Low Cost Particulate Matter Sensors in Hamilton, Ontario, Canada

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About Me

- Professor in the Department of Geography, Geomatics and Environment at the University of Toronto Mississauga
- Research Group examines urban air pollution
- Coming to you from Dundas (Hamilton, ON).

Overview

- Air Sensors
- Particulate Matter
  - Air Monitors Overview
- Our Experience with PM Sensors in Hamilton
- Best Practices
- Recommendations

Terms: Air Monitor vs. Air Sensor

Air Monitor – Defined in North America by EPA Standards ($$$)	Air Sensor – Low-cost device ($)

• Must meet specific performance guidelines
  • Federal Reference Methods
  • Federal Equivalent Methods
	• No performance guidelines

Air Pollution Sensors

- Air sensors are low-cost
- Often portable devices
- Should be easily operated
    - i.e. minimal technical training

Air Sensor Use: Education

Excellent for education

Demonstrate increased pollution due to point source, e.g. idling vehicle

Air Sensor Use: Information /Awareness

Using sensors for informal air quality awareness

Air Sensor Use: Personal Monitoring

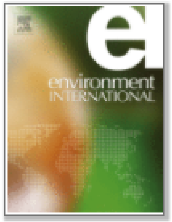
A growing market exists for personal monitoring using air sensors.

Air Sensor Use: Supplementing Monitoring Network

ELSEVIER

Environment International

Volume 99, February 2017, Pages 293-302



Full length article

Can commercial low-cost sensor platforms contribute to air quality monitoring and exposure estimates?

Nuria Castell [a], Franck R. Dauge [a], Philipp Schneider [a], Matthias Vogt [a], Uri Lerner [b], Barak Fishbain [b], David Broday [b], Alena Bartonova [a]

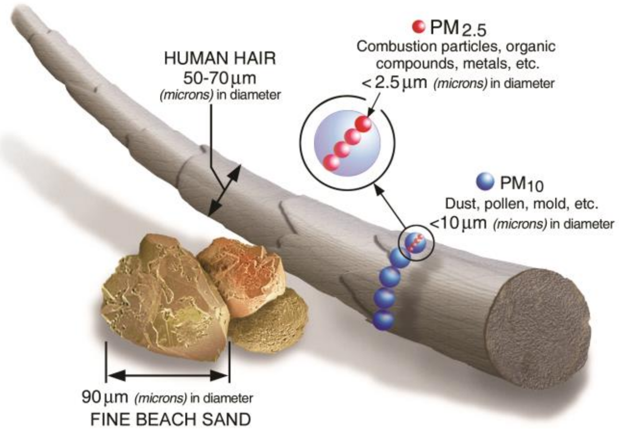
Air Sensor Use: Source Identification and Characterization

Establishing possible emission sources by monitoring near the suspected source.

https://www.coleparmer.ca/

Particulate Matter

- Mixture of solid particles and liquid droplets found in the air
  - Not a single chemical or pollutant
- May be directly emitted into the atmosphere
- Forms by chemical reactions from combinations of other pollutants



https://www.epa.gov/pm-pollution/particulate-matter-pm-basics

$PM_{2.5}$ Federal Reference Method

- 24-hour samples
- Air is drawn at a constant rate into a specially shaped inlet and through a particle size separator
- Particles <2.5 microns are collected on a PTFE (Teflon) filter.

Met One Instruments –
E-FRM-DC Reference Method Particulate Sampler

https://metone.com/products/e-frm-dc-reference-method-particulate-sampler/

Particle Separation

Aerosol Impaction

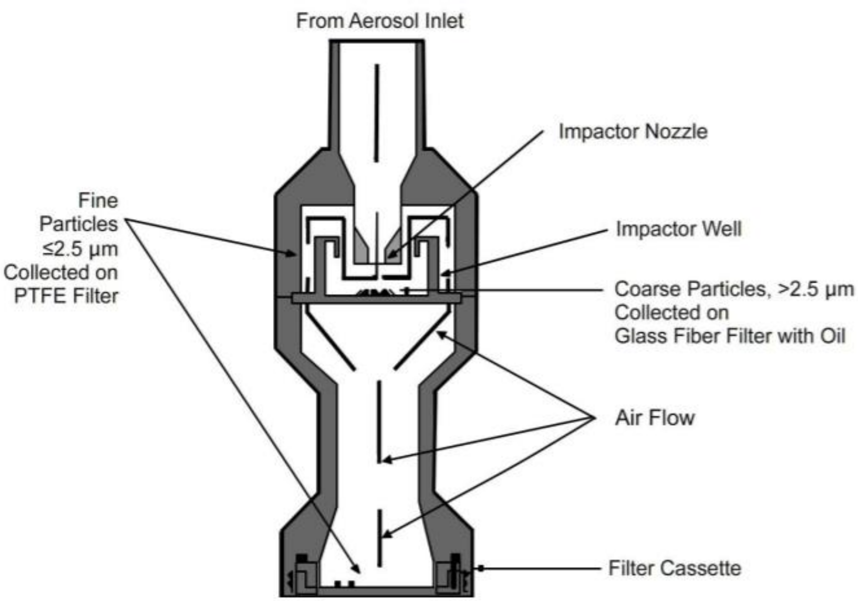
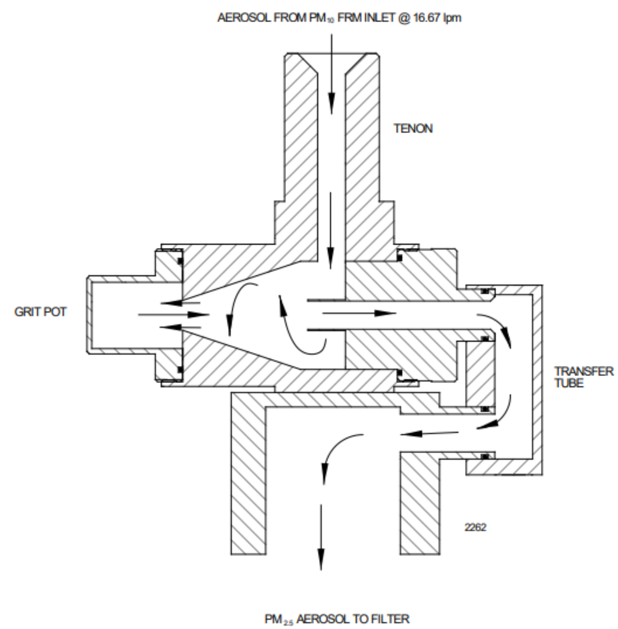


Figure 4-15. WINS particle impactor and filter holder assembly.

