NIWA
Taihoro Nukurangi

An investigation of the performance of different PM monitors in Reefton

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Executive summary

The West Coast Regional Council is responsible for managing air quality in its region. The town of Reefton is currently designated as a polluted airshed, where the Council have been monitoring concentrations of airborne particulates, in the form of PM_{10} (Particulate Matter with an aerodynamic diameter of ten micrometres or less), for many years. The Council has recently purchased a new instrument - a Teledyne T640x - which uses a different measurement principle from the instrument it replaces, a Thermo Fisher beta attenuation monitor (BAM). The two have been operated side by side for a period and the T640x returns consistently different results from the BAM. This has implications for reporting pollution concentration values according to the National Environmental Standards for Air Quality and for comparisons of contemporary measurements with historical ones.

The Council therefore commissioned NIWA, via an Envirolink grant, to examine the data from the two instruments and compare them to the results from a gravimetric reference method. The key objective of the work was to derive adjustment factors for both the T640x and the BAM relative to a reference method to enable them to be compared to each other and to measurements made elsewhere. A secondary objective was to comment on the characteristics of the local aerosol and how that might relate to the measurement differences between the two instruments.

A measurement campaign was carried out to assess the performance of the newly purchased Teledyne T640x compared to a gravimetric method and to the BAM that it replaces. A Rupprecht & Patashnick Partisol 2025 dichotomous gravimetric sampler was installed alongside the T640x and BAM at the Reefton monitoring site for two months in the winter of 2020. The Partisol measures PM in two fractions, fine ($PM_{2.5}$) and coarse ($PM_{10-2.5}$). A fault with the instrument meant that the coarse fraction channel was not working, so definitive relationships between the three instruments was not possible. However, we have managed to derive interim relationships that can be used until further data can be collected.

The interim relationships are;

- PM_{10} [T640x] =1.35x[Partisol]
- PM_{10} [T640x] =1.9x[BAM]
- $PM_{2.5}$ [T640x] =1.35x[Partisol]

We recommend that, once the problem with the Partisol coarse fraction channel is resolved, the winter monitoring campaign should be repeated to refine the interim adjustment factors. If resources allow, co-located measurements should be undertaken at other times of year to further refine the adjustment factors by subjecting the instruments to a greater range of aerosol types as previous studies have found seasonal differences in BAM/Gravimetric adjustment factors.

Due to the instrument problem it is not possible to comment on the character of that local aerosol but collection of the filters from the Partisol will enable chemical analysis and hence source apportionment to be carried out on the particles, which will provide much greater information on the characteristics of the local aerosol.

1 Introduction

The West Coast Regional Council (WCRC) is required to evaluate air quality in the Reefton airshed as stipulated by the Resource Management Act and the National Environmental Standards for Air Quality (NES). The WCRC currently monitors air quality in Reefton at the Reefton Area School (https://www.lawa.org.nz/explore-data/west-coast-region/air-quality/reefton/reefton-aq-at-school-pool/) using two instruments – a Teledyne T640x ($PM_{2.5}$ & PM_{10}) and a Thermo Fisher beta attenuation mass monitor (BAM) (PM_{10} only). These machines generate different results for their PM_{10} measurements, which raises significant uncertainties around the scale of the air quality issue, and compliance with national environmental standards. Reefton is currently classified as a polluted airshed based solely on this measurement data, so it is important to have reliable and accurate data to continue to assess the status of the airshed.

In anticipation of proposed changes to the NES to include a $PM_{2.5}$ standard, WCRC needed to purchase a new air quality monitor to enable collection of $PM_{2.5}$ data. The existing instrument, a Beta Attenuation Monitor (BAM, measuring PM_{10}), is nearing the end of its life in terms of manufacturer support, and is unable to collect both $PM_{2.5}$ & PM_{10} data simultaneously. The new instrument is a Teledyne T640x, which uses a different method from the BAM to measure particles.

