Comparison of Particulate Monitoring Methods at Fort Air Partnership Monitoring Stations

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Executive Summary

Historically FAP has acquired $PM_{2.5}$ monitoring data using the R&P (now Thermo Scientific) Tapered Element Oscillating Microbalance (TEOM) device and the Met-One Beta Attenuation Monitor (BAM) 1020 particulate monitor. In the National Air Pollution Surveillance (NAPS) program it has been established that the TEOM continuous $PM_{2.5}$ instruments do not meet the data quality objectives (DQOs) that have been recommended for comparison with the reference method (FRM) which is a filter-based, 24-hr particulate sampling method. NAPS managers have determined that instruments approved as U.S. EPA Class III Federal Equivalent Monitoring (FEM) methods do meet the NAPS DQOs.

Since 2010 FAP has installed two Thermo Scientific Synchronized Hybrid Ambient Real Time Particulate (SHARP 5030) monitors and a light scattering photometer (Grimm EDM 180) monitor to measure $PM_{2.5}$ in the FAP network. These recently implemented continuous monitoring methods have been approved as FEM methods after meeting a high level of comparability to the FRM. While the approved FEM methods compare within certain slope and intercept limits to the FRM, the FEM methods may not necessarily compare exactly with each other. The various continuous monitoring methods (both historical and FEM) use very different physical principles for measurement of mass and a diverse physical makeup of particulates may bias the measurements differently. Seasonal factors may also affect the comparability of various PM monitoring methods.

To help better understand the inter-comparability of the particulate monitors (both historical and currently in operation) in the FAP network, FAP carried out a number of short-term inter-comparisons including: the co-location of a TEOM and SHARP at the Fort Saskatchewan site (May 25, 2012 to May 31, 2013); co-location of a filter-based Partisol (FRM) with a BAM1020 at the Lamont County station (August 2012 to September 2013) and co-location of Grimm 180 with an FRM at the Bruderheim station (August 2012 to September 2013). Additionally, the changes in historical data trends were examined when older TEOM monitors were replaced with SHARP 5030 monitors at the Elk Island and Fort Saskatchewan AQM stations.

The results from the Fort Saskatchewan inter-comparison of the continuous SHARP and TEOM instruments matched results that have been obtained in numerous locations. Although the instruments are well correlated the SHARP reports substantially higher concentrations in the cold months than the TEOM with more comparable results obtained in the warm months. Reported annual mean and annual 98^{th} percentile $PM_{2.5}$ concentrations were significantly higher for the SHARP instrument over the one year study period.

Correlations between the continuous and filter-based methods at Bruderheim and Lamont County were excellent for both warm and cold season. The best agreement on slope and intercept was during the cold months with the continuous instruments reading highest relative to the filter based method in the warm months. Reported mean and 98^{th} percentile $PM_{2.5}$ concentrations were higher for the continuous methods at both sites for the one year study period. The performance of the BAM1020 instrument at the Lamont County site relative to a filter based measurement is typical of results from many other sites.

It has been demonstrated that FEM continuous instruments do read higher than filter-based reference methods and this is often due to loss of volatile components from the filter-based samplers during warmer temperatures.

A recommendation from a recent monitoring network assessment commissioned by the FAP Technical Working Group (Sonoma, 2012) suggested that FAP consider adopting a consistent monitoring technology network-wide to facilitate direct comparisons of air quality throughout the region. Based on the results of the preceding data analyses this recommendation can be supported. Additionally, it is recommended that a co-located reference method sampler should be operated at one site or more on an ongoing basis.

When comparing the before TEOM replacement (Sep. 2009 to Aug. 2011) and after replacement (Sep. 2011 to Aug. 2013) data sets at Elk Island there was a constant difference between the SHARP and TEOM results at the lower percentiles of about 1.5 $\mu g/m^3$. At higher percentiles the differences were larger and may reflect the different performance in the cold and warm season of the TEOM and SHARP instruments. A similar offset in the lower percentiles is seen in the Fort Saskatchewan before TEOM replacement (May 2007 to April 2010) and after (May 2010 to April 2013) results although the offset did not appear until 2011 and then seemed to reduce in 2013. At higher percentiles the differences were larger at the site. Since there was no reference measurement to compare with, the differences between results may be due to normal variations in ambient conditions but based on the preceding data analysis it's very likely that the change in instrumentation has resulted in higher reported concentrations and thus the changeover will complicate the analysis of historical trends at the sites.

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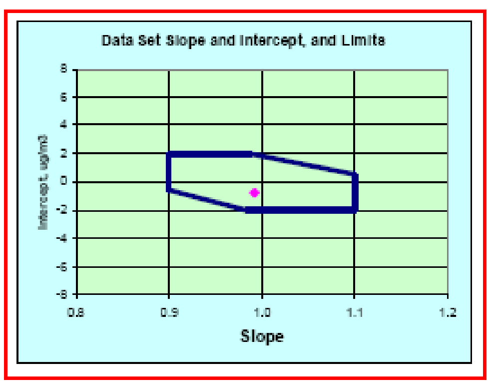
Background/Context

Fort Air Partnership (FAP) has employed a variety of fine particulate matter ($PM_{2.5}$) monitors since 2003. Monitors were acquired as FAP assumed monitoring from industry and from Alberta government stations, resulting in a network that has employed several different particulate monitoring methods.

FAP has acquired many years of historical particulate monitoring data as measured with the R&P (now Thermo Scientific) Tapered Element Oscillating Microbalance (TEOM) devices and with the Met-One Beta Attenuation Monitor (BAM) 1020 particulate monitor. In their current configurations these are no longer approved Federal Equivalent Monitoring (FEM) methods by the National Air Pollutant Surveillance (NAPS) program or by the United States Environmental Protection Agency (EPA).

Since 2010 FAP has installed two Thermo Scientific Synchronized Hybrid Ambient Real Time Particulate (SHARP 5030) monitors and a light scattering photometer (Grimm EDM 180) monitor to measure $PM_{2.5}$ in the FAP network. These recently implemented continuous monitoring methods have been approved as Federal Equivalent Monitoring (FEM) methods after meeting a high level of comparability to the Federal Reference Method (FRM), an integrated filter-based, 24-hr particulate sampling method. While the approved FEM methods compare within certain slope and intercept limits to the FRM, as illustrated in Figure 1, the FEM methods may not necessarily compare exactly with each other. The various continuous monitoring methods use very different physical principles for measurement of mass and a diverse physical makeup of particulates may bias the measurements differently. Seasonal factors may also affect the comparability of various PM monitoring methods (Felton, 2011).

Figure 1: Illustration of range of monitoring values that meet acceptance criteria when comparing a FEM to the FRM.



The monitors that have been employed in the FAP network are described in Table 1.

To help understand the inter-comparability of the particulate monitors in the FAP network, FAP co-located two FRM monitors with existing continuous monitors. In addition, FAP installed a TEOM, co-located with the new SHARP monitor at Fort Saskatchewan.

Table 1: Summary of FAP continuous Particulate Monitor service, by station

Station Name	Historical Method	Present Method	Approved?
Fort Saskatchewan	TEOM 1400ab @40C Nov 2001 – April 2010*	SHARP 5030 May 2010 - Present	Yes, FEM
Elk Island	TEOM 1400ab @40C Jan 2003 – Aug 2011	SHARP 5030 Sept 2011 – Present	Yes, FEM
Lamont County	BAM 1020, A-Series Jan 2003 - Present		No
Lamont County	Partisol FRMP2000 $PM_{2.5}$ air sampler Discrete 24-hr samples, Aug 2011 – Dec 2011, and August 2012 – Sep 2013		Yes, FRM
Redwater Industrial	TEOM 1400ab @40C Jan 2003 - Present		No
Bruderheim	Grimm 180 May 2010 - Present		Yes, FEM
Bruderheim	Partisol FRMP2000 $PM_{2.5}$ air sampler Discrete 24-hr samples, Aug 2011 – Dec 2011, and August 2012 – Dec 2013		Yes, FRM

* Also operated from April 19, 2012 to May 31, 2013 co-located with SHARP 5030 instrument

A recommendation from a recent monitoring network assessment commissioned by the FAP Technical Working Group (Sonoma, 2012) suggested that FAP consider adopting a consistent monitoring technology network-wide to facilitate direct comparisons of air quality throughout the region. In order to prioritize the implementation of new technologies, it is important to understand where biases might be experienced in the monitoring data.

There are several years of monitoring data already recorded. While the technologies differ, there has been some work done to assess how comparable the existing monitoring methods are to one another. There are two primary questions that FAP wishes to examine with respect to particulate monitoring studies discussed in this report:

1. How do the various monitoring technologies and monitoring results compare with each other? Is there a monitoring bias with one technology over another? How is this expressed on a seasonal basis?
2. When considering long-term air quality trends, how does the data from the historical monitors compare with the data from the newer ones?

FAP has implemented several short-term $PM_{2.5}$ monitoring studies to obtain a better understanding of how the different monitoring technologies compare with one another. A discussion of these monitoring studies to date is discussed in three parts:

Part A: Using co-located monitors, compare particulate monitoring data from the historical TEOM monitoring method with the current SHARP 5030 monitor at the Fort Saskatchewan AQM Station. Data from both devices were available from May 25, 2012 to May 31, 2013. An earlier data period (April 19 to May 24, 2012) was examined initially and results are contained in an internal FAP report (Larsen, 2012).

Part B: Compare 24-hr FRM filter-based (Partisol) $PM_{2.5}$ monitoring with the co-located continuous BAM1020 at Lamont County AQM Station, and the Grimm 180 at the Bruderheim AQM Station. Data were available from August 2012 to September 2013.

Part C: Review and illustrate changes in historical data trends when older TEOM monitors were replaced with SHARP 5030 monitors at Elk Island and Fort Saskatchewan AQM Stations. Periods compared were two years prior to and after changeover (September 2011) at Elk Island and three years prior to and after changeover (May 2010) at Fort Saskatchewan.

Results

Part A: Compare co-located continuous particulate monitoring technologies: TEOM and SHARP monitors at the Fort Saskatchewan AQM Station.

Objective:

To compare $PM_{2.5}$ monitoring data obtained with co-located TEOM and SHARP 5030 particulate monitors.

Methods:

A TEOM 1400ab $PM_{2.5}$ monitor, configured as used prior to May 2010 at the Fort Saskatchewan AQM Station, was co-located with a SHARP 5030 $PM_{2.5}$ monitor that is currently the reporting instrument for the Fort Saskatchewan AQM Station.

In the TEOM (tapered element oscillating microbalance) instrument, particles are drawn through a size-selective inlet and as they are deposited on a filter, the mass of the filter cartridge increases and the frequency of the oscillating system decreases. By accurately measuring the frequency change, the mass of the particles are measured. The TEOM uses a dryer to remove excess moisture and this was set at 40°C consistent with historical practice. Data from this instrument was considered to be representative of historical data as measured with a TEOM at the Fort Saskatchewan AQM Station prior to May 2010.

The SHARP 5030 monitor that is co-located with the TEOM operates with a beta attenuation detector integrated with a nephelometer (a device that measures the degree by which a particle disperses light) for fast response. It was configured per the manufacturer's recommendations.

