Assessing long-term trends in PM_{10} concentrations in Invercargill

Prepared for Environment Southland
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August 2009

Envirolink Project Number ESRC223

Executive Summary

In Invercargill concentrations of PM_{10} regularly exceed the National Environmental Standard of 50 µg m^{-3} (24-hour average) during the winter months. Historically monitoring of PM_{10} has been carried out in Miller Street using a high volume sampler that measured PM_{10} from mid day to mid day. In 2006 the method was changed to a beta attenuation monitor (BAM) and the monitoring period from midnight to midnight. The change in monitoring method and the measurement period have the potential to influence recorded PM_{10} concentrations. Another influencing factor is meteorological conditions which can vary in pollution potential from year to year.

An evaluation of PM_{10} data for Miller Street shows very high concentrations and a large number of recorded exceedences from 2003 to 2005 and lower maximum concentrations and fewer exceedences from 2006 to 2008. The objectives of this study were to advise Environment Southland on reasons for the apparent decrease in PM_{10} concentrations and to characterise the meteorological conditions giving rise to high pollution.

Around 20% of the difference in PM_{10} concentrations between 2003-2005 and 2006-2008 was found to occur as a result of the change in monitoring method from a high volume sampler to a BAM in 2006. However, after adjusting for this and accounting for year to year variations occurring as a result of meteorology a decrease in PM_{10} concentrations was still apparent. Results suggest a statistically significant decrease in 90^{th} percentile PM_{10} concentrations ($p<0.02$) with a reduction potentially in the order of around 39%. A reduction in median concentrations was also observed but had a higher probability that the decrease occurred as a result of chance ($p<0.07$). A reduction in the proportion of days with high pollution potential that resulted in breaches of the NES also decreased from around 40% in 2003 to around 15% in 2008.

Potential explanations for the decrease in concentrations include a reduction in PM_{10} emissions from 2003 to 2008 or changing the period of measurement from mid day to mid day to midnight to midnight or a combination of both. Potential emission reductions were investigated and it was found that the number of households using wood and coal in Invercargill had decreased from 2001 to 2006 by 15% and 10% respectively. It is uncertain whether this is the sole reason for the observed decrease or whether other factors such as the change in measurement period has also contributed.

The analysis indicated that the very high PM_{10} concentrations measured during 2003 to 2005 were able to be explained by low wind speeds.

The meteorological condition with the greatest potential of resulting in a breach of the NES was an average wind speed between 5pm and midnight of less than or equal to 0.7

ms^{-1}. A further split on the high pollution dataset found the highest pollution events were most likely to occur when the wind speed was less than or equal to 0.4 ms^{-1}.

Analysis of synoptic forcings for each terminal node of the identified pollution classes (of grouped PM_{10} tree) provides evidence that each class is indeed representative of distinct atmospheric conditions and not just a manifestation of statistical analysis. Generally, anticyclones located east of the country potentially decrease air quality in Invercargill, whereas anticyclones that are situated to the west of the country usually promote good air quality.

Ongoing monitoring of trends in PM_{10} concentrations in Invercargill is likely to be difficult because of the relocation of the Miller Street monitoring site to Pomona Street in 2009. It is recommended that monitoring be carried out at Miller Street every few years to allow for trend analysis until 5 to 10 years of data are available from the Pomona Street air quality monitoring site.

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1 Introduction

Concentrations of PM_{10} in Invercargill breach the National Environmental Standards (NES) for PM_{10} which specify a limit of 50 μgm^{-3} (24-hour average). The PM_{10} standard, which allows for one breach per year, must be met by 2013 or Councils are unable to grant resource consents for discharges to air in the airshed. The NES also requires Councils to demonstrate that they can comply with the straight line path (SLiP) to compliance. The starting points of the SLiPs are typically based on maximum or second highest PM_{10} concentrations and the end points are compliance with the NES. Councils that cannot demonstrate compliance with the SLiP are unable to grant resource consents for significant discharges of PM_{10} unless the impact is offset by equivalent reductions in PM_{10}.

Environment Southland has undertaken scientific research to establish sources of PM_{10} and causes of breaches of the NES. In 2004 an emissions inventory was completed. The results indicate that domestic heating is the main source of PM_{10} emissions in Invercargill, with 96% of PM_{10} emissions coming from this source (Wilton, 2004). Further work has been undertaken to assess the effectiveness of different strategies to reduce PM_{10} concentrations to meet the NES by 2013 (Wilton et al, 2009).

The Regional Air Quality Plan for Southland has been operative since 1999 and does not contain regulations to control discharges to air from domestic home heating. Review of the plan will be required to reduce PM_{10} concentrations to meet the NES.

The reduction in PM_{10} concentrations required to meet the NES is typically based on the highest 99.7 percentile PM_{10} concentration (or second highest per year) over the monitoring period. In Invercargill, monitoring of PM_{10} has been carried out at Miller Street since 2003. In 2005 a 99.7 percentile concentration of 126 $\mu g\ m^{-3}$ was used to estimate a required reduction in PM_{10} concentrations of around 60%. This value was reconsidered in 2009 as a result of air quality monitoring at Pomona Street during 2009 (Wilton, et. al., 2009) but retained as the most appropriate reduction required based on the information available at that time.

The Miller Street PM_{10} concentrations are unusual, however, in that the very high concentrations and frequency of exceedence recorded from 2003 to 2005 did not occur during 2006 to 2008. For example, estimated exceedences dropped from 11 per year (average 2003 to 2005) to 1 per year at Miller Street for 2006 to 2008. Year to year variations in concentrations can occur as a result of variability in meteorological conditions. Other factors which may contribute to the observed changes include the change in monitoring methods (from high volume sample to a BAM) in 2006, and changing the monitoring period from measuring PM_{10} for a 24-hour period starting at mid day to the NES requirement of midnight to midnight. The former sampling period is more likely to result in higher PM_{10} concentrations because the pollution event is not split across two separate monitoring days.

Another potential reason for a change in concentrations is a reduction in PM_{10} emissions. This would seem an unlikely explanation for this observation, in the absence of air quality management regulations, unless there was a localised source contributing to PM_{10} that ceased operations post 2005.

The purpose of this study is to evaluate the impact of year to year variability in meteorology on PM_{10} concentrations to evaluate the reasons for apparent changes in PM_{10} concentrations between 2003 to 2005 and 2006 to 2008. In particular the study aims to determine:

- If meteorological conditions can explain the higher PM_{10} concentrations measured during 2003 to 2005.
- If lower maximum concentrations and frequency of exceedences from 2006 to 2008 reflect a real trend in PM_{10} concentrations.
- Any other possible contributing factors.