The BAM collects particles on a filter tape and measures the changes in adsorption (attenuation) of a stream of beta radiation through the collected mass of particles as that mass increases. The mass of particles is proportional to the attenuation of the beam. The T640 is an optical instrument which measures the scattering of a light beam passed through the sample of air. The scattering of the light is related to the number, size and shape of the particles in the air. This information is converted to a mass by using a proprietary algorithm which uses assumptions about the typical densities and scattering properties of particles. Because of the different operating principles, the two instruments can give significantly different results depending on the properties of the aerosol. Ideally, all instruments should be calibrated in situ at any location to allow for the localised properties of an aerosol. In practice, this is resource-intensive and rarely happens, with the vast majority of users relying on the manufacturer's standard calibration.

Despite these differences, both instruments have been granted "Equivalent" status by the USEPA, meaning that they are close enough to the USEPA's gravimetric Federal Reference Methods (FRM) to be used in "non critical" compliance measurements. Reference methods for PMx are gravimetric, that is they collect particles on filters using prescribed flow rates and size separation techniques to determine the mass of particles per unit volume of air (usually $\mu g/m^3$). Instruments that use other techniques can be granted equivalent status if they can demonstrate similar results. The USEPA stipulates that equivalent methods may only be used in "non-critical" locations, the New Zealand legislation makes no distinction, so equivalent methods have become de-facto standard methods.

In order to allow for continuity of the PM_{10} data record and to allow for the transition to the new instrument, WCRC need to better understand how these monitors measure particulate matter in the Reefton airshed and how the unique emission source profile of the airshed influences measurements.

Understanding how these instruments perform in the Reefton airshed compared to a gravimetric reference method, and hence determining an adjustment factor for both instruments, will give the Council the option of carrying out further comparative air quality investigations within Reefton, or the wider West Coast if instruments are moved to new airsheds.

There are many complicating factors involved in these current discrepancies, including how the two instruments operate and how different particle types influence these measurements. Substantial quantities of coal are burned in Reefton for domestic heating and the relationship between instruments is likely to differ from other airsheds where wood is the dominant fuel source.

Goals of the project:

- Comment on the nature of $PM_{2.5}$ & PM_{10} particles in context with their potentially unique nature in Reefton and how this might influence sampling discrepancies.
- Assess particle measurements currently being collected compared to a reference method.
- Calculate adjustments that can be used to convert $PM_{2.5}$ & PM_{10} data between instruments and allow for comparison between historic and future datasets.
- Advise the WCRC on future methods for assessing air quality in Reefton.

2 Methods

The key task was to assess the performance of the two particle monitors used by WCRC, namely a Teledyne T640x (API Teledyne, CA, USA) and a Thermo Fisher FH62 beta attenuation monitor (Thermo Fisher, MA, USA) so that their results can be compared to each other and to results from other places.

In order to determine their relative performances, a reference instrument was installed alongside the two WCRC instruments. The reference instrument was a Partisol 2025 (Rupprecht & Patashnick, NY, USA). This instrument is a Dichotomous sampler that can measure both $PM_{2.5}$ and PM_{10}. The 2025 has U.S. EPA Reference Method Designations RFPS-0498-118 ($PM_{2.5}$) and RFPS-1298-127 (PM_{10}). This instrument passes the sample of air through a PM_{10} size selective inlet; the air flow is then split into two – $PM_{2.5}$ and coarse ($PM_{10-2.5}$) fractions. The sum of the $PM_{2.5}$ and coarse fractions is the PM_{10} result.

Filters for the Partisol were purchased pre-weighed from Hills Laboratories (https://www.hill-laboratories.com/) and returned to them for weighing after sampling by WCRC.

All three instruments were installed at the WCRC monitoring site at Reefton Area School from 8th July to 10th September 2020. After the removal of the Partisol, the T640x and BAM continued to run. A fault with the BAM meant that data was not available from 6th to 12th August and from 20th August to 23rd September. Data from both instruments were provided to NIWA by WCRC up to 1st October.

The BAM and T640x are continuous instruments recording every ten minutes, whilst the Partisol gives a result for each 24-hour period (midnight to midnight). To compare results, 24-hour averages were calculated for the BAM and T640x.

