Sonoma Technology, Inc.
Environmental Science and Innovative Solutions

Evaluation of the AirBeam Particulate Matter Sensor

by Tim Dye, Adam Pasch, Sean Raffuse, Paul Roberts

October 17, 2014

Introduction

Any new technology that monitors air quality must be evaluated to demonstrate its strengths and weaknesses relative to existing, proven technologies. An evaluation typically involves collecting data from new sensors and from a reference instrument and then evaluating the two datasets using statistical and qualitative methods. We can characterize the real-world performance of the new technology by performing these evaluations near different pollutant sources under a range of weather conditions and concentrations. This collocation method is a common way to evaluate a new device.

This small study characterized the performance of HabitatMap's AirBeam particulate matter (PM) sensor system. Because the AirBeam particle sensor is part of Sonoma Technology, Inc.'s (STI) Kids Making Sense program (www.KidsMakingSense.org), we wanted to better understand how well it performs and identify limitations. Our analysis methods and results are described in this document.

STI is an independent consulting firm that delivers science- and technology-based solutions for environmental challenges worldwide. For over 30 years, we have evaluated, tested, and deployed air quality and meteorological instruments to acquire data to help our clients make informed, timely decisions about environmental issues. We specialize in evaluating new devices and identifying technology that better addresses our client's needs. STI does not own, endorse, or represent any instrument/sensor technology, method, or approach.

Methods

Our approach was to evaluate the AirBeam by collocating a reference instrument next to several AirBeams (**Figure 1**). Specifications of the reference instrument and sensors are listed in **Table 1**.

Figure 1. Collection platform for the Thermo pDR-1500 (PDR), six AirBeam particle sensors, Arduino and Android phone data logger, and supporting power cables.

Table 1. List of specifications of the reference instrument and AirBeam sensors.

Specification	Thermo pDR-1500 (PDR) (Reference)	AirBeam (Test Sensor)
Picture		
Number of units	1	6
Measurement method	Light scattering	Light scattering
Particle size	$PM_{2.5}$ and smaller	All particles
Averaging time	1 second	1.5 seconds
Reporting units	Microgram per cubic meter ($\mu g/m^3$)[a]	Hundreds of particles per cubic foot (hppcf)
Weight	2.5 lb	½ lb
Cost estimate (USD)	$6,000	$200

[a] The PDR has been shown to compare well against EPA reference instruments (http://enviromonitoring.wordpress.com/2012/06/08/evaluation-of-the-thermo-scientific-pdr-1500-personal-nephelometer-as-a-highly-time-resolved-pm2-5-surrogate-measurement/)

We tested the AirBeams under a range of different conditions (**Table 2**). After each test, we averaged data into 1-minute samples, computed statistics (**Table 3**), and qualitatively described the sensor performance during four case studies. The next two sections, Summary and Case Studies, provide some statistical results and specific case studies that highlight the performance under different conditions.

Table 2. Summary of collocation tests.

Case Study Name	Date	Particle Source	Location	PM Range ($\mu g/m^3$)
Candle	Aug 24, 2014	Smoke from candle	Indoor; fixed	2 to 106
Vacuuming	Aug 30, 2014	Dust from vacuum	Indoor; fixed	4 to 22
Ambient	Sept 10-13, 2014	Neighborhood sources (trucks, smoking, dust, etc.)	Outdoor; fixed	0 to 32
Wildfire Smoke	Sept 19, 2014	Burning wood	Outdoor; mobile	2 to 255

Table 3. Statistics used in the quantitative analysis.

Precision	Computed using the relative standard deviation when measuring zero or a steady concentration as an indication of the repeatability of the measurements from the AirBeams and the PDR.
Correlation	Indicates the strength of the relationship between two measured variables (In other words, do they increase and decrease together?). Correlations of +1 indicate a perfect relationship. When comparing measurements from two devices, a correlation above 0.7 is good; above 0.8 is very good; greater than 0.9 is excellent.