Hourly data were collected from both devices for the period of the study (May 2012 to May 2013).

Data:

Data from the TEOM for the period of May 25, 2012 to May 31, 2013 were retrieved from the instrument directly and not from a logger or the CASA Data Warehouse.

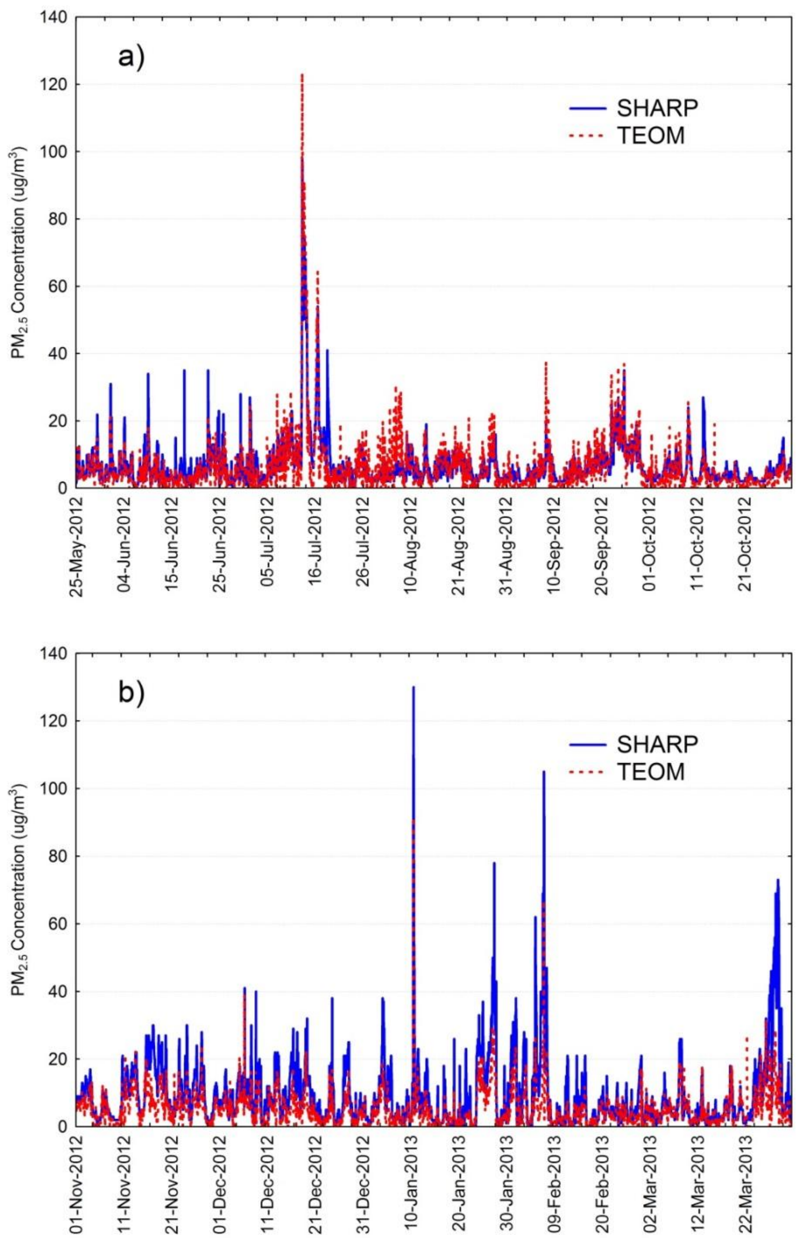
Negative values that were observed from the TEOM throughout the study period were corrected per Alberta particulate data handling protocols, where values <-3 $\mu g/m^3$ were deleted and values between -3 $\mu g/m^3$ and zero were set to equal zero. There were no negative values observed with the SHARP monitor. Data from the SHARP 5030 monitor were retrieved from the CASA Data Warehouse for the period of interest.

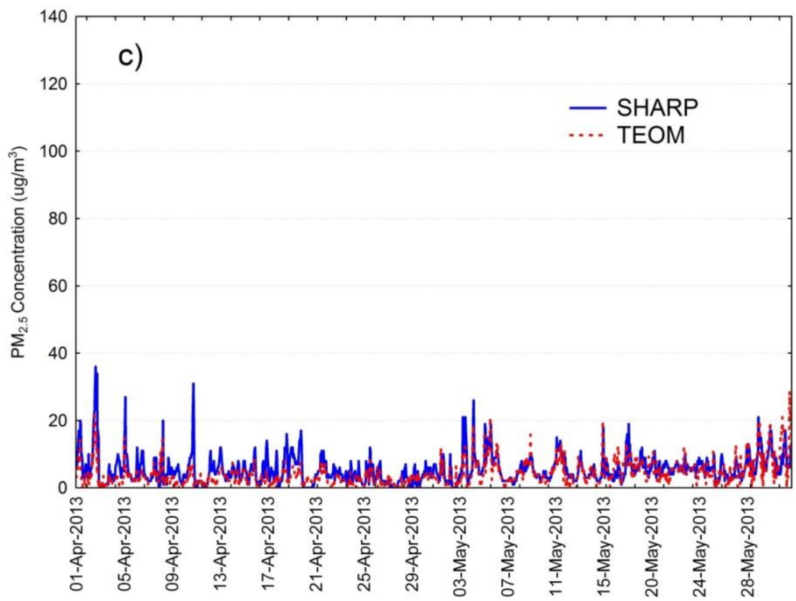
Data Analysis (May 25, 2012 to May 31, 2013):

The results as compared on an hourly basis:

Hourly data for the SHARP and TEOM instruments are shown in Figure 2 for two warm periods (May-Oct, 2012 and Apr-May, 2013) and for the cold period (Nov, 2012 to Mar, 2013). It is clear that during the cold months the SHARP is recording higher peaks than the TEOM. During the warm months there are hours with significant variability between instruments but not as consistent bias.

Figure 2: Hourly data comparison for TEOM and SHARP at Fort Saskatchewan: a) May-Oct b) Nov-Mar c) Apr-May.





A linear regression analysis for the overall hourly data set and for the combined warm and cold time periods is provided in Figure 3. The slope, intercept and correlation coefficients for the best fit linear equation are also shown in the Figures. It's clear from the figures that a different relationship exists between the instruments for the warm and cold months. The correlations for these two periods are further examined as a function of concentration in Figure 4. The highest correlations between analyzers occurs at concentrations > 40 µg/m^3 with a large amount of scatter in the 20 to 40 µg/m^3 range. Warm season correlations were higher than cold season correlations for concentrations > 20 µg/m^3.

Figure 3: Linear regression analysis for TEOM and SHARP at Fort Saskatchewan: a) All Data b) Cold Months c) Warm Months.

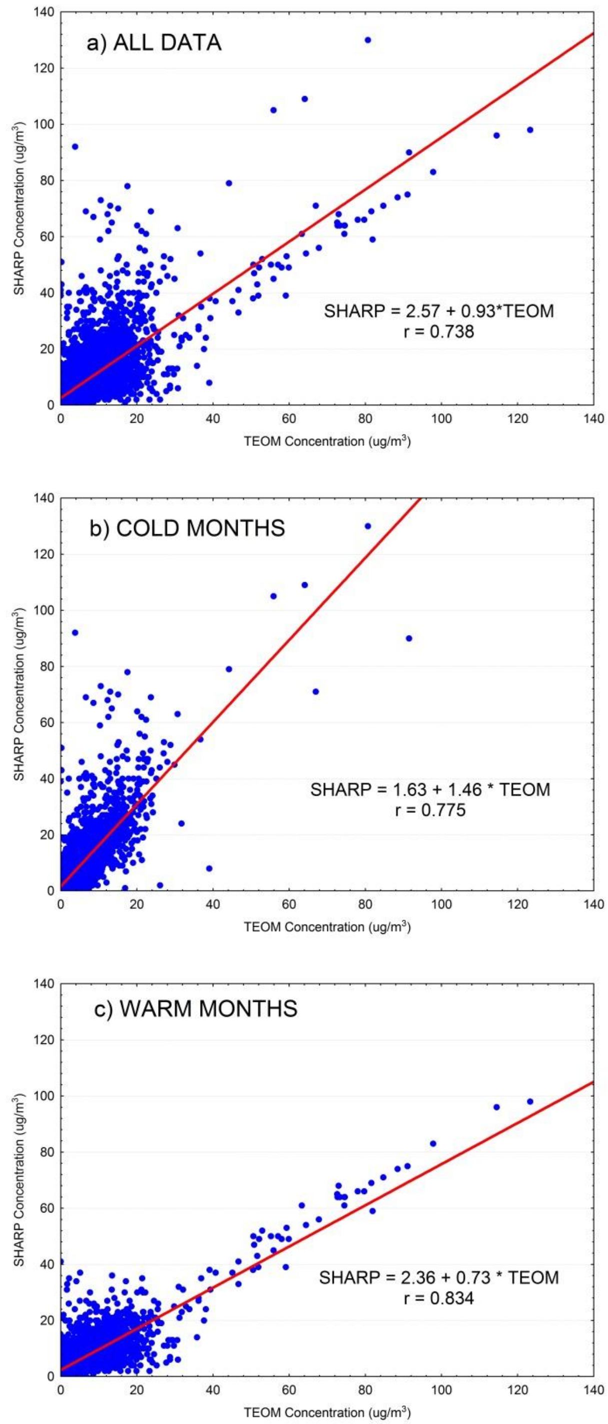
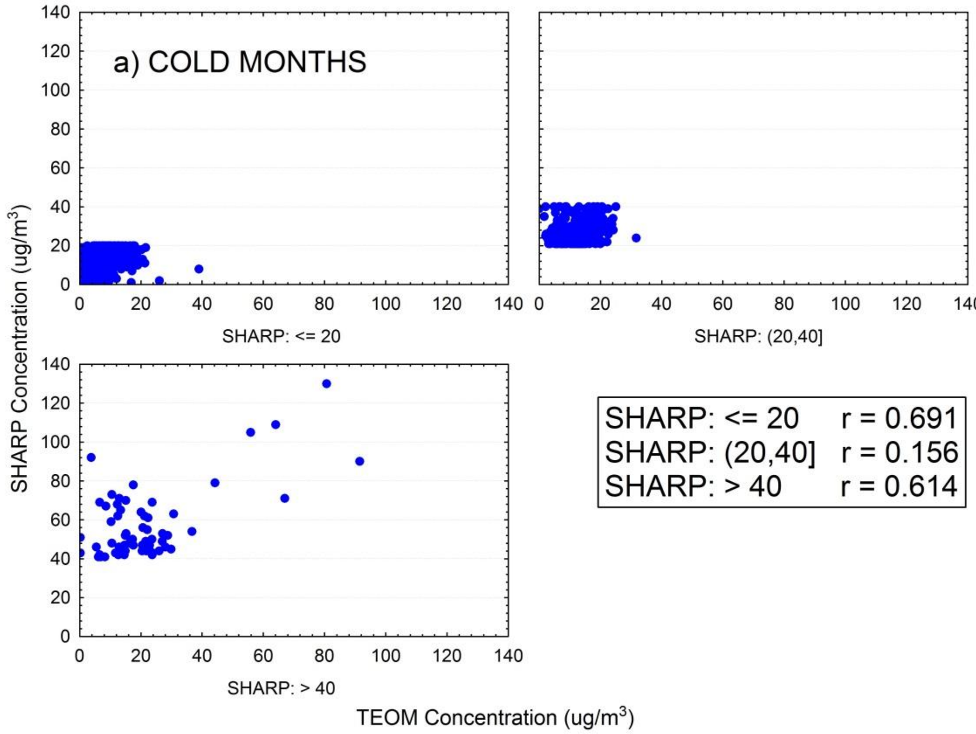
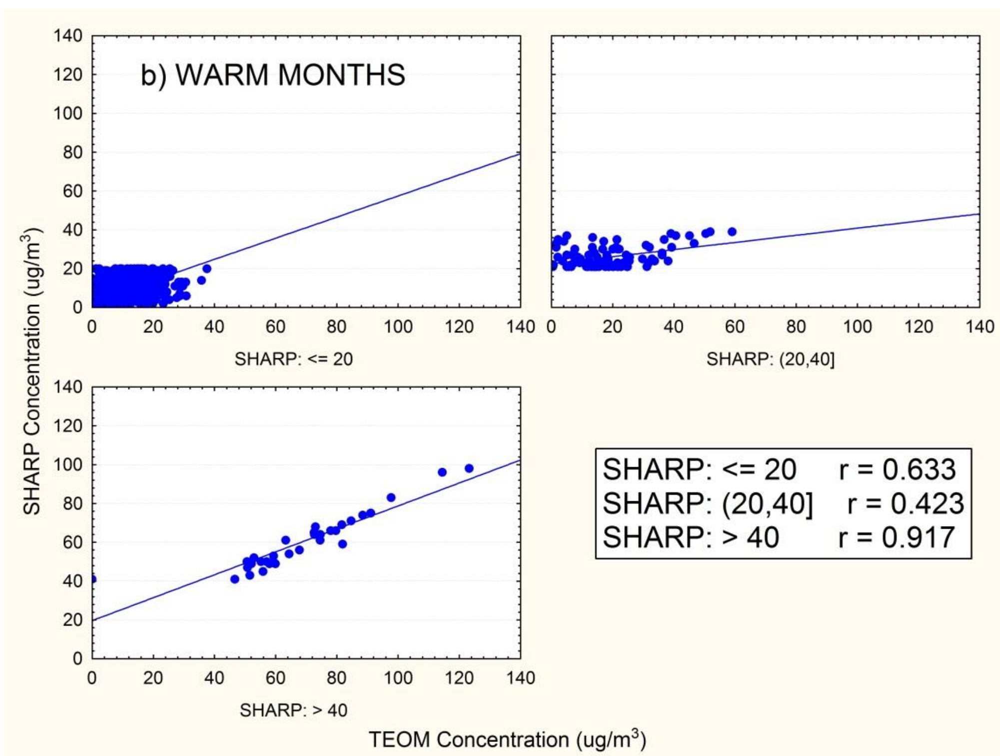