3 Results

Data for the PM_{coarse} channel of the Partisol were all (except 1) returned as below the detection limit. This means that there are no results for the coarse fraction and hence PM_{10} cannot be reconstructed. The reason for this is still being investigated at the time of writing; we believe the instrument was working properly, flow rates were correct, and no warning messages were displayed on the instrument. For the time being, our quality assurance process gives us no reason to disregard the $PM_{2.5}$ channel. The consequence of this is that some of the objectives of the study will not be achievable with the available data, particularly a direct comparison of the reference PM_{10} value with the BAM. The BAM only reports PM_{10} and one of the aims of the study was to derive an adjustment factor relative to a reference instrument. Comments on the character of the Reefton aerosol will also not be possible without gravimetric data to establish PM_{10} to $PM_{2.5}$ ratios. Other objectives, such as the relationship of the $PM_{2.5}$ results from the T640x to reference, are still achievable, as is advising WCRC on future methods for monitoring air quality in Reefton.

Summaries of the data are given in Table 1, Table 2 and Table 3

Table 1. Summary of all data captured during the Reefton monitoring campaign

Instrument	**BAM**	**T640x**		**Partisol**	
Size Fraction	**PM_{10}**	**PM_{10}**	**$PM_{2.5}$**	**PM_{10}**	**$PM_{2.5}$**
Measurement Resolution	10 minutes	10 minutes	10 minutes	24 hours	24 hours
Datapoints recorded	6467	11502	12234	1	52
Number of 1-hour values	1110	1920	2040	NA	NA
Number of 24-hour values	47	82	85	1	52

Table 2: Summary of Hourly data captured during the Reefton monitoring campaign

Hourly data	BAM	T640	
Size Fraction	PM_{10} (µg/m³)	PM_{10} (µg/m³)	$PM_{2.5}$ (µg/m³)
Number of samples	1110	1920	2040
Minimum	-9.0	0.8	0.2
25%	6.2	9.6	5.4
50% (Median)	12.8	16.6	10.9
75%	22.8	32.2	20.5
Maximum	125.0	259.2	179.0
Mean	17.9	28.2	18.3

Table 3: Summary of daily (24hr) data captured during the Reefton monitoring campaign

Daily data	BAM	T640		Partisol
Size Fraction	PM_{10} (µg/m³)	PM_{10} (µg/m³)	$PM_{2.5}$ (µg/m³)	$PM_{2.5}$ (µg/m³)
Number of samples	47	82	85	52
minimum	0.1	6.8	5.5	3.2
25%	12.8	17.3	11.5	9.7
50% (Median)	15.5	23.6	15.9	12.5
75%	21.4	32.1	21.3	16.9
Maximum	47.7	94.4	65.9	43.1
Mean	18.0	27.7	18.4	14.8

Minimum daily and hourly values for the BAM are influenced by the averaged ten-minute data including negative data points. There is ongoing discussion in Aotearoa New Zealand on how to manage negative values from BAMs, with no definitive or agreed method used by operators. The National Environmental Monitoring Standards (NEMS) group are developing guidelines for air quality monitoring (http://www.nems.org.nz/documents/pm10/) which may address this question.

3.1 PM_{10}

PM_{10} results are available from the T640x and the BAM and daily 24-hour values are shown in Figure 1 and the two plotted against each other in Figure 2. Figure 3 shows the hourly values. It can be seen that the T640x gives consistently higher values than the BAM but the relationship between daily mean values is almost linear, with a very small intercept and an r value of 0.98. This linearity gives confidence that whilst the instruments give very different values, they are responding to the same signal and therefore that, once instrumental problems with the Partisol have been resolved, an adjustment factor can be found.

