

Comparison of Low-Cost Versus Federally-Certified Methods of Measuring Fine Particle Pollution

Introduction

Fine particle pollution¹ is monitored for comparison with national ambient² air quality standards by state, local and tribal governments, as well as by some industrial facilities. These entities use monitoring instruments that are federally certified for regulatory purposes. Recently, the availability of low-cost air monitoring sensors (hereafter referred to as sensors) has led to increased interest by private citizens and non-governmental groups in monitoring local air quality.

The suitability of using these sensors to monitor ambient air quality is uncertain. Despite this uncertainty, private citizens and non-governmental organizations have, at times, used data from sensors to draw comparisons with national standards. These types of comparisons have the potential to result in a mischaracterization of the air quality if sensors are not capable of accurately measuring the amount of pollution in the air. To help understand how to interpret data from sensors, studies are being conducted to compare measurements made by sensors with those made by federally-certified instruments (see Further Reading section).

To evaluate sensor performance for measuring ambient fine particle pollution under conditions found in Wisconsin, the Wisconsin Department of Natural Resources (DNR) conducted a comparison of three federally-certified instruments with one commonly-used sensor at a DNR air monitoring site in the city of Waukesha.

Materials and Methods

The instruments included in the study (Table 1) were compared over an approximately 2-month period during the late summer and early fall (August / September) of 2017. All instruments were located on the roof of the shelter at the Waukesha air monitoring site. Because the sensor (the Dylos DC 1100 PRO-PC, hereafter referred to as the Dylos), was not designed for long-term use outdoors, a plywood shelter was built to protect the sensor from rain and ultraviolet light interference.

TABLE 1. Instruments compared in this study.

Name	Manufacturer / Model	Federally certified?	Time increment	Data units*	Measurement principle	Cost (estimate)
Reference	Thermo 2025i	Yes	1 day	µg/m ³	Mass of particles on a filter	\$13,500
BAM	Met One 1020	Yes	1 hour	µg/m ³	Radiation transmission through a filter containing particles	\$19,500
T640X	API Teledyne T640X	Yes	5 seconds	µg/m ³	Light scatter from particles in air	\$36,500
Dylos	Dylos DC 1100 PRO-PC	No	1 minute	# particles / 0.01 ft ³	Light scatter from particles in air	\$290

* µg = microgram or 0.000001 gram

¹ Fine particle pollution is a mixture of solid particles and liquid droplets with diameters of 2.5 micrometers or smaller.

² Ambient air is the portion of the atmosphere to which the general public has access..

Instruments

The reference instrument used for this study is considered by the U.S. Environmental Protection Agency (EPA) to be a “gold standard” for measuring fine particle pollution. This instrument measures fine particle pollution by determining the mass of fine particles on a filter that has had air pulled through it with a pump. Another federally-certified instrument used in this study is referred to as the beta attenuation monitor or BAM. This instrument also collects fine particles on a filter from air pulled through the instrument. Instead of determining particle mass by weighing the filter, as is done with the reference instrument, the BAM determines fine particle concentrations based on the difference in beta rays passing through the filter before and after sampling. The third federally-certified instrument included in this study is the T640X. This instrument is most similar to the Dylos sensor in that both instruments use the same measurement principle. Both the T640X and Dylos determine particle counts and size characteristics by scattering light off particles that have been pulled into a sampling chamber with a pump. In the T640X, particle counts and sizes are then converted to fine particle pollution concentration using proprietary information. To be accurate, this conversion process requires relatively detailed information about particle sizes and estimations of particle densities. The Dylos does not perform this conversion, but instead reports results as particle count concentration.

To receive federal certification, the manufacturers of the reference instrument, BAM, and T640X were required to submit their instruments to specific, vigorous test conditions to verify the instruments meet federal requirements for accuracy and repeatability of measurements. The Dylos, and sensors in general, have not undergone these tests and are therefore not federally-certified.