2 Methodology

2.1 Monitoring data

Air quality monitoring for PM_{10} at the Miller Street site commenced in June 2003. The site is located to the south of central Invercargill at Peacehaven Rest Home and is downwind of a large residential area. The meteorological conditions at the site are conducive to poor air quality, and include low wind speed and inversion layers occur frequent during winter. Parks and reserves are directly north and to the west of the site. A few small trees and bushes are within a 30 metre radius. The nearest dwelling is 25 metres from the site and is 4 to 5 metres in height. The location of the Miller Street site is shown in Figure 2.1.

From mid 2003 a high volume sampler measured PM_{10} concentrations on a one day in two sampling regime during the winter and one day in six during the summer. From May 2006 to the beginning of 2009 a Thermo Scientific FH 62 Beta Attenuation Monitor (BAM) that continuously measured hourly PM_{10} was located at the Miller Street site and was the official method for measuring compliance with the NES as it measures PM_{10} from mid night to mid night. In 2008 a high volume sampler was co-located at the Miller Street site. Figure 2.2 shows the both samplers at the Miller Street site during 2008. In winter 2009 the BAM was moved to a new site at Pomona Street.

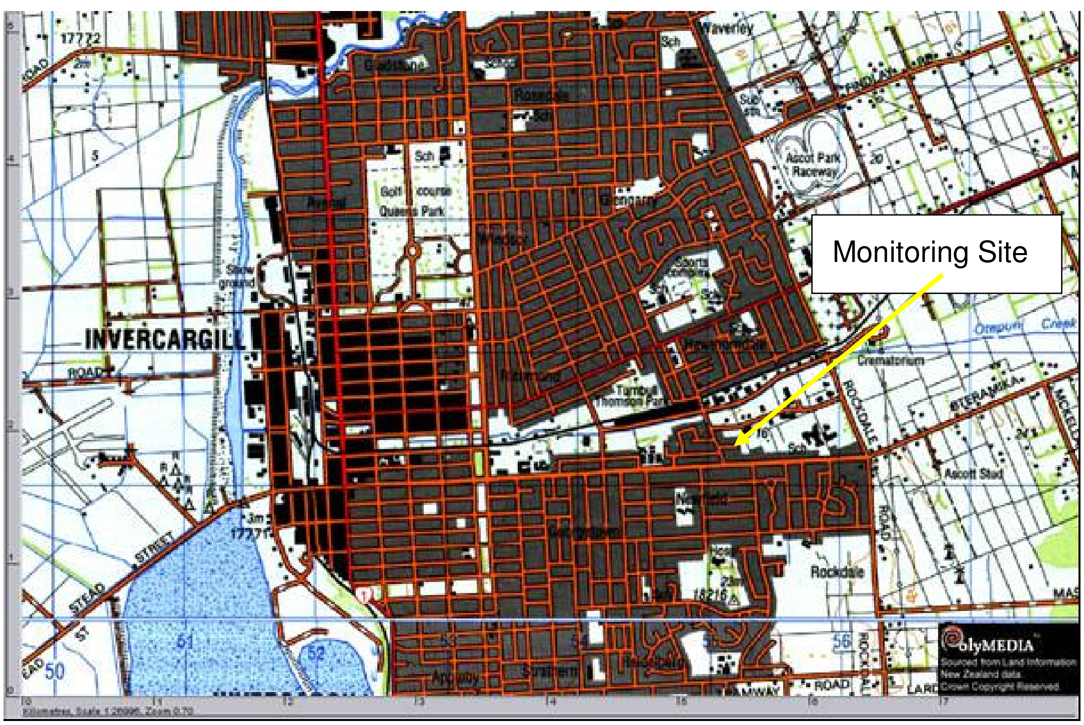


Figure 2.1: Location of air quality monitoring site at Miller Street

Figure 2.2: Air quality monitors at Miller Street

This study uses 24-hour average PM_{10} concentrations measured at Miller Street between 2003 and 2008. A total of 520 days of PM_{10} monitoring data during the months May to August was collected over this 6 year period.

Of this, around 29% was collected using the high volume sampler (pre 2006) and 71% using the BAM. A comparison between the BAM and high volume sampler was carried out for this study and indicates that the BAM under measures compared with the high volume sampler by around 20% at concentrations around 50 µg m^{-3} (Appendix A). During the period that this report was prepared Environment Southland had not decided whether BAM concentrations would be adjusted for gravimetric equivalency in determining compliance with the NES. In this analysis BAM data have been adjusted upwards to be equivalent to gravimetric measurements to allow a more true representation of any trends in PM_{10} concentrations from 2003 to 2008.

2.2 Statistical Analysis

Classification and regression tree analysis was used to investigate meteorological potential to produce elevated concentrations of PM_{10} in Invercargill. Classification and Regression Trees (CART) describe a statistical procedure that was introduced by Breiman et al. (1984). Classification and Regression Trees have been applied to a wide variety of environmental studies including air quality problems (eg. Zheng et al. 2009, Hendrikx et al. 2005). Slini et al. (2006) evaluated four different statistical techniques to forecast PM_{10} concentrations for Thessaloniki, Greece and concluded that CART proved satisfactory in capturing concentration trends.

Based on a set of predictor variables, this statistical approach repeatedly splits the response into a set of classes (or nodes) with maximum possible class purity at each split stage and arranges the final splits into a decision tree diagram. It stops when no further split can be found at a specified significance level or the resulting class size would be less than a specified number of observations. For an in-depth description of the recursive partitioning algorithm used in this study refer to Hothorn et al. (2006). Note that for the used algorithm no boosting or pruning is required.

Analysis was restricted to winter months May to August as this is the period when exceedences of the NES occur. Lagged information of several meteorological variables was taken into account to capture possible autocorrelation processes. Information on vertical atmospheric structures was not available at satisfactory temporal resolution.

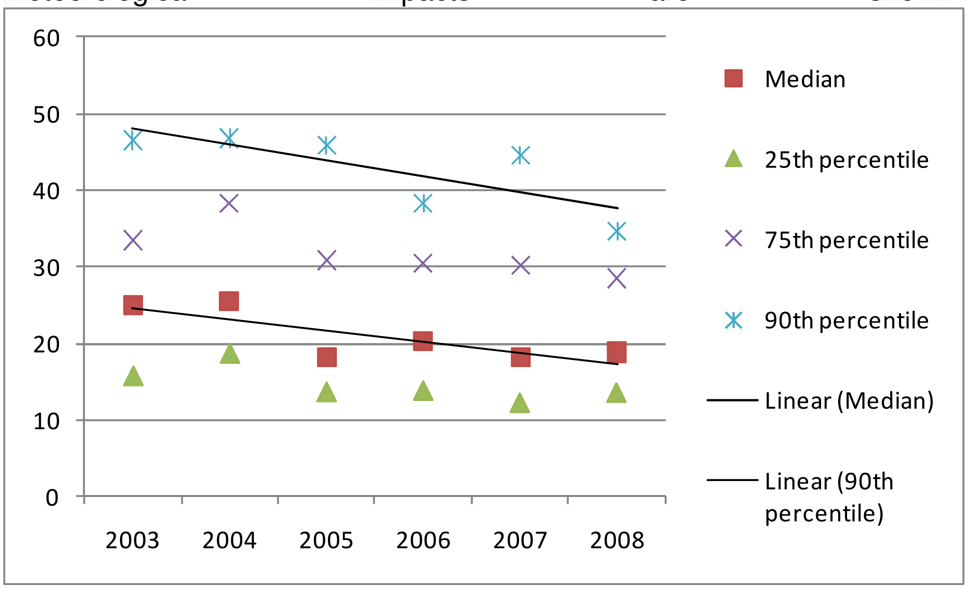
In the final step, data from the identified high pollution class was broken down into year and subjected to trend analysis. Linear regression was used to determine the significance of the trend. This method was applied because the PM_{10} concentrations within each final class were normally distributed.