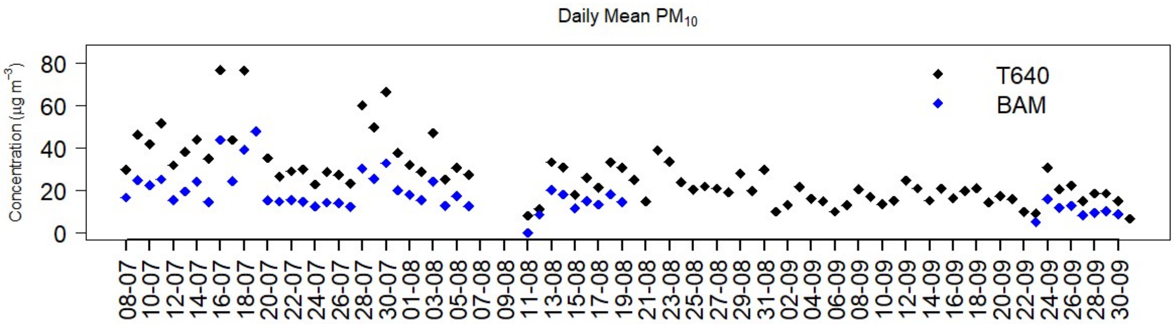

Figure 1: Timeseries of daily (24 hr) PM_{10} values in Reefton as measured by T640x and BAM

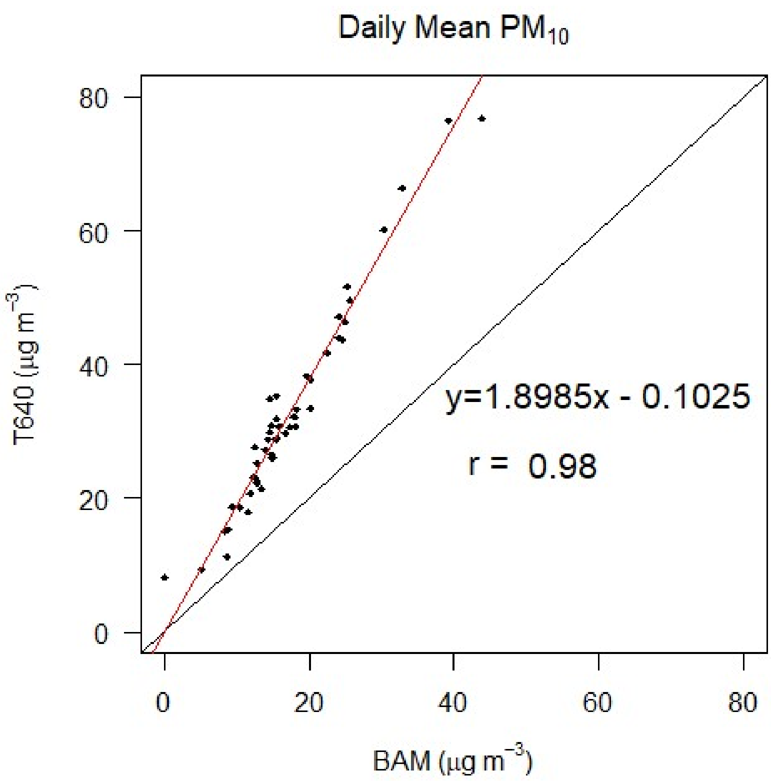

Figure 2: Relationship between daily (24 hr) PM_{10} measurements from T640x and BAM during the Reefton Campaign