The amount of air being pulled through each of the federally-certified instruments was verified by DNR staff on a regular basis during the study period to ensure the instruments were working properly. There is no way to verify how much air is being pulled through the Dylos, so regular checks to ensure this sensor was working properly were not possible. These types of checks are known as quality control verifications and are required in a federally-approved monitoring network.

Data Processing and Summarization

Due to differences in how each instrument operates, measurements from each instrument are made over different time increments (Table 1). To be able to compare data from the other instruments to the reference, values from the other instruments were averaged to the time base used by the reference (that is, daily measurements).

When averaging data, federal guidelines for data completeness were followed. If more than one quarter of the data from the day was missing, the data were considered incomplete. Over the 52 days during which the Dylos was running, the Dylos had five days of incomplete data. During this same period, the T640X had four incomplete days (due to operator training) and the reference instrument had one. The BAM had no days of incomplete data (all day were complete).

The Dylos data required an additional level of processing prior to averaging. All other instruments produce data in micrograms per cubic meter ($\mu\text{g}/\text{m}^3$) while the Dylos reports values in number of particles per 0.01 cubic foot. To convert Dylos data to micrograms per cubic meter, some information about particle density is required. This information is not available in the Dylos documentation,

however. The DNR contacted the Dylos Support Team, and was provided with a formula that can be used for an approximate conversion³ (personal communication, Dylos Support Team, 9/29/2017).

Results and Discussion

Table 2 shows the average fine particle pollution measured by the reference instrument in comparison to the BAM, T640X and Dylos. The comparison was made for all days in the study period when the two instruments being compared both had complete days (which resulted in slightly different numbers of samples for each comparison). These data show that the BAM and T640X compared well with the reference over the study period. In contrast, average Dylos values were quite different, recording an overall pollution concentration more than twice as high as that measured by the reference.

TABLE 2. Comparison of average fine particle pollution measured over the study period.

Comparison Instrument	Reference Instrument	Number of samples*	Average fine particle pollution ($\mu\text{g}/\text{m}^3$)	
			Comparison Instr.	Reference Instr.
BAM	Reference	51	8.2	9.5
T640X	Reference	48	10.9	9.7
Dylos	Reference	46	21.5	9.6

* Instruments are compared two at a time for all days where both instruments had complete days.

The daily averages of the four instruments were also graphed over time (Figure 1). Figure 1 shows that peaks in daily averages generally occurred at similar times for all instruments. The Dylos measurements, however, were much more variable and often much higher than those made by the federally-certified instruments. On average for daily data, the BAM recorded 13 percent⁴ less fine particle pollution compared to the reference and the T640X recorded 14 percent more. In contrast, the Dylos recorded average daily values that were on average 123 percent higher than values measured by the reference, a difference that was almost ten times greater than that shown by the two federally-certified comparison instruments.

The data were evaluated further at a finer time scale (Figure 2) to determine whether higher average concentrations measured by the Dylos were driven by only a few very high Dylos measurements. Figure 2 shows measurements over time at a 1-hour time increment for the BAM, T640X and Dylos (data from the reference are not available at time increments finer than one day). It is apparent in Figure 2 that the trend seen in the daily data is mirrored in the hourly data, with the timing of peaks corresponding well across all instruments, but with the Dylos regularly recording much higher values than the federally-certified instruments. Dylos data at a 1-minute time increment were also spot-checked for hours associated with some of the higher 1-hour average Dylos values. This checking found higher Dylos values recorded consistently over the hour. It does not appear that high Dylos values were driven by one or two unusually high readings, but instead the Dylos simply appears to have been reading higher values compared to the other instruments.

Some of the variability in Dylos values could have been due to changes in relative humidity. Other studies have noted some sensitivity of Dylos data to humidity (see Further Reading section), especially for humidity of 95 percent or higher. Moisture in the air can adhere to some particles, interfering with

³ The instructions given were to subtract the “Large Counts” reading from the “Small Counts” reading on the instrument, and then divide the resulting value by 100 to achieve an approximate fine particle concentration in micrograms per cubic meter.

⁴ Percent difference values reported here are based on samples with at least $3 \mu\text{g}/\text{m}^3$ of fine particle pollution measured, as is generally preferred for federal comparison guidelines.