The classification tree enables an assessment of air quality by assigning any given day into a pollution potential class based on its atmospheric set up.

3 Trends in PM_{10} concentrations

3.1 Annual average PM_{10} concentrations

Trends in PM_{10} concentrations adjusted for changes in monitoring method but not meteorological impacts are shown in



.1. Data illustrated includes the median (middle ranked 24-hour average PM_{10} concentration) and 25th, 75th and 90th percentile concentrations for the months May to August for each year. Results suggest some decrease in both median and upper end PM_{10} concentrations from 2003 to 2008.

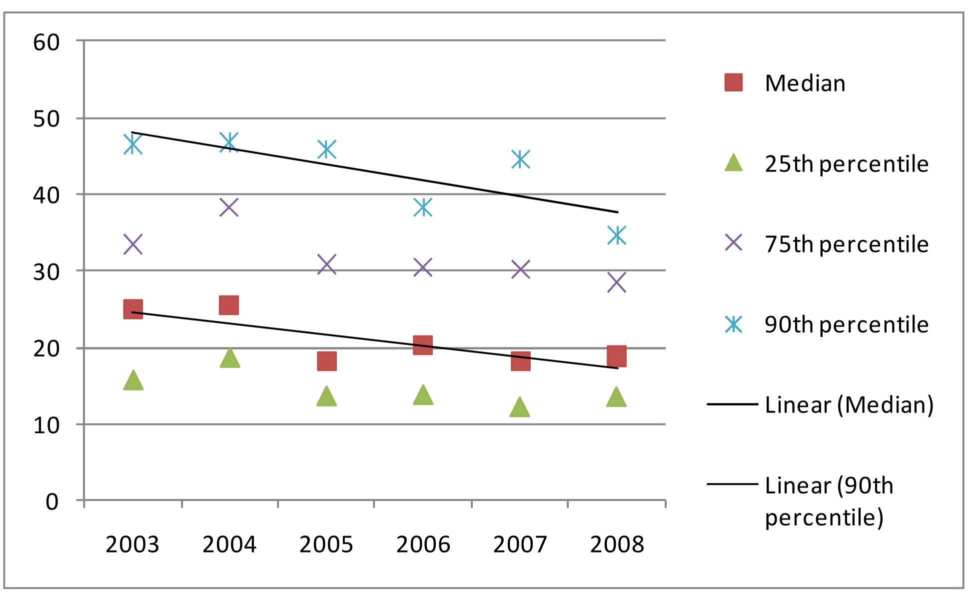


Figure 3.1: 24-hour average PM_{10} concentrations by year for Invercargill 2003 to 2008

3.2 Identifying and grouping days with highest PM_{10} concentrations

Meteorological data for the period 2003 to 2008 were collated based on the variables in **Error! Reference source not found.**. A range of meteorological variables were included to allow the CART algorithm to determine which variables most significantly explain variations in 24-hour average PM_{10} concentrations and which were the greatest indicators of elevated PM_{10}.

Table 3.1: Meteorological classifications used for the analysis

	Period	PM_{10}	Wind speed (ms^{-1})	Temperature (°C)	Wind direction (°N)
24-hour average	Midnight to midnight	✓	✓	✓	
7-hour average	5 pm to midnight		✓	✓	
4-hour average	8 pm to midnight		✓	✓	
6-hour average	6am to midday		✓		
6-hour average preceding day	6pm to midnight		✓		
Minimum 1-hour	Midnight to midnight		✓	✓	
Minimum following day 1-hour	Midnight to midnight			✓	
Minimum sample day less minimum day following 1-hour	Midnight to midnight			✓	
Maximum 1-hour	Midnight to midnight		✓	✓	
Hourly average	5 pm		✓	✓	✓
Hourly average	8 pm		✓	✓	✓
Number of hours	5 pm to midnight		<1ms-1 <2 ms-1 <3ms-1	<1 ºC <5 ºC <10 ºC	

Initially, ungrouped PM_{10} data was analysed using a regression tree (Figure 3.2) utilising the complete set of meteorological predictors shown in Table 3.1. In order to capture a maximum amount of variance within the PM_{10} concentrations, size of the terminal nodes was allowed to be small (10 observations) and significant splits were accepted at p-values < 0.05.

Next, PM_{10} observations were grouped based on the Ministry for the Environments air quality indicator categories (Table 3.1) and were analysed using a classification tree. The purpose of the latter grouping of data was to refine the response towards the assessment of exceedences rather than focusing on more subtle variability in PM_{10} concentrations. However, in order to compensate for loss in variance of the response variable and to avoid loss of information on meteorological variability, frequency predictors (number of hours of a variable below or above a certain threshold – refer to the last row of Table 3.1) were excluded. This step was necessary as frequency measures are very robust predictors with high statistical power, but often do not retain enough variability to reflect atmospheric processes.

Figure 3.3 shows the classification tree for the grouped PM_{10} concentrations. For this, the set up of the algorithm was conservative (minimum final class size was set to 50 observations and splits were only allowed if highly significant at p-values < 0.01) in order to capture a wider range of local meteorological variance. This approach evaluated the synoptic conditions that may be controlling local meteorology that promotes elevated levels of particulate pollution.

Comparison of the two trees is somewhat difficult as the set of meteorological predictors varies in both approaches. However, it is evident that wind speed controls most of the variability in PM_{10} concentrations. The only non wind speed variable found to make a significant contribution to explaining the variability in ungrouped PM_{10} concentrations (Figure 3.2) is number of hours of temperature below 5°C between 1700hrs and 2400hrs which only accounts for a small portion of the overall variance - splitting 28 observations in a final split.

It is not surprising that wind speed conditions have a major impact on PM_{10} concentrations in Invercargill as they govern dispersion of pollutants to a high degree, especially as atmospheric stratification information is not available. The relative unimportance of temperature conditions for explaining (at least) some of the air quality variability may be attributed to Invercargill's exposed coastal location. There is no 'protective topographical barrier' that shelters Invercargill from predominant westerly to southwesterly flow. Therefore, even though these synoptic flow conditions may advect cold air over the region, wind speeds tend to be high during these periods and hence dominate meteorological control on Invercargill's air quality. A more detailed discussion on influential synoptic conditions is in Section 4.

