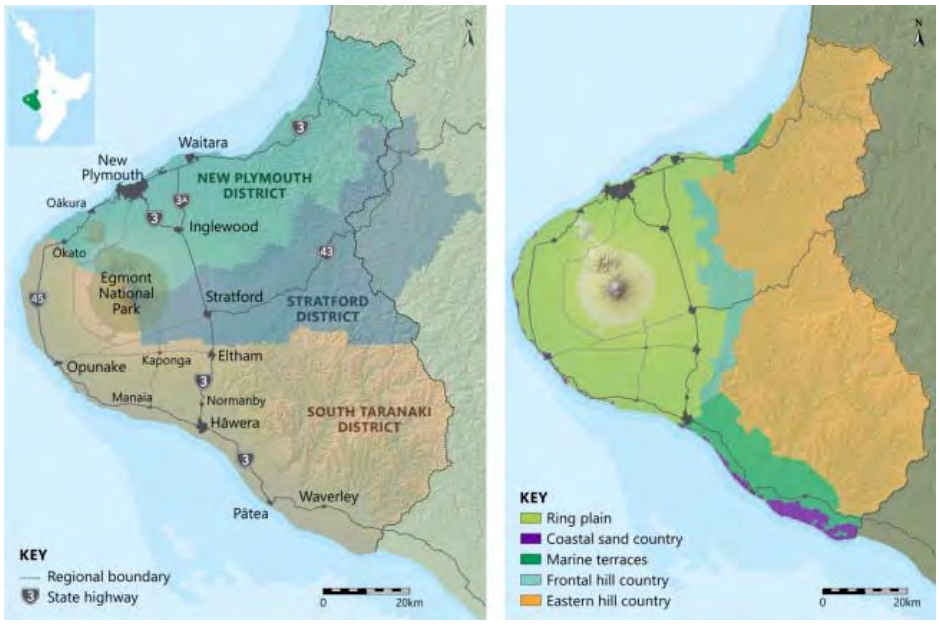


Figure 2 Left: Districts and settlements of the Taranaki region. Right: Major landforms of the Taranaki Region

Taranaki's climate is largely determined by its exposed position on the west of the North Island. Here, it lies in the path of weather systems as they migrate over the Tasman Sea before moving inland. As a result, the region is one of the windiest in New Zealand, while having a maritime climate of moderate temperatures and regular rainfall throughout the year. In New Plymouth, Westerly and South-Easterly winds dominate. South-Easterly winds are predominantly dry, and arise due to a combination of the deflection of southerly winds around Mt Taranaki, the south-easterly drainage of cold air from the slopes of the mountain, and night-time land breezes (Chappell, 2014), together with the downwind effects of low pressure systems moving across the South Island.

Rainfall patterns across the Taranaki region are closely related to elevation and exposure to the rain-bearing Northerly to Westerly winds. As a result, average annual rainfall varies from around 1000 mm on the Southern coast, to 2400 mm on the highest points of the ring plain, around Stratford. New Plymouth averages around 1500 mm of rainfall per annum.

2 Monitoring methodology

2.1 Introduction

Section 35 of the RMA sets out an obligation for the Council to gather information, monitor, and conduct research on 'the state of the whole or any part of the environment of its region'.

The Taranaki region has a well-established record of excellent air quality, and monitoring of both industry and other consent holders enables the Council to anticipate whether any changes in overall air quality can be expected. In the past, the Council has demonstrated that the region continues to meet the NES for inhalable particulate by undertaking PM_{10} monitoring approximately every 5 years.

The purpose of the monitoring is to provide information, on the regional level, of inhalable particulates, to the MfE's environmental monitoring and reporting programme. In anticipation of a revision to the NES for inhalable particles, $PM_{2.5}$ levels were monitored for the current monitoring run, instead of PM_{10}. The data gained by the Council from the monitoring programme is robust, defensible, and of the high quality required to support and inform the Council in decisions regarding air quality management policies and practice.

2.2 Site location

Site selection was made following the guidance of *AS/NZS 3580.1.1:2016 Ambient Air-Guide for the siting of sampling units* as closely as possible. Given the general topography and setting of the Taranaki, site selection for air quality monitoring on a regional scale is not straight forward. As illustrated in Figure 2 and Figure 3, the general topography of much of the region conically slopes from Mt Taranaki outward to the coast, with many sheltered stream and river valleys. The influence of this relief on wind patterns is such that, regionally, there are not many natural air sheds. The NES for air quality stipulate that monitoring must be undertaken where people may be exposed, and where the standard is breached by either the greatest margin, or most frequently. Given that New Plymouth is the largest urban area in the region, and has the highest concentration of industry and traffic (even though only moderate intensity by national comparison), a central city site location was selected as most suitable to give information on the 'worst case scenario' for $PM_{2.5}$ levels and exposure in the Taranaki region. The North-East corner of Central School, on the corner of Lemon and Gover streets, was chosen as a suitable location for the $PM_{2.5}$ monitoring site. The Central School site, shown in Figure 4 and Figure 5, is centrally located, with the edge of the New Plymouth CBD and main traffic routes 100-200 m to the north, and residential area surrounding the site to the south, west, and east. The site is located at the 'crossroad' of the prevailing wind directions from the west and south-east, lying in the path of air flows that have either just passed over, or are about to impinge, on residential areas. The site is thus located in a sensitive area, which is exposed to possible $PM_{2.5}$ emissions from traffic, commercial, and residential sources.

The TRC received written approval from Central School's board of trustees on the 26th August 2015 for installation of the monitoring station, with installation carried out on 26th of February 2016. A further memorandum of understanding with regard to the ongoing operation of the monitoring site was signed between TRC and Central School Te Kura Waenga O Ngāmotu, (Appendix I), on 8th October 2018. In addition to the monitoring station, the TRC also installed a surveillance camera facing the monitoring station to reduce any chances of vandalism. The camera has also proved useful for investigating possible nearby sources of spikes in $PM_{2.5}$ levels.

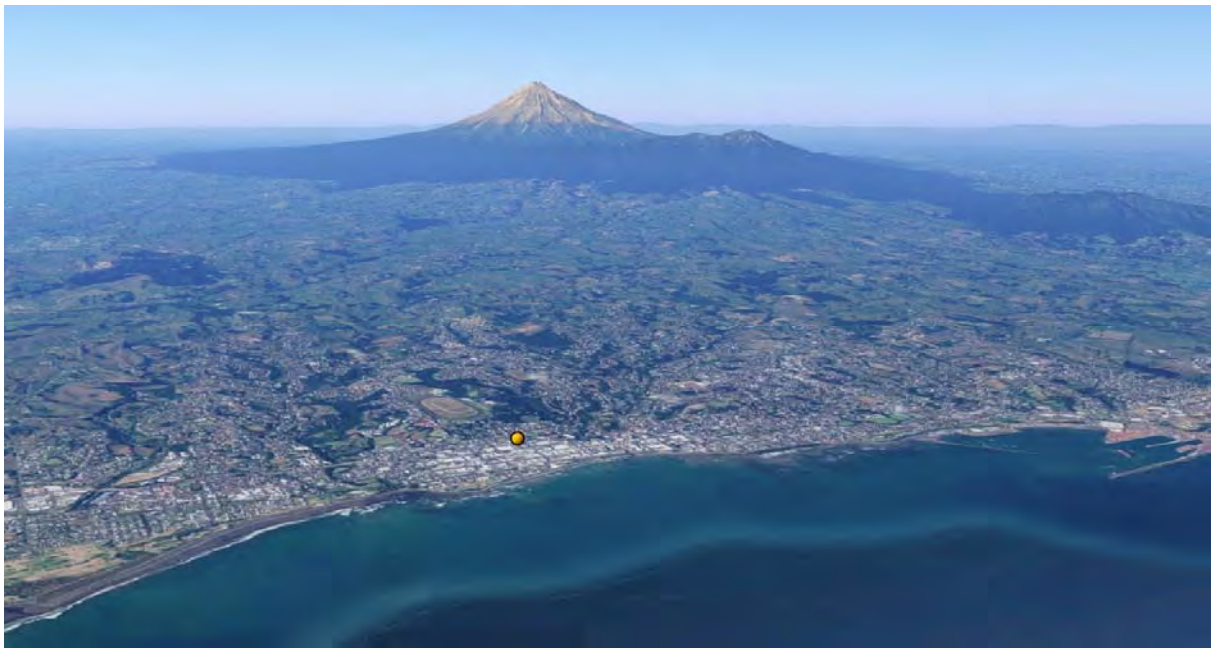


Figure 3 Overview of the regional setting of the Central School $PM_{2.5}$ monitoring site (yellow dot). The image is taken facing true South. (Background image: Google, 2020)

Figure 4 Location of the Central School $PM_{2.5}$ monitoring site within New Plymouth

Figure 5 Location of the $PM_{2.5}$ monitoring site in the NE corner of Central School (yellow dot)

2.3 Monitoring equipment and method

The United States Environmental Protection Agency (USEPA) categorises particulate monitoring methodologies as either reference, or equivalent methods. Reference methods are gravimetric, where direct measurements of the weight of the collected sample are taken. Equivalent methods are alternative methodologies that have been certified as giving results equivalent to the reference method.

A Beta attenuation monitor (BAM), is one such recognised equivalent method. Here, a measured amount of ambient air is vacuum pumped through a paper-band filter. The concentration of particulate matter is then determined by measuring the decrease in radiation intensity between a constant beta source on one side of the filter, and a sensitive scintillation detector on the other side. The mass concentration of particulate matter on the filter is proportional to the decrease in beta radiation count, and can be calculated via the Beer-Lambert law. From this, the volumetric concentration of particulate matter in the ambient air can be determined.

In this survey, a Met Instruments Inc. Model E-BAM measurement system (Figure 6) was used to automatically measure and record airborne $PM_{2.5}$ concentration levels at the selected study site. While the beta attenuation method is one of four general recognised equivalent methods for $PM_{2.5}$ monitoring, the E-BAM system employed is not currently designated as a US EPA Federal Equivalent Method (FEM). It was, however, deemed to be the most appropriate instrument to use in this case, given that this monitoring programme represents a first test both of continuous monitoring at a permanent ambient air site, and of SEM $PM_{2.5}$ monitoring in the region. Although the E-BAM system is not an FEM, it is designed to accurately predict FEM concentration measurements, with a comparative study between the E-BAM and BAM instruments showing that, if anything, the E-BAM overestimates PM levels, when in humid conditions (Schweizer et al. 2016).

The E-BAM instrument was operated and configured during this monitoring programme as per the requirements detailed in:

- *AS/NZS 3580.1.1:2016 Ambient Air-Guide for the siting of sampling units*
- *AS/NZS 3580.9.12:2016 Methods for sampling and analysis of ambient air; Determination of suspended particulate matter – $PM_{2.5}$ beta attenuation monitors*
- *MfE Good Practice Guide for Air Quality Monitoring and Data Management 2009*
- *E-BAM Particulate Monitor Operation Manual*

The E-BAM was set up to sample ambient air through a size-selected $PM_{2.5}$ inlet.

Figure 6 E-BAM set-up and instillation at Central School, New Plymouth

2.4 Data collection and processing

2.4.1 E-BAM measurements

Two records of $PM_{2.5}$ concentration are measured simultaneously by the E-BAM unit: the first a quasi-real-time record consisting of 10-minute averages of the E-BAM's constant 1-minute measurements, and the second, a higher accuracy measurement taken on an hourly cycle.

The 1-hour measurement record is used for all analyses carried out in this report due to its higher level of accuracy and lower detection limit when compared to the 10-minute averaged measurements. The hourly concentration measurement is based on two 4-minute long beta counts, one at the beginning, and the other at the end of each sample hour. The two counts are used to calculate the particulate mass that has accumulated on the filter tape within the hour. This measurement is combined with measurements of the internal air flow taken throughout the hour, to determine particulate concentration.

While the 10-minute averaged measurements gives a quasi-real-time record of $PM_{2.5}$ concentrations, it has both a lower accuracy, and higher detection limit compared to the hourly measurements. This is due to the small amount of particulate which deposits on the filter tape during each short sampling time, along with the comparatively small volume of air that is sampled for each measurement. The 10-minute average record is useful, however, in helping identify periods of unscheduled data loss, and pinpointing anomalous events in the data record.

In addition to $PM_{2.5}$ concentration and airflow, the E-BAM unit is equipped with sensors to measure air temperature, relative humidity and air-flow through the measurement unit, with data recorded every 10 minutes. A separate ambient air temperature sensor was also set up at the monitoring site, while rainfall and wind data was collected at the nearest, best-fitting, meteorological site, as detailed in Section 2.5. All data from the E-BAM and associated sensors was recorded to an external on-site data logger with telemetry sent directly to TRC, where a complete database was compiled.

Maintenance and servicing of the E-BAM was undertaken to the guidelines given in the *E-BAM Particulate Monitor Operation Manual*. Notes on all maintenance and service were inserted directly into the central database. In accordance with the *MfE Good Practice Guide for Air Quality Monitoring and Data Management 2009*, data collected during calibration and maintenance period was removed, including sufficient time for instrument stabilisation. Data screening was also undertaken, with data removed for periods where the E-BAM air-flow rate dropped by more than 5% from its usual steady state of 16.7 L/min. Spikes in $PM_{2.5}$ levels were also investigated, with data removed when the spike was found to be due to monitor malfunction, or other anomalous events – such as when it was found people were smoking directly underneath the monitoring equipment.

In line with *MfE 2009,* negative data values were left in the data record. This is particularly important given the generally low ambient concentrations of $PM_{2.5}$ measured, as there were a notable number of hourly measurements with $PM_{2.5}$ concentrations between 0 and -5 $\mu g/m^3$. These measurements are, within analytical uncertainty, indistinguishable from the lower detection limit of the E-BAM, so were retained in the overall data set as to avoid artificially increasing the average ambient concentration. The exception to this was between midnight and 01:00 each day, when the E-BAM automatically undertook a filter change and recalibration. Here, a large negative spike was consistently encountered in the record. The decision was made to omit the 24:00 to 01:00 hour from daily average calculations, resulting in 23-hour averages been calculated, rather than 24-hour.

All hourly averages in the main database apply to the preceding hour (e.g. the hourly measurement for 13:00 represents data collected between 12:00 and 12:59). However, for compatibility reasons, all measurements were stepped back one hour when imported into R software. Thus in all plots and statistics in this report, data assigned to e.g. 13:00 is for the time period 13:00 to 13:59. All measurements are recorded and reported in NZST.

2.4.2 Filter analysis

In order to further investigate what different sources could be contributing to $PM_{2.5}$ levels at the monitoring site, the Council sought to have selected filters, collected from the E-BAM monitor at various times throughout the monitoring period, analysed for elemental composition. The analysis of the morphology and atomic % elemental composition of seven samples, including a blank, was undertaken by scanning electron microscopy at the Research Centre for Surface and Materials Science, University of Auckland. The results of the filter analysis are compared to site $PM_{2.5}$ levels and meteorological conditions recorded on each associated day. The full report from the University of Auckland is presented in Appendix II.

2.5 Meteorological data

In order to investigate the correlations between $PM_{2.5}$ levels and different meteorological conditions, data, including rainfall, wind direction and wind speed, was recorded throughout the duration of the monitoring programme. Meteorological data was obtained from two stations; New Plymouth Waste Water Plant (prior to 6th May 2017) and Hillsborough (after 6th May 2017). The stations lie approximately 4 km north-east and 5 km east away from the Central School monitoring site respectively (Figure 7). The location of the meteorological station was changed mid-way through the survey, from the exposed coastal location of the Waste Water Treatment Plant, to the more in-land location of Hillsborough, in order to be more representative of a number of the Council's survey sites. Data from both stations were recorded simultaneously for a period, in order to ensure consistency between the two sites, before the Waste Water Plant station was decommissioned. South-easterly and west to south-westerly winds dominate in the study area (Figure 8), with westerly winds bringing the majority of rainfall (Figure 9). It should be noted in Figures 7 and 8 that the convention is to show the direction **from** which the wind has come.

Figure 7 Location of Meteorological Stations with respect to the Central School monitoring site

2.6 Data analysis methods

All statistical analyses and plots produced in this report were undertaken and produced using the R statistical software (R Development Core Team. 2011), using the package 'openair' (Carslaw and Ropkins. 2012).

The Theil-Sen approach was used to explore for any long term trends in the overall data record. This was carried out using de-seasonalised monthly-mean $PM_{2.5}$ records. The Theil-Sen approach gives an estimate of the slope of any observed trend through calculating the slope between all data points in the record and taking the median value. The method has the significant advantage of being resistant to outliers in the data, and accurately determining confidence intervals, both important qualities when analysing air quality data. The accuracy of both the estimated trend, and associated confidence intervals were further improved through boot-strap resampling.

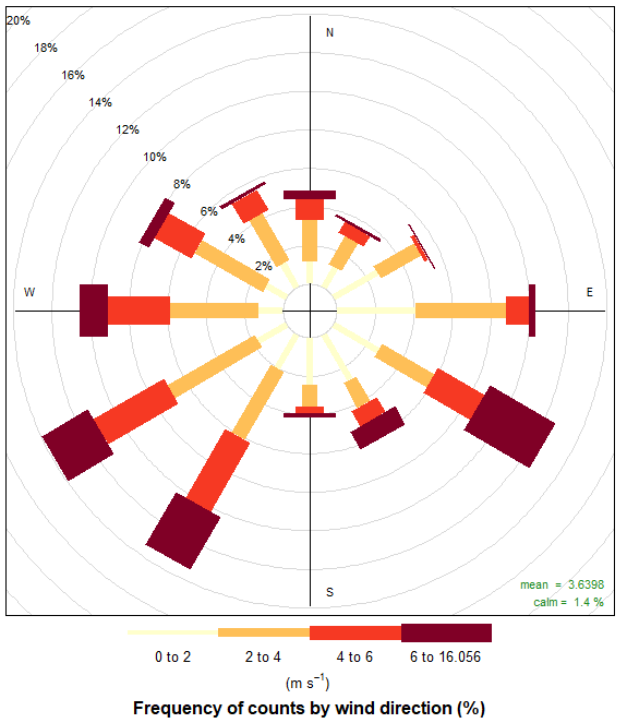


Figure 8 Wind rose for the whole monitoring period (from hourly data)

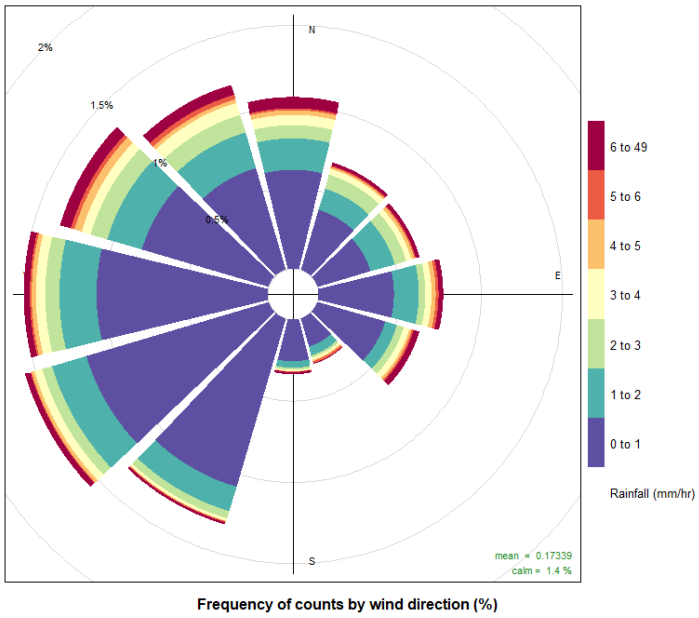


Figure 9 Frequency of rainfall for different wind directions throughout the monitoring period (from hourly data)

3 State of $PM_{2.5}$ levels

The data analysed for the purposes of this report consists of $PM_{2.5}$ concentration levels at the Central School site monitored continuously between 26/02/2016 13:00 and 10/04/2020 24:00, a time span of 36131 hours. Throughout the monitoring period, a total of 27 hours of record was lost to scheduled maintenance and servicing of the E-BAM, with another 657 hours counted as unscheduled gaps, with data lost due to equipment failure. In addition, the hour between midnight and 1am each day, during which the EBAM underwent a filter change was removed, with 1478 hours of record routinely removed over the monitoring period. As a result, data capture over the entire monitoring period, at the hourly scale, was 94.1%, with 94.0% valid data. In this calculation, the removal of the midnight hour of data, although routine, was counted as unscheduled data loss.