VSCC (Very Sharp Cut Cyclone)



https://aqicn.org/air/view/products/specs/Particulate-Matter-Sampling.pdf

Gravimetric Analysis ($PM_{2.5}$ FRM)

- Filters are conditioned to a constant temperature and RH.
- Prior to sampling filters are weighed
- Post sampling filters are reweighed and the difference in mass is used along with the volume of air to determine concentration

$PM_{2.5}$ Federal Equivalent Method
Real-time monitors

- Beta Attenuation Mass Monitor
  - Particles are collected on a filter and particle mass is determined by change in beta radiation absorption
- Tapered element oscillating microbalances (TEOM)
  - Filter is oscillating increased mass changes oscillation rate.
- Light scattering continuous ambient particulate monitor
  - Particles flowing past a light cause scattering. The scattered light pulse is related to particle size.

Measurement Units

- Micrograms per cubic meter of air
  - µg/m^3

- Perspective
  - Dime is 1750 µg
  - Grain of salt is 300 µg
  - Eyelash is 40 µg

PurpleAir Sensor

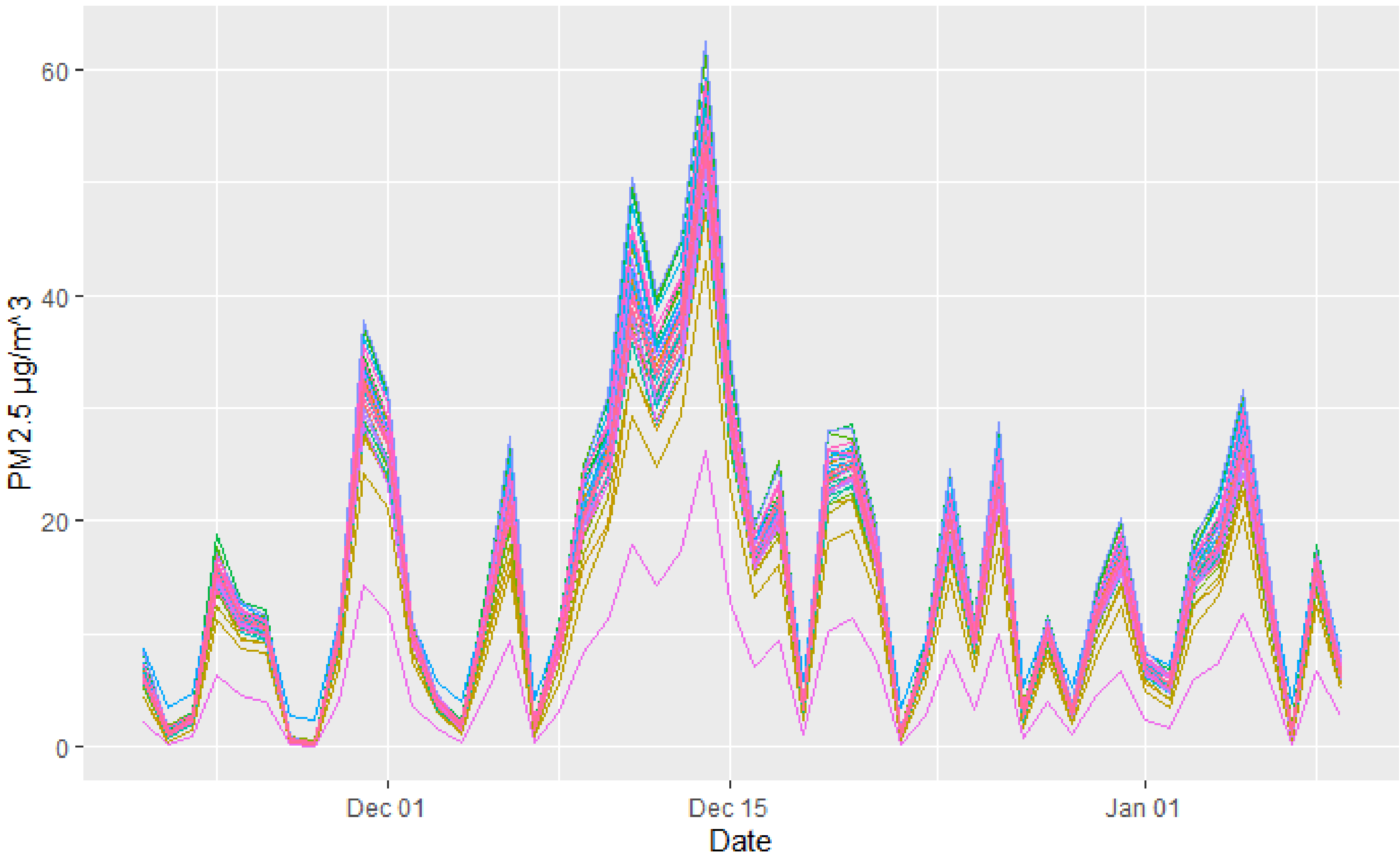
- Laser Particle Counters
    - Two in each unit
- Particles are classified into five size bins
    - Particle mass is estimated
- Provides PM_1, **$PM_{2.5}$** and PM_{10} concentration data
- Connects to Wi-Fi

Performance When New

Collocation of the air sensors and an air monitor for 59 days.

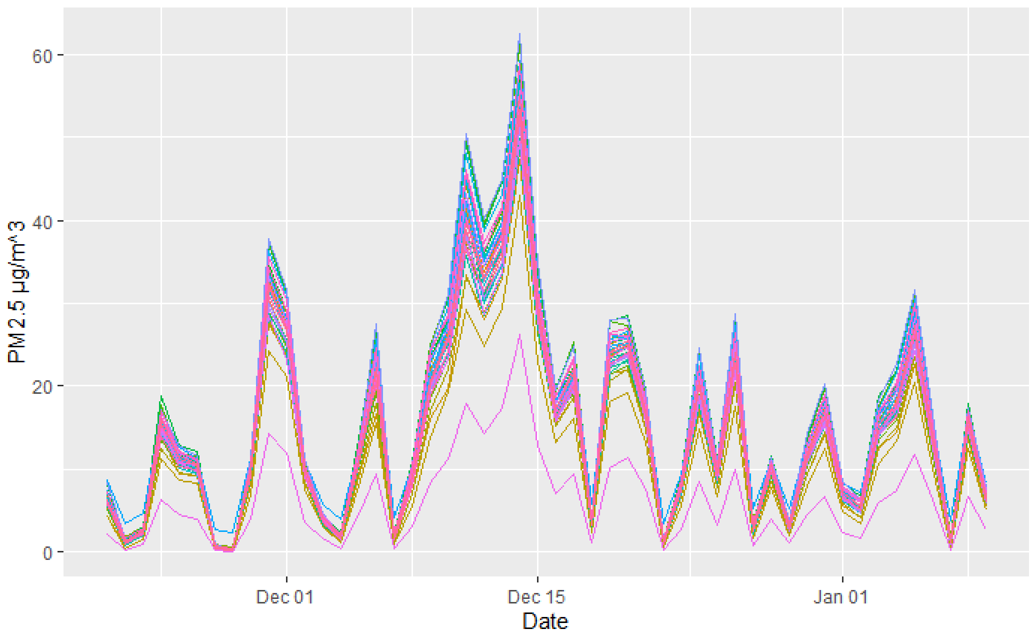
Both used light scattering as the principle of operation.