Using the MfE indicator classifications forces the model to only examine exceedences of the NES rather than further separations in high pollution data and therefore provides an output that is more directed at predicting exceedences. The dataset for the latter classification was 90 days from 2003 to 2008 compared with 21 for the highest PM_{10} node in ungrouped data. The MfE indicator classification tree was used for the purposes of trends assessments because 21 data points was considered inadequate for the purposes of assessing trends.

Table 3.2: Environmental Performance Indicator categories for air quality (MfE, 2002)

Category Number	Category Name	Value relative to guideline	Comment
1	Good	Up to 33% of the guideline	Peak measurements in this range are unlikely to affect air quality
2	Acceptable	Between 33% and 66% of the guideline	A broad category, where maximum values might be of concern in some sensitive locations but generally they are at a level which does not warrant urgent action
3	Alert	Between 66% and 100% of the guideline	This is a warning level, which can lead to exceedences if trends are not curbed
4	Action	More than 100% of the guideline	Exceedences of the guideline are a cause for concern and warrant action, particularly if they occur on a regular basis

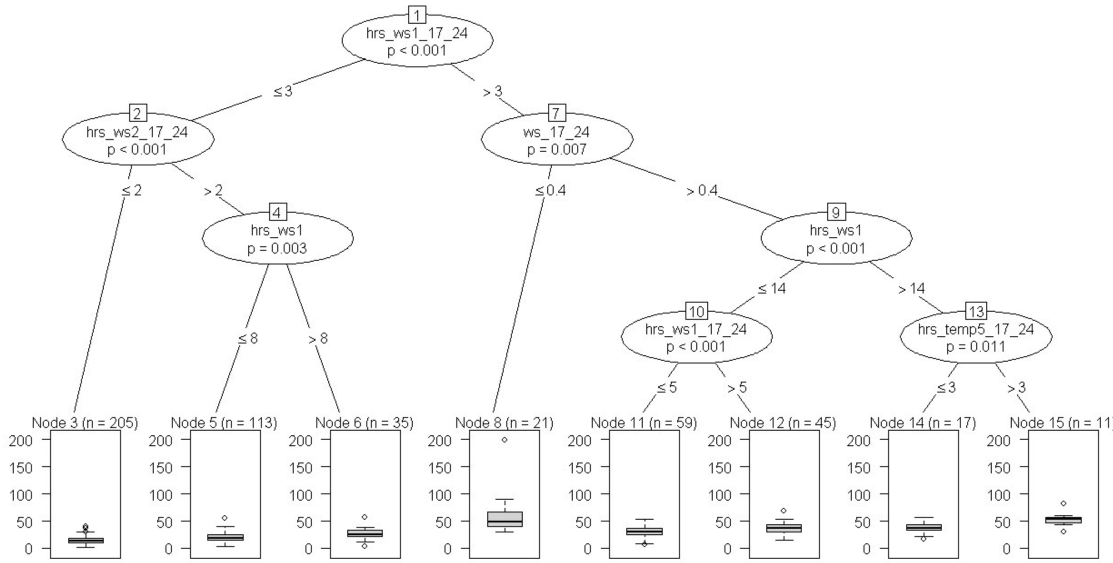


Figure 3.2: Regression tree on ungrouped PM_{10} data.

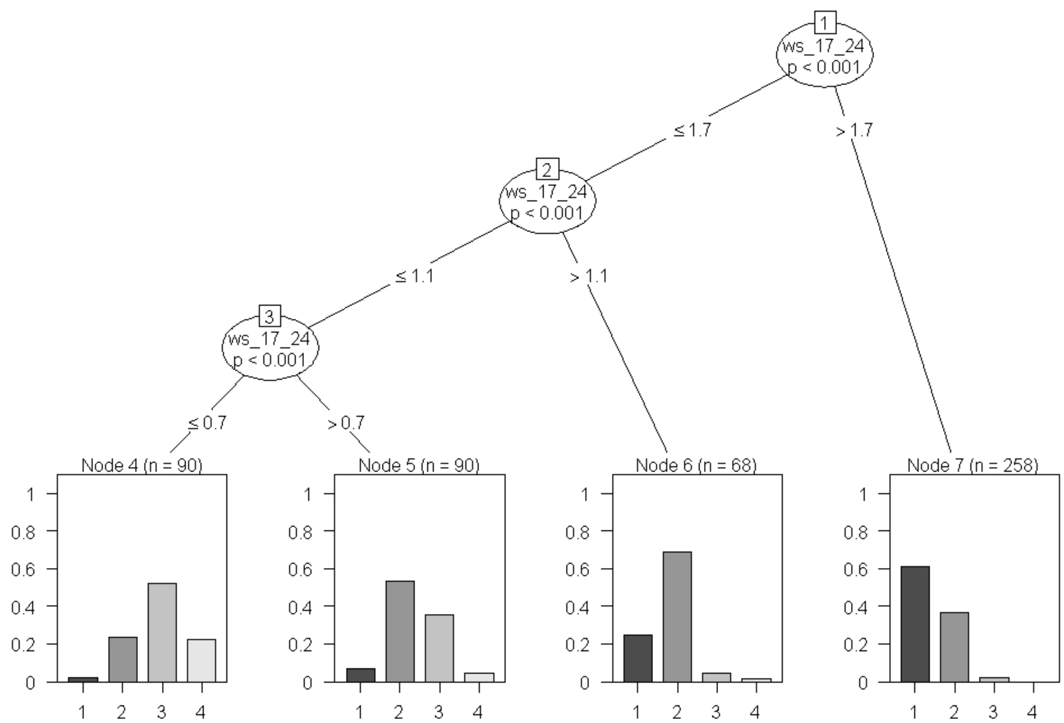


Figure 3.3: Classification tree on PM_{10} concentrations classified by MfE air quality indicator categories.

Integrating the results of both trees, the highest pollution data set are characterised by the average wind speed from 5pm to midnight being less than or equal to 0.7 ms^{-1}. For days when these conditions were met, the average PM_{10} concentration was 43 µg m^{-3} compared with an average of 31 µg m^{-3} for days when the wind speed was greater than 0.7 ms^{-1}.

The highest pollution dataset contained 81% of all exceedences of 50 µg m^{-3} with 15% (four breaches) occurring under the second highest pollution dataset (average wind speed from 5pm until midnight of more than 0.7 ms^{-1} but less than or equal to 1.1 ms^{-1}). One further breach occurred when the average wind speed from 5pm was greater than 1.1 ms^{-1} and less than or equal to 1.7 ms^{-1}).

3.3 Trend analysis of days with high pollution potential

An evaluation of PM_{10} concentrations by year in the high pollution subset can be used to determine trends in PM_{10} when some of the impact of meteorological conditions is accounted for.