Summary

We collected close to 300 hours of collocated data and found the following:

- The AirBeams had a precision ranging between 4.0% to 4.8%. The precision of the PDR was 6.0%. It is encouraging that the AirBeam's relative precision is comparable to the more expensive PDR.
- The AirBeam performed well for concentrations less than 300 $\mu g/m^3$ and very well for concentrations less than 100 $\mu g/m^3$ (**Table 4)**. Analysis indicated that the AirBeam tracks the reference PDR with very good correlation.

Table 4. Correlation of AirBeams with the PDR for all data collected as part of this study. A correlation above 0.7 is good; above 0.8 is very good; and above 0.9 is excellent.

AirBeam	Correlation with Reference	
	< 100 µg/m^3	< 300 µg/m^3
AirBeam	0.88	0.69
AirBeam 2_7	0.79	0.72
AirBeam 2_8	0.83	0.66
AirBeam 2_9	0.81	0.81
AirBeam 2_10	0.85	0.85
AirBeam 2_11	0.87	0.87

Case Studies

Test Name: Candle

Approach: Test the response of AirBeams to smoke from a candle. We extinguished a candle (creating smoke) four times over a 4-hour period.

Results: All AirBeams detected the rapid increase of $PM_{2.5}$ as measured by the PDR each time the candle was extinguished (**Figure 2**). In addition, the AirBeams showed the gradual decrease in $PM_{2.5}$ concentrations as the smoke dispersed throughout the room. It is clear that some of the AirBeams had an offset and show consistently higher measurements than the other AirBeams. Notice that the smoke from the candle lingered for hours after the candle was extinguished. The correlation for each of the AirBeams with the PDR was excellent during this period and ranged from 0.89 to 0.93.

Test Name: Vacuuming

Approach: Examine how AirBeams respond to dust lofted by vacuuming.

Results: All AirBeams detected the rapid increase of $PM_{2.5}$ from dust when vacuuming (11:11 PDT to 11:30 PDT) as shown in **Figure 3**. As in the candle experiment, the dust persisted for 45 minutes until about 12:00 PDT. At this time, fresh air from an opened window dispersed the dust and lowered the $PM_{2.5}$ concentrations. All AirBeams performed well by detecting the rise, leveling off, and decrease in $PM_{2.5}$ concentrations. The AirBeams did not detect the peak in $PM_{2.5}$ concentrations from 11:30 to 11:40 PDT that was measured by the PDR. The correlation for each of the AirBeams is excellent with the PDR during this period and ranges from 0.89 to 0.94.