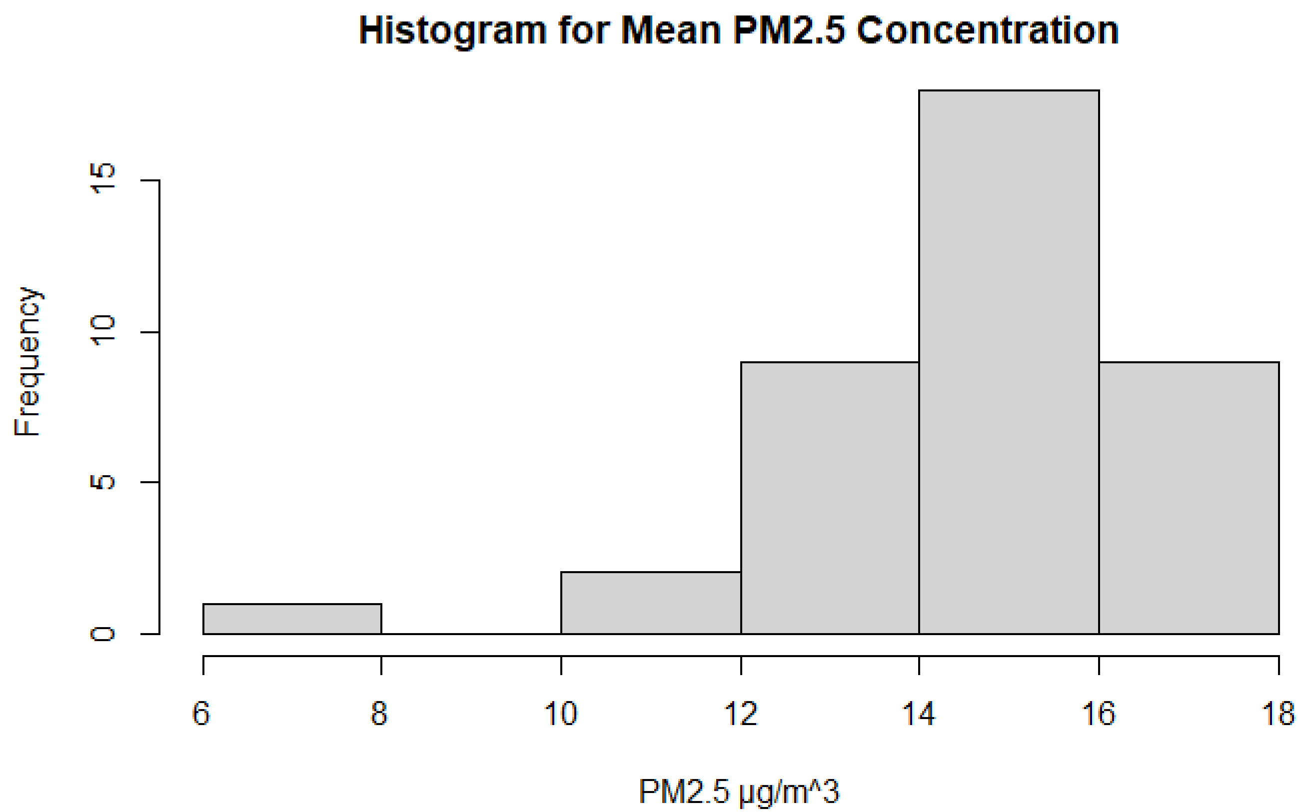
Performance When New

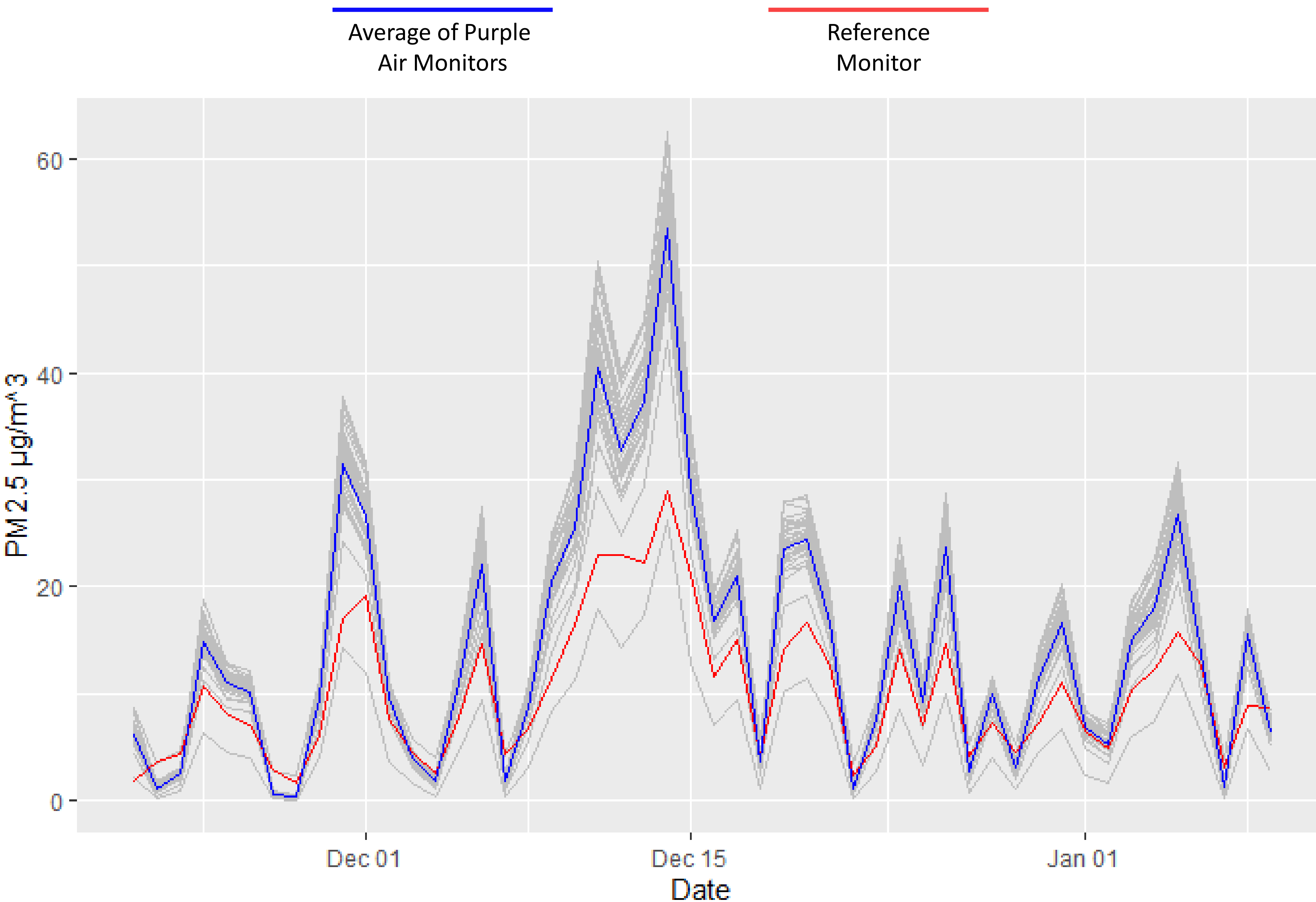


Averaged Sensor Pairs

- Correlation is high
  - Capture the same trends
- Absolute values are very different