The 90 days identified as having meteorological conditions conducive to elevated pollution were separated by year of monitoring. Trends in 24-hour average PM_{10} concentrations within this dataset are displayed in **Error! Reference source not found.**4.

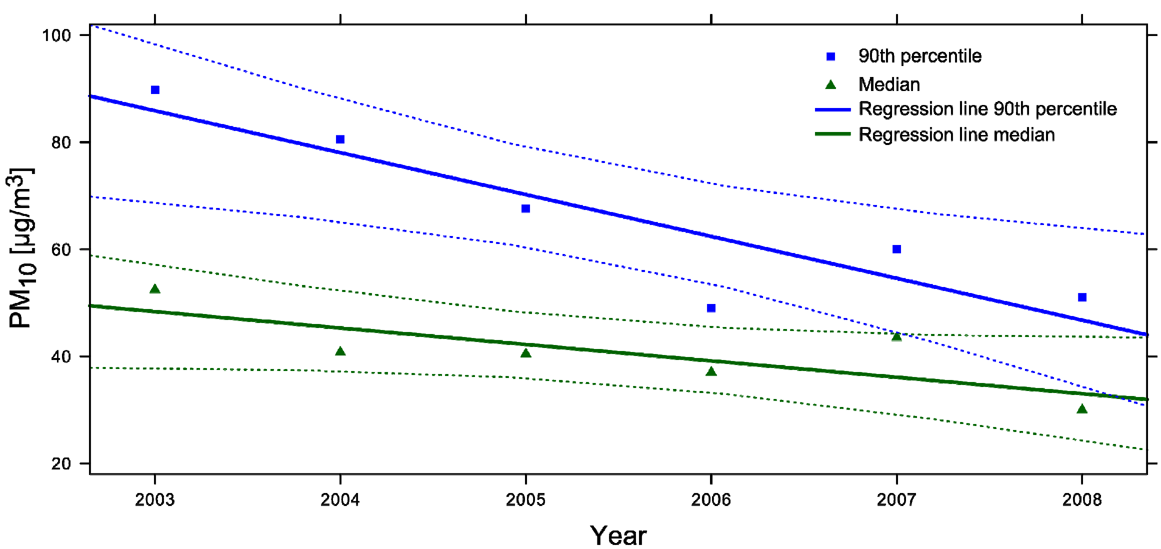


Figure 3.4: 90th percentile and median of PM_{10} concentration for the 90 days when the wind speed less than 0.7 ms^{-1} from 5pm to midnight. Dotted lines denote 95% confidence band of trend line.

Error! Reference source not found.4 suggests some decrease in PM_{10} concentrations particularly within the higher (90th percentile) concentrations. A test of year-to-year differences in PM_{10} for statistical significance was carried out using linear regression analysis. This showed that the observed decrease in concentrations was significant for the 90th percentile PM_{10} concentrations ($p = 0.02$) and less significant ($p = 0.07$) for the median PM_{10} concentrations. However, the 95% confidence bands for both figures indicate that there is great caution to be taken when interpreting the presented trends. The reduction in 90th percentile PM_{10} concentrations from 2003 to 2008 was around 39%.

3.4 Trends in exceedences of the PM_{10} NES

Table 3.3 shows the distribution of the 26 days when PM_{10} exceeded 50 µg m^{-3} (24-hour average) between years and the meteorological classifications for these. The number of days when high pollution conditions occurred each year is also shown. The year-to-year variation in the percentage of high pollution potential days when PM_{10} concentrations exceeded 50 µgm^{-3} (24-hour average) is shown in

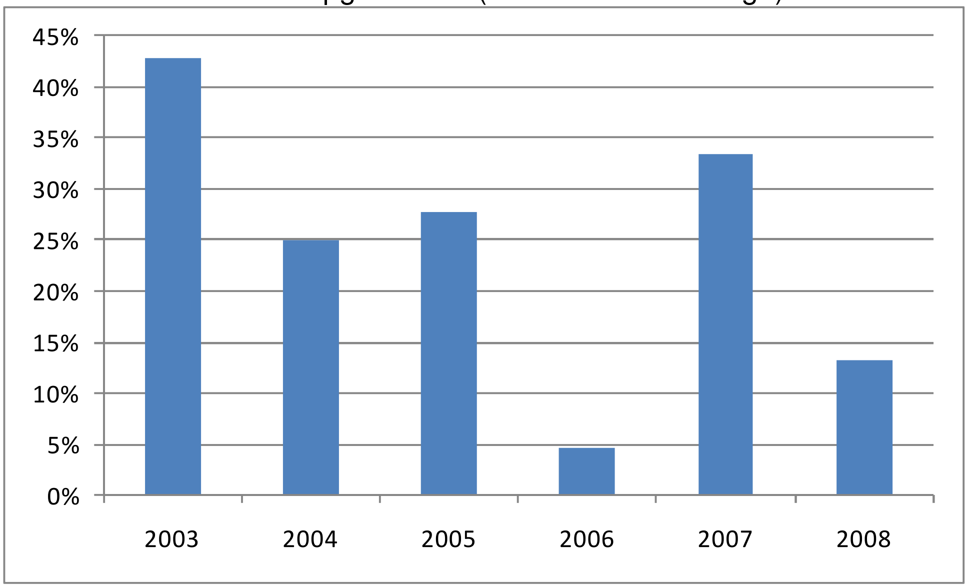


Figure 3.5. This suggests a reduction in the proportion of NES breaches on high pollution potential days from 2003 to 2008.

Table 3.3: Summary of exceedence days for 2003 to 2008 days by meteorological classifications.

	Meteorological conditions for high pollution (ws average ≤0.7 ms^{-1} from 5pm to midnight)			Other meteorological conditions	
	Number of exceedences	Number of days	Proportion of exceedences	Number of exceedences	Meteorological conditions (ws 5pm to midnight)
2003	3	7	43%		
2004	4	16	25%	1	>1.1 ms^{-1} ≤1.7 ms^{-1}
2005	5	18	28%		
2006	1	22	5%		
2007	6	18	33%	3	>0.7 ms^{-1} ≤1.1 ms^{-1}