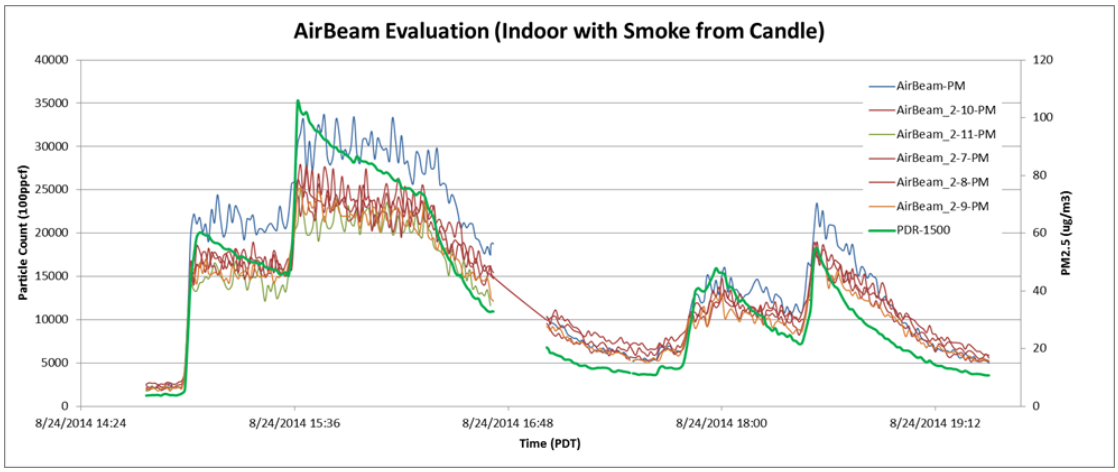

Figure 2. Time series of reference PDR and AirBeams detecting smoke from candle

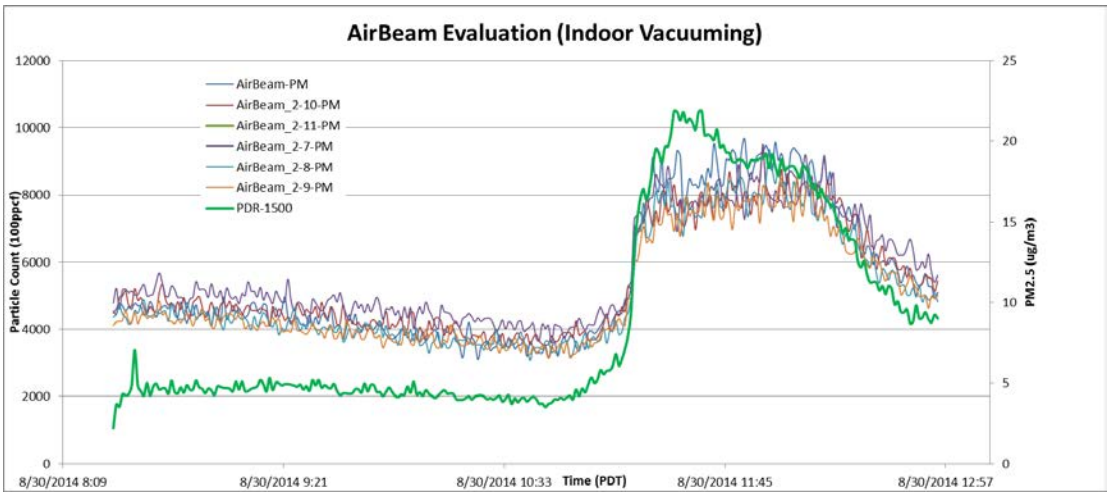

Figure 3. Time series of reference PDR and AirBeams detecting dust from vacuuming.

Test Name: Ambient

Approach: Operate AirBeams outdoors over a 4-day period with changes in temperature, humidity, and $PM_{2.5}$ concentrations.

Results: Both AirBeams detected the day-to-day changes in $PM_{2.5}$. In addition, there were several spikes (likely from cigarette smoke) that both the AirBeams and the PDR detected (see **Figure 4**). However, there were some periods during which the AirBeams did not detect the change in $PM_{2.5}$ measured by the PDR. The correlation of 0.87 and 0.90 for the two AirBeams with the PDR was good to excellent during this period.

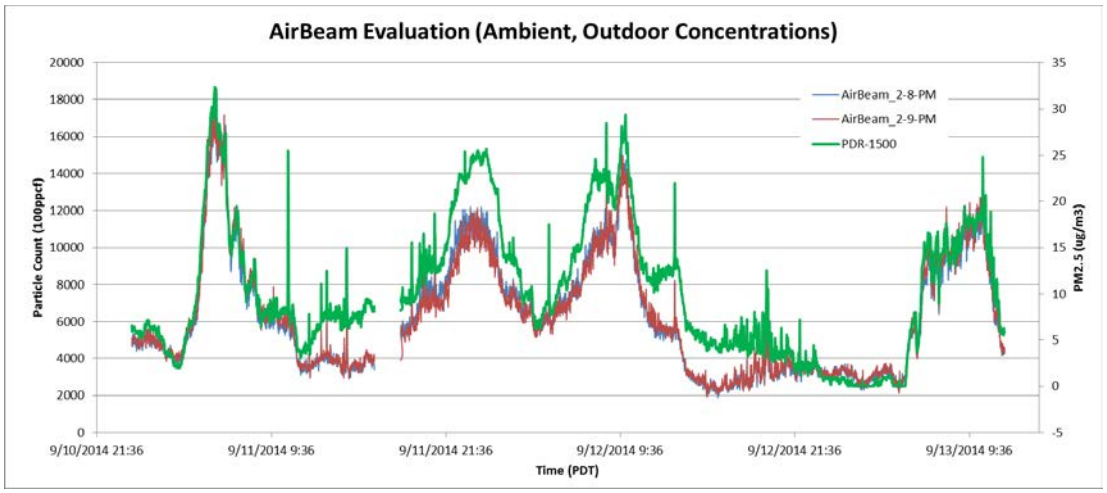

Figure 4. Time series of reference PDR and AirBeams detecting outdoor concentrations of particles.