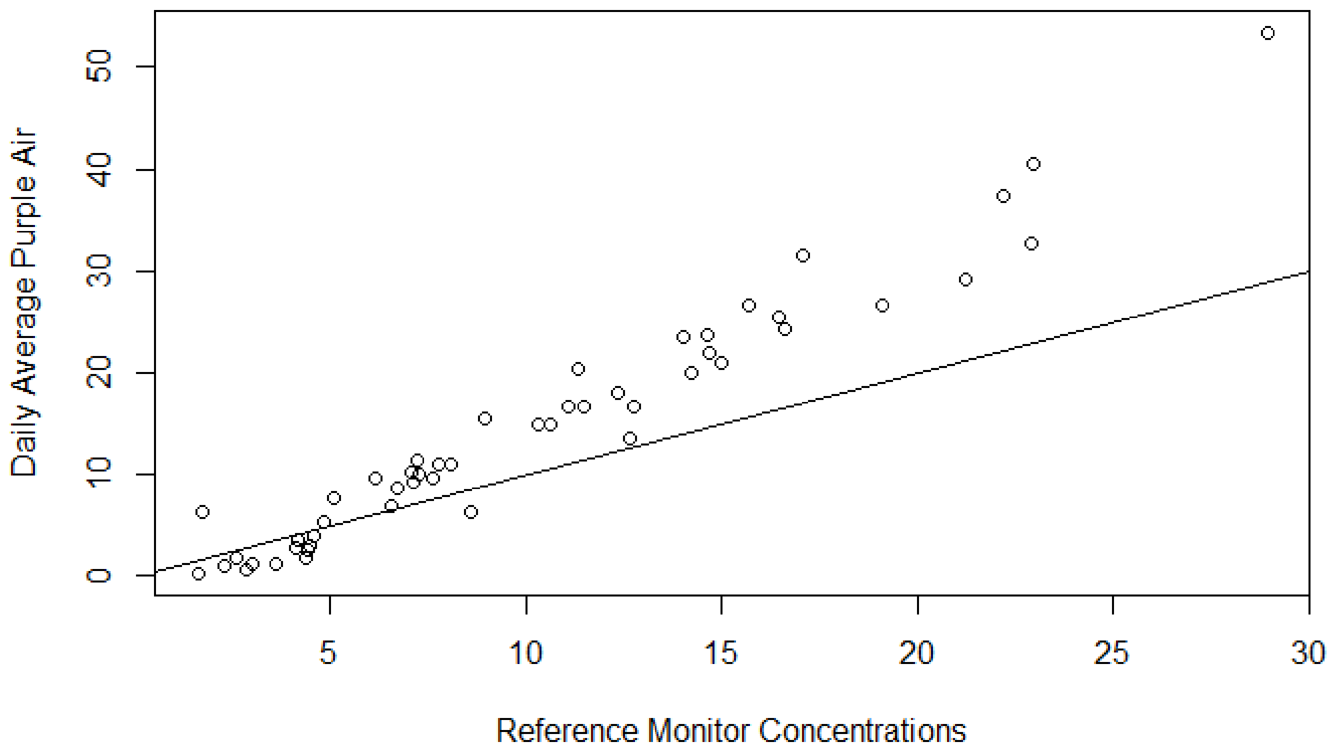



Histogram for Mean PM2.5 Concentration
Frequency
0
5
10
15
6
8
10
12
14
16
18
PM2.5 µg/m^3


Average of Purple Air Monitors
Reference Monitor
PM 2.5 µg/m^3
60
40
20
0
Dec 01
Dec 15
Jan 01
Date

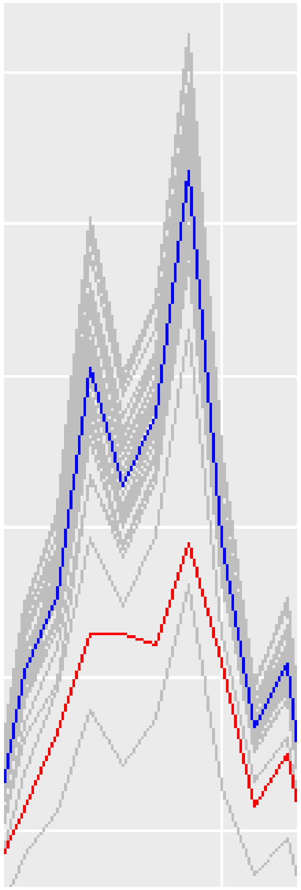
Daily Averages

- Reference Monitor
  - Range: 1.6 - 29 μg/m^3
  - Average (Mean): 10.2 μg/m^3
- Average Error for PA Sensor
  - +4.4 μg/m^3