3.1 Summary statistics

Daily means were calculated from the hourly data when the 75% data acceptance threshold was met. In most cases, this led to a 23-hour average over the day. Of the 1506 days covered by the monitoring period, valid daily averages were obtained for 1477 days, or 98.1% of the monitoring period. A summary of data from the entire monitoring period, and for each year, is given in Table 3 and Figure 10, below. The individual year statistics from 2020 are not included as data is only available up to April 20. Summary statistics would thus not be representative of the entire year, Likewise, although the 75% data threshold is met for the year 2016, it is noted that there may be some bias in the 2016 statistics, as the summer months of January and February were not included in the monitoring period.

Table 3 $PM_{2.5}$ air quality summary statistics based on daily means

	Complete Monitoring Period	2016 (Feb 26-)	2017	2018	2019
# Data Points	1506	310	365	365	365
% Data Capture	98.1	84.7	94.2	97.8	100
% Valid Data	98.1	84.7	94.2	97.8	100
Mean	4	4	4	4	4
Maximum	14	14	13	11	13
Median	4	4	4	4	4
Standard Deviation	1.98	2.15	1.88	1.87	2.01
Interquartile Range	2	3	2	2	2
25^{th} percentile	3	3	3	3	3
75^{th} percentile	5	5	5	5	5
95^{th} percentile	8	8	7	7	8
99^{th} percentile	10	10	10	9	11

3.2 Comparison to WHO guidelines

Overall, data across the entire monitoring period shows that New Plymouth experiences low concentrations of $PM_{2.5}$, with the annual mean remaining steady at 4 $\mu g/m^3$ throughout the monitoring period. All annual means are well below the threshold of 10 $\mu g/m^3$ set by WHO. In addition, there were no exceedances of WHO's daily mean threshold of 25 $\mu g/m^3$, with a maximum daily mean recorded of 14 $\mu g/m^3$. The 95^{th}

percentile is noted to be only around 60% of the maximum daily value that was recorded, indicating that it is only a few days that have mean $PM_{2.5}$ levels significantly higher than the typical range.

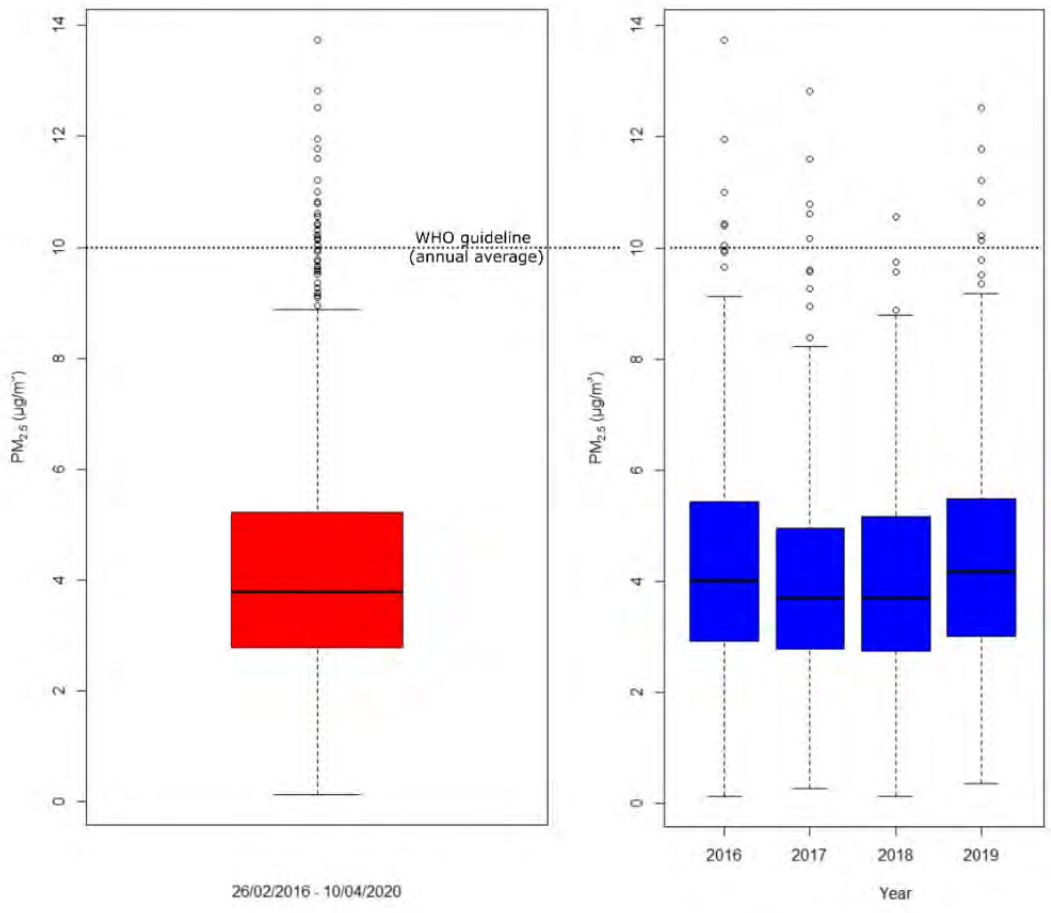


Figure 10 Boxplots of $PM_{2.5}$ for (left) the complete monitoring period, (right) data from each year of the monitoring period. The WHO guideline for daily average concentration is 25 µg/m^3, well above the maximum recorded concentration, and outside the bounds of the plot

The MfE ambient air quality guidelines (MfE 2002) propose that regional air quality can be categorized based on a comparison with the ambient guidelines. These categories are set out in Table 4, using the WHO daily mean threshold of 25 µg/m^3 as a reference. The results show that the air in New Plymouth can be considered 'excellent' or 'good' 96% of the time, and 'acceptable' at all times, with these percentages relatively constant across the 4 years that the study spanned. Further details on the air quality categories recorded for each year are given in Table 4 and Figure 11.

Table 4 Categorisation of results into environmental performance indicator air quality categories

Category	Category values ($\mu g/m^3$)	# Days in Category (%)					
		Complete Period	2016	2017	2018	2019	2020
Excellent	<2.5	283 (19%)	58 (19%)	70 (20%)	74 (21%)	53 (14%)	28
Good	2.5 – 8.3	1136 (77%)	234 (75%)	264 (77%)	274 (77%)	294 (81%)	70
Acceptable	8.3 -16.6	58 (4%)	18 (6%)	10 (3%)	9 (2%)	18 (5%)	3
Alert	16.6 – 25	0	0	0	0	0	0
Action	>25	0	0	0	0	0	0

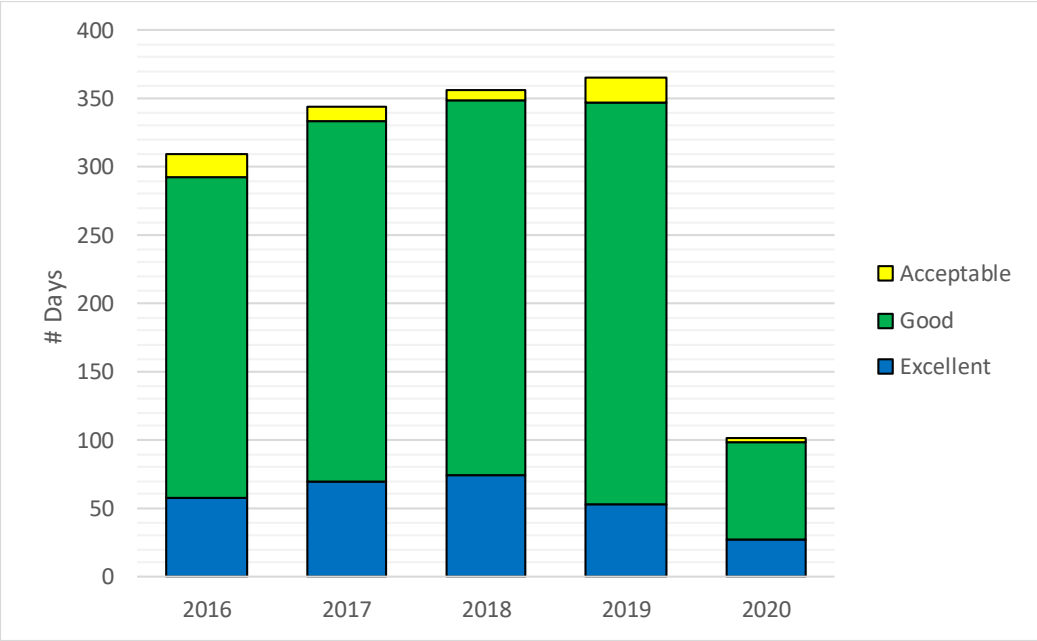


Figure 11 Number of days per year with $PM_{2.5}$ concentrations in each air quality category

4 Trends in $PM_{2.5}$ levels

The air quality at any particular site is dependent on what the contributing sources of pollution are present. These can vary temporally, and are often dependent on the different meteorological conditions which control the atmospheric stability at and near the site. In order to try and better understand the air quality at a site, it is thus important to investigate the combination of emission sources and meteorological conditions present.

4.1 Diurnal and seasonal variations in $PM_{2.5}$

The daily, weekly and monthly variations in $PM_{2.5}$ concentration at the Central School site are shown in Figure 12. While overall $PM_{2.5}$ levels are low, there are notable variations in concentrations, both on a seasonal, and a daily scale. Mean $PM_{2.5}$ concentrations are observed to be comparatively high during the colder months of May – July, with significantly lower levels observed during late summer (February – May). Mean concentrations are also higher during the earlier summer months of November to January.

At first look, the overall diurnal variation in $PM_{2.5}$ appears to have two peaks, one in the morning and one in the evening. On closer inspection, however, the strong seasonality observed in mean $PM_{2.5}$ levels biases the apparent overall diurnal pattern. A comparison of the diurnal variation in $PM_{2.5}$ concentrations between the different seasons is given in Figure 13, and shows that the diurnal variation during the cold winter months follows a distinctly different pattern than the other seasons. The winter months of June, July and August, show the most pronounced diurnal variation, with two clear peaks in $PM_{2.5}$ levels each day. The large smooth peak in $PM_{2.5}$ concentrations observed in evenings is consistent with the influence of home heating being used throughout winter, while the smaller morning peak could be due to some households relighting burners during the cool morning hours. When diurnal patterns during individual months are compared (Appendix IV), it can be seen that a similar, if less pronounced, diurnal pattern is also observed during May, when temperatures are cooling. This has an influence on the autumn diurnal variation seen in Figure 13.

In contrast, the diurnal variation of $PM_{2.5}$ during spring and summer does not show two distinct peaks, but more generally a spike in $PM_{2.5}$ concentrations in the morning, followed by a gradual decrease throughout daylight hours. It is not immediately possible to identify what is controlling or contributing to this overall diurnal trend, as there are a number of possible sources of $PM_{2.5}$ whose contributions vary throughout daylight hours. These include coastal land and sea breezes, as well as human activity in general. It can, however, be noted that PM2.5 levels do not vary much between week days and weekends, suggesting that human activities (with the exception of home heating in winter) may not have a large influence on overall levels. In addition to this, the overall diurnal pattern does not appear consistent with being driven by traffic patterns, in which peak emissions would be expected at popular commuting times. This suggests that although traffic emissions may contribute somewhat to overall concentrations, they are not likely to be the main driver of $PM_{2.5}$ pollution at the site.

In order to further narrow down what is contributing to the recorded $PM_{2.5}$ levels at different times, a closer look at meteorological and anthropological factors is required. This is provided in the following sections.

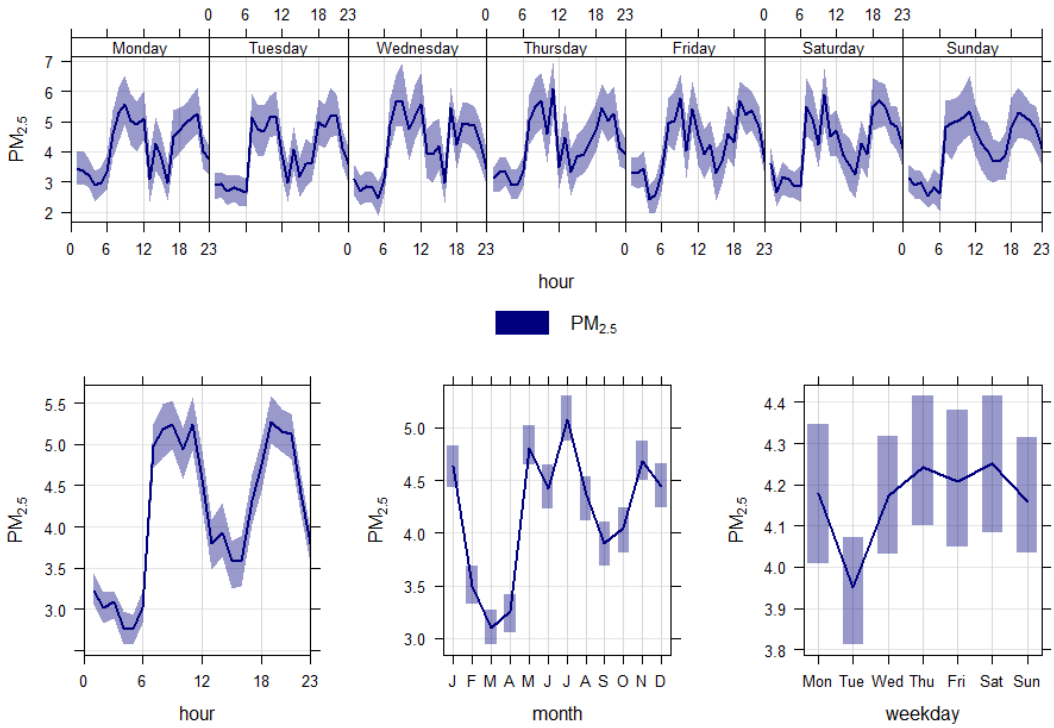


Figure 12 Temporal variations in $PM_{2.5}$ concentration at the Central School site between 2016 and 2020. The four plots show the variation in $PM_{2.5}$ concentration by: hour and day of the week, hour of the day, month of the year, and day of the week. 95% confidence intervals for the means are shown by the shaded areas

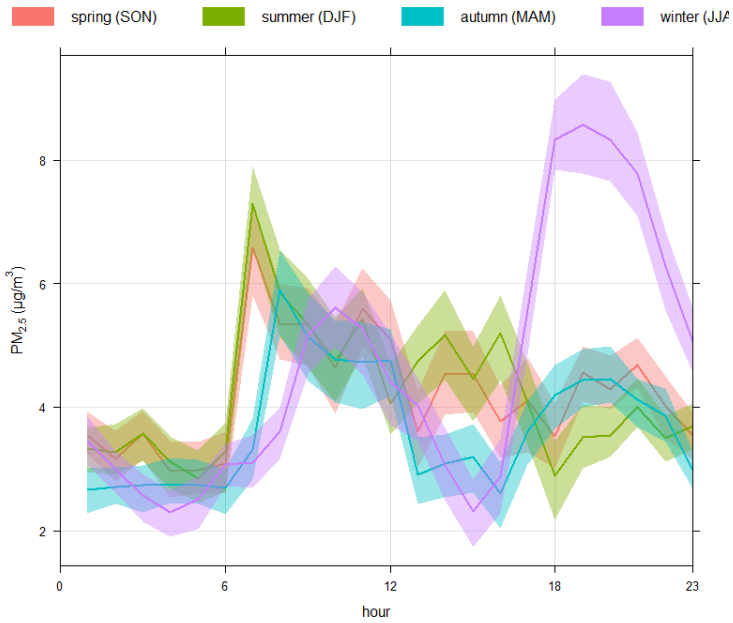


Figure 13 Comparison of the diurnal variation in $PM_{2.5}$ concentration during different seasons. 95% confidence intervals for the means are shown by the shaded areas

4.2 Comparison of $PM_{2.5}$ with meteorology

A Pearson's correlation analysis was undertaken between $PM_{2.5}$ concentrations and different meteorological variables, using the daily means from throughout the entire monitoring period. The resulting matrix (Figure 14) shows that there is no evidence of a correlation between overall $PM_{2.5}$ levels and either temperature or rainfall. While care must be taken when taking daily averages of wind direction, the overview given by looking at the dataset as a whole can be insightful. Indeed, the strongest correlation present is that between $PM_{2.5}$ levels and wind direction.

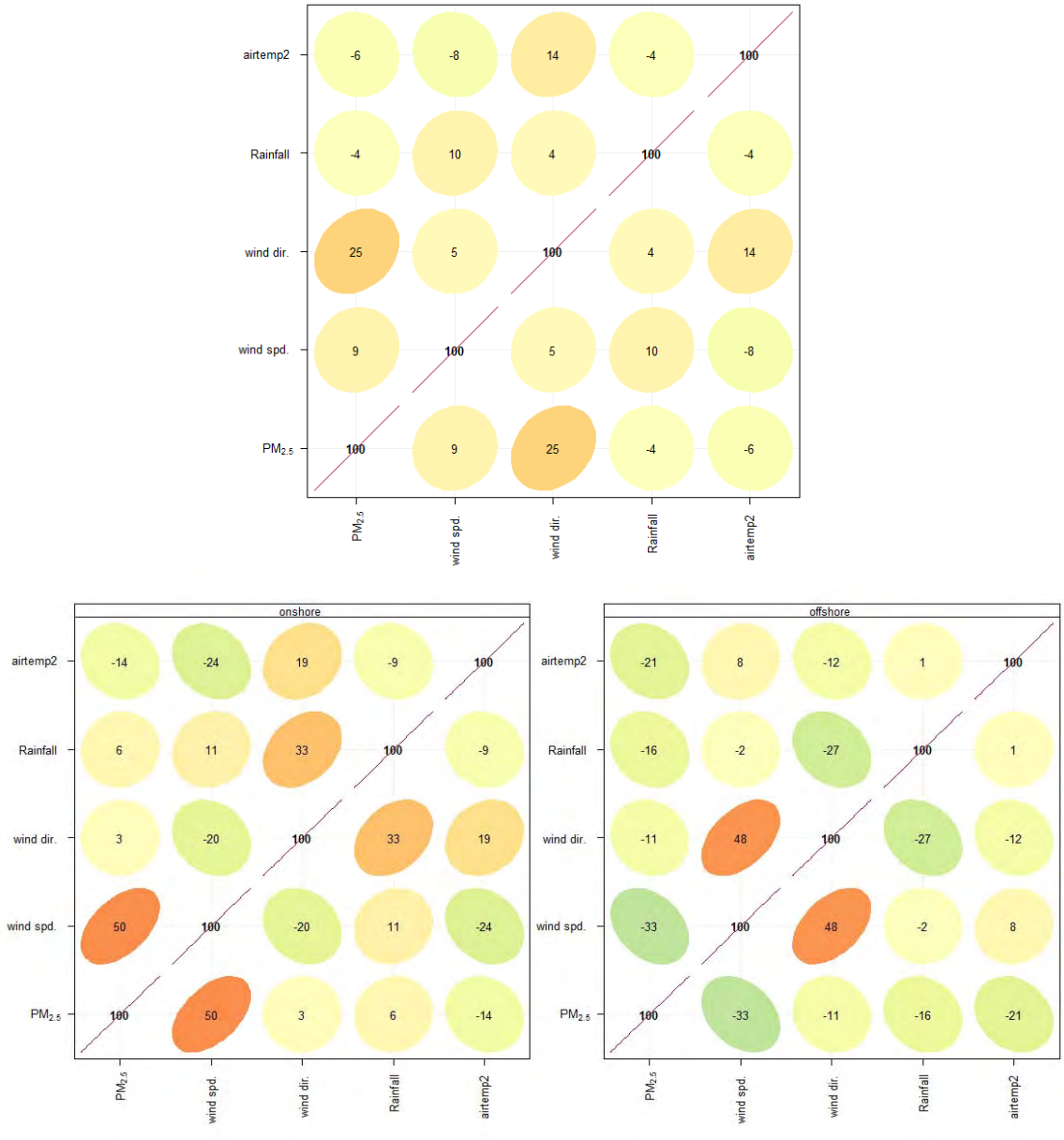


Figure 14 Pearson's correlation matrix of $PM_{2.5}$ with different meteorological variables, calculated from daily means over the entire monitoring period. When daily $PM_{2.5}$ means are split into two categories; those days with prevailing onshore (180°-360°) winds, and those with offshore winds (0°-180°) the opposite correlations between $PM_{2.5}$ levels and wind speed depending on wind direction is seen.