Figure 4: Linear regression analysis for TEOM and SHARP at Fort Saskatchewan: Cold (a) and Warm (b) Months categorized by concentration.





Another way of observing the relationship between the monitors is to plot their differences. Figure 5 shows the differences (mean and 95th confidence interval) between the instruments (SHARP – TEOM) as a function of temperature. The same analysis is carried out in Figure 6 for hours with TEOM and SHARP concentrations both below or equal to 10 µg/m^3; in Figure 7 for hours with SHARP greater than or equal to µg/m^3 and in Figure 10 for hours with SHARP greater than or equal to 60 µg/m^3. Using all hourly data mean differences are positive (i.e. SHARP reads higher) at temperatures less than 15 °C and become negative (TEOM reads higher) at temperatures > 20 °C. For the low concentration case (< 10 µg/m^3) differences are always positive and reach a minimum at both high and low temperatures. This may be a result of the fact that the TEOM often read negative and values were often set to zero. Another reason could be related to a possible zero offset on the SHARP instrument. For the higher concentration (> 40 µg/m^3 and > 60 µg/m^3) cases the differences with temperature were similar to the all data case.

Figure 5: SHARP minus TEOM mean hourly concentration differences at Fort Saskatchewan as a function of temperature (All data).

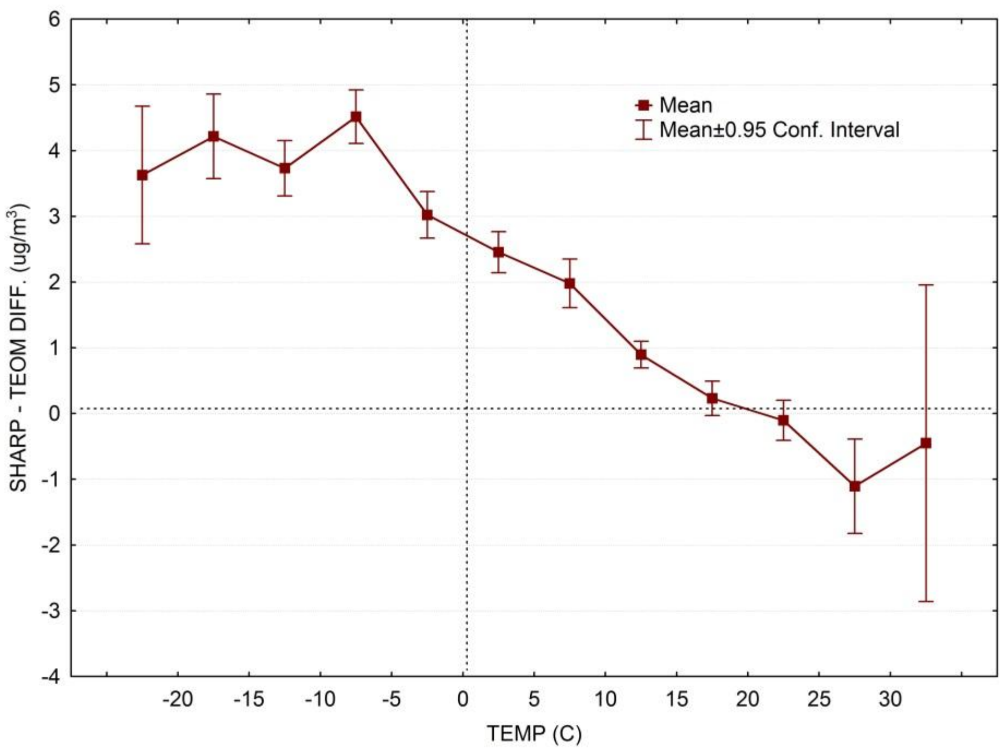


Figure 6: SHARP minus TEOM mean hourly concentration differences at Fort Saskatchewan as a function of temperature (SHARP and TEOM hourly concentrations both less than 10 µg/m³).

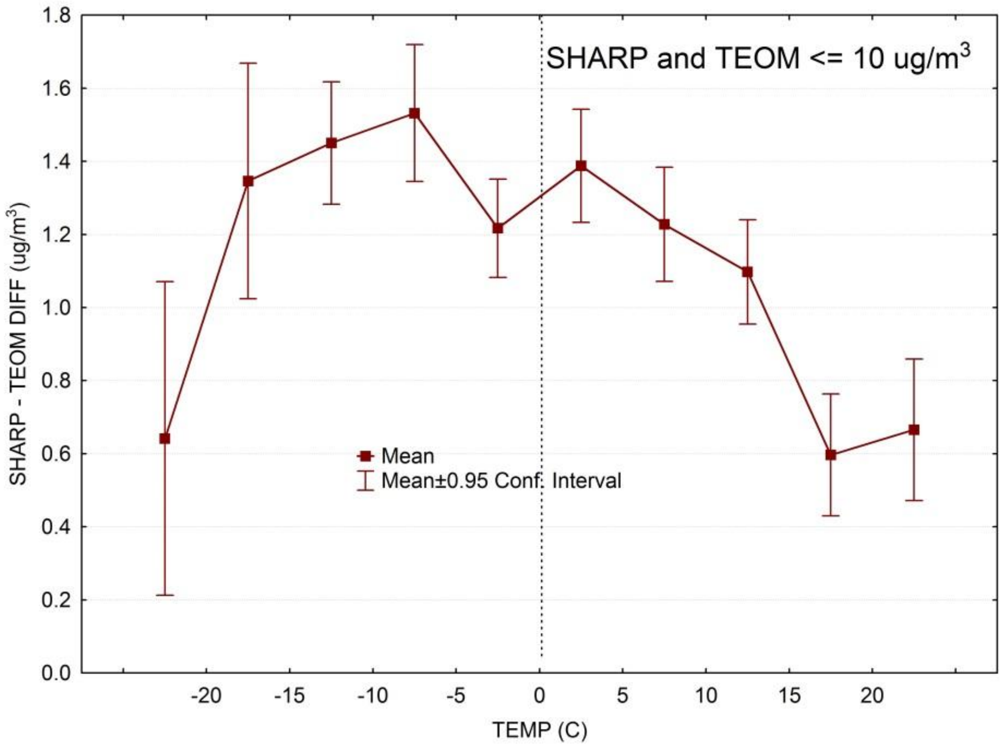


Figure 7: SHARP minus TEOM mean hourly concentration differences at Fort Saskatchewan as a function of temperature (SHARP hourly concentrations greater than or equal to 40 µg/m³.