Two Options

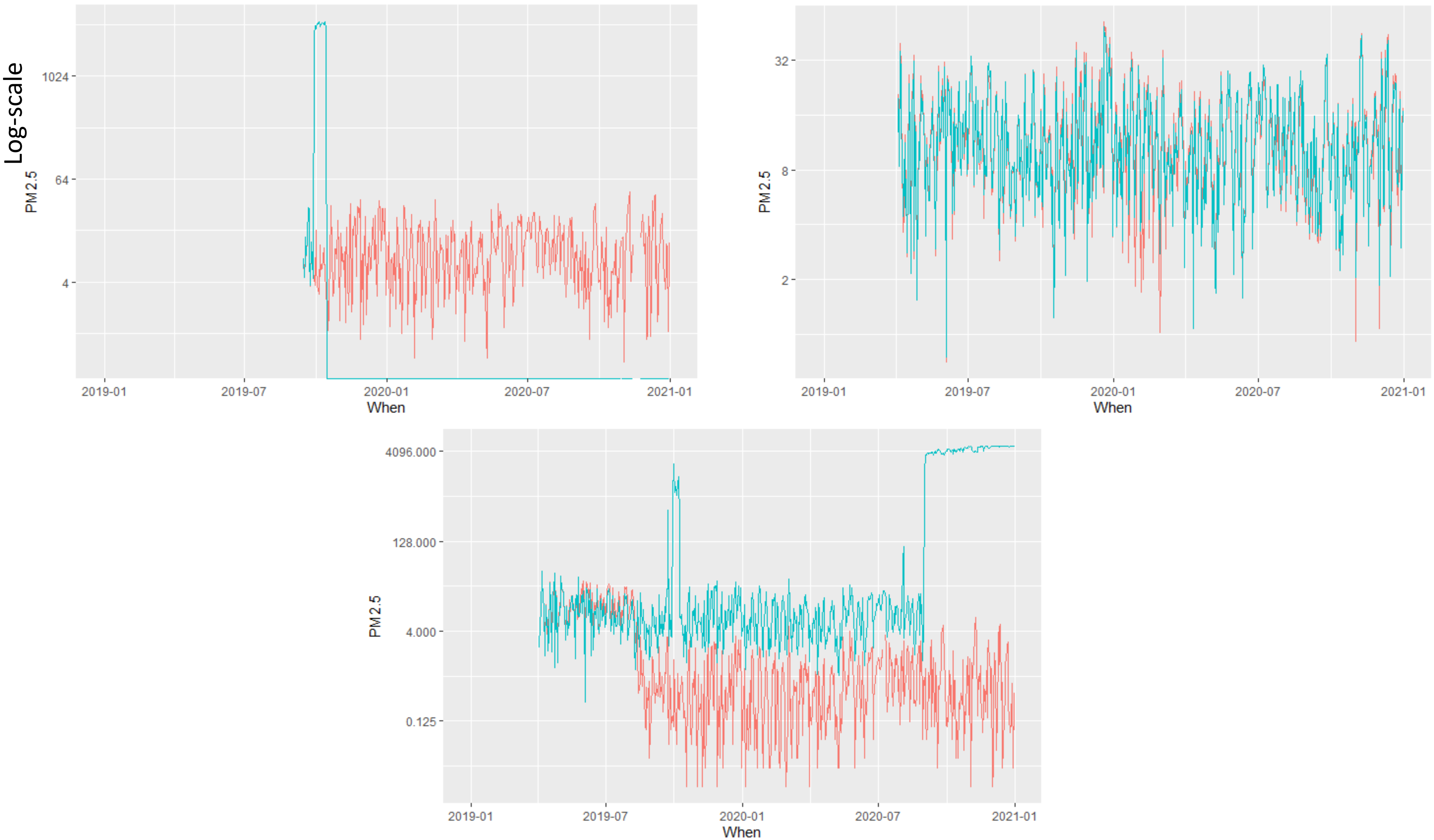
- Overall Average Correction Factor
  - We would expect improvements of ~ 4 μg/m^3
  - Retain the individual monitor variations.
- Individual monitor calibration
  - Starts to get murky when you are building so many unique models to "adjust" the data.



Installation

- Thanks to Environmental Hamilton!
  - We were able to identify volunteers to host air sensors.
- Distributed 35: 26 Set-up
  - Many disappeared
  - Compatibility issues

How long do they last in the field?

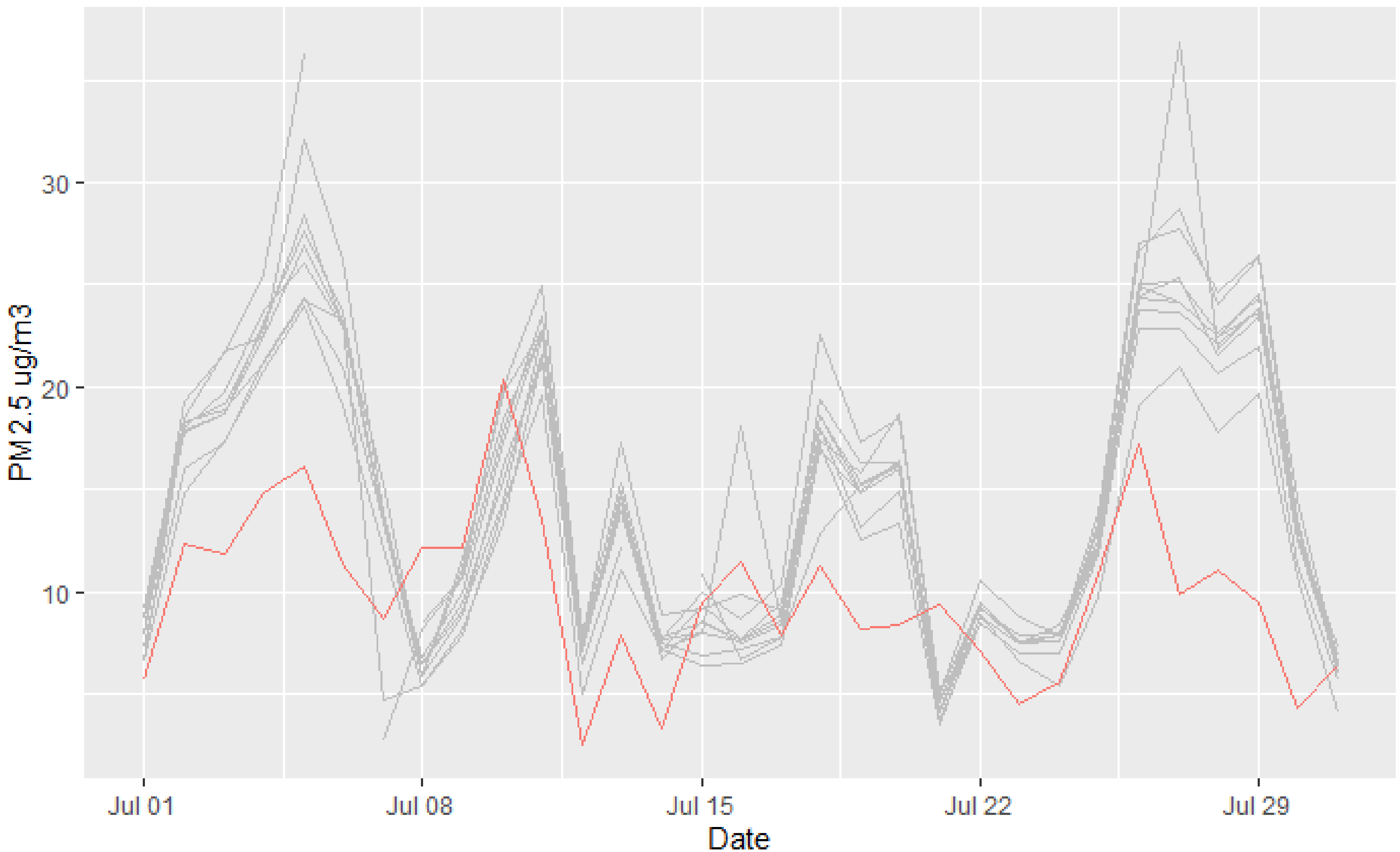


How long do they last in the field?