A pollution rose comparing hourly $PM_{2.5}$ concentrations with wind direction throughout the monitoring period is shown in Figure 15. From this it can be seen that higher $PM_{2.5}$ concentrations occur with greater frequency when the wind is from a Westerly direction. Conversely, a higher frequency of low $PM_{2.5}$ levels occur with Easterly winds. In order to investigate this trend closer, the $PM_{2.5}$ record is split into two categories; those days with prevailing onshore winds, and those with offshore winds. For this analysis, onshore was defined as winds from 180-360° (i.e. the westerly directions), while offshore was defined as 0-180°. While this definition does not fit on a local scale around the monitoring site, it was decided on due to the regional setting and weather patterns experienced at the site. In this case, winds experienced from the south west originate from the coast, and thus when considering the potential sources of $PM_{2.5}$, are considered onshore.

Interestingly, while there is only a very low correlation between wind speed and $PM_{2.5}$ levels when the $PM_{2.5}$ dataset is considered as a whole, when it is split into onshore and offshore winds, two clear different correlations are apparent. As seen in Figure 14 there is a moderate positive correlation between wind speed and $PM_{2.5}$ concentrations when the prevailing wind is onshore. In contrast, there is a somewhat weaker, but still moderate, negative correlation between wind speed and $PM_{2.5}$ concentrations when the prevailing wind is offshore.

This pattern is especially apparent when the monitoring period is split into days of different $PM_{2.5}$ air quality categories, and the wind patterns of each compared, as in Figure 16. It is immediately apparent that the vast majority of days that fall in the 'Acceptable' category, the worst classification recorded at the Central School site, occur on days with moderate to strong westerly (onshore) winds. Meanwhile, days with prevailing light onshore winds generally having 'Excellent' or 'Good' $PM_{2.5}$ levels. This is in contrast to the pattern observed with prevailing Easterly (offshore) winds. In these cases, days with moderate to strong winds fall exclusively in the 'Excellent' or 'Good' categories, while the very few days with prevailing Easterly winds which fall in the 'Acceptable' category, occur when winds are light and conditions are relatively calm. Overall, this suggests the sources of $PM_{2.5}$ emissions recorded in offshore winds are relatively local to the monitoring site. In contrast, the correlation between stronger westerly winds and higher $PM_{2.5}$ levels suggests that the main sources of $PM_{2.5}$ recorded in onshore winds are comparatively further from the monitoring site.

Another feature that can be seen when the $PM_{2.5}$ data is subset into days with onshore and offshore prevailing winds is the differing correlations between $PM_{2.5}$ levels and rainfall, depending on wind direction. This is a feature which is averaged out when the data set is looked at as a whole. For days where there is a prevailing offshore wind, there is a moderate negative correlation between rainfall and $PM_{2.5}$ levels. This is consistent with the common assumption that drier periods increase dust burdens in the atmosphere. In contrast, for days with a prevailing onshore wind there is a weak positive correlation between rainfall and $PM_{2.5}$ levels. This is, however, weaker than the correlation between wind speed and $PM_{2.5}$ levels on the same days. This is consistent with the findings from previous PM_{10} studies undertaken in New Plymouth. In these studies, sea spray was found to be the major source of PM_{10} in the area, with the contribution from wind-blown sea spray found to be more significant than that from rain deposited sea spray. The similar behaviour observed in $PM_{2.5}$ levels in the current survey suggest that sea spray in general, and more particularly, wind-blown sea spray, is a significant source of $PM_{2.5}$ in New Plymouth.

Interestingly, when the Pearson's correlation matrices in Figure 14 are split into different seasons and months (Appendix IV), some further features become notable. Firstly, it can be seen that there is no seasonality to the correlation between onshore wind speed and $PM_{2.5}$ levels, with a moderate to strong correlation between the two variables all year round. In contrast, the negative correlation between offshore wind speed and $PM_{2.5}$ levels is strong during the cold months of May through August, but is variable throughout the rest of the year. This is highly consistent with high $PM_{2.5}$ levels being caused in these cases by the use of domestic heating on cold evenings with stable atmospheric conditions. Similarly, when pollution roses are plotted for each season, it is notable that offshore winds contribute to overall $PM_{2.5}$ levels proportionally more in winter and autumn than in summer and spring (Appendix IV).

Figure 15 Pollution rose showing the frequency of different PM concentration levels with wind direction through the study period. The pollution rose is centered on the Central School monitoring site, allowing reference to potential sources in close proximity to the site, as well as further away. (Background image: Google, 2020)

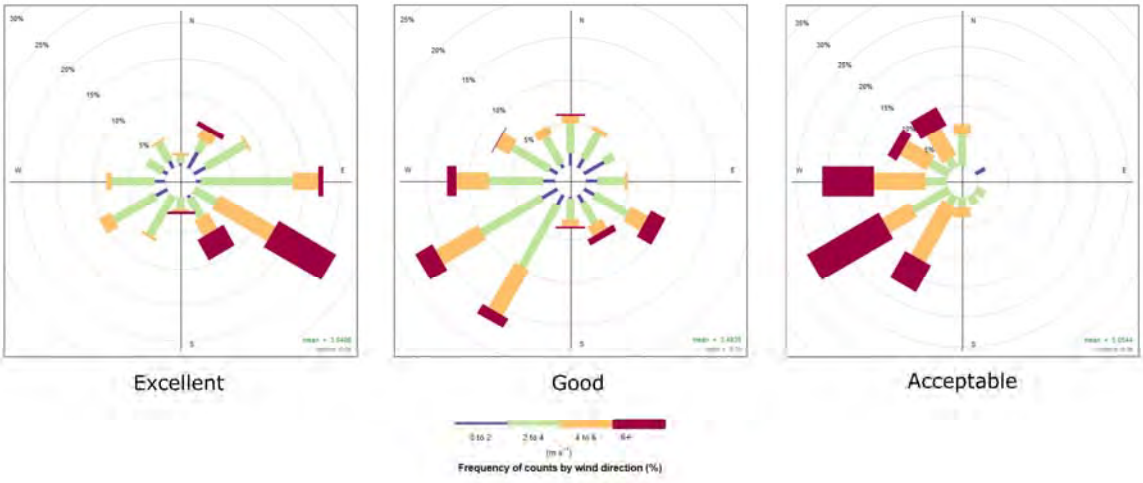


Figure 16 A comparison of wind roses for days falling into different $PM_{2.5}$ air quality categories (as defined in Section 3.2. Wind data is taken as daily averages of prevailing wind direction and speeds

4.3 Long term trends

Mean daily $PM_{2.5}$ concentrations throughout the entire monitoring period are shown in Figure 17. Long term trend analysis was carried out on the Central School measurement records using a non-parametric Theil-Sen approach. Long term trends are more easily identified in longer continuous data sets than that currently recorded at this site, or when a known change of regulations or conditions has occurred in the region. However, an exploratory analysis is none-the-less undertaken in this case. The Theil-Sen trend estimate, undertaken on de-seasonalised monthly-mean data, along with the 95% confidence interval, is shown in Figure 18. Data is analysed between March 2016 and February 2020, over the span of four complete years. Given the breadth of the 95% confidence interval, which encompasses 0, it is indeterminate whether $PM_{2.5}$ levels are increasing, decreasing, or remaining steady.

Interestingly, when trend analysis is undertaken on data split by wind direction (Figure 19), there appears to be an increasing trend in $PM_{2.5}$ levels with northerly winds, and a decreasing trend seen in those measured during southerly winds. It is noted, however, that the monthly means calculated for this analysis do not meet 75% data thresholds, meaning that no robust conclusions can be drawn from the analysis. In addition, there is relatively little data for northerly and southerly winds compared to the more prevalent west to south west and south easterly winds. Further analysis of how robust these apparent trends are, and what may be causing them, would require further monitoring data and detailed source apportionment investigations.

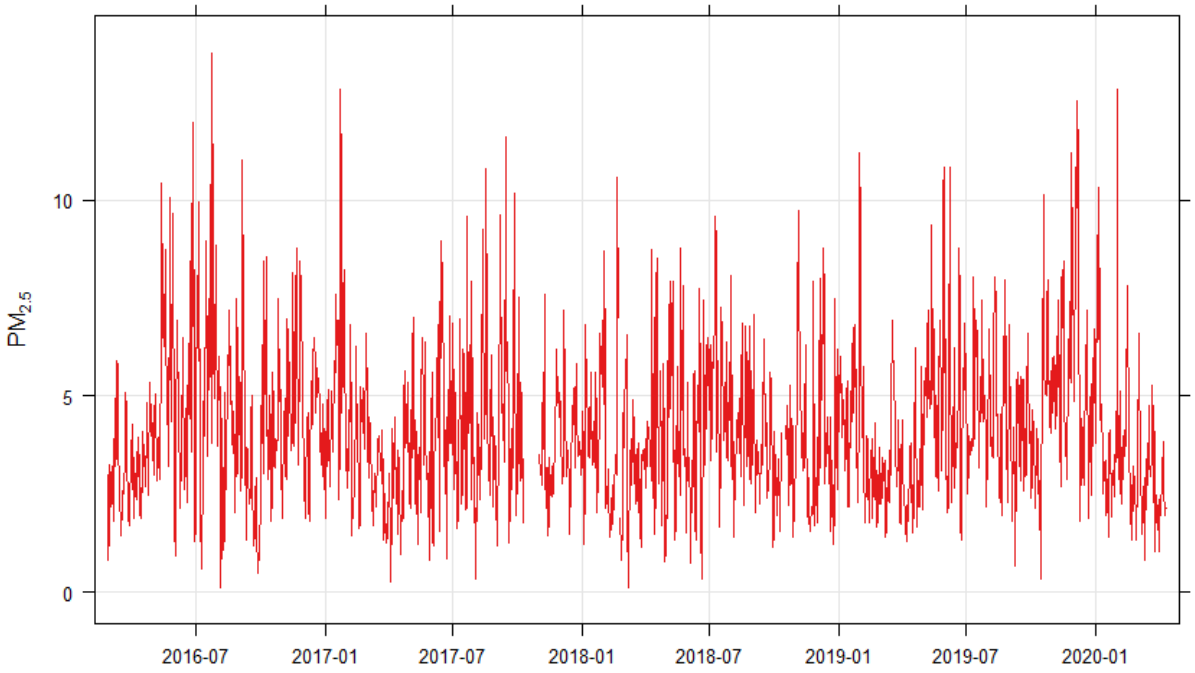


Figure 17 Daily average time series of PM2.5 for the monitoring period.

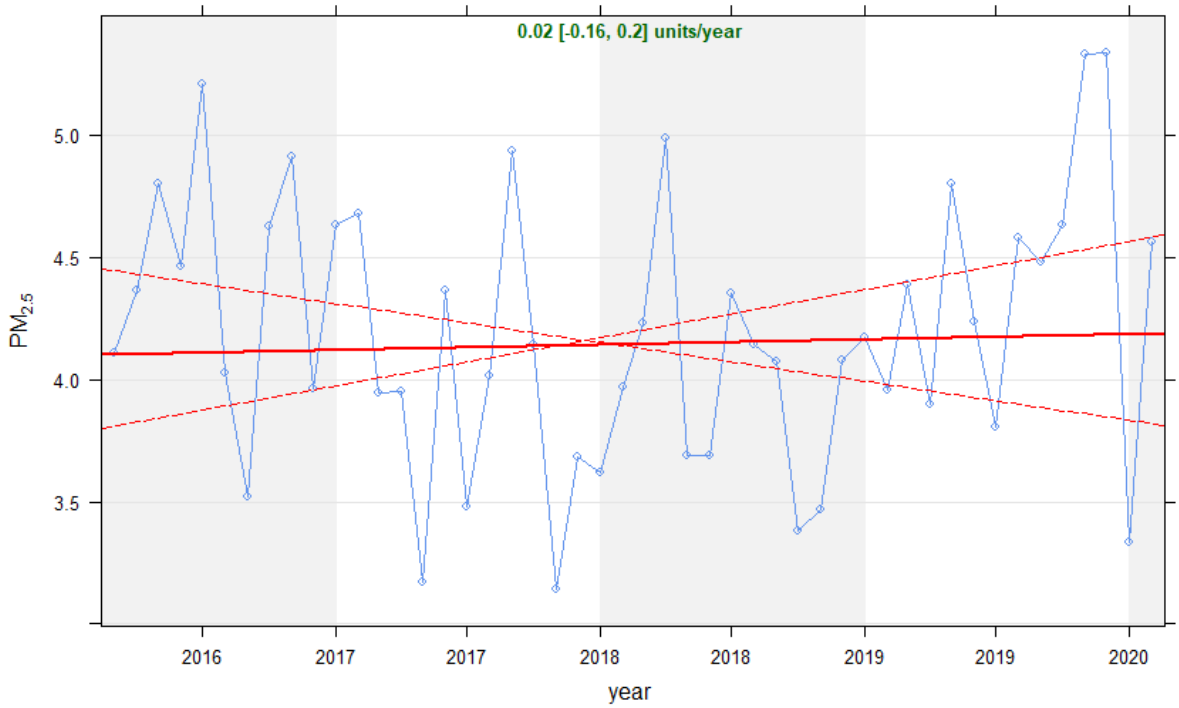


Figure 18 De-seasonalised monthly mean $PM_{2.5}$ concentrations and Theil-Sen trend line for data from the Central School site between March 2016 and February 2020 (4 complete years). Dashed red lines represent the trend lines containing the 95% confidence interval

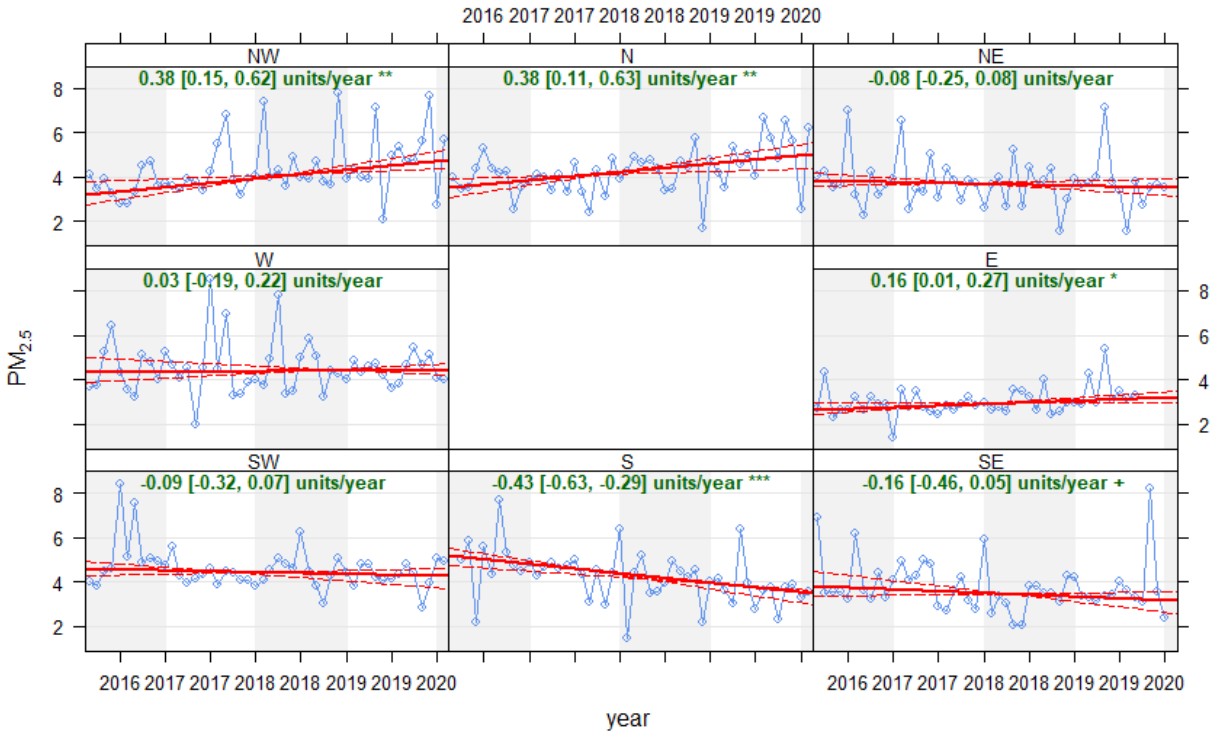


Figure 19 De-seasonalised monthly mean $PM_{2.5}$ concentrations calculated from daily $PM_{2.5}$ means, split by daily mean wind direction. Theil-Sen trend lines are shown in red, with dashed red lines representing the 95% confidence intervals

5 Identification of $PM_{2.5}$ sources

The health risk posed by air-borne particulates is determined not only by the size of the particulates, but also their composition and the duration of time that people are exposed to them. Significant risk is posed not only through long term exposure to fine particulates, but also short term exposure to very high concentrations (WHO 2013). In addition, the specific composition of fine particulates can be a determining factor in the health risk that they pose. While traffic and industrial related combustion products are perhaps the most-investigated contributors to PM levels, studies have shown that the products of burning organic matter are no less harmful. In contrast, exposure to marine aerosols and other natural particulates has been shown to have minimal health effects compared to exposure to the same level of combustion sourced PM (WHO 2013). It is therefore of interest to not only monitor overall PM levels, but also to identify what sources are contributing to the measured levels.

5.1 Regional sources of $PM_{2.5}$

One emissions inventory has previously been undertaken in Taranaki, during 1998 (Kuschel and Petersen, 2000), wherein the relative contribution of different sources to $PM_{2.5}$ emissions in the region were estimated. Here, domestic heating, industry and motor vehicles were identified as sources, contributing 50%, 32% and 18% of total $PM_{2.5}$ emissions, respectively. Importantly, however, this inventory did not include natural contributors of $PM_{2.5}$ such as sea spray, secondary sulphate. The following is thus an updated brief overview of the sources of $PM_{2.5}$ that may impact air quality in the New Plymouth area.

5.1.1 Emissions from home heating

The National Air Emissions Inventory 2015 (Emission Impossible Ltd, 2018), found that in 2015 residential emissions made up 33% of all anthropogenic $PM_{2.5}$ emissions recorded nationally. This figure increases during winter months, when home heating is most prevalent, and represents the largest single contributor to $PM_{2.5}$ pollution nationally.

While these national figures provide a good overview, included in them are a number of emission sources that are predominantly rural. The contribution of home heating emissions to overall $PM_{2.5}$ levels in urban areas can thus be expected to be more significant than the national figure implies. Indeed, local emission inventories commissioned by various regional councils indicate that home heating can be responsible for up to 91% of $PM_{2.5}$ measured on winter days (MfE, 2018).

The 2018 census found that wood burners were the most common form of home heating used in the Taranaki, with 43.1% of households using one as their primary source of heating (compared to 32.3% nationwide). A further 0.8% of households in Taranaki use pellet fires or coal burners as heating sources. The use of coal for home hating is much lower in Taranaki than in the South Island. Given that the majority of emissions from home heating is finer particulates, it can be expected that they will be a significant contributor to New Plymouth's overall $PM_{2.5}$ levels. This is especially so during winter, when the effects of the heavy use of wood burners can be exacerbated by meteorological conditions.

The composition of the PM produced in home heating emissions is also a cause of concern, with benzo(a)pyrene, a known carcinogen, being a product of the incomplete combustion of organic matter. In addition, emitted PM can include heavy metals if treated timber (arsenic) and painted timber (lead) are burned.

5.1.2 Traffic and road emissions

Along with being a significant source of carbon monoxide and nitrogen oxide emissions, motor vehicles are also a source of particulate matter, with emissions from on-road vehicles found to be the most important non-biomass combustion source of PM nationally (MfE, 2018). In addition to emissions from vehicle

exhaust, further PM is generated by the wearing and abrasion of the road surface, vehicle tyres, and brake pads. Although, the PM generated in these cases is mostly coarser particles, a certain fraction will be within the $PM_{2.5}$ range. These emissions are generally localised to near the road and its surface, however in windy and gusty conditions, the PM can be re-suspended and influence air quality across a larger area. Such emissions have been found to be sources of heavy metals such as zinc, cadmium, barium and copper. The National Air Emissions Inventory 2015 (Emission Impossible Ltd, 2018) found that nationally, on-road vehicles and road dust contributed 9% and 2% of anthropogenic $PM_{2.5}$ emissions, respectively. Comparatively, this is 1/3 of the quantity of emissions produced by home heating.