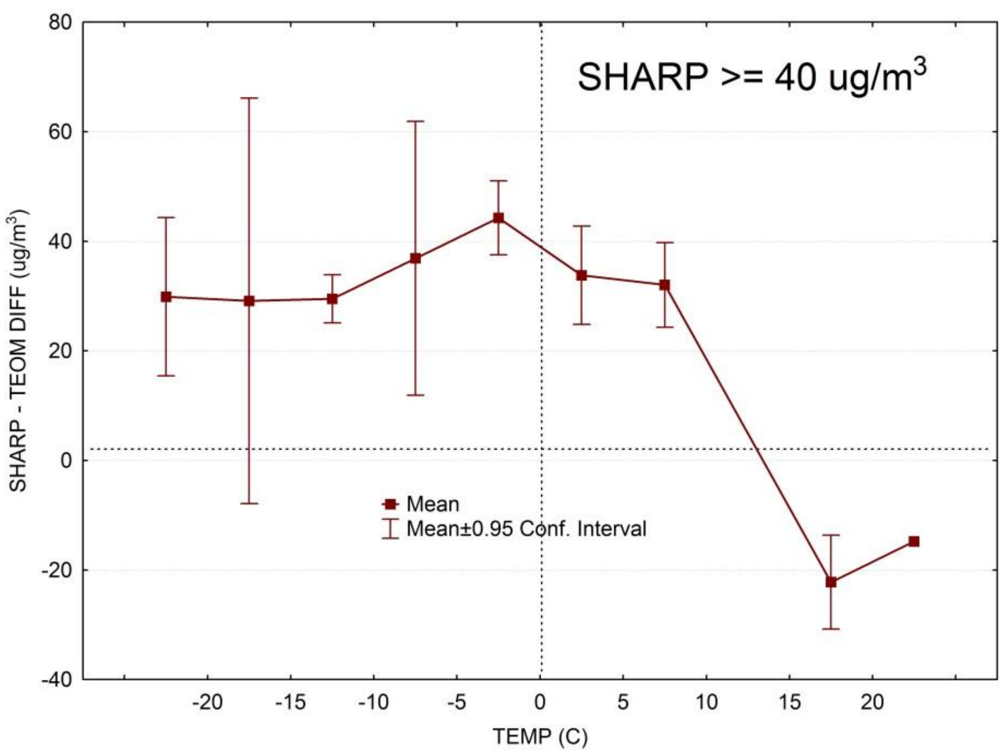
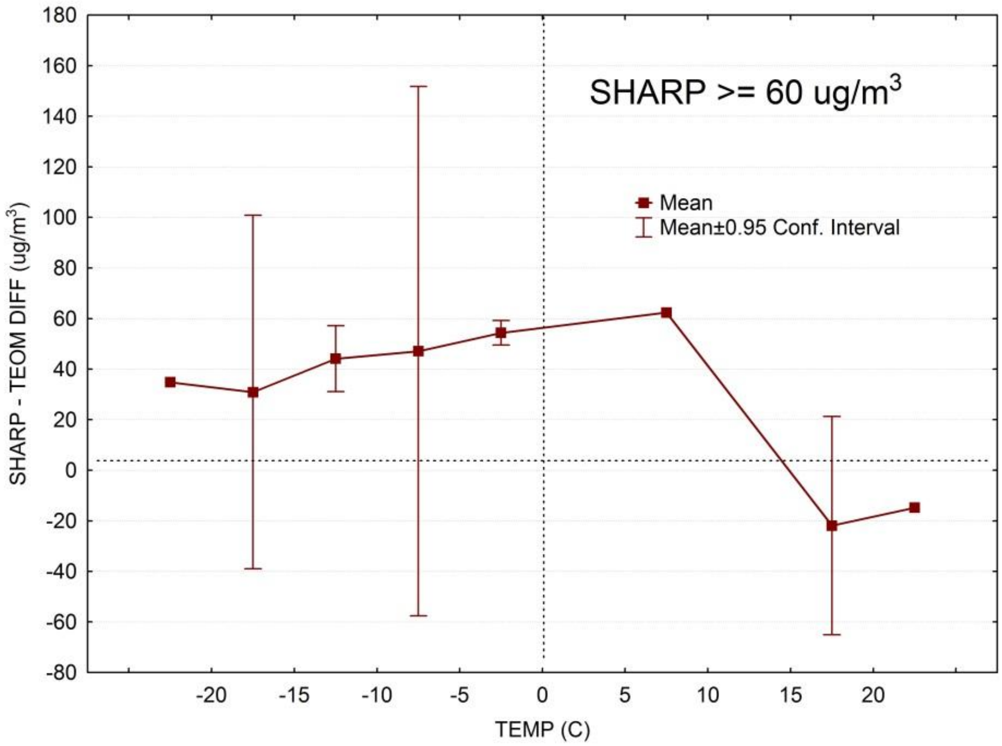


Figure 8: SHARP minus TEOM mean hourly concentration differences at Fort Saskatchewan as a function of temperature (SHARP hourly concentrations greater than or equal to 60 µg/m³.



Using all the hourly data as shown in Figure 9 a general equation can be arrived at relating SHARP – TEOM mean differences to temperature. Overall the SHARP read higher than the TEOM for 70% of total hours as shown in Figure 10.

Figure 9: Relationship between SHARP minus TEOM mean hourly concentration differences at Fort Saskatchewan to temperature.

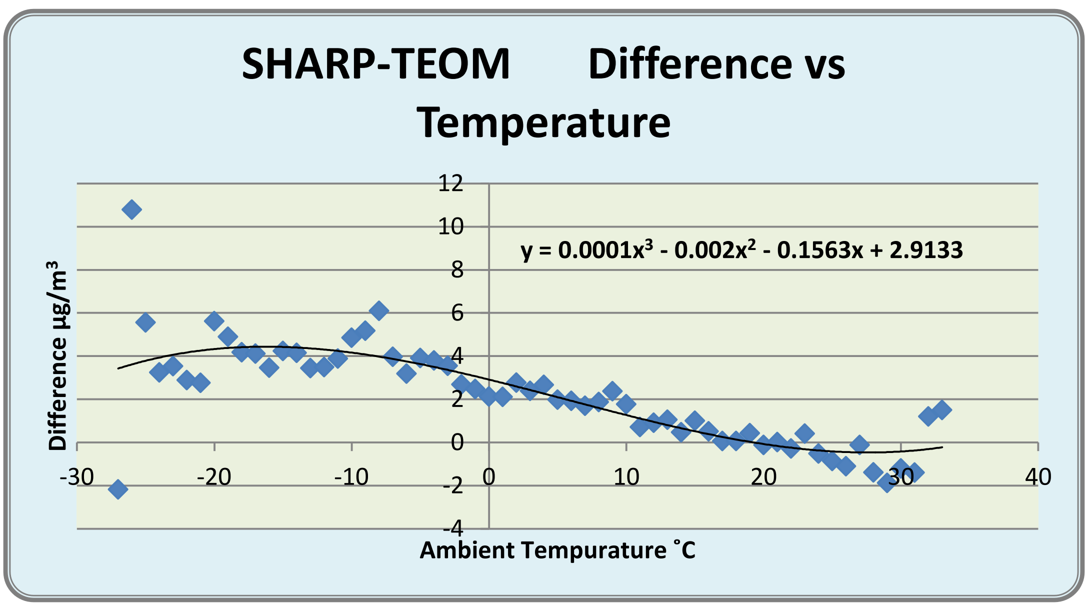
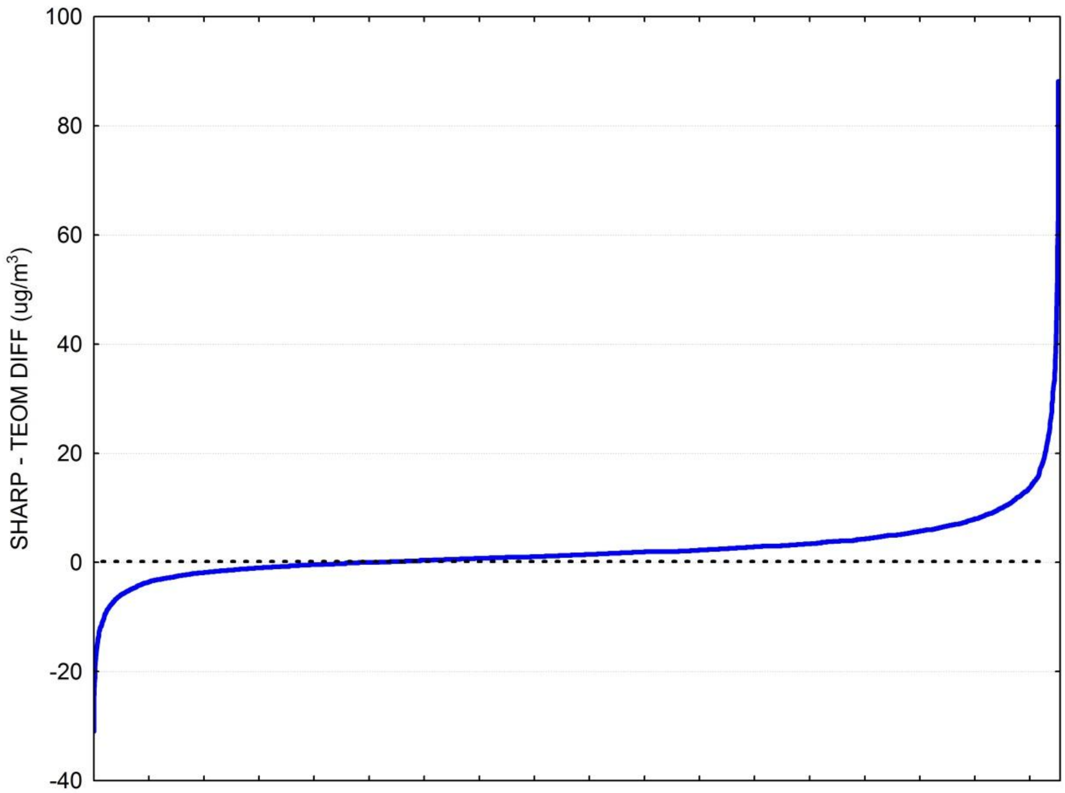


Figure 10: Distribution of SHARP minus TEOM mean hourly concentration differences at Fort Saskatchewan.



The results compared on a 24-hr basis:

Twenty-four hour averages from the two monitors were calculated from the hourly data. A valid 24-hr average required 18 hours or more of valid hourly data. Linear regression analysis was carried out on the 24-hr data in a comparable manner to that carried out in previous NAPS inter-comparison studies including the removal of outliers. Overall results for all days and for warm and cold time periods are shown in Table 2. Warm and cold time periods for the 24-hr analysis were based on average daily temperatures above or below 10 °C. Also shown in the table are results from other SHARP/TEOM comparisons from a number of Canadian sites. In Table 3 the results for Fort Saskatchewan are provided with the TEOM as the x-Axis variable. Comparing 24-hour results yields better correlation than comparing one-hour results. A graphical display of results is contained in Figure 11.

The results from the Fort Saskatchewan inter-comparison of a SHARP and TEOM instruments essentially match results that have been obtained in numerous locations. Although the instruments are well correlated the SHARP reports substantially higher concentrations in the cold months than the TEOM with more comparable results obtained in the warm months.

Table 2: Linear Regression results for 24h Average Data for SHARP and TEOM for Fort Saskatchewan and Other Canadian Sites (TEOM on X-axis).