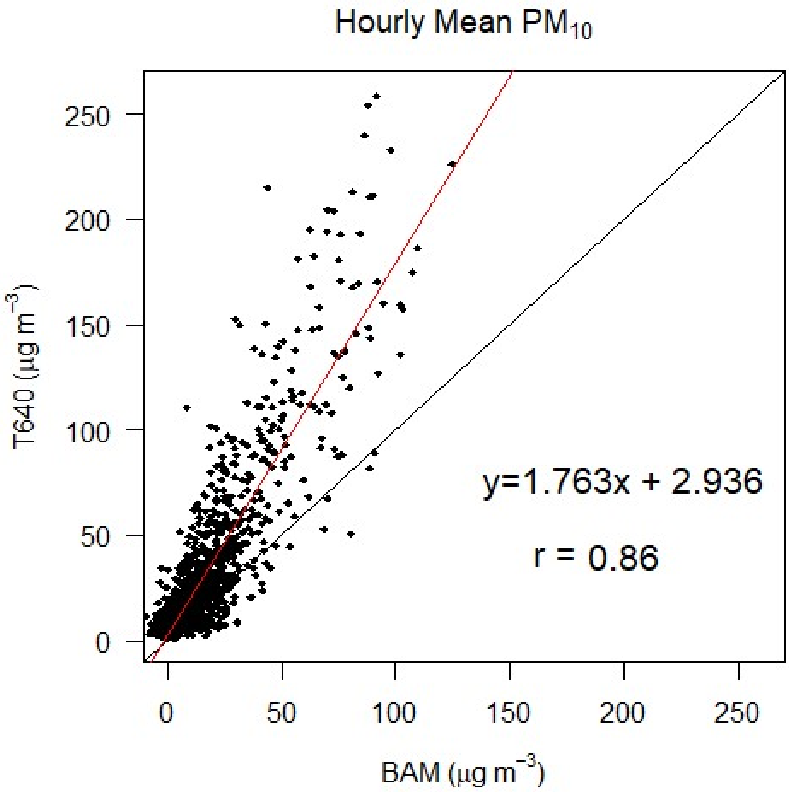

Figure 3 Relationship between hourly PM_{10} measurements from T640x and BAM during the Reefton Campaign

3.2 $PM_{2.5}$

$PM_{2.5}$ results are available from the T640x and the Partisol and are shown in Figure 4 and Figure 5. As the Partisol does not give hourly values, only daily 24-hour results are used. Again, the T640x reports consistently higher concentrations than the other instrument but with a linear relationship and small intercept.

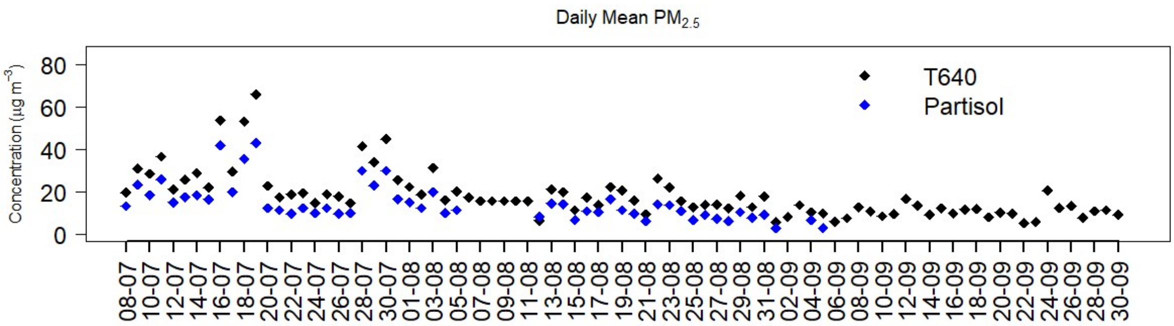

Figure 4: Timeseries of daily (24 hr) $PM_{2.5}$ values in Reefton as measured by T640x and Partisol