New Plymouth has relatively low traffic volumes in comparison to many other urban areas in New Zealand. The major traffic routes of SH45 and SH3 lie approximately 100-200 m to the NW, and 350 m to the NE, respectively, of the sample site. At this point, SH45 constitutes two one-way roads, each of which see around 14000-16000 vehicles per day while SH3 experiences around 13500 vehicles per day. Around 19% of this traffic is counted as being heavy vehicles (data from NZTA, averaged from annual 30-day surveys over the last 5 years). Traffic patterns on these roads has previously been shown to be relatively constant, with three clear peaks in traffic volume observed throughout a normal week day (morning, midday and afternoon). In contrast, a single, midday, peak is observed during weekends. Traffic focussed ambient air quality surveys have been previously undertaken by TRC at Port Taranaki (2012) and Bell Block Bypass (2014), with both surveys recording very low levels of $PM_{2.5}$ (2.6 and 2.5 $\mu g/m^3$, respectively). Interestingly both surveys found no evidence for a correlation between traffic volumes and PM levels, indicating that there is no strong relationship between a particular traffic density event and overall PM levels in this area. (TRC, 2012 & 2014). This indicates that the contribution from traffic is low by comparison with other, more dominant sources.

Traffic is considerably less on the roads directly adjacent the Central School monitoring site. NPDC traffic counts from October 2017 show that Gover St, which runs SE-NW past the monitoring site, has a daily average traffic count of 1800-1900 cars, with a maximum of 310-360 cars experienced between 8 and 9 am. Data from 2013 shows that Lemon St, running SW to NE past the monitoring site, has roughly half the average traffic count (940), with a maximum of 170 vehicles between 5 and 6 pm. Given the monitoring site is located on school property, the traffic on these roads could be expected to show peaks in traffic around school drop off and pick up times (8-9 am and 3-4 pm), as well as evening traffic.

5.1.3 Industrial emissions

Emissions from industrial and trade operations in the region require discharge permits for their activities. There are currently around 350 resource consents for air discharges in the Taranaki region, most of which are for companies in the oil and gas sector, and lie outside of the New Plymouth area. The closest permit holders to the Central School monitoring site are clustered in two areas; around Port Taranaki, approximately 4 km to the West, and the lower Waiwhakaiho area, 3-5 km to the North-East. Air permits range from landfills and wastewater treatment plants, to chemical processing, and port operations. A map and list of the closest consent holders to the monitoring site is given in Appendix III.

In general, while individual industrial or trade operations may have comparatively significant effects on air quality in their immediate local surroundings (noting that consent conditions restrict effects to minor or less), they are not often regionally significant. It is worth noting, however, that an ambient air quality survey undertaken at Port Taranaki in 2018 showed that $PM_{2.5}$ levels in the immediate vicinity of activity can border WHO regulations thresholds during operational times (TRC, 2018). However, given the coastal environment, this should not be taken as pinpointing any or all industrial activities as the cause (see 4.1.4 below). Meanwhile, permit holding companies in the Lower Waiwhakaiho area demonstrated a high level of environmental performance during compliance assessments undertaken in 2018-2019 (TRC, 2020).

5.1.4 Natural sources of $PM_{2.5}$

Natural sources of PM can include, but are not limited to, sea salt, windblown dust, pollen, and secondary sulphur from oceanic phytoplankton. Unlike anthropogenic sources of PM, natural sources cannot be managed, and so require special consideration in air quality studies. New Zealand is an island nation with 15,000 km of coastline, and as such, sea salt has been shown to be the largest natural contributor to PM levels nationally. Given Taranaki's location on the West Coast, it should be noted prevailing winds from the western hemisphere can generate and carry significant levels of sea salt, along with other marine aerosols.

The results of previous PM_{10} studies undertaken by TRC show that sea salt is a major contributor to overall PM_{10} levels *(TRC, 2004, 2010)*. While sea salt, and other natural PM, are generally coarser particulates, they can still be a significant contributor to $PM_{2.5}$ levels. Nationally, marine aerosols have been found to make up an average of 21% of total $PM_{2.5}$ levels on days where there is no exceedance of WHO guidelines *(MfE, 2018)*. The proportional contribution is significantly less on days with exceedances, being 3%. This indicates that while sea salts may contribute greatly to background levels of $PM_{2.5}$, nationally they are not primarily responsible for peak pollution events.

5.2 Elemental analysis of filters

In order to try and further determine what sources of $PM_{2.5}$ are prevalent in New Plymouth at different times, and in various weather conditions, seven sample EBAM filters, including one blank, were sent to the University of Auckland for elemental and scanning electron microscopy (ScEM) analysis. Each EBAM filter holds the total $PM_{2.5}$ deposited throughout one day, and thus give a snapshot of what sources of $PM_{2.5}$ were present on that day. Samples were mostly selected from days with higher than average levels of $PM_{2.5}$, with one sample chosen from an 'average' day, to give an idea of the constituents of background $PM_{2.5}$ in the area.

Overall, the filters were found to fall into two categories, examples of which are given in Figure 20 and Figure 21. Optically lighter filter samples show an increase in calcium and other salt deposits, with electron microscopy photos clearly showing the crystal like structure of these particulates (Figure 21). Meanwhile the optically darker filter samples showed higher carbon and nitrogen content. In images from these filters, the particulates have a 'fluffy' morphology, indicative of being hydrocarbon particulates, and consistent with being soot (e.g. Figure 20). None of the samples analysed contained any fungus or pollen.

The results of the elemental analysis of filters match well with the observations already made regarding $PM_{2.5}$ concentrations and wind patterns, and allow the identification of two of the main contributors to overall $PM_{2.5}$ levels. The report from the elemental analysis can be found in Appendix II, while the full set of figures comparing the elemental composition results from each filter with the wind patterns recorded on each day are given in Appendix V. It is noted that the filters are Silicon based, so the high levels of Silicon recorded are omitted from analysis.

5.2.1 Home heating

It was found that the two darkest filters, which show elevated levels of carbon and nitrogen, both correspond to winter days where the wind has calmed into a still evening (04/07/2016 and 16/06/2017). As seen in Figure 20, while $PM_{2.5}$ levels are low throughout the day, concentrations peak in the evening as cool and calm conditions lead to temperature inversions and increased atmospheric stability, exacerbating the effect of emissions from home heating.

The results agree with previous findings from this survey, and confirm that the higher overall levels of $PM_{2.5}$ observed in the winter months, and in particular, the significant evening peak observed in the diurnal trend, are due to domestic heating. The findings also agree with the negative correlation found between offshore

wind speed and $PM_{2.5}$ levels during colder months, in that the effect of $PM_{2.5}$ emissions from home heating are exacerbated on calm evenings when temperature inversions are at their strongest.

Neither of the two filters displaying high $PM_{2.5}$ concentrations from home heating show any sign of arsenic above the detection limit. There is thus no evidence of copper chrome arsenate (CCA)-treated timber being used in domestic solid fuel heaters. However, given that the home heating $PM_{2.5}$ emissions recorded are likely from the area immediate to the monitoring site, it is possible that the burning of treated timber may remain an issue in other areas of New Plymouth.

5.2.2 Marine aerosols

The remaining sampled filters, including that taken as a background sample, are all notably optically lighter, with sodium chloride, calcium, and other salt deposits found to be evident on the samples. These samples, which all show similar elemental compositions, are taken from varying times of the year, giving no evidence of the main sources being seasonal. Wind patterns for each sampled day show that onshore winds of varying strengths predominated all day (Appendix V). The results of these filter analyses, when combined with the observation that elevated $PM_{2.5}$ levels are often observed with stronger winds from the western hemisphere, suggest that such periods of elevated $PM_{2.5}$ concentrations may be due to increased levels of marine aerosols. Given the presence of sodium chloride and other sea salts on the background filter sample, it can be suggested that marine aerosols are also a major contributor to background $PM_{2.5}$ concentrations. These observations mirror the results of previous PM_{10} monitoring studies undertaken in New Plymouth, where it was observed that air quality in the region varies significantly dependent on wind direction, with sea salts being a main contributor to overall levels.

While marine aerosols are predominantly larger than the $PM_{2.5}$ fraction, given New Plymouth's coastal location, exposure to strong westerly winds, and generally low total $PM_{2.5}$ concentrations, it is possible that marine aerosols contribute proportionately more to overall $PM_{2.5}$ levels in New Plymouth than in other cities and settings.

5.2.3 Other contributing sources

With the exception of the background sample, there was a relatively constant presence of Sulphur recorded across the 6 filters analysed, with spot analyses showing that this was frequently as a constituent of Calcium Sulphates. Given the exposed coastal setting of New Plymouth, it is suggested that the sulphur recorded is more likely to be due to secondary sulphates, rather than being traffic generated. The lack of sulphur recorded on the background filter sample, together with the comparatively low levels of both overall, and particularly diesel, traffic in the area lend weight to this theory. Potential sources of secondary sulphate could be marine phytoplankton activity and shipping activity at the port. However, due to the low levels of sulphates measured, along with the small number of filters analysed, a firm source identification cannot be made without a more thorough source apportionment study.

Similarly, the source of nitrates present on a number of the filters is difficult to firmly identify within the scope of this survey. The relatively constant levels recorded on filters at different times of the year may suggest that the source is not seasonal, however this is difficult to confirm without more intensive sampling and analysis. Potential sources of nitrates, aside from soot from home heating, include traffic emissions, or wind-blown fertilizer from the agricultural areas inland of New Plymouth. The latter of these could be expected to be seasonal, whereas traffic emissions are relatively constant throughout the year.

Along with sulphur and nitrogen, a number of other elemental components are consistently identified in low percentages on all or most of the filters. However, given the inevitable overlap in elemental composition between different potential sources of $PM_{2.5}$, it is impossible to firmly identify the sources of these particulates without a detailed and in depth source apportionment study. Such an investigation is outside the scope of this report.

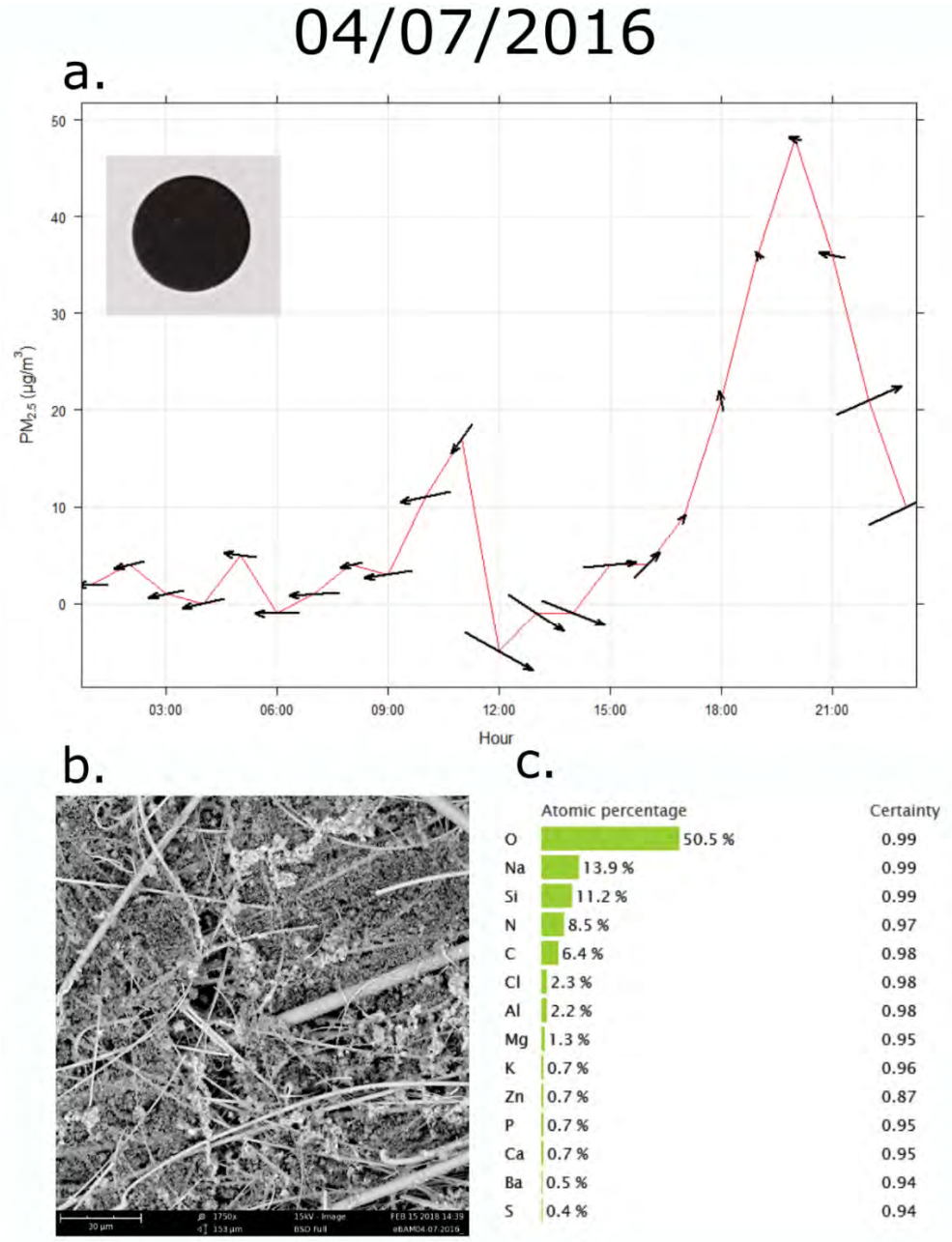


Figure 20 ScEM analysis of the EBAM filter from 4th July 2016, when a mean $PM_{2.5}$ concentration of 10 µg/m^3 was recorded. (a) Variation of $PM_{2.5}$ concentration through the day, with wind direction and relative speed overlaid. (Inset: Photo of the EBAM filter). (b) ScEM sample photo, clearly showing a 'fluffy' morphology, consistent with being organics. (c) Percentage elemental composition of a region of the filter sample, which shows elevated content of sodium chloride and organic particulates

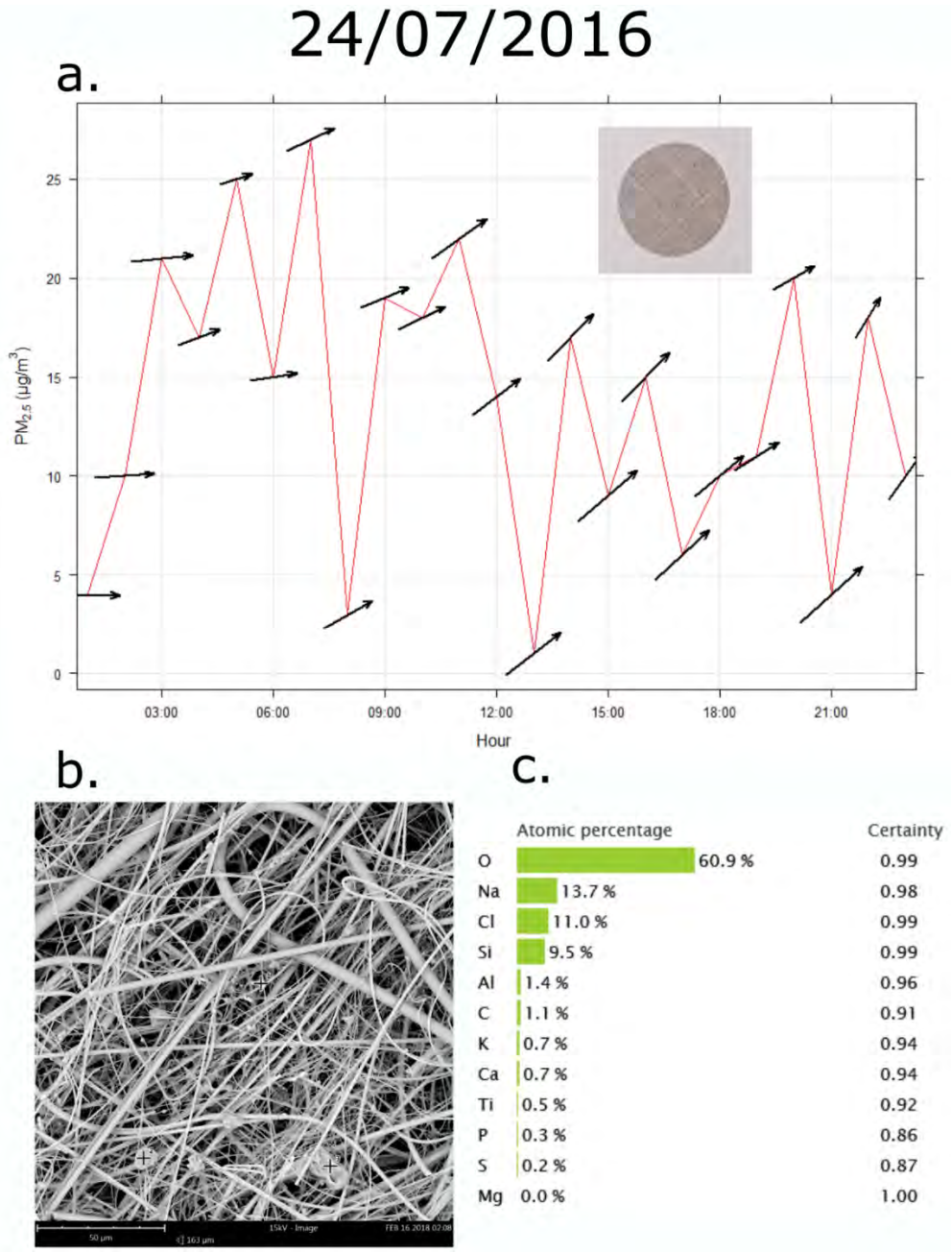


Figure 21 ScEM analysis of the EBAM filter from 24th[th] July 2016, when a mean daily $PM_{2.5}$ concentration of 14 µg/m^3 was recorded. (a) Variation of $PM_{2.5}$ through the day, with wind direction and relative speed overlaid. (Inset: Photo of the EBAM filter). (b) ScEM sample photo, with three spots of salt crystals identified with black + symbols. (c) Percentage elemental composition of one spot of the sample, Spots analysis showed the presence of chlorides, calcium sulphate, nitrate salts and calcium salts

6 Discussion

6.1 Summary

Overall, the results of this survey, and all regional monitoring to date, show that Taranaki has very clean air, with no significant pressures upon the quality of the air resource on a regional basis. $PM_{2.5}$ concentrations are consistently very low in New Plymouth, with an annual mean of 4 µg/m^3 recorded throughout the entire monitoring period, well below the threshold of 10 µg/m^3 set by WHO. 96% of days in the monitoring period were categorised as having 'Excellent' or 'Good' $PM_{2.5}$ levels, with the remaining 4% falling into the 'Acceptable' category. There were no exceedances of WHO's daily mean threshold of 25 µg/m^3.

Analysis of the $PM_{2.5}$ measurements recorded at Central School show $PM_{2.5}$ levels at the site are dependent on a combination of wind direction and wind speed. Higher levels of $PM_{2.5}$ are recorded year round in the presence of medium to strong onshore winds. In contrast, low concentrations of $PM_{2.5}$ are recorded when there are medium to strong offshore winds.

This is consistent with sea spray and its constituent salts being a major contributor to $PM_{2.5}$ levels in the region, a result which agrees with the findings of both previous regional PM_{10} monitoring surveys, and national $PM_{2.5}$ surveys.

A strong seasonal trend is observed in $PM_{2.5}$ levels due to domestic heating in the colder months. The increase in $PM_{2.5}$ concentrations recorded due to domestic heating emissions is correlated with cold calm evenings when the dispersal of pollutants is reduced by stable atmospheric conditions which result in temperature inversions. While no exceedances of the WHO recommended daily limit were recorded at the monitoring site, it is possible that the effect of domestic heating emissions is greater in other localised areas in the region. Such vulnerable areas include non-coastal sites and sheltered valleys. Here, air drainage from the surrounding higher land may lead to stronger temperature inversions and an increased level of trapped $PM_{2.5}$ emissions near ground level.

Higher background $PM_{2.5}$ levels are recorded in November through January, which may be due to the increased frequency of north-westerly winds during this period. The monitoring site lies around 650 m south-east of the coast at its nearest approach. Winds from the north-west are thus likely to hold a higher concentration of marine aerosols when they reach the monitoring site compared to onshore winds from other directions.