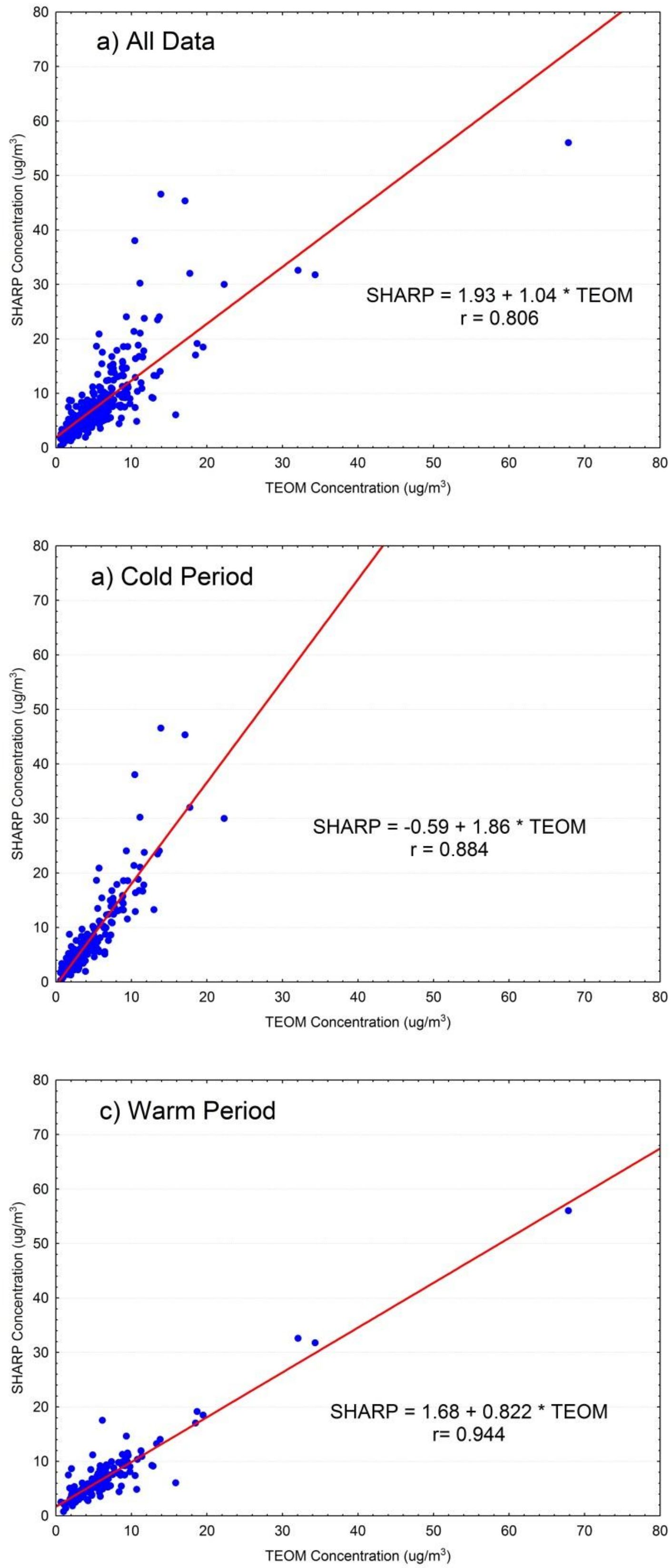
PERIOD	N	MEAN SHARP	MEAN TEOM	SLOPE	INTERCEPT	r	SHARP P_{98}	TEOM P_{98}
Fort Saskatchewan (2012 - 2013)								
ALL	361	7.6	5.4	1.04	1.95	0.806	30.2	17.7
WARM	149	7.0	6.4	0.85	1.63	0.963	31.8	32.1
COLD	204	8.1	4.7	1.86	-0.58	0.883	30.2	13.7
35 Canadian Sites (2010 - 2012)								
ALL (AVG)		8.7	5.4	1.33	1.50	0.906	25.9	16.4
WARM (AVG)		7.1	6.1	0.92	1.47	0.942	20.4	19.6
COLD (AVG)		9.2	5.2	1.49	1.35	0.925	26.9	16.0

Table 3: Linear Regression results for 24h Average Data for SHARP and TEOM for Fort Saskatchewan (SHARP on X-axis).

PERIOD	N	MEAN SHARP	MEAN TEOM	SLOPE	INTERCEPT	r	SHARP P_{98}	TEOM P_{98}
Fort Saskatchewan (2012 - 2013)								
ALL	361	7.6	5.4	0.62	0.69	0.806	30.2	17.7
WARM	149	7.0	6.4	1.10	-1.31	0.963	31.8	32.1
COLD	204	8.1	4.7	0.42	1.27	0.883	30.2	13.7

Canadian Ambient Air Quality Standards (CAAQS) for $PM_{2.5}$ were established in October 2012. There are two CAAQS for $PM_{2.5}$: an annual mean standard of 10 µg/m^3 for the year 2015 and 8.8 µg/m^3 for the year 2020; and, a standard based on the 98th percentile of 24-hour average $PM_{2.5}$ of 28 µg/m^3 for the year 2015 and 27 µg/m^3 for the year 2020. Achievement is to be based on the average over 3 consecutive years. Table 2 also illustrates the difference in reported mean and 98th percentile $PM_{2.5}$ concentrations from the two samplers. The SHARP instrument reported a 98th percentile for the year greater than the CAAQS target whereas the TEOM value was well below the CAAQS.

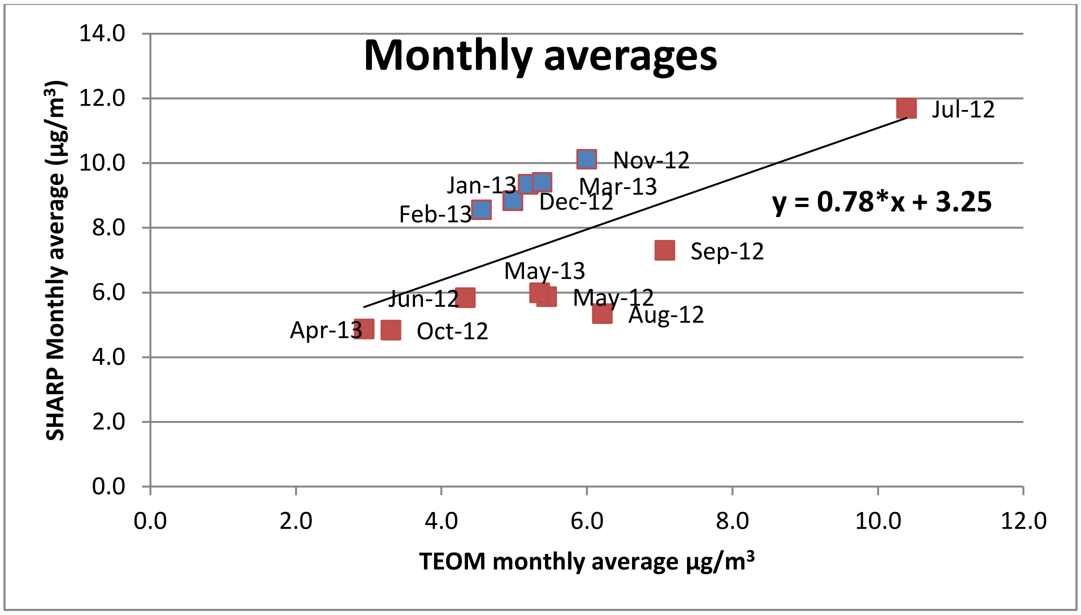
Figure 11: Correlation between 24-hr averages, TEOM vs SHARP monitors at Fort Saskatchewan for a) All Data, b) Cold and c) Warm periods (based on 10 °C).



The results compared on a monthly basis:

An examination of the monitoring data on a monthly basis is shown in Figure 12 with the warm months and the cold months contrasted. Again there is a separation in comparability between the warm and the cold months.

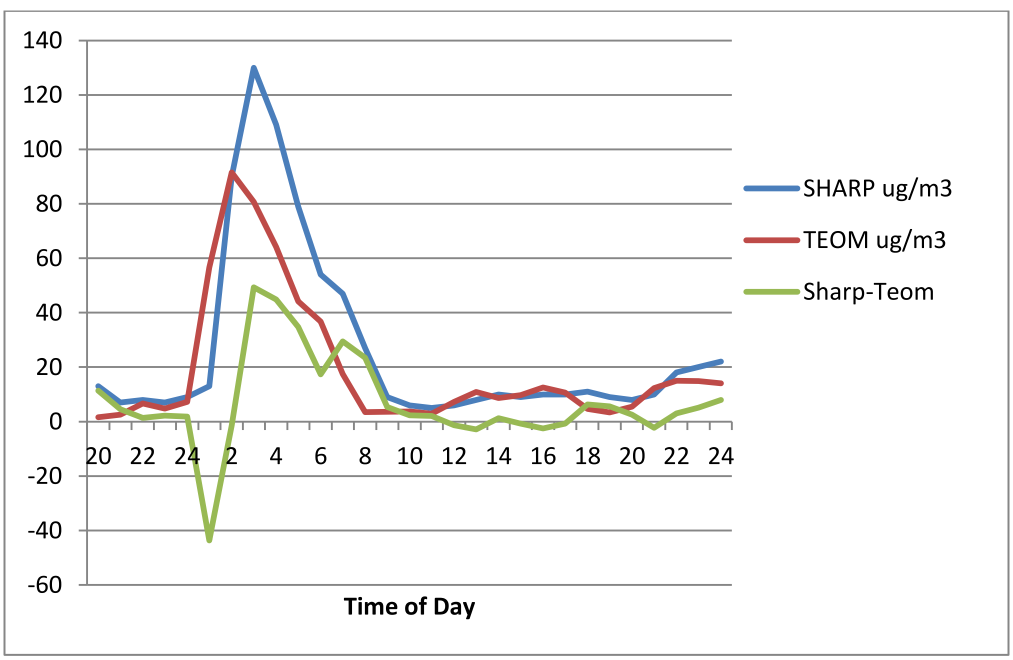
Figure 12: Correlation between monthly averages, TEOM vs SHARP monitors at Fort Saskatchewan.



Performance during an Episode:

Figure 13 shows reported results from the two samplers during the regional episode that occurred on January 11, 2013.

Figure 13: Performance of $PM_{2.5}$ Instruments During a regional $PM_{2.5}$ Episode (January 11, 2013).



Observations/Conclusions:

All the continuous monitors originally installed in the NAPS network used the tapered element oscillating microbalance (TEOM) measurement principle. It has been established that the TEOM continuous $PM_{2.5}$ instruments (with and without SES dryers) deployed across the Canadian monitoring networks since the mid-1990's do not meet the data quality objectives (DQOs) that have been recommended for comparison with NAPS reference method samplers (Allen, 2010). Specifically, TEOMs often under-report levels in comparison to manual filter-based samplers due to the loss of semi-volatile particulate matter caused by heating of the sampled air to 30 or 40° C in order to remove unwanted water. This loss is typically larger in the winter than in the summer because of the larger differences between the TEOM filter and ambient temperatures in winter and higher concentrations of semi-volatile nitrates in winter.

The results from the Fort Saskatchewan inter-comparison of a SHARP and TEOM instruments essentially match results that have been obtained in numerous locations. Although the instruments are well correlated the SHARP reports substantially higher concentrations in the cold months than the TEOM with more comparable results obtained in the warm months. Reported annual mean and annual 98th percentile $PM_{2.5}$ concentrations were significantly higher for the SHARP instrument over the one year study period.

NAPS managers have determined that instruments approved as U.S. EPA Class III FEM meet the NAPS DQOs. The first $PM_{2.5}$ instruments (Met-One BAM) received EPA approval in March 2008 and there are now more than 5 instruments that have received Class III FEM approval (EPA, 2013). Alberta and other monitoring agencies across Canada have replaced their older $PM_{2.5}$ monitors with Class III FEM instruments such as the SHARP. There is no doubt that the change in instrumentation will result in higher reported concentrations and hence complicate analysis of historical trends. Some efforts have been made to develop so-called ‘transformation’ functions that adjust historical TEOM data to more closely compare with FRM or FEM equivalent measurements (Dann, 2012 and Allen, 2010). These types of transformations, however, are best carried out on a pooled national or regional basis and are most useful for long term trend analysis.

Part B: Compare reference filter-based (Partisol) $PM_{2.5}$ monitoring measurements to continuous BAM1020 and Grimm 180 measurements.

Objective:

Understand the potential bias between two continuous monitoring methods using the filter-based method as a reference.