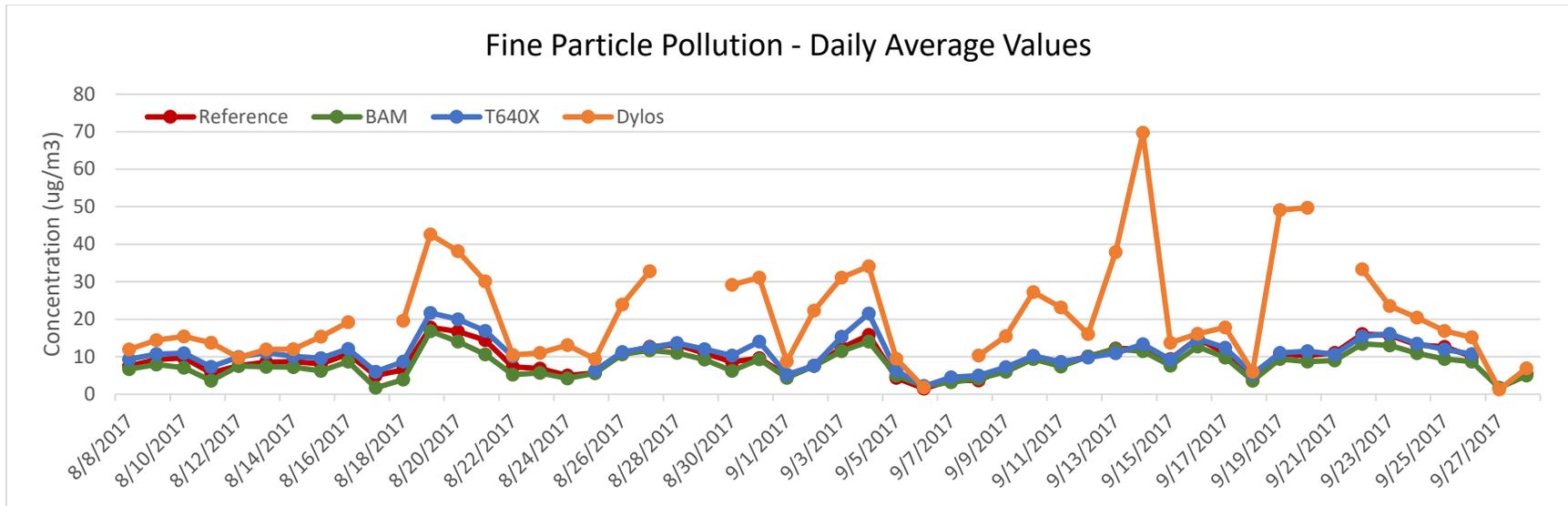


Figure 1. Daily average concentrations of fine particle pollution measured by four air monitoring instruments at Waukesha, Wisconsin.