While it is probable that traffic emissions and secondary sulphate contribute to $PM_{2.5}$ levels in New Plymouth, due to the low overall levels of $PM_{2.5}$ in the region, it is difficult to quantify these contributions. The results of this survey, together with those of previous inhalable particulate surveys undertaken at traffic sites in New Plymouth, indicate that the contribution to overall $PM_{2.5}$ levels from traffic sources is likely much less than that from both marine aerosols and domestic heating. There is no evidence of a significant contribution to regional $PM_{2.5}$ levels from industrial emissions. A detailed source apportionment study would be required in order to further quantify the contributions from these, and other, sources.

6.2 Covid-19, lockdown and $PM_{2.5}$ levels

On March 26 2020, New Zealand entered a state of national lock-down in an effort to stop the spread of the Covid-19 coronavirus. With strict travel restrictions and the shutdown of most industries, there should be a corresponding significant decrease in emissions that are from traffic and industry sources, although obviously not for natural sources. Indeed, lockdowns elsewhere are noted to have resulted in considerable drops in air pollution in large cities around the world. The measured records from this study were thus analysed to see if there is a drop in overall $PM_{2.5}$ levels coincident with New Plymouth going into lockdown and traffic and industry activity greatly reducing. Unfortunately, the measured $PM_{2.5}$ records end on the 10th

of April, 16 days after lockdown was entered, when the pump on the E-BAM instrument failed, meaning that analysis of the full 4.5 weeks of lockdown is not possible.

When daily mean $PM_{2.5}$ levels are compared throughout March and April 2020 (Figure 22), it is seen that there is a decrease in levels coincident with the start of lock-down on March 26th. However, this drop in daily mean $PM_{2.5}$ is also coincident with a change in weather system, with a period of prevailing south-easterlies immediately following the beginning of lockdown. Given that very low $PM_{2.5}$ concentrations are often recorded when there are prevailing moderate to strong south-easterly winds, it is impossible to distinguish if, or how much, the drop in anthropogenic emissions due to lockdown contributes to the overall observed drop in $PM_{2.5}$ levels. However, when $PM_{2.5}$ levels are compared over the same time period for each year of the monitoring survey (Figure 23), it is seen that the levels recorded during lockdown are within the same range recorded during other years. There is, thus, no evidence that the Covid-19 lockdown resulted in significantly reduced $PM_{2.5}$ levels in New Plymouth.

Throughout the COVID-19 corona pandemic, it has become apparent that many of the pre-existing medical conditions that increase the risk of death in COVID-19 patients are the same diseases that are caused or exacerbated by long-term exposure to fine particulate air-pollution. While the situation is still developing, and such studies are in their early days, a cross-sectional nation-wide study of data from the USA indicates that even a small increase in long-term exposure to $PM_{2.5}$ is linked to a large increase in COVID-19 mortality rates (Wu et al. 2020). In the report, an increase of 1 $\mu g/m^3$ in $PM_{2.5}$ was associated with an 8% increase in the COVID-19 death rate (with a 95% confidence interval of 2-15%). Such findings highlight the detrimental health effects of long-term exposure to fine particulate matter, and the importance of air quality regulations and monitoring to ensure that regional fine particulate levels are kept as low as possible.

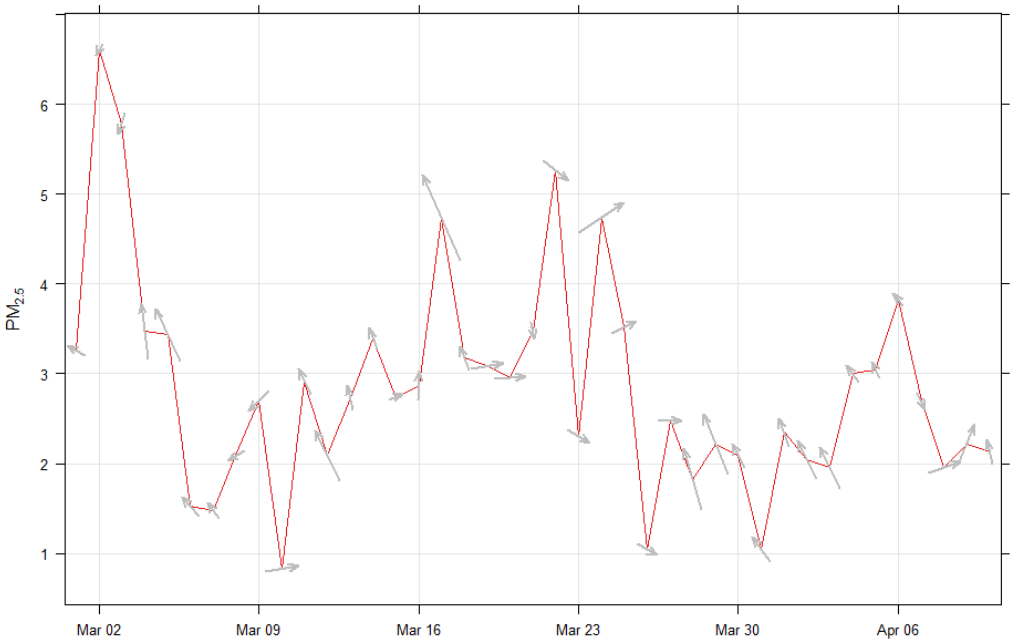


Figure 22 Daily mean $PM_{2.5}$ concentrations from March 1st – April 10th 2020, with mean daily wind vectors overlaid

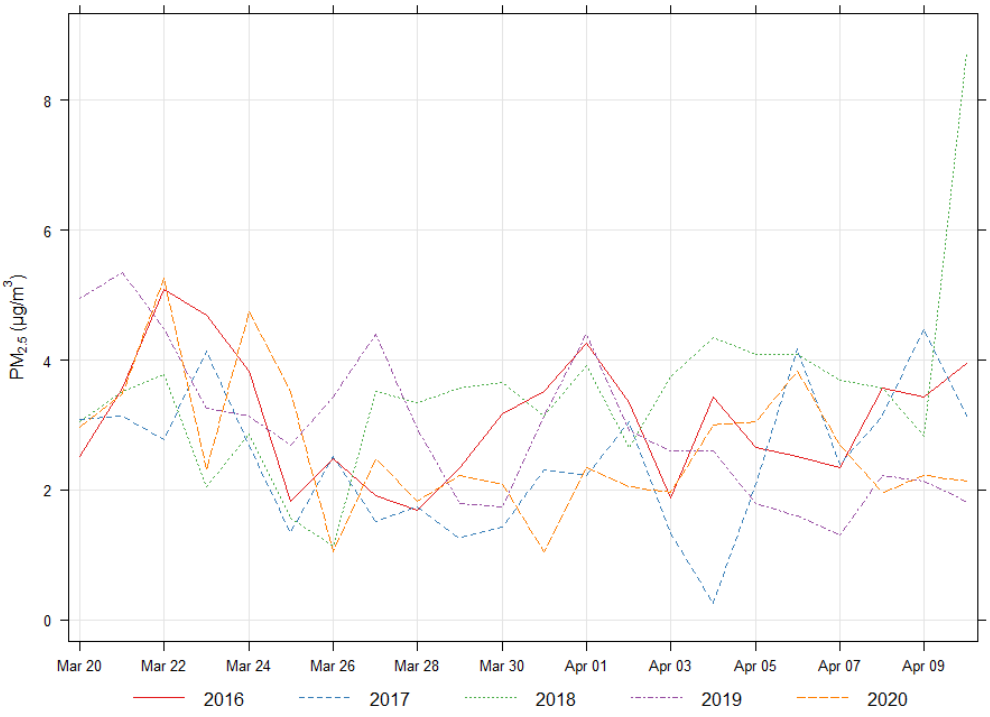


Figure 23 Daily mean $PM_{2.5}$ concentrations during the period March 20th - April 10th for each year of the monitoring survey

7 Recommendations

1. THAT it be noted that Taranaki Regional Council has now carried out continuous gathering of $PM_{2.5}$ data in New Plymouth's CBD for a period of 4 years, spanning February 2016 – April 2020.
2. THAT it be noted that $PM_{2.5}$ monitoring of ambient air in New Plymouth has shown low mean $PM_{2.5}$ concentrations, with no exceedances of WHO recommended thresholds.
3. THAT it be noted that sea spray is a major contributor of $PM_{2.5}$ in the Taranaki region year-round, with domestic heating also being a significant contributor during winter months.
4. THAT the Taranaki Regional Council continues to conduct continuous monitoring of $PM_{2.5}$ in New Plymouth.
5. THAT the Taranaki Regional Council undertakes investigative monitoring of winter $PM_{2.5}$ levels in vulnerable areas such as sheltered urban valleys, where worst-case $PM_{2.5}$ levels are likely due the combination of home-heating emissions and strong temperature inversions.

Bibliography and references

Chappell, P.R. 2014: *The climate and weather of Taranaki.* NIWA Science and Technology Series 64, 40 pp.

Carslaw, D.C. and K. Ropkins. 2012: *openair - an R package for air quality data analysis.* Environmental Modelling & Software. Volume 27-28, pp.52–61, doi: 10.1016/j.envsoft.2011.09.008.

Google. 2020: [Overview aerial image of New Plymouth]. Retrieved May 20, 2020 from https://www.google.co.nz/maps/@-39.0196346,174.0845403,1365a,35y,181.69h,77.4t/data=!3m1!1e3.

Kuschel, G. and Petersen, J. 2000: *Air Emissions Inventory for the Taranaki Region in 1998.* NIWA Client Report No. AK00044.

Ministry for the Environment. 2002: *Ambient air quality guidelines – 2002 update*. Air Quality Report No. 32, Wellington.

Ministry for the Environment. 2009: *Good-practice guide for air quality monitoring and data management 2009*. Report No. ME 933. Wellington: Ministry for the Environment.

Ministry for the Environment & Stats NZ. 2018: *New Zealand's Environmental Reporting Series: Our air 2018.* Retrieved from www.mfe.govt.nz and www.stats.govt.nz.

Ministry for the Environment. 2020: *Proposed amendments to the National Environmental Standards for Air Quality: particulate matter and mercury emissions*. Consultation document. Wellington: Ministry for the Environment.

R Development Core Team. 2011: *R: A language and environment for statistical computing. R Foundation for Statistical Computing*, Vienna, Austria. Retrieved from http://www.R-project.org/

Schweizer, D., Cisneros, R., & Shaw, G. 2016: *A comparative analysis of temporary and permanent beta attenuation monitors: The importance of understanding data and equipment limitations when creating PM2. 5 air quality health advisories*. Atmospheric Pollution Research, 7(5), 865-875.

Taranaki Regional Council. 1996: *State of the Environment – Taranaki Region 1996.* TRC publication.

Taranaki Regional Council. 2003: *Taranaki – Our Place Our Future. Report on the state of the environment of the Taranaki region – 2003.* TRC publication.

Taranaki Regional Council. 2004: *Inhalable particulate (PM_{10}) Regional Monitoring Programme Report 2003,* Technical Report 2003-99.

Taranaki Regional Council. 2006: *Trends in the quality of the surface waters of Taranaki.* TRC Internal Report.

Taranaki Regional Council. 2009: *Taranaki Where We Stand. State of the Environment Report 2009.* TRC publication.

Taranaki Regional Council. 2010: *Inhalable particulate (PM_{10}) Regional Monitoring Programme Report 2010,* Technical Report 2010-45.

Taranaki Regional Council. 2012: *Inhalable Particulate Monitoring at Port Taranaki,* Internal memorandum, October 2012.

Taranaki Regional Council. 2014: *Ambient Air Quality Survey at Bell Block Bypass,* Internal memorandum, July 2014.

Taranaki Regional Council. 2015: *Taranaki – as one. State of the Environment Report 2015.* TRC publication.

Taranaki Regional Council. 2018: *Ambient Air Quality Survey at Port Taranaki Ltd in May-June 2018,* Internal memorandum, June 2018.

Taranaki Regional Council 2020: *Lower Waiwhakaiho Air Discharges Compliance Monitoring Programme Annual Report 2018-2019,* Technical Report 2019-71.

Wu, X., Nethery, R.C., Sabath, M.B., Braun, D., Dominici, F. and Sabath, B. 2020: *Exposure to air pollution and COVID-19 mortality in the United States: A nationwide cross-sectional study*. Correspondence.

Appendix I

Memorandum of Understanding between TRC and Central School Te Kura Waenga O Ngāmotu

Memorandum of Understanding

Dated: 8 October 2018

PARTIES:

Taranaki Regional Council (the TRC), of 47 Cloten Road (Private Bag 713), Stratford,

and

Central School Te Kura Waenga O Ngāmotu (the School), of 40 Lemon St, New Plymouth, 4310

Background

A. Regional Councils monitor air quality in accordance with the National Environmental Standards for Air Quality (Air Quality NES) and the World Health Organisation (WHO) guidelines. The Taranaki Regional Council monitors, evaluates and responds to ambient air quality conditions and trends in the Taranaki region. The Council, therefore, has been seeking support from the Taranaki community for continuation of the ambient monitoring and data collection. In 2016, the TRC deemed it desirable to enter into an agreement with the School for the purposes of performing an ambient air quality monitoring study at a site representing urban New Plymouth.

B. The School provided an adequate location and space of at least two (2.0) square meters for the installation and construction of, and electrical power to the TRC for operation of, one temporary Air Quality Monitoring Station (the AQM Station) and its accessories, to operate and maintain the same within the said space, free of charge for the duration of the agreement.

C. On 26 February 2016, the TRC, at its own cost and expense, installed the AQM Station on the School's property. The AQM Station is a very delicate scientific equipment, which monitors particulate matter PM 2.5. The monitoring information gathered by the TRC is valuable for both Taranaki and New Zealand, as it is used by the Ministry for the Environment in its reports on levels of PM 2.5 pollution in airsheds across the country.

D. Prior to installing the AQM Station, the TRC received prior verbal approval of the AQM location from the School's Principal and prior written approval from the School's Board of Trustees dated 26 August 2015.

E. The TRC paid for the purchase and installation of a surveillance camera (on top of the wall under the roof of the School's building) facing the AQM Station to be able to receive a relevant CCVT footage from the School as necessary.

1. **Purpose**

   The parties agree to enter into this Memorandum of Understanding (the MOU) to formally define their mutual understanding and obligations in regards to the AQM Station installed.

2. **Term**

   This MOU will commence on **8 October 2018** for a period of five (5) years, and end on 8 October 2023, unless sooner terminated by the TRC or School pursuant to the provisions of this MOU.

   This MOU may be renewed or extended subject to agreement between the TRC and the School.

3. **TRC's Responsibilities**

   1) At its own cost and expense, except as provided herein, operate, maintain, conduct inspections and remove the AQM Station on the School's property.

   2) Record continuous fine particulate (PM 2.5) observations.

   3) Use all reasonable endevours to make the annual air quality monitoring reports, based on the data collected from the AQM Station, available through the TRC's webpage www.trc.govt.nz.

   4) The TRC shall assume costs for the AQM Station's troubleshooting, repair and maintenance.

   5) Provide monetary compensation for the use of electricity by the AQM Station in the amount of $109.50 annually (based on approximately 30 cents per day).

   6) All equipment related to the AQM Station, and all data obtained from the AQM Station, is owned by the TRC.

   7) When accessing the AQM Station during school hours (8:00am – 4:00pm), the TRC's staff and/or supervised contractors are required to sign in and out at the School Office.

   8) No vehicles shall be brought onsite by the TRC's staff and/or supervised contractors during school hours without prior communication with the School.

4. **School's Responsibilities**

   The School shall continue to:

   1) Allow the TRC to operate and maintain the AQM Station within the allocated space, free of charge for the duration of this MOU.

   2) Provide the TRC with, and invoice annually for the amount of $109.50 for, the electrical power to support the AQM Station for the duration of this MOU.

   3) Allow the TRC's staff and supervised contractors reasonable access to the AQM Station for the calibration, maintenance and routine air monitoring activities. The TRC staff member(s) will normally need to visit the AQM Station approximately once a month for about one hour.

   4) Promptly notify the TRC of any AQM Station's visible damage.

   5) Promptly provide a footage of the surveillance camera facing the AQM Station, when and as requested by the TRC.

   6) Provide the TRC with a copy of the up-to-date School's Health and Safety Policy and any specific Health and Safety requirements related to the location of the AQM Station.

5. **Police Vetting for the property-related workers**

   The TRC will ensure that any Officer that requires access to the School for monitoring purposes will have been through a Police vetting check and will have been given a full clearance. The TRC will met the costs associated with these checks, will ensure checks remain current, and are completed prior to any access to Central School.

6. **Termination**

This MOU may be terminated by either party by giving written notice at least twelve (12) months prior to the effective date of termination, or otherwise by mutual agreement.

Upon termination, whether due to expiration of the Term or as a result of agreement of the parties, the TRC shall remove all equipment related to AQM Station from the School's property and restore such property to a condition as good as it was when the TRC first took occupancy, within thirty (30) calendar days after the termination or expiration of this MOU.

7. **Communications**

The following persons shall be the contact persons for all communications regarding the performance of this MOU:

For the **Taranaki Regional Council**: Brian (Vladislav) Cheyne, Environmental Scientist - Air Quality), phone: (06) 7657127, email: Brian.Cheyne@trc.govt.nz

For the **Central School Te Kura Waenga O Ngāmotu**: Juliet Ormrod, Principal, phone: (06) 7583240, email: principal@central.school.nz, with the Maintenance Officer copied in where suitable: bryan.sutherland@central.school.nz

8. **Air Quality Education**

As consideration for the School's performance under this MOU, the TRC agrees to provide to the School an educational Air Quality Programme directed to the School's students.

9. **Health and Safety**

The TRC operates a comprehensive Health and Safety system which all employees and supervised contractors are required to comply with. TRC Staff will also actively comply with the School's specific Health and Safety systems in place at the location of the AQM Station, and should be made aware of these requirements by the School.

10. **General Provisions**

Review: It is intended that this MOU is reviewable at any time as agreed between the TRC and the School.

Changes: Any changes to the terms and conditions of this MOU must be in writing, signed by the duly authorised representatives of the parties.

Assignment: Neither party may assign or delegate its rights or obligations under this MOU, in whole in part, without the express prior written consent of the other party.

Hold harmless: Each party to this MOU shall be responsible for its own acts and/or omissions and those of its officers, employees and agents. No party to this MOU shall be responsible for the acts and/or omissions of entities or individuals not a party to this MOU.

Force Majeure: No party is in breach of this MOU for any act, omission or failure to fulfil its obligations under this MOU, if such act, omission or failure arises from any cause reasonably beyond its control.

Applicable law: The law of New Zealand shall govern the interpretation of the MOU.

Compliance: The parties shall comply with all applicable laws, regulations and standards necessary for the performance of this MOU. The Parties shall comply with the terms and conditions of this MOU.

Disputes: Any dispute that may arise in the interpretation or implementation of this MOU shall be resolved amicably through mutual good faith negotiation and consultation.

Once signed, this MOU will replace all or any oral agreement previously reached between the parties.

Execution:

Signed for the **Taranaki Regional Council**:	Signed for the **Central School Te Kura Waenga O Ngāmotu**:
Basil Chamberlain Chief Executive Date: 6/10/18	B G Chamberlain Chief Executive Officer Taranaki Regional Council	Juliet Ormrod Principal Date: 8/10/18.

Appendix II

Phenom ScEM report from University of Auckland

THE UNIVERSITY OF AUCKLAND
NEW ZEALAND

ENGINEERING

20 February 2018

Brian Cheyne
Private Bag 713,
Stratford 4352

RCSMS, FoE
B201E.143, 15 Williams Street
Auckland, New Zealand
T+64 9 373 7599 x 87172
Www.rcsms.auckland.ac.nz/en/rcsms.html
The University of Auckland
Private Bag 92019
Auckland 1142
New Zealand

Dear Mr Cheyne

Re: Phenom SEM examination of Filters

The 7 samples supplied by you were 6 sampling spots from glass filter tapes and a blank. The samples were all labelled "eBAM(PM2.5) then a code as follows:
Blank
2/04/2016
04/07/2016
24/07/2016
02/10/2016
22/01/2017
16/06/2017

RCSMS was asked to check for particles 0-2.5µm.

Preparation
A small portion was cut from the centre of each sample and attached to a standard SEM pin stub with double sided adhesive conductive carbon tape. The samples were coated with approximately 20nm of Pt to help reduce charging effects.