Test Name: Wildfire Smoke

Approach: Examine how AirBeams detect smoke from wildfires during the King Fire (http://inciweb.nwcg.gov/incident/4108/) in Northern California. During this test, we used the sampling platform in a car (**Figure 5**) and drove into smoke from the wildfires.

Results: During the 2½-hour drive, we detected $PM_{2.5}$ concentrations from 1 µg/m^3 to over 255 µg/m^3 (see **Figure 6**). All three AirBeams detected the large-scale changes in $PM_{2.5}$ concentrations. However, the AirBeams responded differently and non-uniformly when $PM_{2.5}$ levels were above roughly 100 µg/m^3. AirBeam 2-7 had a very high correlation of 0.95 and tracked the PDR quite well. The correlation for the other two AirBeams was 0.80 and 0.84. We are not sure what caused one AirBeam to perform better than the others. However, the challenging environment (mobile monitoring in a car during wildfires) likely produced inconsistent sampling conditions at times across all devices. We also found that the AirBeams were not consistently responding above 300 µg/m^3.

Figure 5. Sampling platform in car for mobile monitor.

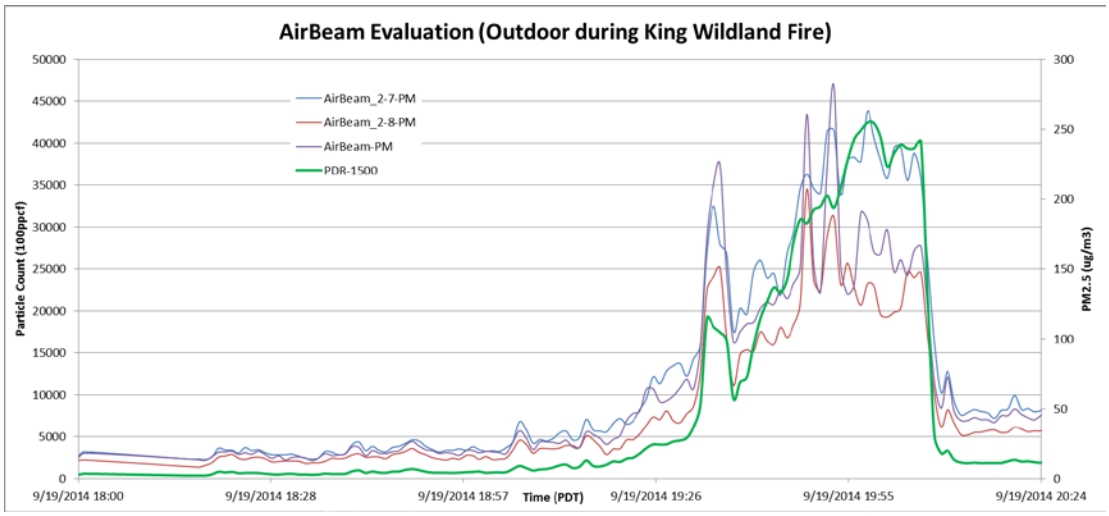

Figure 6. Time series of reference PDR and AirBeams detecting smoke from wildfires.

Conclusion

We found that the AirBeams are useful device for detecting particles from 0 to about 300 µg/m^3 and had very good to excellent correlation with the reference instrument.

Acknowledgments

The authors would like to thank George Allen of NESCAUM for loaning the Thermo pDR-1500 to the study and Michael Heimbinder of HabitatMap for answering questions about the AirBeam.