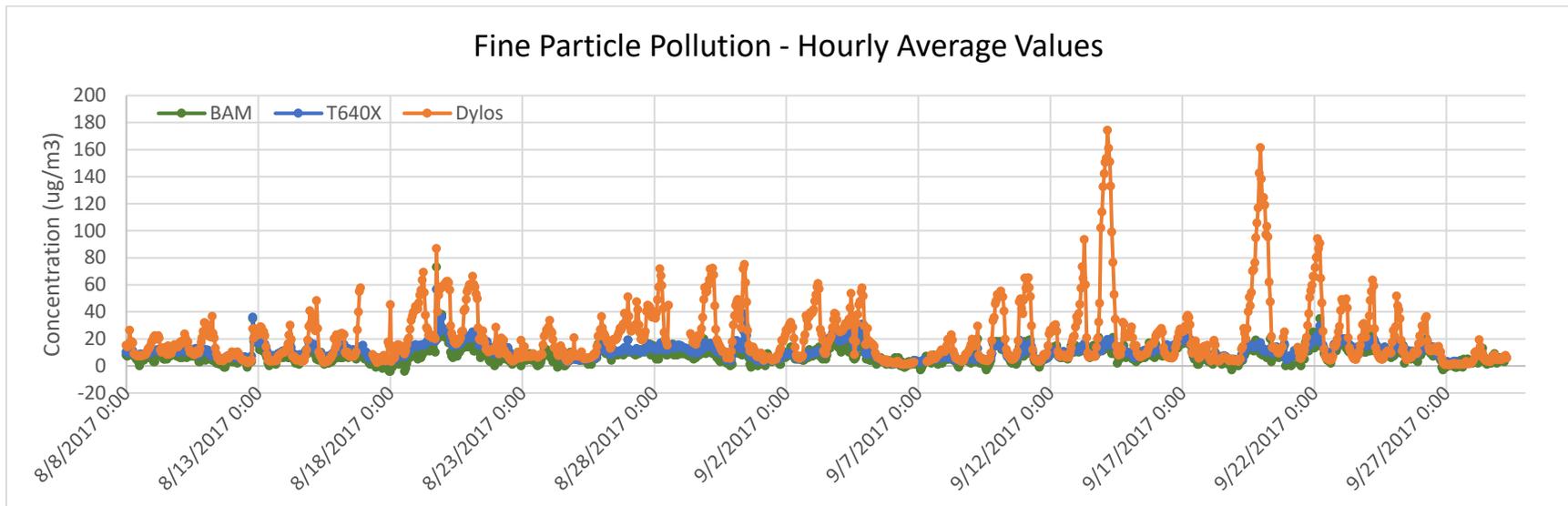


Figure 2. Hourly average concentrations of fine particle pollution measured by three air monitoring instruments at Waukesha, Wisconsin.

measurements made using the light-scattering method. To reduce the impacts of humidity and improve accuracy, the T640X uses a heated sample path to maintain a relatively constant humidity in the air sample being measured. The Dylos does not have a mechanism for managing sample humidity levels. Although relative humidity was not measured at the study site, DNR staff noted some warm humid weather toward the end of September (high temperatures above 75°F and humidity above 80% occurred between 9/13 – 9/16 and 9/19 – 9/26), which may have contributed to higher Dylos measurements during that time.

Because the timing of peaks in Dylos measurements generally corresponded well with that of the other instruments (Figures 1 and 2), the Dylos could qualitatively be used to locate areas experiencing elevated concentrations. However, much caution should be used in assuming that the Dylos readings at those times / locations are representative of the actual amount of fine particle pollution in the air or that those readings are comparable to federal air quality standards. The results of this study suggest that values recorded by the Dylos may be substantially higher than pollution concentrations measured by federally-certified instruments.

Study limitations

One study limitation was the process used for converting Dylos data to units that could be compared with the federally-certified instruments. Based on information provided by the Dylos Support Team, a single value was used to convert Dylos readings from number of particles per 0.01 cubic foot to micrograms per cubic meter. Using a single value for this conversion assumes the relationship between the number of particles by size and the mass of those particles was always the same and was well represented by the single value provided by the manufacturer. It is not clear that these assumptions are valid.

Another study limitation is that data were collected for only two months (August and September). Data collected for a longer time (six or more months), or during different months (that is, during a different season), could yield different results. In the same way, data were collected at only one monitoring site, so conducting this type of study at a different site or additional sites could yield different results.

Conclusion

This study is a comparison of one low-cost sensor with three federally-certified instruments to measure ambient fine particle pollution. Results suggest that the timing of higher-pollution peaks generally corresponds well among all instruments; however, the measurements recorded by the sensor are not necessarily representative of actual pollution levels. Dylos readings were generally higher than values recorded by federally-certified instruments. Data from the Dylos should therefore be interpreted with caution when attempting to determine pollution levels relative to national standards.

Further Reading

Williams, R., A. Kaufman, T. Hanley, J. Rice, and S. Garvey. 2014. Evaluation of Field-deployed Low Cost PM Sensors. EPA/600/R-14/464. 76 pages.

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(<https://www.atmos-meas-tech.net/9/5281/2016/amt-9-5281-2016.pdf> accessed 12/1/17).