2008	2	15	13%	1	>0.7 ms^{-1} ≤1.1 ms^{-1}

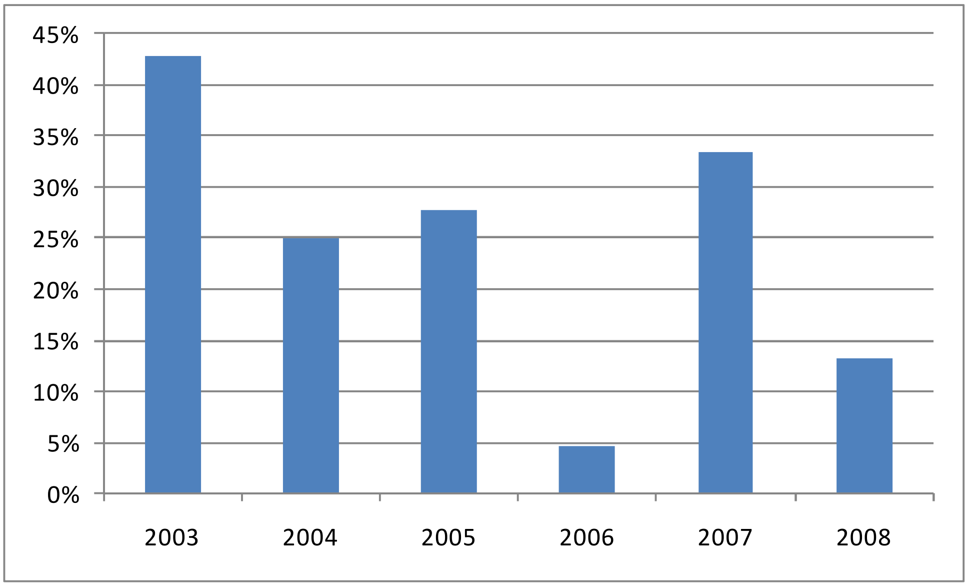


Figure 3.5: Year-to-year variation of the percentage of high potential pollution days (node 8) with PM_{10} concentrations of greater than 50 µgm^{-3} (24-hour average).

3.4.1 Potential causes of trend

Results from the trend analysis of high pollution days and the proportion of pollution potential days in which exceedences occurred suggests a decrease in PM_{10} from 2003 to 2008. The cause of this decrease is uncertain as Environment Southland has implemented minimal air quality management regulations during this period. In areas where wood burners are a major contributor to PM_{10} concentrations, decreases with time are predicted as a result of the conversion of older more polluting burners to lower emission burners meeting the NES design criteria. However, the high use of multi fuel burners in Invercargill means any such trends here would be negligible.

To further investigate potential explanations for a reduction in PM_{10} census data on households using wood and coal for home heating were evaluated. This found that the number of households reportedly using wood for home heating had reduced from 9837 in 2001 to 8793 in 2006. Similarly households using coal had decreased from 8700 to 7335. These equate to reductions of 15% and 10% respectively. Some of this reduction is likely to have occurred from 2003 to 2006 and is a likely explanation for at least some of the observed reduction in PM_{10}.

In addition to a downward trend in PM_{10} concentrations both approaches suggest some deviance to the observed trend in 2007. The proportion of pollution potential days which experienced breaches jumps from 5% in 2006 to 33% for 2007 before settling at 15% for 2008. Similar increases are also observed in the median, mean and 90^{th} percentile PM_{10} concentrations for 2007. Causes for this have not been examined.

3.5 Meteorological conditions on highest PM_{10} days

The meteorological conditions resulting in highest PM_{10} concentrations are an average wind speed of less than 0.4 ms^{-1} between the hours of 5pm to midnight. This category is identified as the highest pollution conditions in both the PM_{10} ungrouped tree (Figure 3.2) and if a further tree is carried out on the high pollution data from the air quality indicator based tree (Figure 3.3). The result of the latter tree is shown in Figure 3.6.

One potential issue with this split is that the category used for wind speed average (<0.4 ms^{-1}) is below the reported accuracy for anemometer used at the meteorological monitoring site. Typically anemometers are not considered accurate below 0.5 ms^{-1}. Notwithstanding this, the result is rational (higher concentrations occurring under low wind speeds) and the statistical probability of this split occurring as a result of chance is less than 7%.

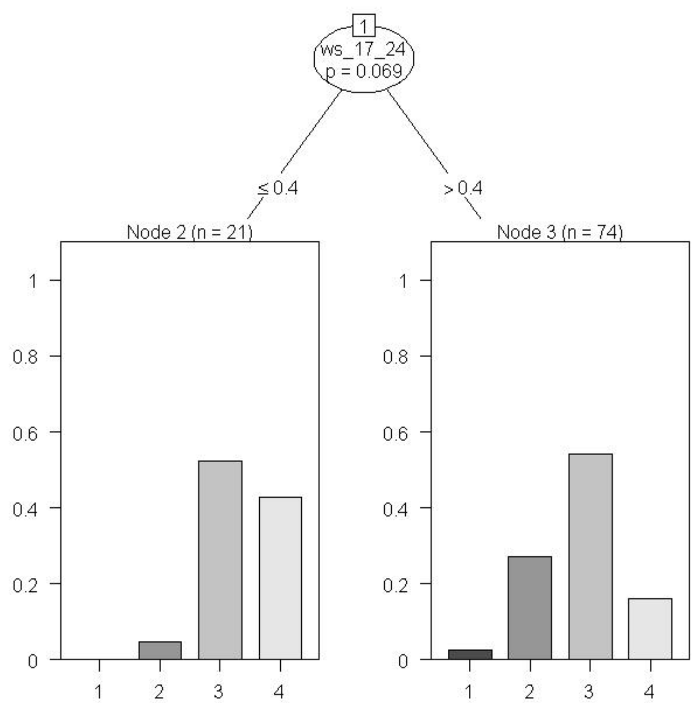


Figure.3.6: Additional split of terminal node 4 from classification tree in Figure 3.5. Tree was restricted to one split at $p<0.10$

Of particular interest in this analysis is the PM_{10} concentration of 198 µg m^{-3} on 18 July 2005 and to a lesser extent concentrations of 88 µg m^{-3} and 80 µg m^{-3} on 17 June and 22 May 2004. Although significantly higher than any other concentrations, meteorological conditions on the 18 July 2005 were more conducive to elevated PM_{10} than any other days; the lowest measured average wind speed from 5pm to midnight was just 0.1 ms^{-1}. A similar wind speed was observed on 22 May 2004. However, the minimum hourly air temperature between 5pm and midnight on 22 May 2004 was 8 degrees compared with 2 degrees on 18 July 2005. On 17 June 2004 the average wind speed during the evening period was 0.4 ms^{-1} and the minimum temperature was 0.2 degrees.

The information generated by this tree can be used to normalise (adjust up or down) PM_{10} data recorded in 2009 to these particular meteorological conditions. When the data has been normalised for these particular meteorological conditions it can then be compared to data from other years and used to evaluate the trends. An example of how to normalise the data is provided in Section 5.

4 Analysis of synoptic conditions

To investigate whether the identified classification tree on grouped PM data is representative of different atmospheric conditions, terminal nodes were analysed towards their synoptic forcings. Figure 4.1 shows the relative increase or decrease in frequency of a set of 12 synoptic types identified by Kidson (2000) for each of the terminal nodes in comparison with their overall distribution. The further a box deviates from the line of expected frequency distribution, the stronger the relationship between the synoptic type and the pollution class. Analysis of the presented differences in synoptic type frequencies with focus on expected associated large-scale airflow over the southern part of New Zealand's South Island suggests that each of the terminal nodes does indeed represent distinctly different atmospheric conditions.