Analysis
The samples were analysed for both morphology and atomic % elemental composition with a Phenom ProX SEM operating in standard SEM mode.

Results and Conclusion
The optically lighter sample dots showed calcium/other salt deposits. The optically darker samples showed higher carbon and nitrogen content, the morphology of these darker samples indicating soot.

There was no fungus or pollen apparent on any of the samples.

Limitations
Soda glass will be present as a background in most analyses, so only the non-glass materials are highlighted.

Pt has been added to the samples deliberately so is present but ignored.

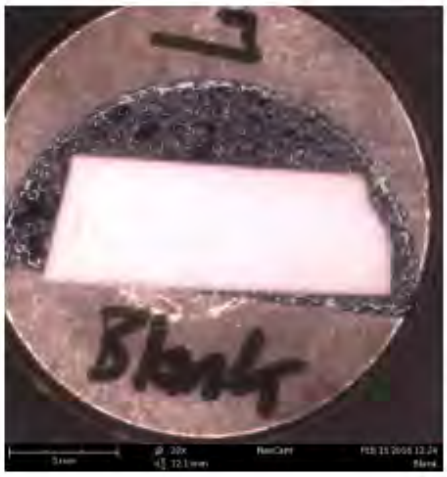
Representative results are tabled below, and further supporting analyses have been supplied electronically along with this report.

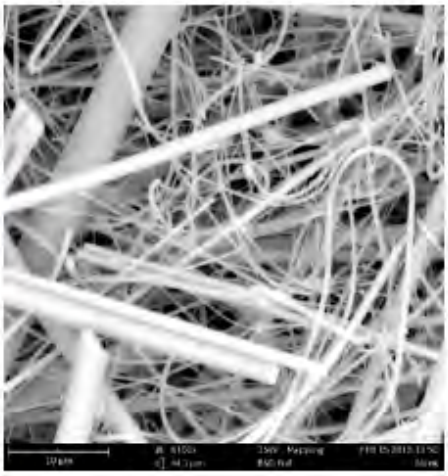
You are welcome to contact me should you have further questions regarding this analysis.

Catherine Hobbis
Technical Officer, RCSMS

Blank

Blank

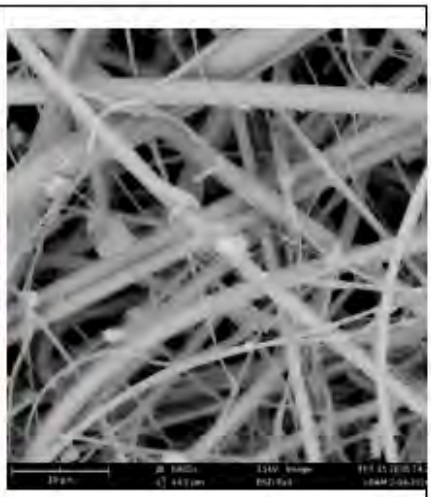


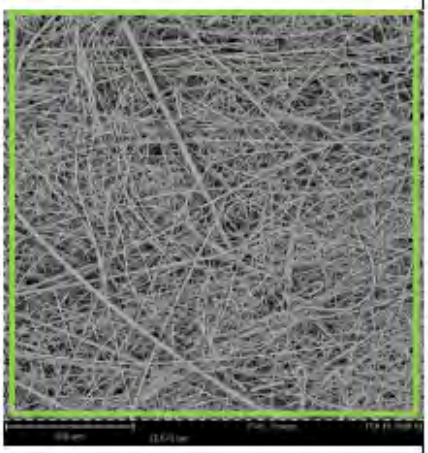


Blank, General Analysis (Glass Background)

	Atomic percentage	Certainty
O	64.1 %	1.00
Si	16.8 %	1.00
Na	12.7 %	0.99
Al	2.6 %	0.99
K	1.1 %	0.98
Zn	1.0 %	0.95
Ca	0.9 %	0.98
Ba	0.7 %	0.98

eBAM (PM2.5) 2/04/2016



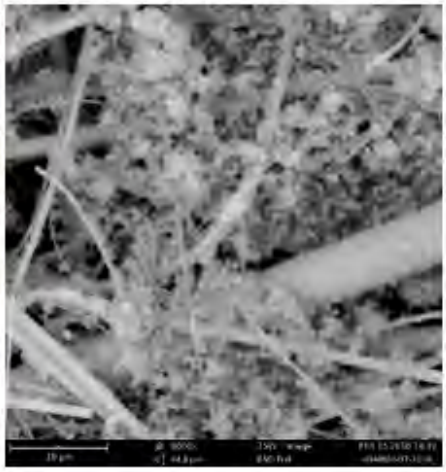


2/04/2016, General Analysis (background)

	Atomic percentage	Certainty
O	65.6 %	0.99
Si	16.2 %	0.99
Na	13.0 %	0.98
Al	2.4 %	0.97
K	1.2 %	0.97
Ca	1.0 %	0.96
Ba	0.7 %	0.95

eBAM (PM2.5) 04/07/2016

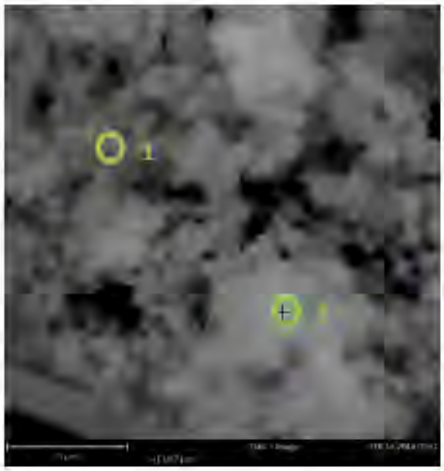
eBAM (PM2.5) 04/07/2016



04/07/2016, General Analysis (Organic material)

	Atomic percentage	Certainty
O	50.5 %	0.99
Na	13.9 %	0.99
Si	11.2 %	0.99
N	8.5 %	0.97
C	6.4 %	0.98
Cl	2.3 %	0.98
Al	2.2 %	0.98
Mg	1.3 %	0.95
K	0.7 %	0.96
Zn	0.7 %	0.87
P	0.7 %	0.95
Ca	0.7 %	0.95
Ba	0.5 %	0.94
S	0.4 %	0.94

Cont...



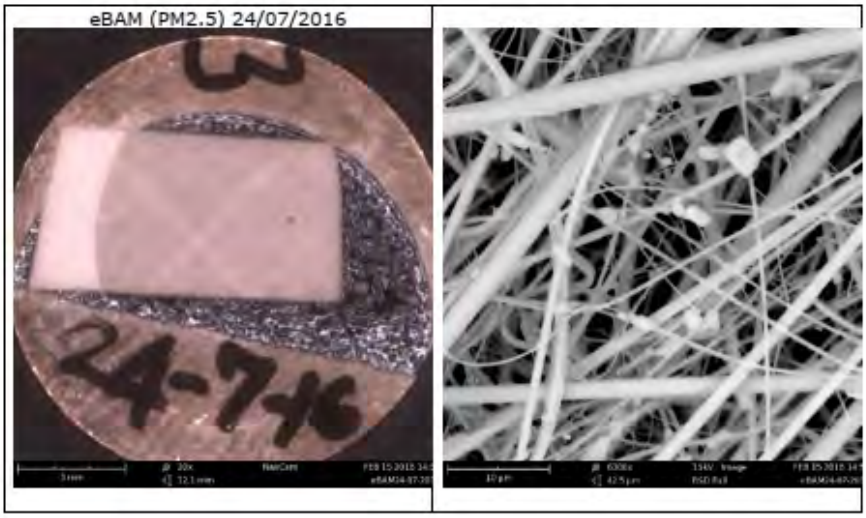
04/07/2016, Spot 1 (Sodium Chloride)

	Atomic percentage	Certainty
Na	40.5 %	0.99
O	33.9 %	0.98
Cl	12.9 %	0.99
Si	5.7 %	0.99
N	4.9 %	0.94
P	0.7 %	0.94
Al	0.5 %	0.89
S	0.5 %	0.93
K	0.4 %	0.91
Ca	0.2 %	0.87
Mg	0.0 %	1.00

04/07/2016, Spot 2 (Organic)

	Atomic percentage	Certainty
O	37.1 %	0.98
Si	17.7 %	0.99
Na	16.8 %	0.99
C	11.0 %	0.98
N	6.2 %	0.95
Al	3.1 %	0.98
Cl	2.0 %	0.97
Mg	1.9 %	0.96
K	1.3 %	0.97
P	1.0 %	0.95
Ca	0.9 %	0.95
S	0.6 %	0.94
Ba	0.5 %	0.93

eBAM (PM2.5) 24/07/2016



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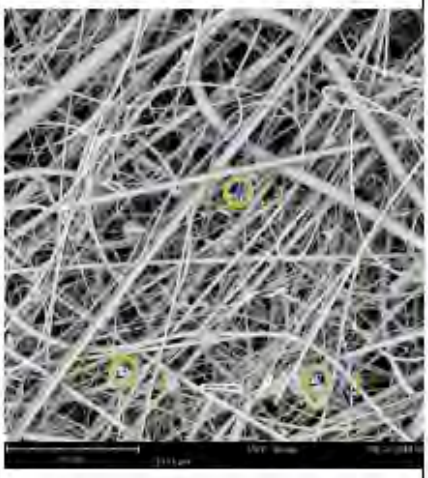


24/07/2016, Spot 1 (Chlorides)

	Atomic percentage	Certainty
O	60.9 %	0.99
Na	13.7 %	0.98
Cl	11.0 %	0.99
Si	9.5 %	0.99
Al	1.4 %	0.96
C	1.1 %	0.91
K	0.7 %	0.94
Ca	0.7 %	0.94
Ti	0.5 %	0.92
P	0.3 %	0.86
S	0.2 %	0.87
Mg	0.0 %	1.00

24/07/2016, Spot 2 (Calcium Sulphate/Nitrate salts)

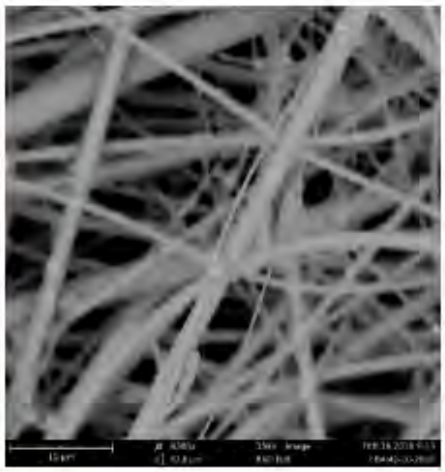
	Atomic percentage	Certainty
O	61.6 %	0.99
S	13.9 %	0.99
Ca	13.6 %	0.99
N	9.1 %	0.96
P	0.8 %	0.97
Si	0.8 %	0.96
C	0.2 %	0.82

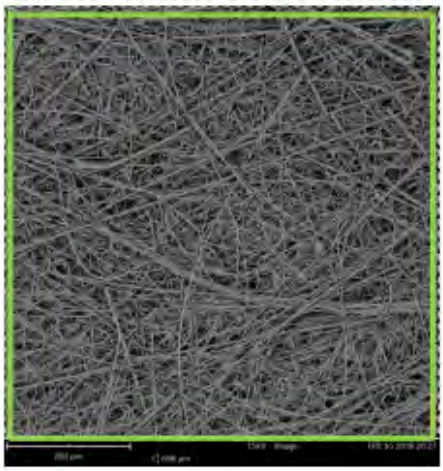
24/07/2016, Spot 3(Calcium salts)

	Atomic percentage	Certainty
O	68.7 %	0.99
S	10.2 %	0.99
N	10.0 %	0.97
Ca	9.5 %	0.99
Si	0.7 %	0.97
P	0.5 %	0.96
C	0.2 %	0.86
Al	0.2 %	0.88

eBAM (PM2.5) 02/10/2016

eBAM (PM2.5) 02/10/2016

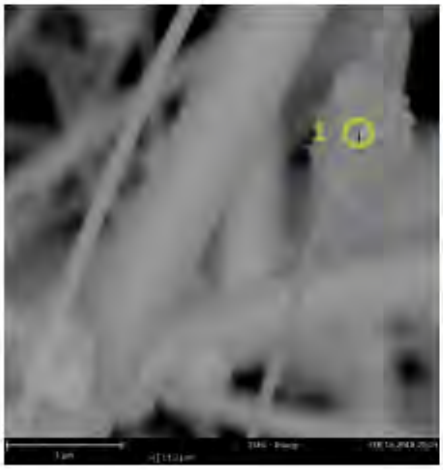




2/10/2016, General Analysis (Background)

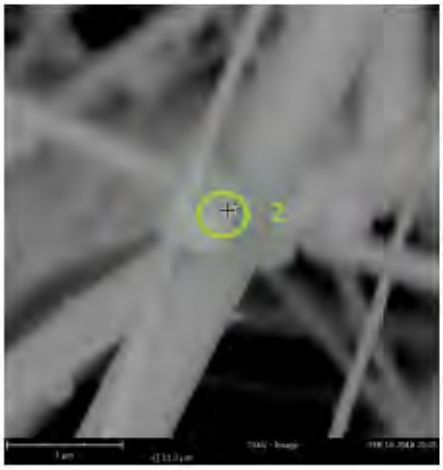
	Atomic percentage	Certainty
O	61.4 %	0.99
Si	12.4 %	0.99
Na	10.6 %	0.99
N	8.8 %	0.98
Al	2.1 %	0.98
K	0.9 %	0.97
Mg	0.8 %	0.94
Ca	0.7 %	0.97
C	0.6 %	0.93
Ba	0.5 %	0.96
Cl	0.4 %	0.94
P	0.4 %	0.94
S	0.3 %	0.93

Cont...



02/10/2016, Spot analysis 1 (Organics)

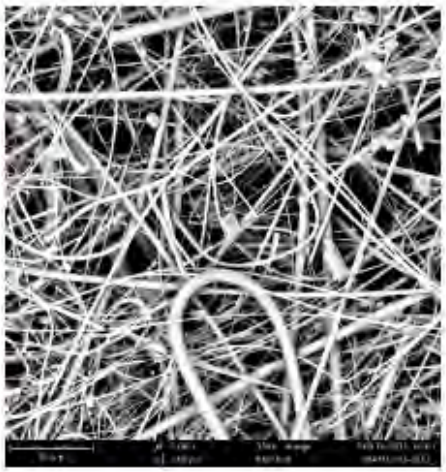
	Atomic percentage	Certainty
O	60.2 %	0.99
Na	13.8 %	0.99
Si	9.1 %	0.99
C	7.5 %	0.98
Mg	2.1 %	0.97
Al	2.0 %	0.98
S	1.2 %	0.97
Ca	1.1 %	0.97
P	0.9 %	0.97
In	0.8 %	0.97
Cl	0.7 %	0.96
Ba	0.6 %	0.96



2/10/2016, Spot analysis 2 (Calcium salts)

	Atomic percentage	Certainty
O	65.1 %	0.99
Na	11.1 %	0.99
N	8.9 %	0.98
Si	7.6 %	0.99
S	2.8 %	0.99
Ca	2.3 %	0.99
Al	1.1 %	0.97
K	0.4 %	0.95
P	0.3 %	0.94
Ba	0.2 %	0.92
C	0.2 %	0.83

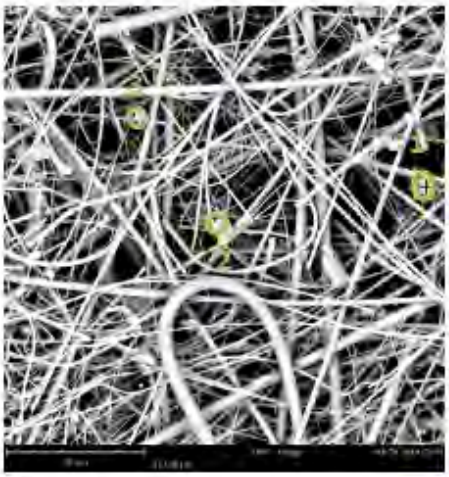
eBAM (PM2.5) 22/01/2017



22/01/2017, General Analysis (Nitrates)

	Atomic percentage	Certainty
O	62.0 %	0.99
Si	12.1 %	0.99
Na	10.7 %	0.99
N	8.6 %	0.98
Al	2.2 %	0.98
Mg	0.9 %	0.94
Cl	0.8 %	0.97
Ca	0.8 %	0.97
K	0.7 %	0.96
Ba	0.5 %	0.95
P	0.4 %	0.94
S	0.4 %	0.94

Cont...



22/01/2017, Spot 1(Calcium Salts)

	Atomic percentage	Certainty
O	67.3 %	0.99
Ca	10.6 %	0.99
N	10.0 %	0.97
S	9.0 %	0.99
Na	1.2 %	0.93
Si	0.9 %	0.97
P	0.5 %	0.96
C	0.3 %	0.89
Al	0.2 %	0.88

22/01/2017, Spot 2 (Calcium Salts)

	Atomic percentage	Certainty
O	73.9 %	0.99
N	9.7 %	0.98
S	6.6 %	0.99
Ca	5.8 %	0.99
Na	2.5 %	0.97
Si	0.8 %	0.98
P	0.4 %	0.95
Al	0.2 %	0.87
C	0.2 %	0.85

22/01/2017, Spot 3 (Calcium Salts)

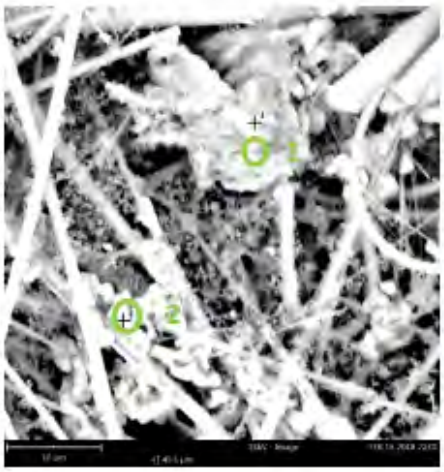
	Atomic percentage	Certainty
O	61.2 %	0.99
Ca	13.0 %	0.99
S	10.5 %	0.99
N	9.6 %	0.97
Na	2.9 %	0.96
Si	1.9 %	0.98
Al	0.4 %	0.93
C	0.2 %	0.88
K	0.1 %	0.85

eBAM (PM2.5) 16/06/2017

16/06/2017, General Analysis (Organics, Nitrates)

	Atomic percentage	Certainty
O	54.1 %	0.99
Na	13.8 %	0.99
Si	11.7 %	0.99
N	8.0 %	0.97
C	3.4 %	0.97
Cl	2.6 %	0.98
Al	2.0 %	0.97
Mg	0.8 %	0.92
Zn	0.8 %	0.87
K	0.8 %	0.96
Ca	0.7 %	0.95
P	0.5 %	0.93
Ba	0.5 %	0.94
S	0.4 %	0.94

Cont...

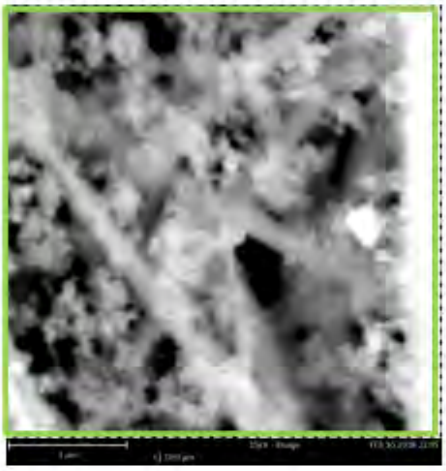


16/06/2017, Spot 1 (Calcium Salts)

	Atomic percentage	Certainty
O	66.3 %	0.99
N	9.6 %	0.98
S	9.3 %	0.99
Ca	8.7 %	0.99
Na	5.6 %	0.98
Si	0.3 %	0.94
C	0.2 %	0.88

16/06/2017, Spot 2 (Sodium Chloride)

	Atomic percentage	Certainty
Na	58.2 %	1.00
Cl	24.5 %	1.00
O	14.6 %	0.97
Si	2.6 %	0.98
P	0.1 %	0.76
Mg	0.0 %	1.00
Al	0.0 %	1.00



16/06/2017, Small Area Analysis (Organics, Nitrates)

	Atomic percentage	Certainty
O	47.3 %	0.99
Na	15.7 %	0.98
Si	11.4 %	0.99
N	7.1 %	0.95
C	6.9 %	0.98
Cl	3.4 %	0.98
Zn	1.8 %	0.92
Al	1.6 %	0.96
K	1.1 %	0.96
Ca	0.9 %	0.95
P	0.8 %	0.94
Mg	0.7 %	0.88
S	0.6 %	0.94
Ba	0.6 %	0.93

Appendix III

Air Discharge Consent Holders

Figure 24 Location of commercial and industrial air emission consents, for the 2016-2019 period, with respect to the $PM_{2.5}$ monitoring site (blue diamond). Consents holders are described in Table 5.