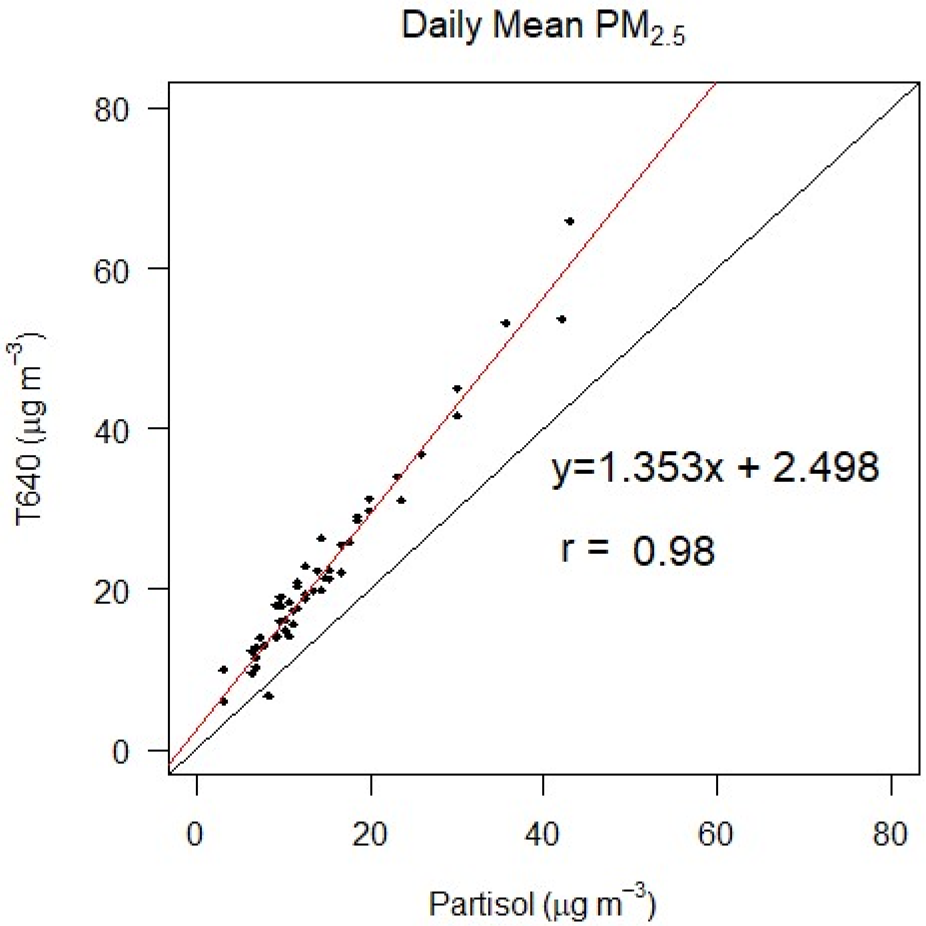

Figure 5: Relationship between daily (24 hr) $PM_{2.5}$ measurements from T640x and Partisol during the Reefton Campaign

4 Discussion

Performance of different particle instruments is known to differ by location, depending on source types and meteorology. It should be borne in mind that when it comes to particle measurement, there is effectively no such thing as a "right answer". Since all particles are different (like snowflakes) all definitions of aerosol particles (e.g., $PM_{2.5}$, PM_{10}, UFP, Black Carbon, Brown Carbon) are, in fact, operational definitions based on the measurement method used. For example, PM_{10} is defined by a measurement using a sharp-cut cyclone with 50% efficiency at a particular flow rate onto a filter, which is then weighed. The cut of the cyclone is also defined by the use of the aerodynamic equivalent diameter of particles, which is only one of several methods of describing the "size" of a particle. By this definition, any measurement made by a different method is not measuring PM_{10} but something else that can be related to and deemed to be "equivalent" to PM_{10}. Results are always dependent on location, source profiles, meteorology and measurement methods.

Bluett et al (2007) found differences between methods compared to reference at several locations around New Zealand but overall found that BAMs typically measure around 7% less than gravimetric methods at 50 μgm^{-3} and 9% less than the gravimetric methods at 100 μgm^{-3}. They found seasonal differences, with BAM results being closer to gravimetric in winter than the other three seasons. They also found a small but statistically significant temperature effect but not for RH or wind speed. They reported a PM_{10} regression of [BAM] = 0.84[Gravimetric] + 3.51 across all data taken in the study.

Aberkane (2020) compared a T640x against a Met One Sequential FRM in Timaru and found [T640x] = 1.28[Gravimetric] + 0.76 for $PM_{2.5}$ and [T640x] = 1.23[Gravimetric] + 1.35 for PM_{10}.

Patel (2019) compared a T640x with a Partisol at Queen St in Auckland and found a relationship of [T640x] = 0.21[Gravimetric] + 4.51 (R^2 = 0.70) for $PM_{2.5}$ and [T640x] = 0.29[Gravimetric] + 8.81 (R^2 = 0.43) for PM_{10}. Patel (2019) also reports a comparison by an unnamed person at the same location at a similar time which found a relationship of [T640x] = 0.63[Gravimetric] + 5.02 (R^2 = 0.74) for PM_{10} between a T640x and gravimetric.