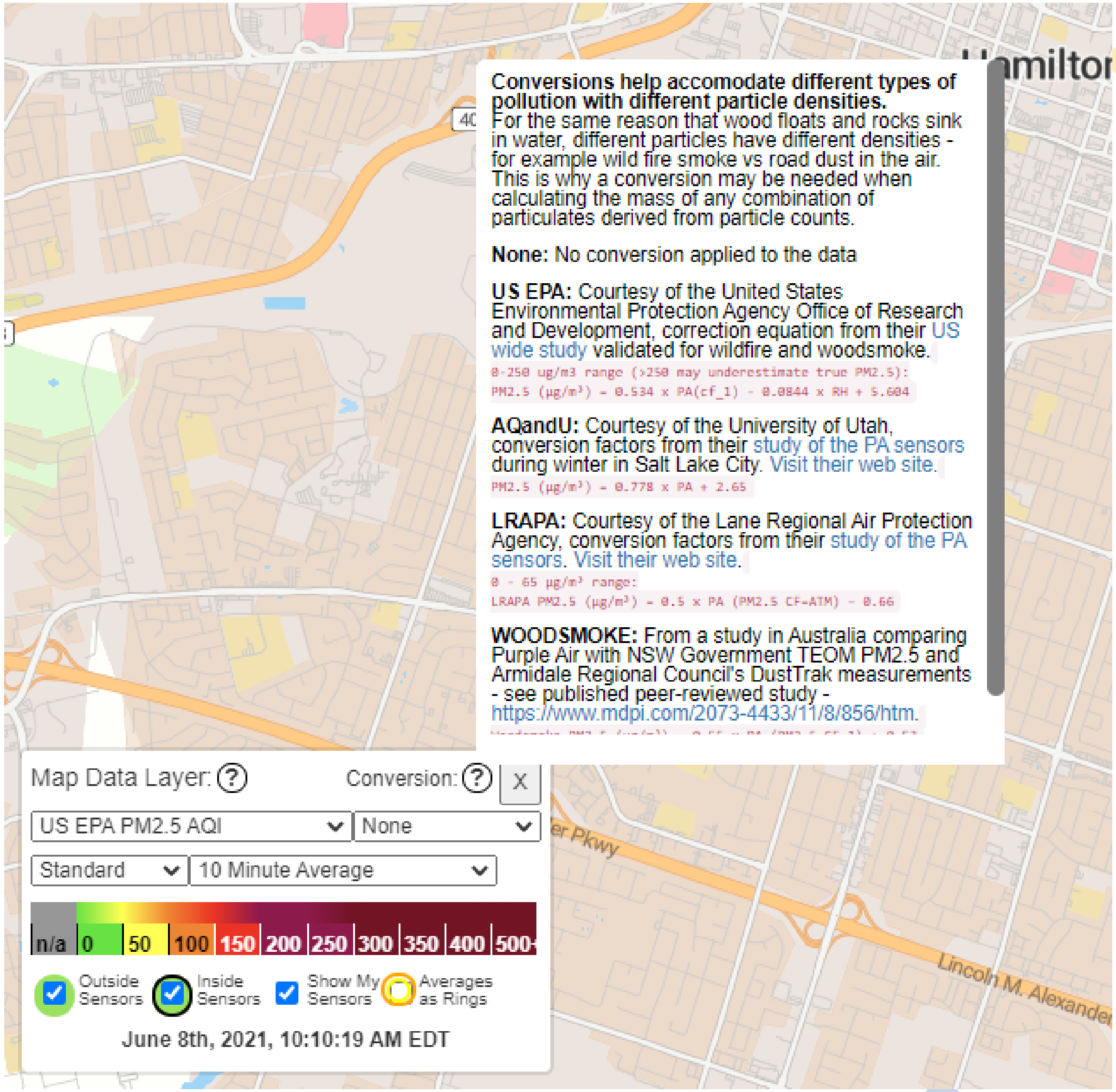
- Not sure how long they should last at this point
- Some as short as a month
- Typically values jump into 1000s $\mu g/m^3$

What can we learn? – July 2019

Uncorrected PurpleAir Daily Averages

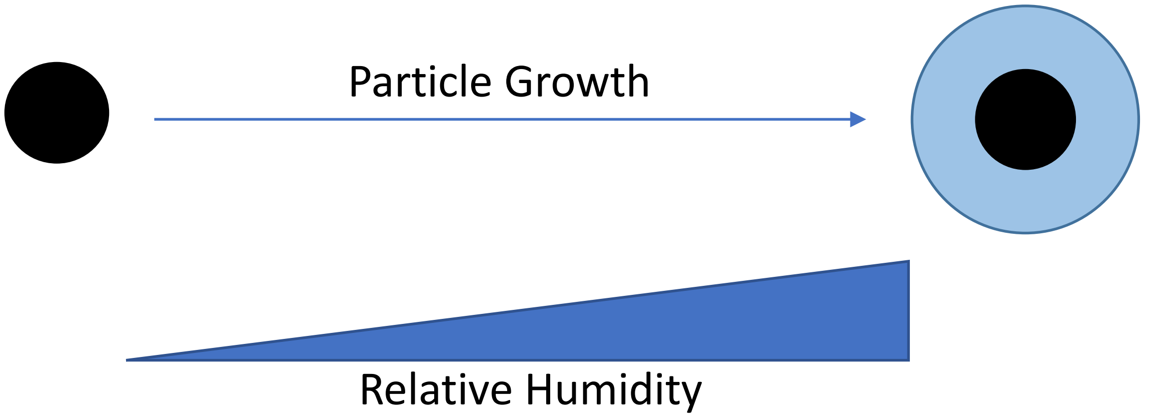


Red is


Conversions help accomodate different types of pollution with different particle densities.
For the same reason that wood floats and rocks sink in water, different particles have different densities - for example wild fire smoke vs road dust in the air. This is why a conversion may be needed when calculating the mass of any combination of particulates derived from particle counts.
None: No conversion applied to the data
US EPA: Courtesy of the United States Environmental Protection Agency Office of Research and Development, correction equation from their US wide study validated for wildfire and woodsmoke.
0-250 ug/m3 range (>250 may underestimate true PM2.5):
PM2.5 (µg/m³) = 0.534 x PA(cf_1) - 0.0844 x RH + 5.604
AQandU: Courtesy of the University of Utah, conversion factors from their study of the PA sensors during winter in Salt Lake City. Visit their web site.
PM2.5 (µg/m³) = 0.778 x PA + 2.65
LRAPA: Courtesy of the Lane Regional Air Protection Agency, conversion factors from their study of the PA sensors. Visit their web site.
0 - 65 µg/m³ range:
LRAPA PM2.5 (µg/m³) = 0.5 x PA (PM2.5 CF=ATM) - 0.66
WOODSMOKE: From a study in Australia comparing Purple Air with NSW Government TEOM PM2.5 and Armidale Regional Council's DustTrak measurements - see published peer-reviewed study - https://www.mdpi.com/2073-4433/11/8/856/htm.
Map Data Layer:
Conversion:
X
US EPA PM2.5 AQI
None
Standard
10 Minute Average
n/a 0 50 100 150 200 250 300 350 400 500+
Outside Sensors
Inside Sensors
Show My Sensors
Averages as Rings
June 8th, 2021, 10:10:19 AM EDT
Lincoln M. Alexander

Why do we need to adjust PA data?