Methods and Data Collection:

FAP acquired two Partisol FRM2000 $PM_{2.5}$ monitors to collect 24-hour particulate samples. One Partisol FRM2000 was co-located with a Grimm 180 at the Bruderheim AQM Station and the other was co-located with the BAM 1020 at the Lamont County AQM Station. Twenty-four hour samples were collected on the same days, with gravimetric analysis performed by Maxxam Laboratories. Same-day hourly data for the continuous monitors was retrieved from the CASA Data Warehouse. The 24-hr average concentrations were calculated from the hourly concentrations and were compared to the gravimetric co-located result.

Data:

An initial study was done for the August – December 2011 sampling period but there appears to have been some problems with data quality so only data for the period August 1, 2012 to September 1, 2013 were used in the flowing analysis and discussion.

Data Analysis (August 1, 2012 to September 1, 2013):

The daily variation in 24-hr concentrations at the two sites for the four different measurement methods is shown in Figure 14. Differences between site concentrations would be expected but the Bruderheim GRIMM most frequently reported the highest measured concentration.

Linear regression analysis was carried out on the 24-hr data in a comparable manner to that carried out in previous NAPS inter-comparison studies including the removal of outliers. Overall results for all days and for warm and cold time periods are shown in Table 4. Warm and cold time periods for this analysis were based on average daily temperatures above or below 10 °C. Correlations between the continuous and filter-based methods were excellent at both sites for both warm and cold season. The best agreement on slope and intercept were during the cold period with slopes close to unity. A slope of 1.36 was calculated for the Bruderheim GRIMM to Partisol in the warm period and 1.14 for the Lamont County BAM. Reported mean and 98th percentile $PM_{2.5}$ concentrations were higher for the continuous methods at both sites.

A graphical representation of these results is provided in Figure 15 for Bruderheim and in Figure 16 for Lamont County.

Figure 14: Daily variation in $PM_{2.5}$ Concentrations (µg/m3) at Bruderheim and Lamont County.

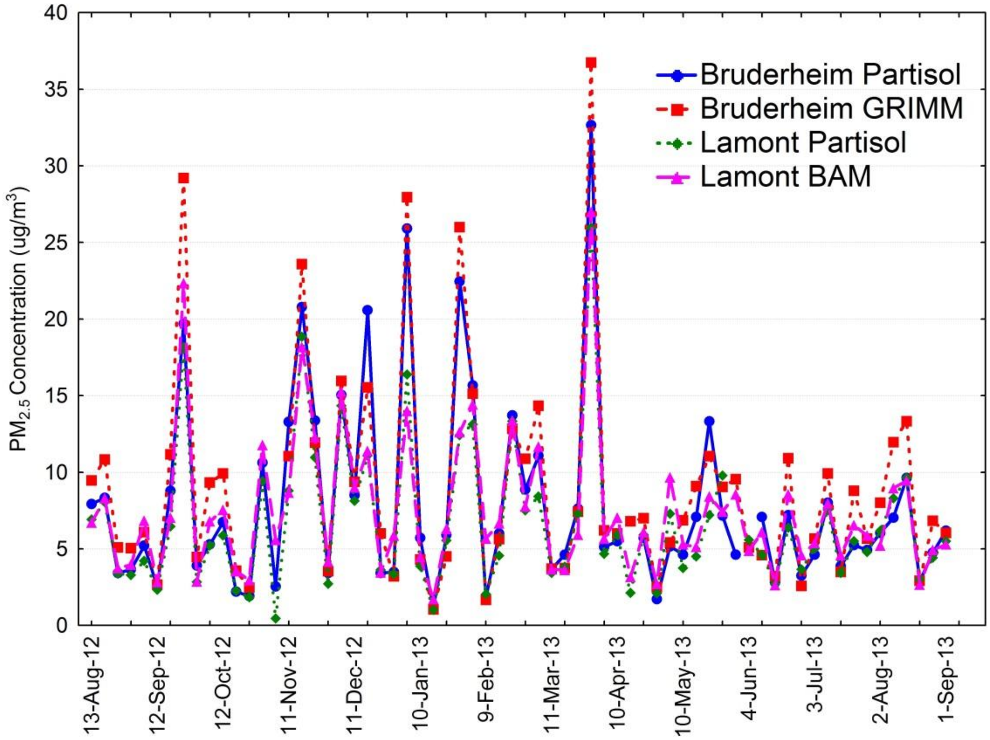


Table 4: Linear regression results for 24h average data for Bruderheim GRIMM and Lamont BAM vs Partisol (Partisol on X-axis).

SITE	TYPE	N	MEAN PART.	MEAN CONTIN.	SLOPE	INT.	r	PART P_{98}	CONT. P_{98}
ALL DATA									
BRUDERHEIM	GRIMM vs PARTISOL	59	8.1	9.1	1.07	0.39	0.957	25.9	29.2
LAMONT COUNTY	BAM vs PARTISOL	64	6.7	7.5	0.98	0.91	0.968	18.8	22.3
WARM Period									
BRUDERHEIM	GRIMM vs PARTISOL	28	6.2	7.9	1.36	-0.58	0.945	19.7	29.2
LAMONT COUNTY	BAM vs PARTISOL	26	6.1	6.7	1.14	-0.36	0.957	18.2	22.3
COLD Period									
BRUDERHEIM	GRIMM vs PARTISOL	30	9.9	10.4	1.06	-0.07	0.976	32.7	36.8
LAMONT COUNTY	BAM vs PARTISOL	37	7.2	8.1	0.94	1.32	0.978	26.0	27.0

Figure 15: Correlation between 24-hr averages, GRIMM vs PARTISOL at Bruderheim for a) All Data, b) Cold and c) Warm periods (based on 10 C).

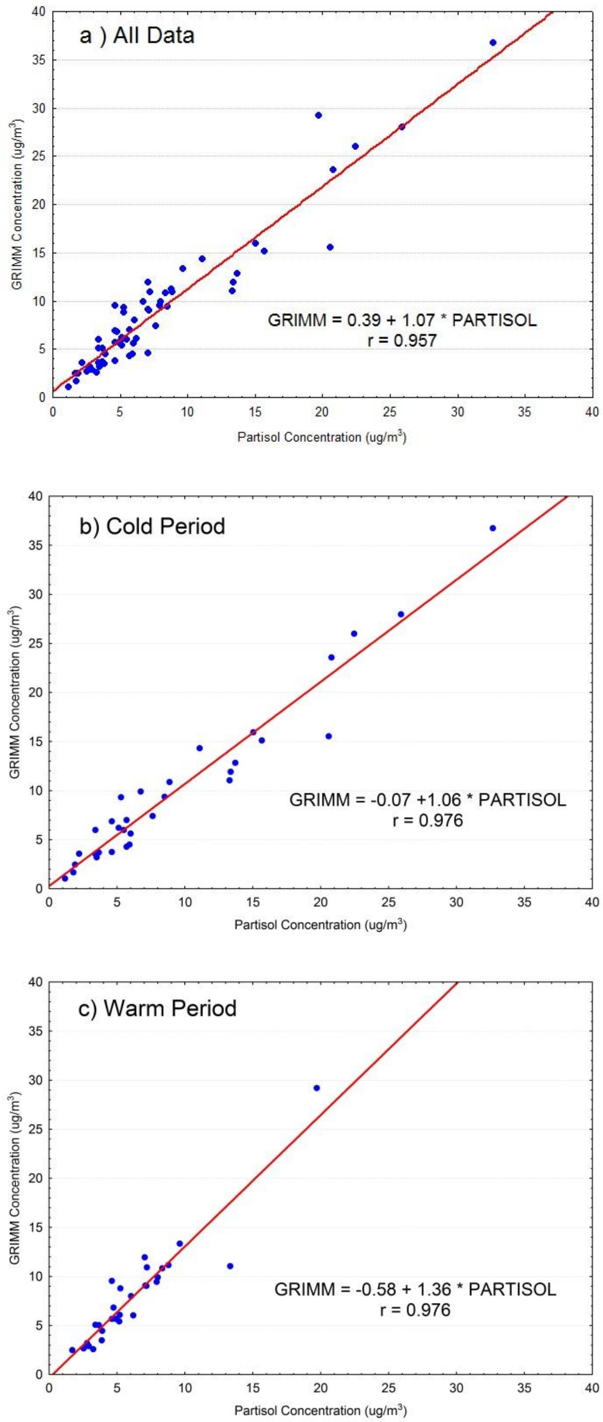
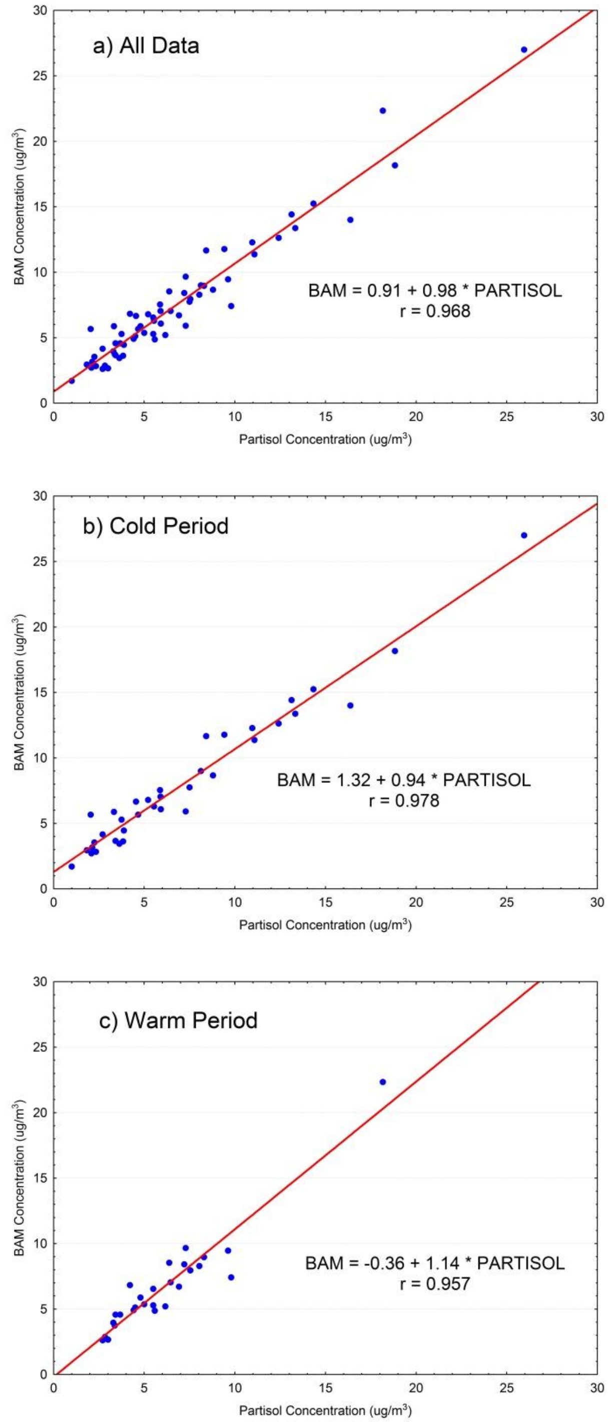
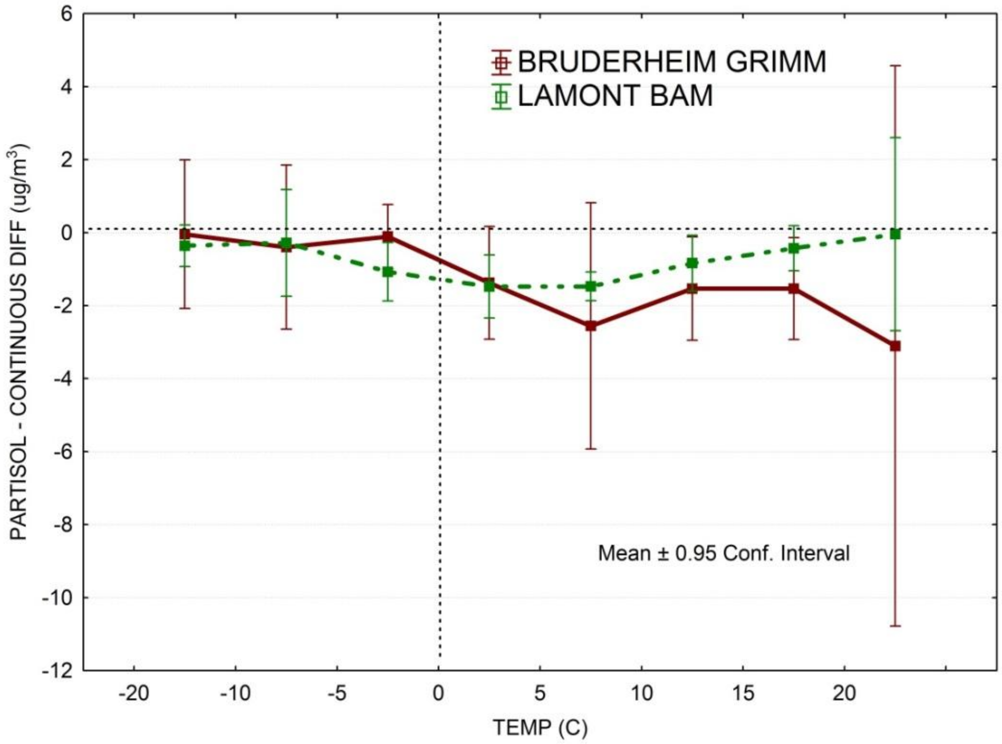