The $PM_{2.5}$ result in Reefton of [T640x] = 1.35[Partisol] is consistent with Aberkane (2020) in Timaru but very different from the Patel (2019) value. The difference from Patel could be due to sources of PM. The Auckland site used by Patel (2020) is very highly traffic influenced, while Timaru and Reefton are dominated by domestic heating in winter. Wilton (2019) reports that in winter some 98% of Reefton's $PM_{2.5}$ emissions come from domestic heating and Smithson (2010) reports more than 90% of PM in Timaru is from domestic heating. It is known that optical instruments such as the T640x have a poor response to traffic emissions as the particles emitted from the tailpipe of an ICE vehicle are an order of magnitude smaller than the wavelength of light used to measure them – making them effectively invisible to optical devices. NIWA is currently carrying out assessments of different instruments, including optical devices in a traffic dominated environment in Auckland. Results are due later in 2021.

Since Aberkane (2020) found a similar adjustment factor for both $PM_{2.5}$ and PM_{10} between the T640x and FRM, we consider that for the time being an adjustment factor of 1.35 without an offset is suitable for the T640x in Reefton for both species until further measurements can be made. Further measurements may include trying to discern the influence of coal burning which is a major fuel type in Reefton and remains a source of uncertainty in the response of optical instruments such as the T640x.

For historical comparisons, comparing BAM results to the T640x values, we found a relationship of 1.9 for daily values, which is a suitable value until further data can be collected. However, considering that the PM_{10} values from the T640x were nearly twice those from the BAM, if the adjustment factor of 1.35 is applied, then the BAM value would underread by about 25%, which is considerably lower than other studies. It is not possible to reconcile these two results without further measurements.

At this stage we cannot comment much on the characteristics of the particle pollution in Reefton due to the lack of coarse particle data. However, another project carried out alongside this one, using a network of NIWA's ODIN next-generation sensors across Reefton will be able to address the question of the potential makeup of Reefton's aerosol. The project is expected to provide information about the spatial distribution of $PM_{2.5}$ across Reefton, which will give an indication of sources and hence possible composition of the aerosol.

5 Conclusions

A measurement campaign was carried out to assess the performance of a newly purchased Teledyne T640x compared to a gravimetric method and to the BAM that it replaces.

A dichotomous Partisol gravimetric sampler was installed alongside the T640x and BAM at the Reefton monitoring site for two months in the winter of 2020. The Partisol measures PM in two fractions, fine ($PM_{2.5}$) and coarse ($PM_{10-2.5}$). A fault with the instrument meant that the coarse fraction channel was not working, so deriving definitive relationships between the three instruments was not possible. However, we have managed to derive interim relationships that can be used until further data can be collected.

The interim relationships are;

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- PM_{10} [T640x] =1.9x[BAM]
- $PM_{2.5}$ [T640x] =1.35x[Partisol]

Further work should include more monitoring to fill in the gaps from the current campaign and to extend the dataset to cover other seasons. The key gap in this campaign was the lack of coarse fraction measurements from the Partisol, so it was not possible to derive a reference adjustment factor for PM_{10} for either the BAM or the T640x. The reasons for the problem with the Partisol coarse channel are still being investigated but once they are resolved, we recommend a repeat of this winter's campaign combined with short campaigns in other seasons.

This project was conducted in winter as that is the season of most interest to WCRC but to understand the full range of the T640x response to particle measurements from other seasons should be conducted. The duration of any future campaigns will, of course, be resource-dependent but we recommend a minimum duration of four weeks for a winter campaign. Depending on resources, seasonal measurements could take a variety of forms, such as one day in six or one week per month measurements throughout the year. Alternatively a two week campaign in summer with a one or two week campaign in each shoulder season would give indicative values to augment adjustment factors.

Opportunistic monitoring may also be able to capture events such as agricultural burning.

As coal is still an important fuel in Reefton and the West Coast in general, the collection of filters from the Partisol will enable elemental analysis and source apportionment to be carried out. This will quantify the contribution of coal to the local pollution and help verify the emission inventory.

6 Acknowledgements

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