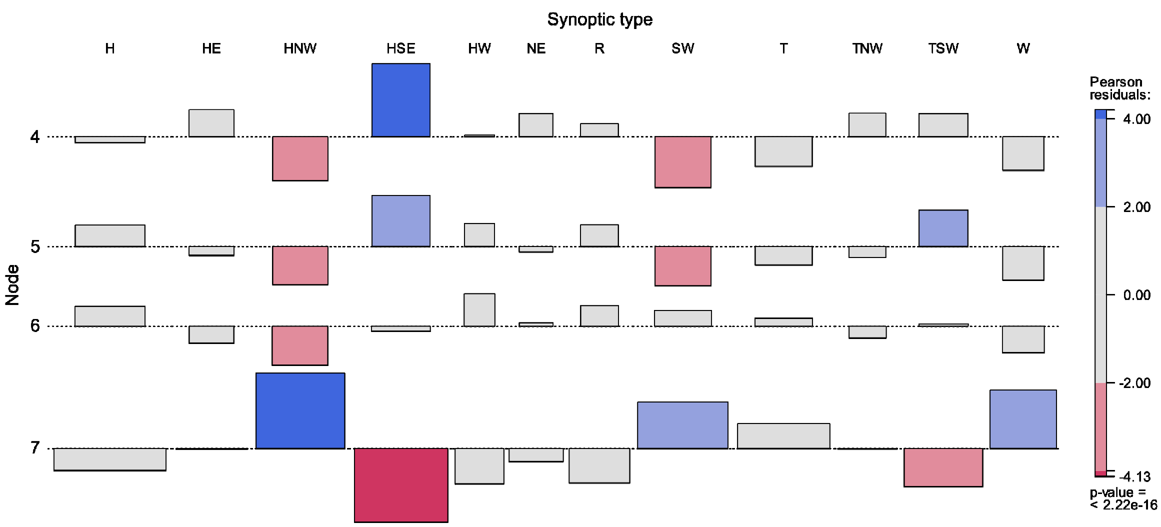


Figure: 4.1: Association plot of deviation from expected frequency of synoptic type per pollution class (node). Width of boxes is proportional to overall frequency of synoptic types. Height of boxes denotes deviation from expected frequency within each pollution class. Darker shades indicate higher significance of deviation.

Node 4 (the high pollution class) shows a significant increase in the occurrence of anticyclonic conditions east of the South Island (HSE and to a lesser extent HE, TNW & NE) and a significant decrease in situations that are likely to promote westerly to south-westerly winds in Invercargill (HNW, SW, W). The increased occurrence of TSW is also in line with expected increase in PM_{10} concentrations as this synoptic class describes a situation with a low pressure system situated just east of the North Island and an anticyclone present to the south-west of the South Island, potentially extending its influence over the southern regions of New Zealand.

Node 7 (the low pollution class) on the other hand, yields an increase in the westerly to south-westerly dominated flow (SW, HW, HNW) and local meteorology can broadly be described as windy which reflects the fact that Invercargill is exposed to advection of air masses from these directions. In line with this is a decrease in all other synoptic types that denote anticyclonic influences (H, HW, R, TSW). There is no deviation of expected frequency for HE and TNW, both of which are likely to result in north-westerly flow over the region. Both HE and TNW show an increase in Node 4, which may indicate that occasionally this flow regime results in blocking and/or flow splitting around the lower South Island creating calm conditions in the lee of the Fiordland region.

In summary, the split criteria and the resulting classes represent local meteorological conditions that are distinct and can be well explained by synoptic features and their resulting flow over the region. Synoptic situations that promote westerly to south-westerly flow over the southern South Island (mostly associated with anticyclones located to the west of the country) are likely to result in good air quality in Invercargill. On the other hand, anticyclones that are located to the east of the South Island potentially promote deterioration of air quality. For a full overview of synoptic types and their associated flow patterns, refer to Kidson (2000).

5 Normalising PM_{10} concentrations

One of the challenges facing Environment Southland is evaluating further trends in PM_{10} concentrations over time. The main issue is the relocation of the PM_{10} monitoring site from Miller Street to Pomona Street in 2009. Whilst the meteorological conditions resulting in high pollution will be applicable to either site, it is probable, given the higher PM_{10} concentrations measured at Pomona Street that a less restrictive wind speed category would be used to characterise exceedences at the Pomona Street site.

Notwithstanding this, it would be possible to use the observations from Miller Street to normalise PM_{10} data from Pomona Street so that trends in PM_{10} concentrations at Pomona Street could be evaluated in the future without redoing the trend analysis. Comparison of Pomona Street data to Miller Street data would not be possible, however, unless the relationship between the two for 2008 could be well characterised. Until a longer term record of PM_{10} concentrations at Pomona Street is obtained, monitoring of PM_{10} concentrations every few years at Miller Street is recommended for the purpose of evaluating trends in concentrations.

As all meteorology has some impact, one of the biggest issues in establishing a methodology for normalising data was determining what constitutes “no impact”, that is, what concentrations should be normalised to. The method used aims to minimise the impact of varying meteorology for high pollution events. To include the majority of the days when 50 $\mu g\ m^{-3}$ is exceeded at least for Miller Street, the method for minimising the impact of meteorology on concentrations has been based on days when the number of hours the wind speed is less than 1 ms^{-1} from 5pm to midnight was greater than three.

It should be noted that the following method provides only an indication of trends in high PM_{10} concentrations and results are not expected to give an indication of day to day variability in PM_{10} emissions but may provide some indication of annual trends in emissions.

PM_{10} data to be included in the normalisation includes all days when the wind speed is less than or equal to 1.1 ms^{-1} from 5pm to midnight. It is proposed that this group alone is used to track changes with time. The following adjustments to data are recommended:

Select days which meet the meteorological criteria (average wind speed is less than or equal to 1.1 ms^{-1} from 5pm to midnight).

- If wind speed between 5 pm and midnight is >0.7 ms^{-1} do not adjust data.
- If wind speed between 5 pm and midnight is ≤0.7>0.4 ms^{-1} subtract 8 $\mu g\ m^{-3}$.
- If wind speed between 5 pm and midnight is ≤0.4 ms^{-1} subtract 30 $\mu g\ m^{-3}$.

The PM_{10} normalising process has been coded into a spreadsheet tool that is provided to Environment Southland. This will allow council staff to evaluate trends in PM_{10} in future data without having to conduct a thorough trends analysis.

An alternative approach which could be used to evaluate future data would be to sort data by meteorological criteria and identify days when either high pollution criteria (ws $\leq$0.7 ms^{-1} from 5pm to midnight) or very high pollution criteria (ws $\leq$0.4 ms^{-1} from 5pm to midnight) are met and then to track changes in average, median and 90 percentile concentrations on these days.