Figure 16: Correlation between 24-hr averages, BAM vs PARTISOL at Lamont County for a) All Data, b) Cold and c) Warm periods (based on 10 C).



Difference in 24-hr averages between the continuous monitors and the Partisols (Partisol – continuous) as a function of temperature is illustrated in Figure 17. At both sites mean differences were always negative (continuous method reads higher) at all temperatures (although mean differences were very small at temperatures below 0 °C). Differences between the GRIMM and Partisol increased with increasing temperature whereas at Lamont differences between the BAM and Partisol were largest at temperatures between 0 °C and 10 °C.

Figure 17: PARTISOL minus Continuous mean 24-hr concentration differences as a function of temperature: Bruderheim GRIMM and Lamont BAM.



Observations/Conclusions:

Correlations between the continuous and filter-based methods were excellent at both sites for both warm and cold season. The best agreement on slope and intercept were during the cold period with the continuous instruments reading highest relative to the filter based method in the warm period. Reported mean and 98th percentile $PM_{2.5}$ concentrations were higher for the continuous methods at both sites for the one year study period.

The performance of the BAM1020 instrument at the Lamont site relative to a filter based measurement is typical of results from many other sites as shown in Table 5. Long term data sets from the GRIMM instrument are more difficult to locate and comparative results were not available. It has been demonstrated that FEM continuous instruments do read higher than filter-based reference methods and this is often due to loss of volatile components from the filter-based samplers during warmer temperatures (Felton, 2011).

A recommendation from a recent monitoring network assessment commissioned by the FAP Technical Working Group (Sonoma, 2012) suggested that FAP consider adopting a consistent monitoring technology network-wide to facilitate direct comparisons of air quality throughout the region. Based on the results of the preceding data analyses this recommendation can be supported. Additionally, it is recommended that a co-located reference method sampler should be operated at one site or more on an ongoing basis.

Table 5: Summary of Slope, Intercept, Correlation and Concentrations by Location and Season (2008 - 2010) for Met-One BAMs at Canadian and U.S. Locations and Comparison with Lamont (BAM on X-Axis).

SITE GROUP	SEASON	NAME	REGION	Sites Used	MEAN FRM (µg/m³)	MEAN CONT. (µg/m³)	SLOPE	INTERCEPT	r	FRM P_{98} (µg/m³)	CONT. P_{98} (µg/m³)
U.S. FEM	COLD	BAM	NE	8	10.7	11.7	0.84	0.99	0.950	24.2	26.9
U.S. Non Ref.	COLD	BAM	NE	14	9.1	11.0	0.86	-0.24	0.961	26.0	29.4
CANADA	COLD	BAM	EAST	3	7.0	8.3	0.95	-0.75	0.970	25.0	25.9
U.S. FEM	COLD	BAM	NW	4	6.8	7.2	0.84	0.81	0.925	18.1	20.8
U.S. Non Ref.	COLD	BAM	NW	13	11.8	12.5	0.97	-0.32	0.962	33.2	33.4
LAMONT	***COLD***	***BAM***		***1***	***7.2***	***8.1***	***1.02***	***-1.04***	***0.978***	***26.0***	***27.0***
U.S. FEM	WARM	BAM	NE	7	10.7	11.9	0.88	0.24	0.969	26.9	29.2
U.S. Non Ref.	WARM	BAM	NE	12	9.5	10.5	0.87	0.35	0.954	23.4	26.0
CANADA	WARM	BAM	EAST	3	7.2	8.4	0.89	-0.14	0.935	21.3	21.8
U.S. FEM	WARM	BAM	NW	3	9.7	9.7	1.01	-0.10	0.960	23.0	22.4
U.S. Non Ref.	WARM	BAM	NW	13	7.3	8.4	0.81	0.53	0.916	16.4	18.4
LAMONT	***WARM***	***BAM***		***1***	***6.1***	***6.7***	***0.80***	***0.81***	***0.957***	***18.2***	***22.3***

Part C: Review and illustrate changes in historical data when TEOM monitors were replaced with SHARP monitors.

Objective:

Determine whether there are observable changes in measured $PM_{2.5}$ concentrations before and after installation of the SHARP monitor at Fort Saskatchewan (May 2010) and Elk Island (September 2011).

Data:

The TEOM particulate monitor (with dryer operating at 40 °C) at Fort Saskatchewan was replaced with a SHARP in early May 2010. The TEOM monitor at Elk Island was replaced with a SHARP in September 2011. Data for a period of two years prior and two years past the change date was obtained from the CASA Data Warehouse at www.casadata.org for Elk Island. For Fort Saskatchewan data for three years prior and three years past was obtained.

Data Analysis:

Summary statistics and percentile distributions were computed for the before and after periods broken down into all, warm months and cold months as shown in Table 5 for Fort Saskatchewan and Table 6 for Elk Island (the period of August 19 to 21, 2010, where the SHARPs recorded very high due to smoke from BC fires, was not included in the statistics). A plot of the hourly data for the before and after time-periods is shown in Figure 18 for Fort Saskatchewan and in Figure 19 for Elk Island. Also shown on the plots is the 10 day moving average of the hourly values. Since there is no reference measurement to compare with, the differences between results may be due to normal variations in ambient conditions.

Examining Table 6 shows there is a constant difference between the SHARP and TEOM results at the lower percentiles at Elk Island of about 1.5 µg/m^3. This can also be seen clearly in Figure 21 where the y-axis is constrained to 10 µg/m^3. At higher percentiles the differences are larger and may reflect the different performance in the cold and warm season of the TEOM and SHARP as discussed in Part A.

A similar offset in the lower percentiles is seen in the Fort Saskatchewan results and is also seen in Figure 20. At Fort Saskatchewan the offset does not appear until 2011 and then seems to reduce in 2013. At higher percentiles the differences are larger.

At Elk Island the reported mean for the two years of data was 5.3 µg/m^3 for the SHARP and 4.1 for the TEOM with 98th percentile values essentially the same. At Fort Saskatchewan the reported mean for three years of data was 7 µg/m^3 for the SHARP and 5.1 µg/m^3 for the TEOM. Calculated 98th percentile values were quite different: 30.8 µg/m^3 for the SHARP vs. 21.1 µg/m^3 for the TEOM.

Table 5: Comparison of Summary Statistics for TEOM (May 2007 to April 2010) and SHARP (May 2010 to April 2013) at Fort Saskatchewan.

Location	Instrument	Season	Start Date	End Date	N	Min.	5	10	25	50	60	75	90	95	98	Max.	Mean	Std. Dev.
Fort Saskatchewan	SHARP	ALL	5/11/10	4/30/13	25346	0	1	1.8	2.8	4.7	5.9	8.3	14.6	20	30.8	137.7	7.0	8.3
Fort Saskatchewan	TEOM	ALL	5/1/07	4/30/10	25539	0	0	0.2	1.5	3.6	4.6	6.7	11.2	14.9	21.1	132.9	5.1	5.9
Fort Saskatchewan	SHARP	COLD	11/1/10	3/31/13	10868	0	1	1.9	3	5.5	7	10.6	18	24.6	37.7	137.7	8.5	9.6
Fort Saskatchewan	TEOM	COLD	11/1/07	3/31/10	10750	0	0	0.3	1.6	3.7	4.9	7.4	12.9	17.9	27	132.9	5.8	7.2
Fort Saskatchewan	SHARP	WARM	5/11/10	4/30/13	14478	0.0	0.7	1.7	2.6	4.1	5.0	7.0	11.3	16.0	23.8	137.1	5.9	7.0
Fort Saskatchewan	TEOM	WARM	5/1/07	4/30/10	14789	0	0	0.1	1.5	3.5	4.4	6.2	10	13	17	73.9	4.6	4.6

Table 6: Comparison of Summary Statistics for TEOM (Sep 2009 to Aug 2011) and SHARP (Sep 2011 to Aug 2013) at Elk Island.

Location	Instrument	Season	Start Date	End Date	N	Min.	5	10	25	50	60	75	90	95	98	Max.	Mean	Std. Dev.
Elk Island	SHARP	ALL	9/1/11	8/31/13	16977	0	1	1.5	2	4	5	7	11	14	19	67	5.3	4.6
Elk Island	TEOM	ALL	9/1/09	8/31/11	17309	0	0	0	1	2.5	3.3	4.9	8.7	11.9	19.4	152	4.1	6.5
Elk Island	SHARP	COLD	11/1/11	3/31/13	7068	0	1	1.5	2	4	5	6.9	11.3	15	20	67	5.3	4.9
Elk Island	TEOM	COLD	11/1/09	3/31/11	7184	0	0	0	1	2.4	3.2	4.9	8.5	11.5	16.4	83.7	3.7	4.8
Elk Island	SHARP	WARM	9/1/11	8/31/13	9909	0	1	1.4	2	4	5	7	10	13	18	47	5.2	4.4
Elk Island	TEOM	WARM	9/1/09	8/31/11	10125	0	0	0	1	2.6	3.3	5	8.8	12.4	23.8	152	4.3	7.5

Figure 18: Hourly $PM_{2.5}$ µg/m^3 Concentrations at Fort Saskatchewan and 10-day moving averages for 3-yr TEOM and SHARP operating periods.