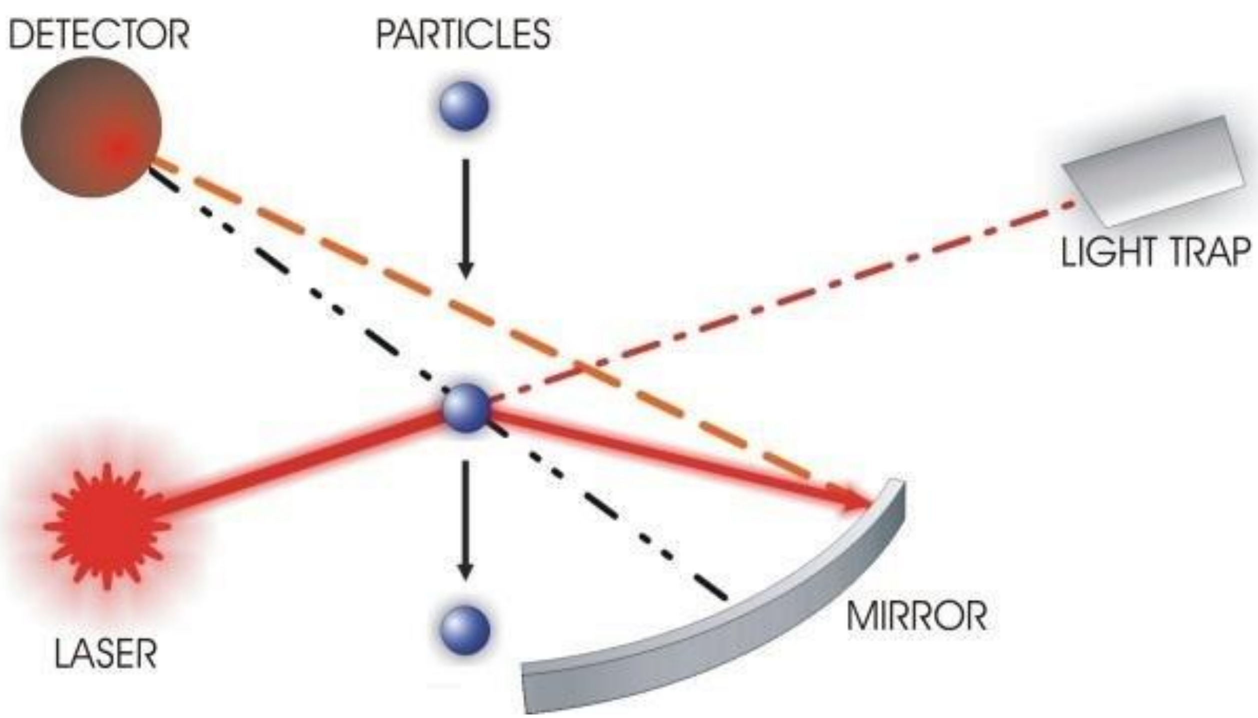
- Hygroscopic Growth



Air pollution monitors heat the incoming sample to address this issue. PA sensors do not.