6 Conclusions

The objectives of this study are to advise Environment Southland on reasons for the apparent decrease in PM_{10} concentrations from 2003 to 2005 and 2006 to 2008. Results of this study indicate that:

a) Around 20% of the difference in PM_{10} concentrations between 2003 to 2005 and 2006 to 2008 occurs as a result of the change in monitoring method from high volume sampler to BAM.

b) High PM_{10} concentrations measured during 2003 to 2005 were able to be explained by very low wind speeds.

c) After adjusting data for gravimetric equivalency a reduction in 90th percentile PM_{10} concentrations has occurred since 2003 and is likely to be in the order of around 39%.

d) The proportion of days with high pollution potential that resulted in breaches of the NES has decreased from around 40% in 2003 to around 15% in 2008.

Potential explanations for the decrease in concentrations include a reduction in PM_{10} emissions from 2003 to 2008 or changing the period of measurement from mid day to mid day to midnight to midnight or a combination of both. Potential emission reductions were investigated and it was found that the number of households using wood and coal in Invercargill had decreased from 2001 to 2006 by 15% and 10% respectively. It is uncertain whether this is the sole reason for the observed decrease or whether other factors such as the change in measurement period has also contributed.

The meteorological condition with the greatest potential of resulting in a breach of the NES was an average wind speed between 5pm and midnight of less than or equal to 0.7 ms^{-1}. A further split on the high pollution dataset found the highest pollution events were most likely to occur when the wind speed was less than or equal to 0.4 ms^{-1}.

Analysis of synoptic forcings for each terminal node of the identified pollution classes (of grouped PM_{10} tree) provides evidence that each class is indeed representative of distinct atmospheric conditions and not just a manifestation of statistical analysis. Generally, anticyclones located east of the country potentially decrease air quality in Invercargill, whereas anticyclones that are situated to the west of the country usually promote good air quality.

Ongoing monitoring of trends in PM_{10} concentrations in Invercargill is likely to be difficult because of the relocation of the Miller Street monitoring site to Pomona Street in 2009.

It is recommended that monitoring be carried out at Miller Street every few years to allow for trend analysis until 5-10 years of data are available for Pomona Street.

References

Breiman L., Friedman J.H., Ohlsen R. and Stone C.J. 1984, 'Classification and regression trees', Wadsworth, Belmont, CA.

Hendrikx J., Owens I., Carran W. and Carran A. 2005, 'Avalanche activity in an extreme maritime climate: The application of classification trees for forecasting', *Cold Regions Science and Technology*, 43, 104 – 116.

Hothorn T., Hornik K. and Zeileis A. 2006, 'Unbiased Recursive Partitioning', *Journal of Computational and Graphical Statistics*, 15, 651-674.

Kidson J.W. 2000, 'An analysis of New Zealand synoptic types and their use in defining weather regimes', International Journal of Climatology, 20, 299-316.

Ministry for the Environment, 2004, *National Environmental Standards for Air Quality,* Ministry for the Environment.

Slini T., Kaprara A., Karatzas K. and Moussiopoulos N. 2006, 'PM_{10} forecasting for Thessaloniki, Greece', *Environmental Modelling & Software*, 21, 559 – 565.

Wilton, E., 2005*, Invercargill and Gore, Air Emission Inventory – 2004*. Unpublished report prepared for Environment Southland.

Wilton, E., and Baynes, M., 2009, *Air Quality Monitoring 2008 Environment Southland*. Unpublished report prepared for Environment Southland.

Wilton, E., Baynes, M, Appelhans, T., Zawar Reza P, 2009, *Management of PM_{10} in Invercargill An assessment of management options to achieve National Environmental Standards,* Unpublished report prepared for Environment Southland.

Zheng H., Chen L., Han X., Zhao X. and Ma Y. 2009, 'Classification and regression tree (CART) for analysis of soybean yield variability among fields in Northeast China: The importance of phosphorus application rates under drought conditions', *Agriculture*, Ecosystems & Environment, 132, 98 – 105.

Appendix A: Relationship between BAM and high volume samplers

A comparison of the PM_{10} concentrations measured using the high volume sampler and the BAM is shown in Figure A.1. The figure shows a good correlation between the two monitoring methods (R^2=0.79) using the RMA regression line. The RMA regression line method is considered more appropriate than the more commonly used Least Squares Regression because the latter assumes that there is no error in the independent variable. In this case the comparison is between two methods both of which contain errors. The RMA regression method assumes that there is error or uncertainty in both PM_{10} datasets. Ayres (2001) recommends RMA for air quality studies such as this.

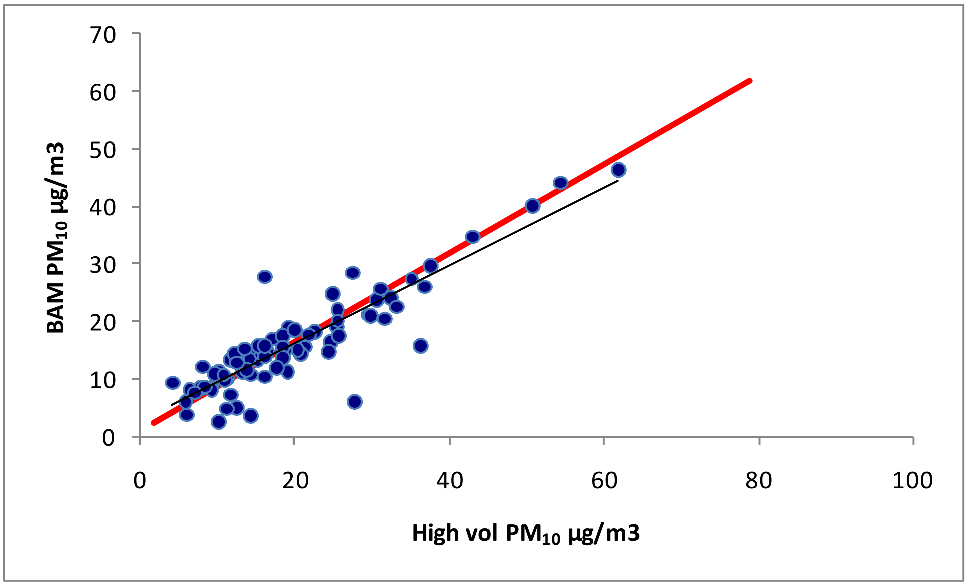


Figure A.1: Relationship between 24-hour BAM and high volume sampler PM_{10} concentrations in Invercargill at the Miller Street site during 2008 (red line = RMA regression line, black line = least squares regression line).

Linear regression using reduced major axis (RMA) was used to derive the equations required to adjust the BAM data. Thus gravimetric concentrations can be estimated using the following:

High volume PM_{10} = 1.3 BAM – 1.4.

Based on this relationship a BAM concentration of 40 is equivalent to a high volume sampler concentration of 50.6 µg m^{-3} and consequently represents a breach of 50 µg m^{-3} if data are being adjusted for gravimetric equivalency.