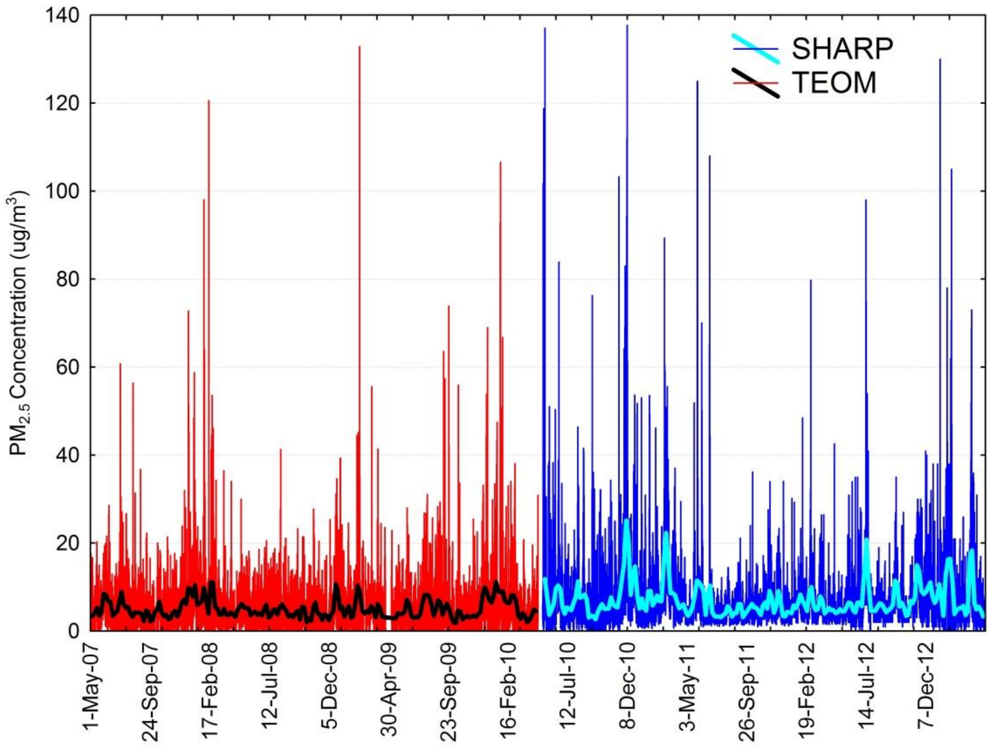


Figure 19: Hourly $PM_{2.5}$ µg/m^3 Concentrations at Elk Island and 10-day moving averages for 2-yr TEOM and SHARP operating periods.

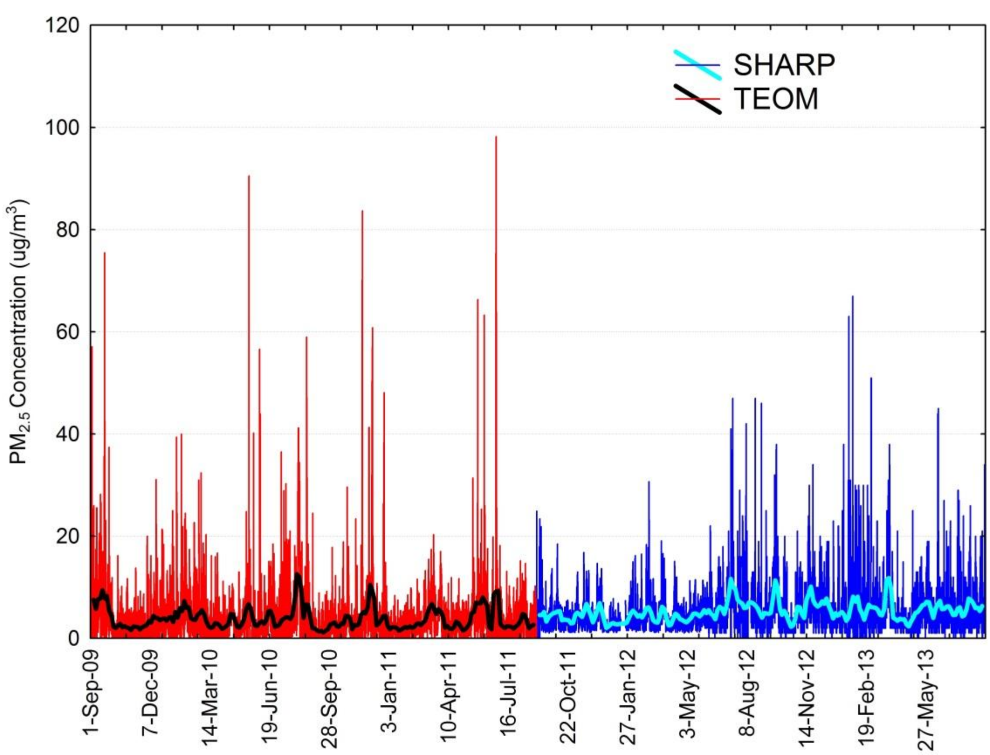


Figure 20: Hourly $PM_{2.5}$ µg/m³ Concentrations at Fort Saskatchewan and 10-day moving averages for 3-yr TEOM and SHARP operating periods – values between 0 and 10 µg/m³ only.

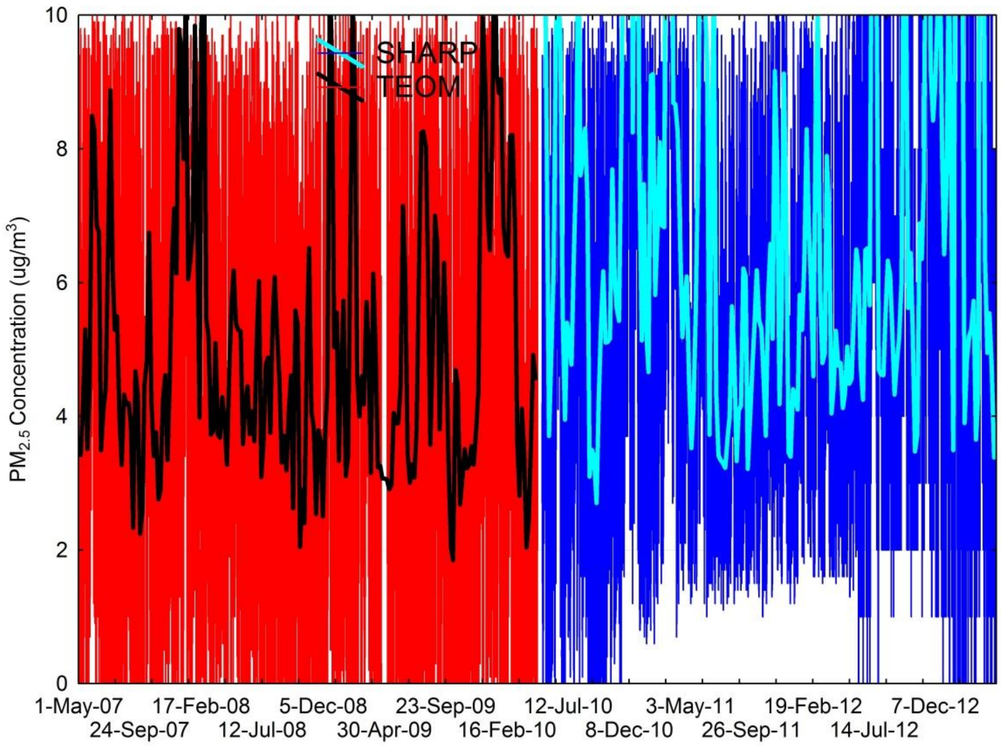
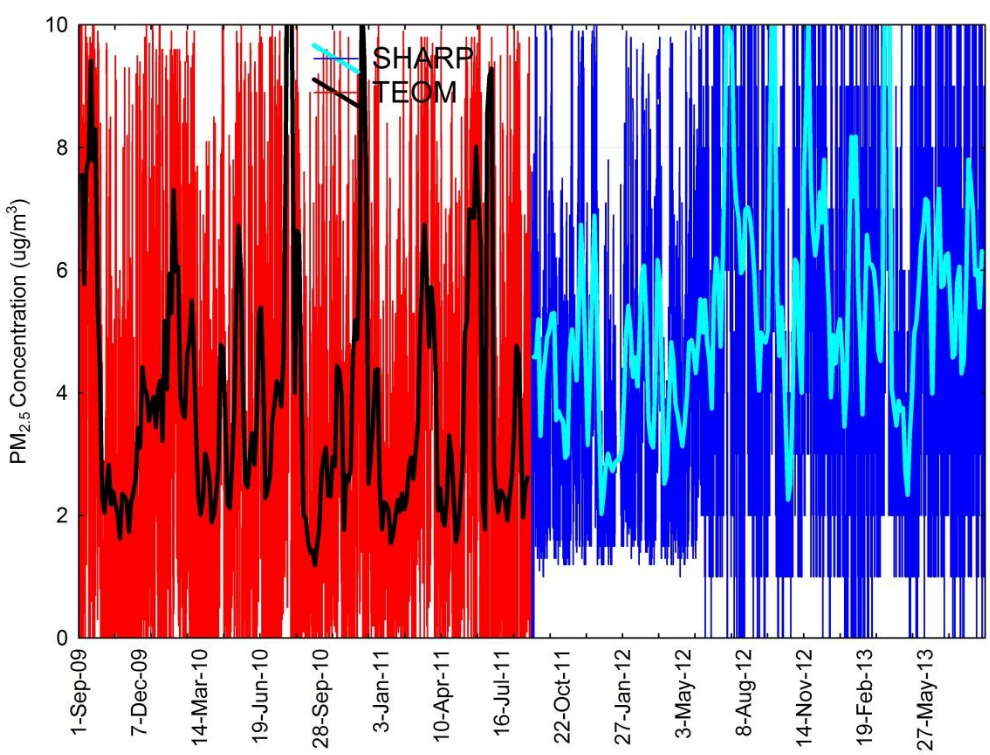


Figure 21: Hourly $PM_{2.5}$ µg/m³ Concentrations at Elk Island and 10-day moving averages for 2-yr TEOM and SHARP operating periods– values between 0 and 10 µg/m³ only.



Observations/Conclusions:

When comparing the before and after data sets at Elk Island there was a constant difference between the SHARP and TEOM results at the lower percentiles of about 1.5 µg/m^3. At higher percentiles the differences were larger and may reflect the different performance in the cold and warm season of the TEOM and SHARP as discussed in Part A.

A similar offset in the lower percentiles was seen in the Fort Saskatchewan before and after results although the offset did not appear until 2011 and then seemed to reduce in 2013. At higher percentiles the differences were larger at the site.

Since there was no reference measurements to compare with at the sites, the differences between results may be due to normal variations in ambient conditions but based on the preceding data analysis it's very likely that the change in instrumentation has resulted in higher reported concentrations and thus the changeover will complicate the analysis of historical trends.

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