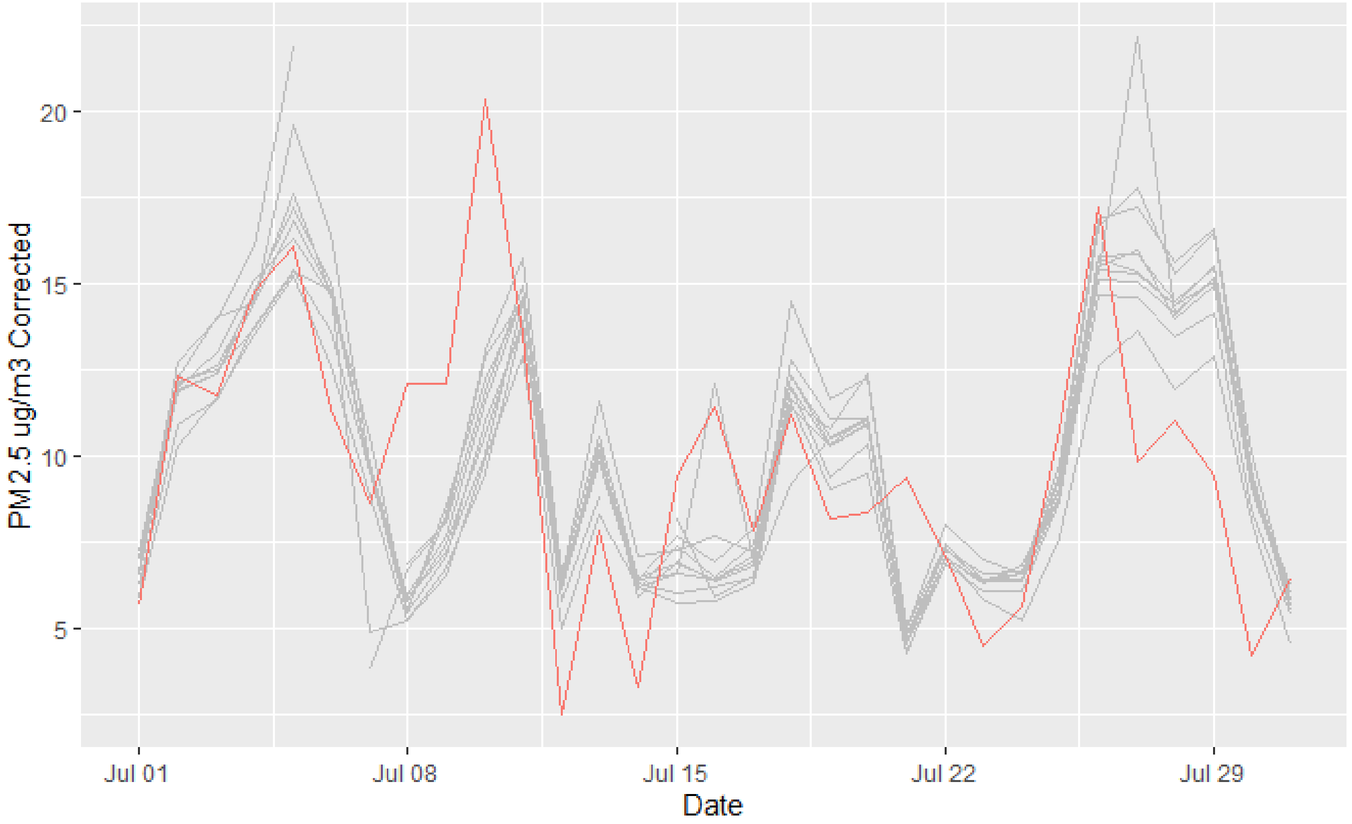
Local Pollutant Conditions

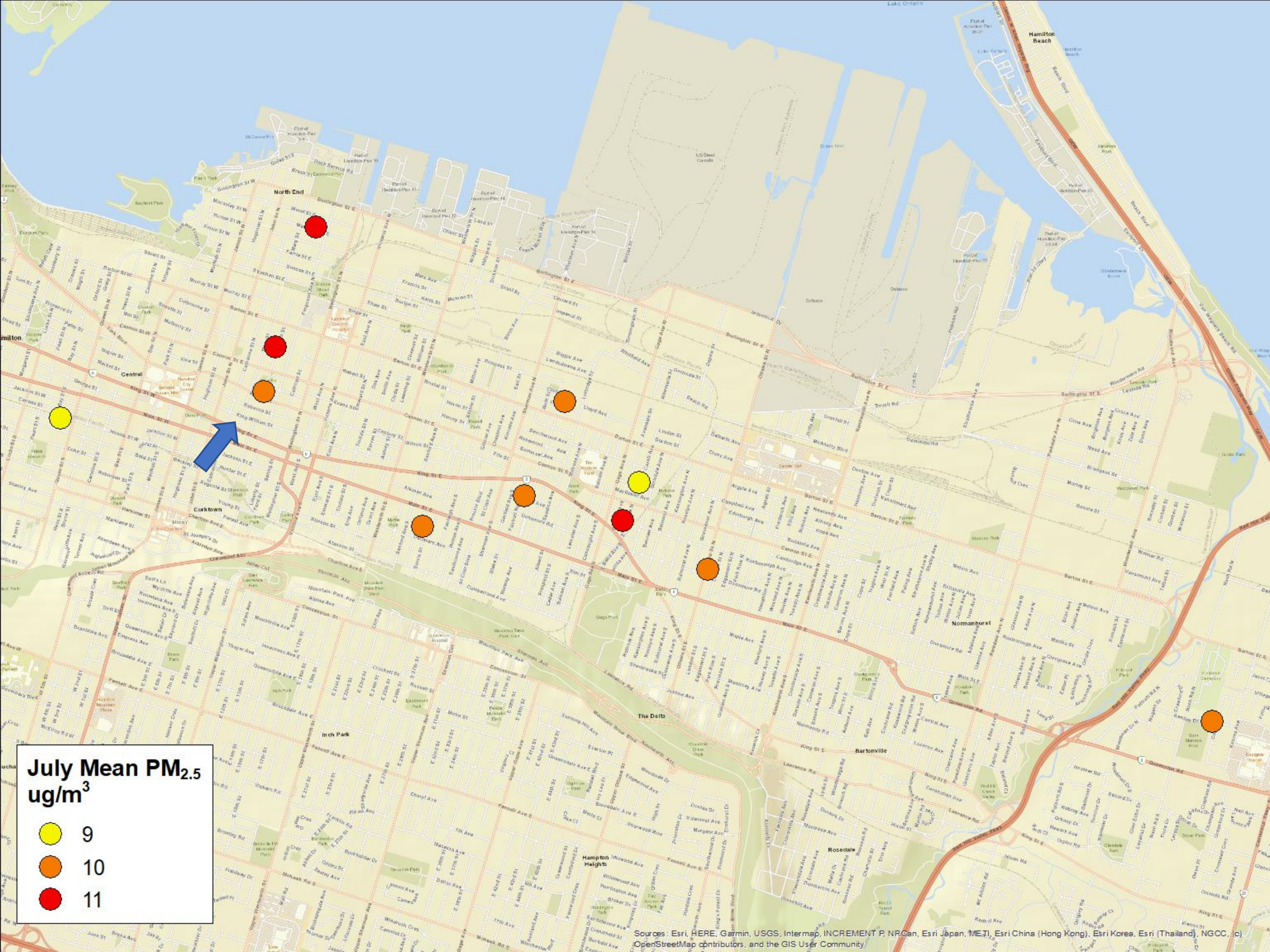
- Particulate Matter is a mix of materials
- PA Sensors rely on light scattering as particles pass through a laser beam to infer mass from size
- Materials can vary in density (mass by volume)



DOI: 10.1117/12.869629

Corrected PurpleAir Daily Averages




July Mean PM2.5 ug/m3
9
10
11
Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community

Conclusions

- PA Sensors on their own will overestimate concentrations ~50-60%
- Corrected data provide little in terms of "new" information about spatial patterns of air pollution at a daily or monthly scale

Conclusions

- Individual Monitors may systematically over or under predict concentrations
  - An individual would not know without collocation
    - Most likely over predict
- Short-term spikes in PA sensors may or may not be an artifact
  - Natural variations within an hour

Best Practices for Air Sensors

- Collocation of sensors with an Air Pollution Monitor
  - Establish local correction factor or validate existing correction factor
- Prefer sensors that measure 2x
- Repeat Collocation often
- Locate sensors at Air Pollution Monitor for length of study
- Life-span expectation: 1 year.

Tools

- AQ-Spec: Air Quality Sensor Performance Evaluation Centre
  - Outdoor Evaluations
  - http://www.aqmd.gov/aq-spec

PM Sensors

Sensor Image	Make (Model)	Est. Cost (USD)	Pollutant(s)	*Field R^2	*Lab R^2	*Field MAE ($\mu g/m^3$)	*Lab MAE ($\mu g/m^3$)	Summary Report
	**Aeroqual** (AQY v0.5) Discontinued	$3,000	$PM_{2.5}$	0.84 to 0.87	0.99		28.8 to 36.0	PDF (1,178 KB)
	**Aeroqual** (AQY v1.0)	$4,000	$PM_{2.5}$	0.76 to 0.81	0.99	4.2 to 5.3	5.4 to 15.1	PDF (674 KB)
			PM_{10}	0.56 to 0.68		35.4 to 38.8		
	**Aeroqual** (S500-PM)	$1,490	$PM_{2.5}$	0.46 to 0.67	0.99	4.4 to 6.2	11.9 to 32.4	PDF (702 KB)
			PM_{10}	0.15 to 0.24		13.5 to 18.0		
	**AethLabs** (microAeth)	$6,500	BC (Black Carbon)	0.79 to 0.94				