Table 5 Significant air discharge consents within 5km of the Central School $PM_{2.5}$ monitoring site

Map Icon	Consent Holder/Location	Air Discharge Consent	Distance from $PM_{2.5}$ monitoring site	Direction from $PM_{2.5}$ monitoring site
	Dow Agrosciences (NZ) Ltd	Agrichemical formulation and packaging plant	4.9	W
	Port Taranaki	Port operations including blowing operations and abrasive blasting	4.1	W
	Dialog Fitzroy Ltd	Abrasive blasting operations	3.5	NE
	Downer NZ Ltd	Asphalt paving mix manufacturing	3.8	NE
	Ravensdown Fertilizer Coop Ltd	Fertilizer production. (Surrendered, no longer current)	3.0	NE
	Katere Surface Coatings	Abrasive blasting and surface coating activities	4.6	NE
	New Plymouth District Council	Composting, abrasive blasting and other activities at Colson Rd landfill	3.7	E

Appendix IV

Additional Figures

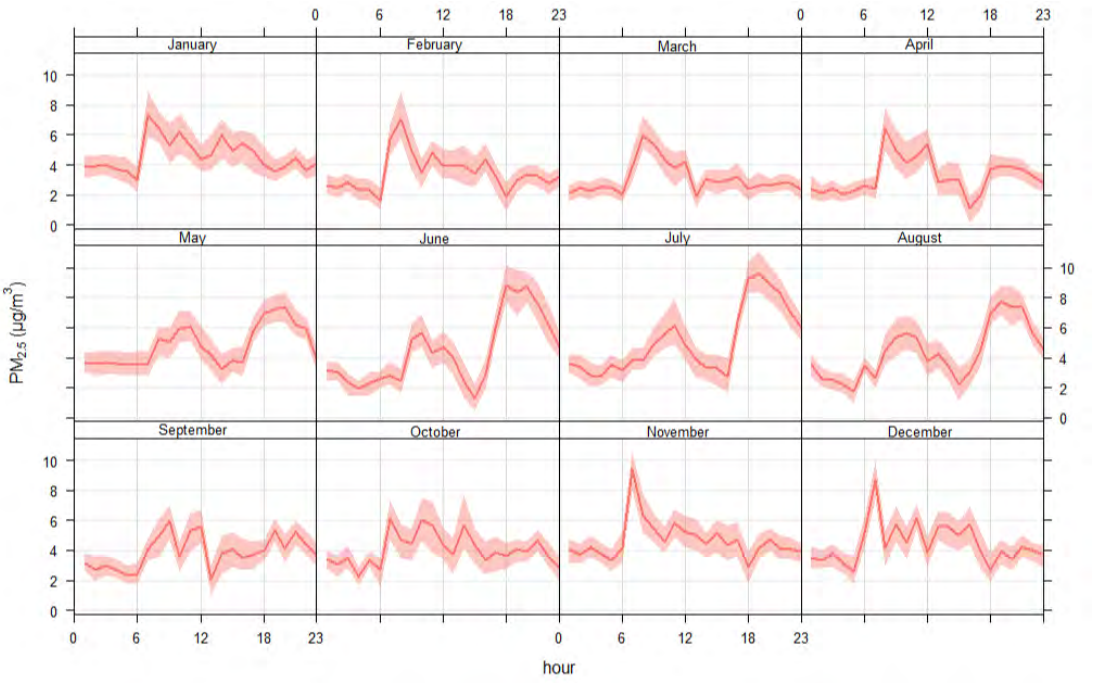


Figure 25 Diurnal variation in $PM_{2.5}$ concentration by month of the year

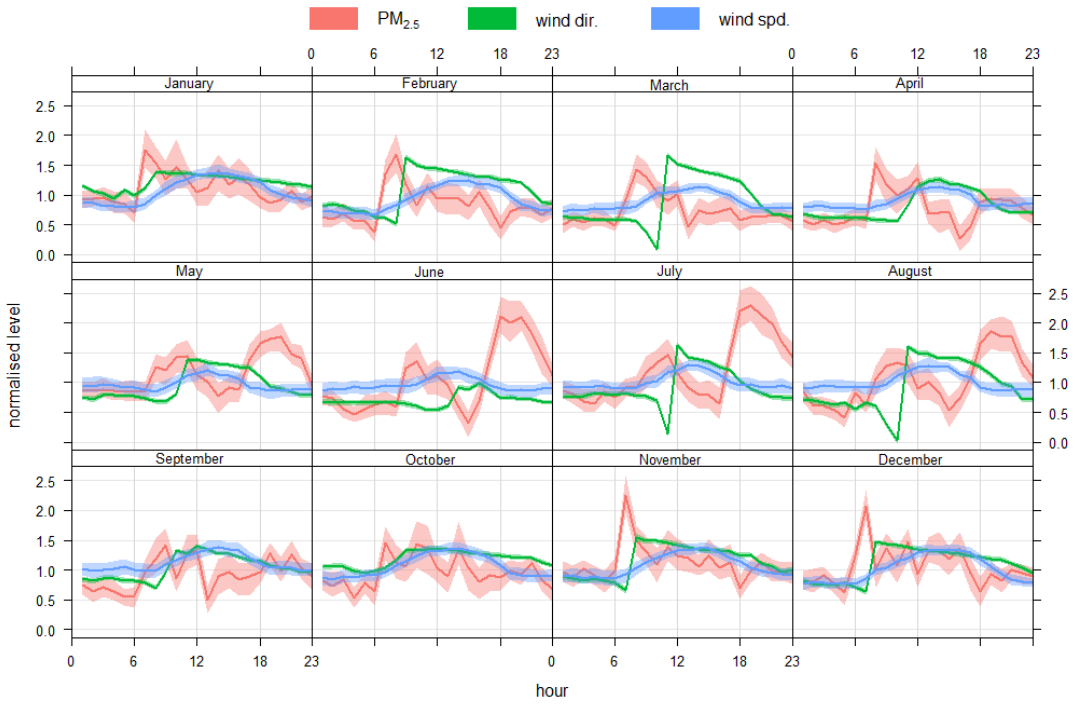


Figure 26 Comparison of normalized diurnal $PM_{2.5}$, wind direction and wind speed variations.

Figure 27 Calendar plot showing the air quality rating of each day in the monitoring period, with the mean wind direction for that day overlaid. Days with an arrow but a white background have no daily $PM_{2.5}$ mean calculated for them as data did not meet the 75% threshold

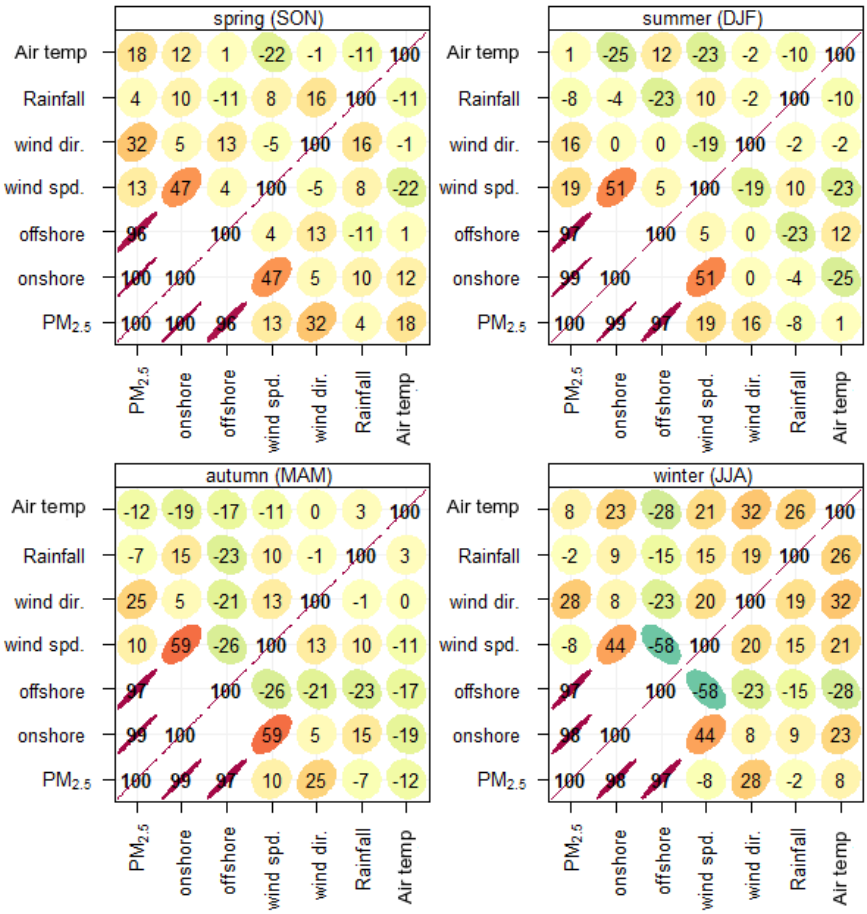


Figure 28 Pearson's correlation matrices for $PM_{2.5}$ and meteorological variables, split by season. The variables "onshore" and "offshore" represent PM2.5 levels for days with predominantly onshore and offshore winds (they are subsets of the variable "PM2.5").

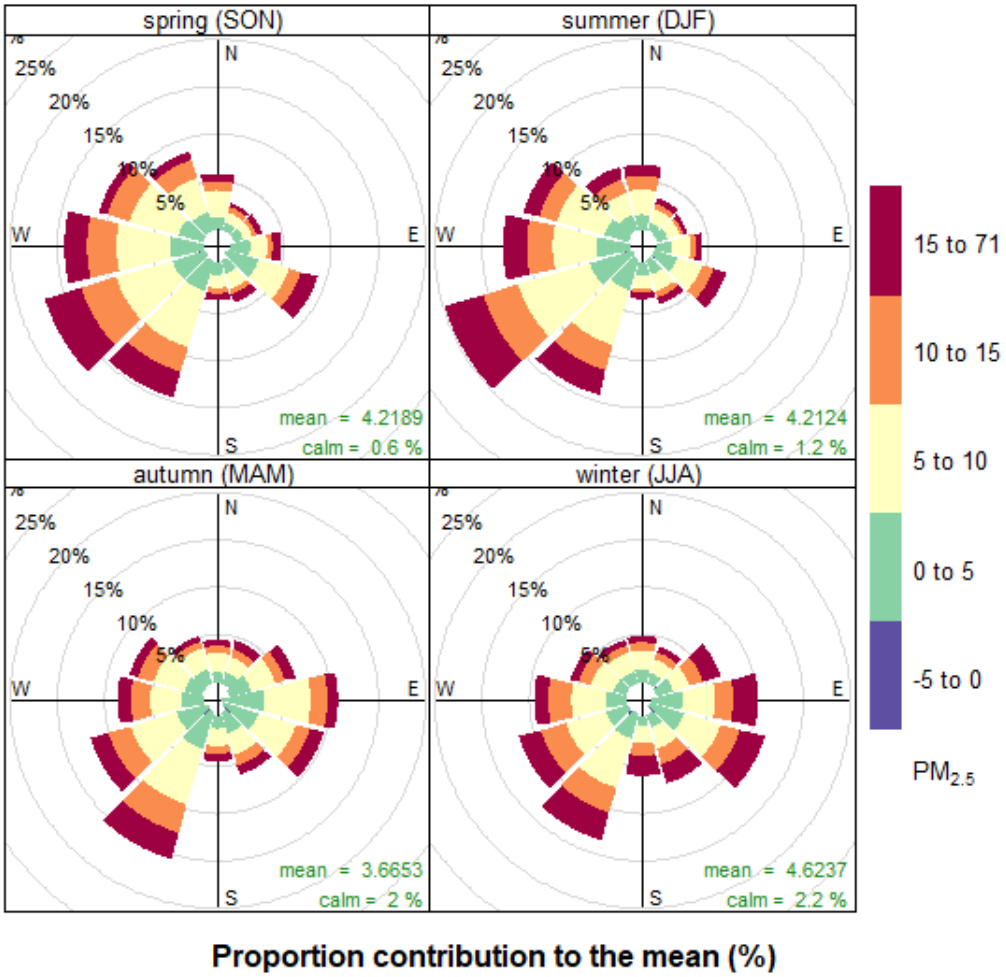


Figure 29 Pollution roses for each season.

Appendix V

Phenom ScEM analysis and $PM_{2.5}$ level comparisons

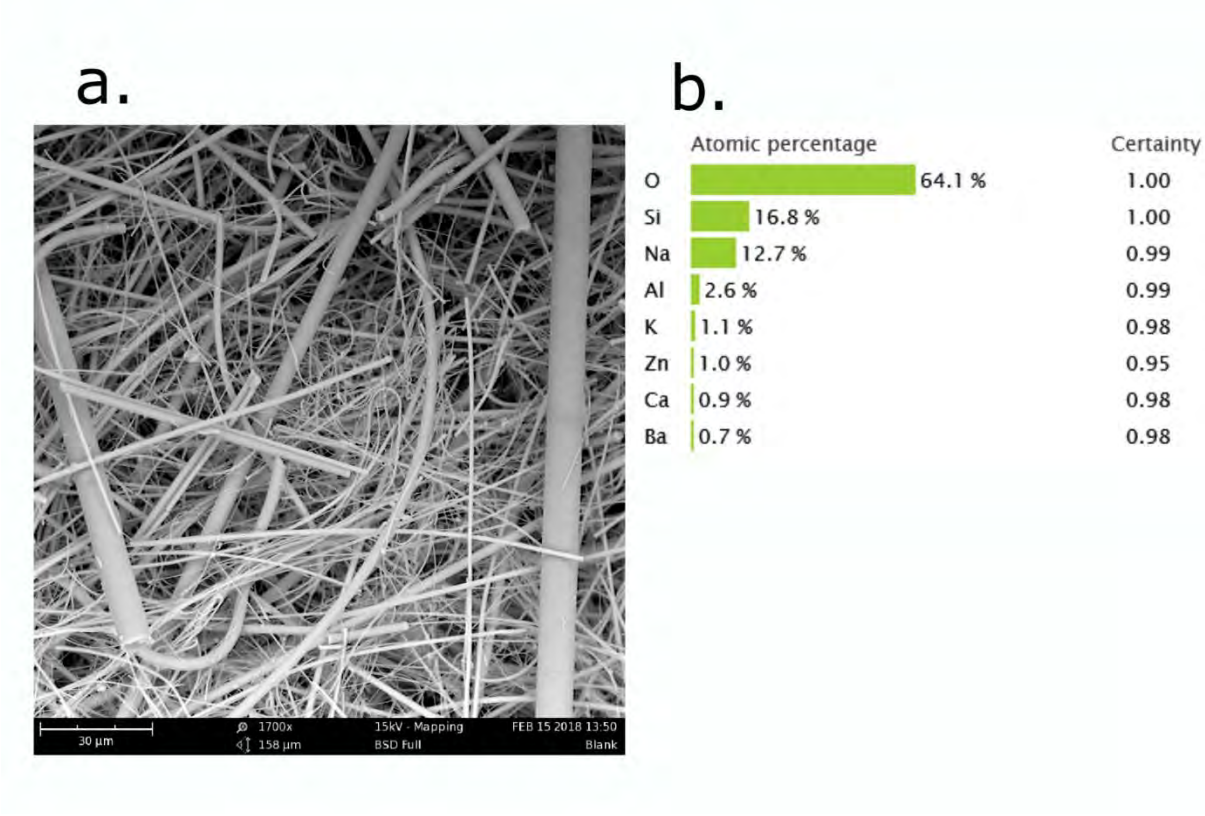


Figure 30 ScEM analysis of a blank filter. (a) Photo of the filter. (b) Percentage elemental composition of the blank filter.

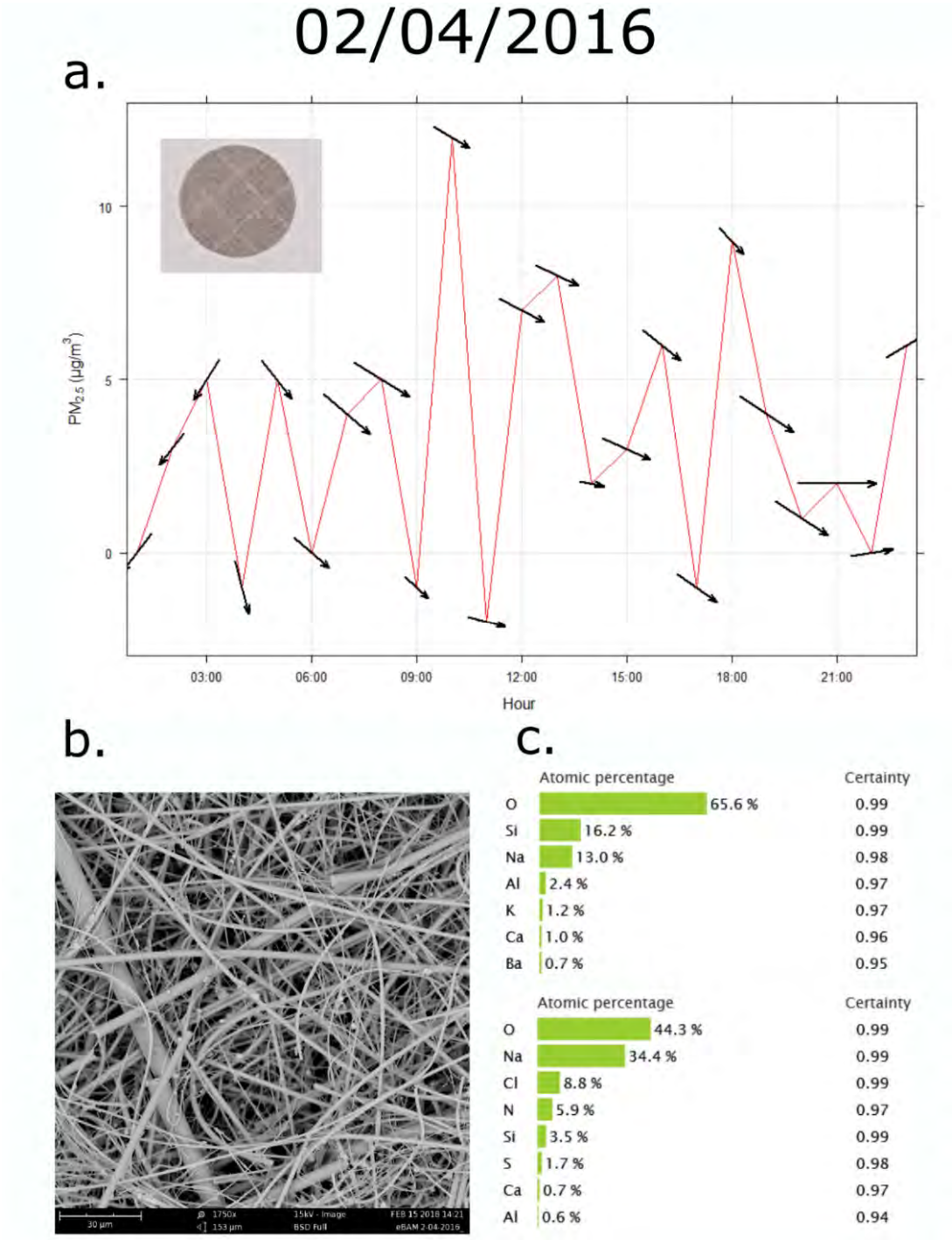


Figure 31 ScEM analysis of the EBAM filter from 2nd April 2016, when a daily mean of 3µg/m^3 was recorded. (a) Variation of $PM_{2.5}$ through the day, with wind direction and relative speed overlaid. (Inset: Photo of the EBAM filter). (b) ScEM sample photo. (c) Percentage elemental composition of a region (above), and point (below) of the sample.

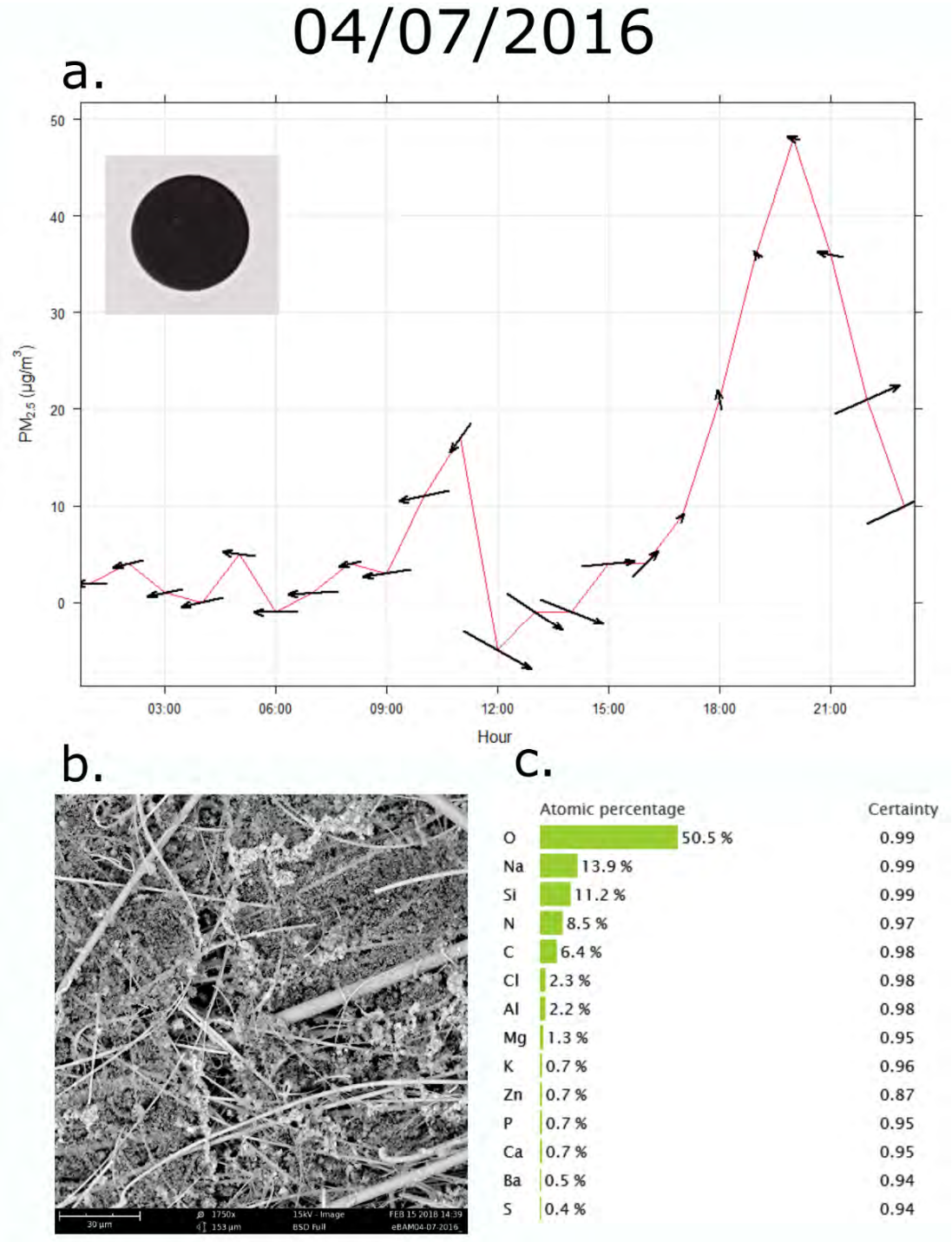


Figure 32 ScEM analysis of the EBAM filter from 4th July 2016, when a daily mean of 10µg/m^3 was recorded.. (a) Variation of $PM_{2.5}$ through the day, with wind direction and relative speed overlaid. (Inset: Photo of the EBAM filter). (b) ScEM sample photo. (c) Percentage elemental composition of a region of the sample, which shows elevated content of sodium chloride and organic particulates

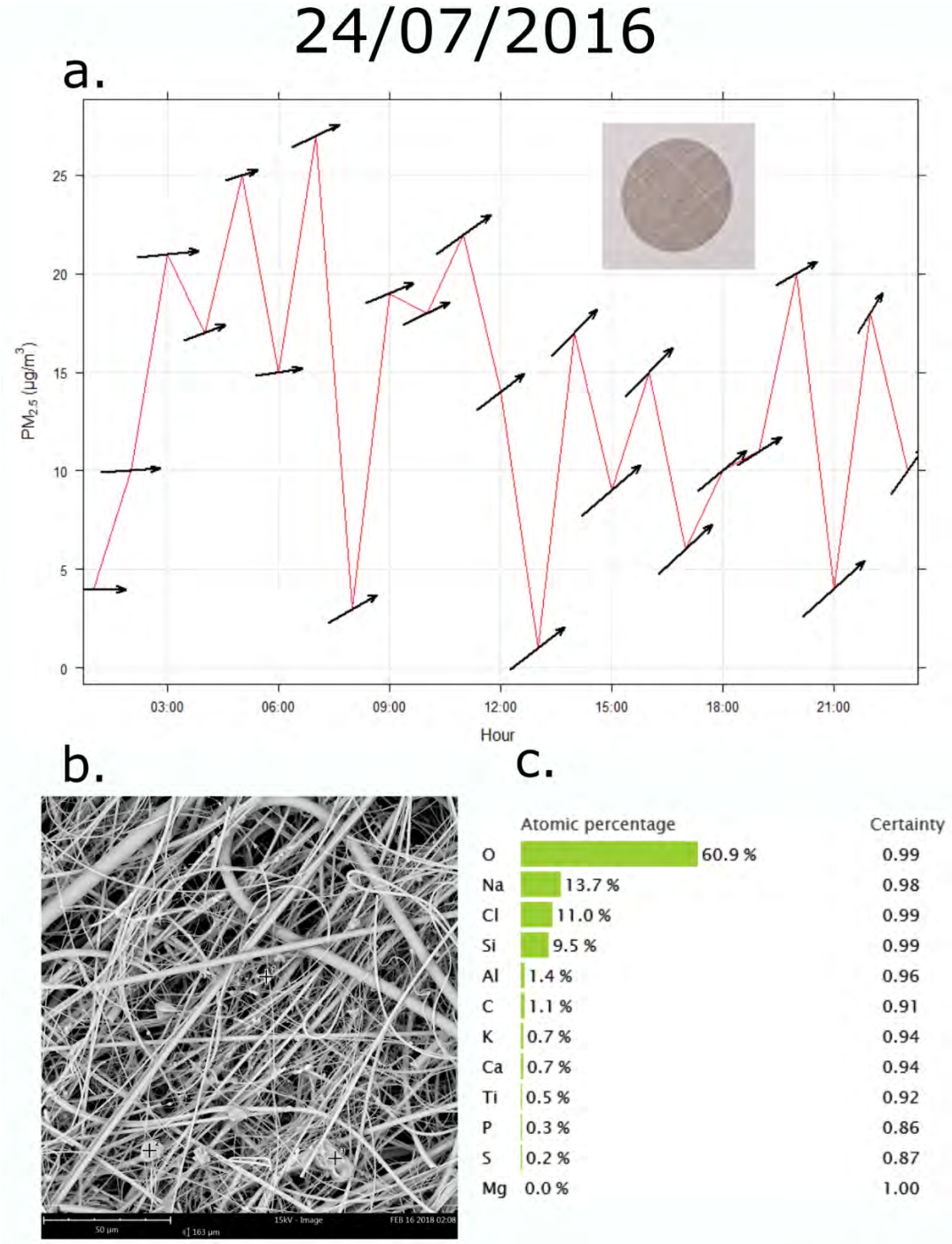


Figure 33 ScEM analysis of the EBAM filter from 24thth July 2016, , when a daily mean of 14µg/m^3 was recorded.. (a) Variation of $PM_{2.5}$ through the day, with wind direction and relative speed overlaid. (Inset: Photo of the EBAM filter). (b) ScEM sample photo. (c) Percentage elemental composition of one spot of the sample, Spots analyses showed the presence of chlorides, calcium sulphate, nitrate salts and calcium salts

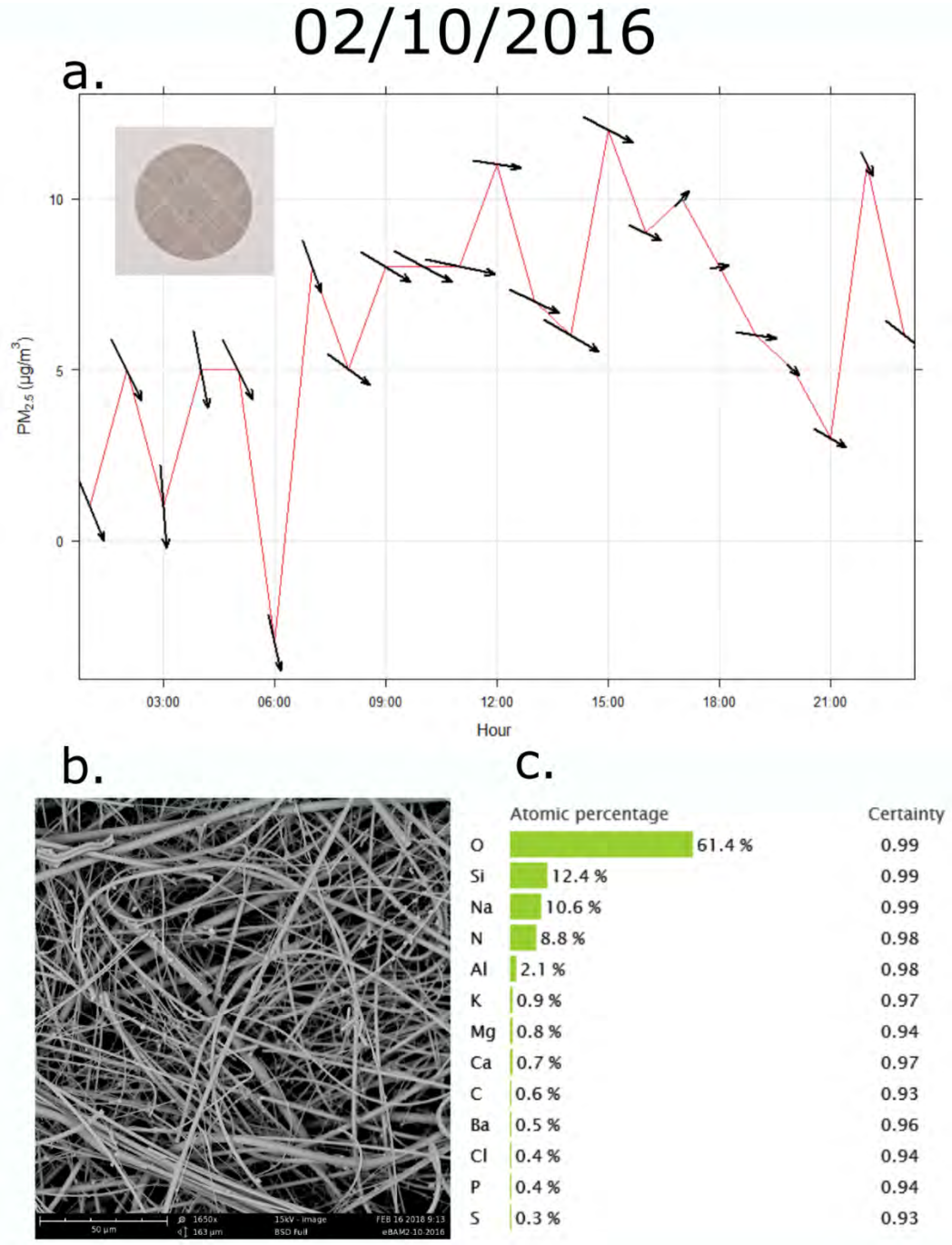


Figure 34 ScEM analysis of the EBAM filter from 2nd October 2016, when a daily mean of 6µg/m^3 was recorded.. (a) Variation of $PM_{2.5}$ through the day, with wind direction and relative speed overlaid. (Inset: Photo of the EBAM filter). (b) ScEM sample photo showing calcium salts. (c) Percentage elemental composition of a region of the sample, which shows elevated content of organics and calcium salts

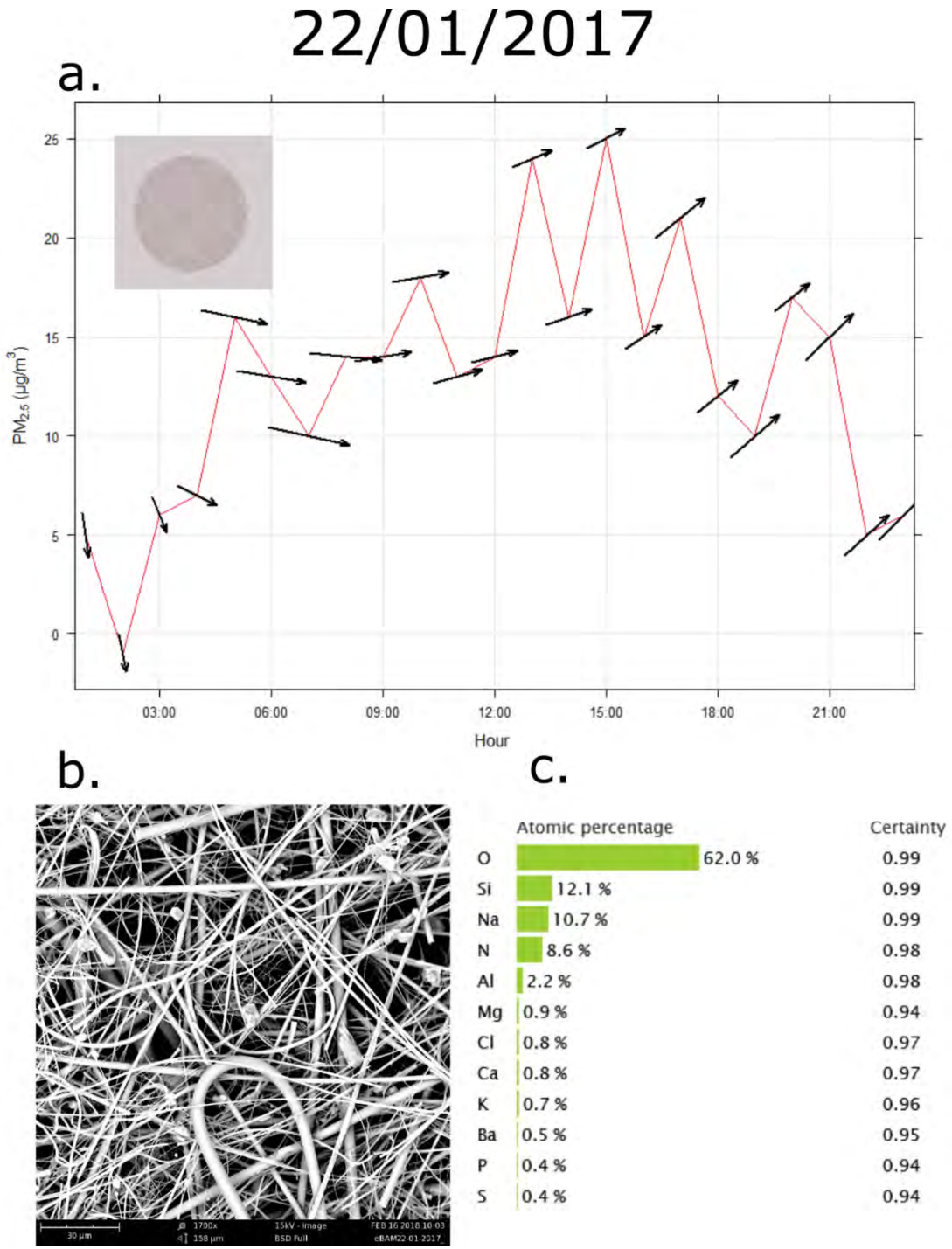


Figure 35 ScEM analysis of the EBAM filter from 22nd January 2017, when a daily mean of 13µg/m^3 was recorded. (a) Variation of $PM_{2.5}$ through the day, with wind direction and relative speed overlaid. (Inset: Photo of the EBAM filter). (b) ScEM sample photo showing calcium salt particulates. (c) Percentage elemental composition of a region of the sample

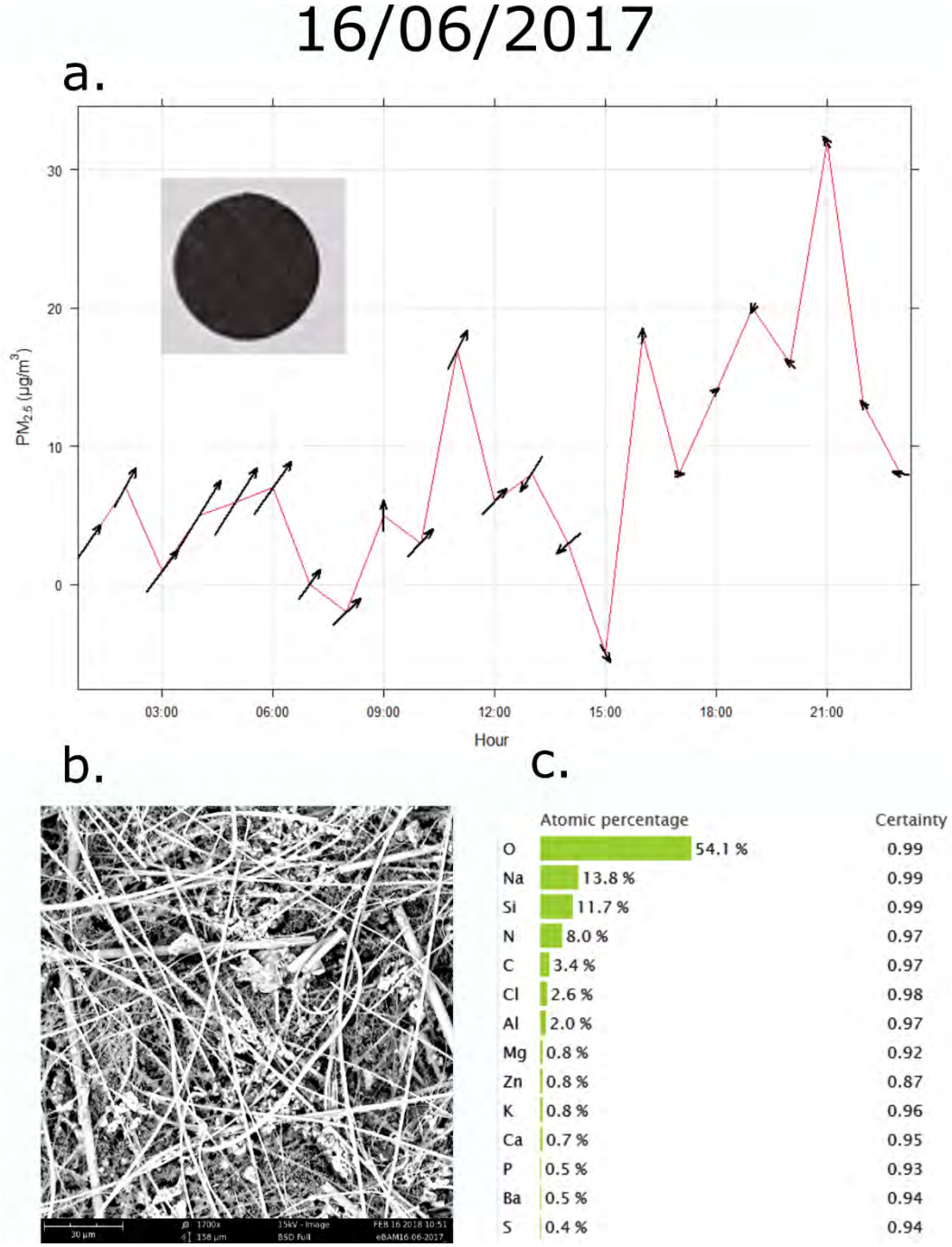


Figure 36 ScEM analysis of the EBAM filter from 16th June 2017, when a daily mean of 14µg/m^3 was recorded. (a) Variation of $PM_{2.5}$ through the day, with wind direction and relative speed overlaid. (Inset: Photo of the EBAM filter). (b) ScEM sample photo, showing carbon content. (c) Percentage elemental composition of the sample from ScEM analysis, showing elevated N, C, Cl and Na content