Results and Lessons Learned from Using Low-Cost PM Sensors to Detect Ambient $PM_{2.5}$ and PM_{10}

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for

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Outline

- Background on air sensors
- Studies
  - PM_{10} coal dust
  - $PM_{2.5}$ winter PM conditions
  - PM_{10} windblown dust
  - $PM_{2.5}$ wood smoke
- Lessons learned

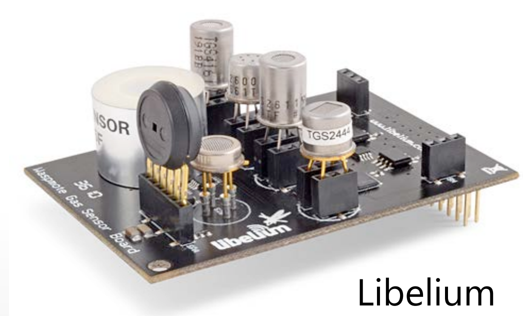
Startups (2014)

AirBase

Sensaris

Cairpol

Airboxlab

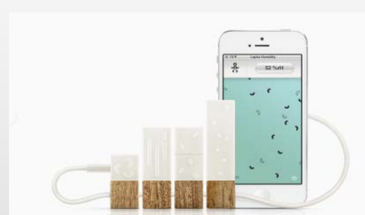


Libelium

Esensors

CubeSensor

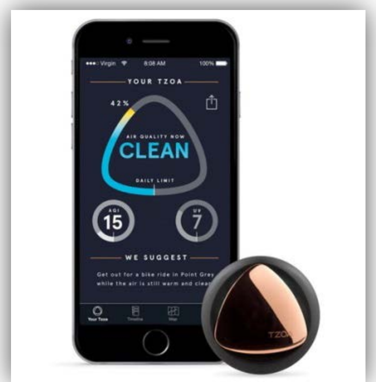
Canary



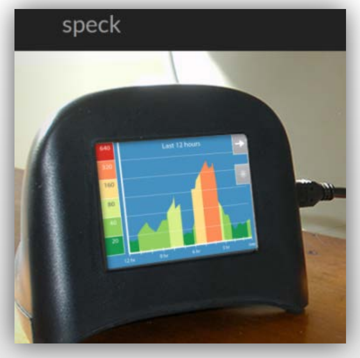
Lapka

Sensordrone

Startups (now)





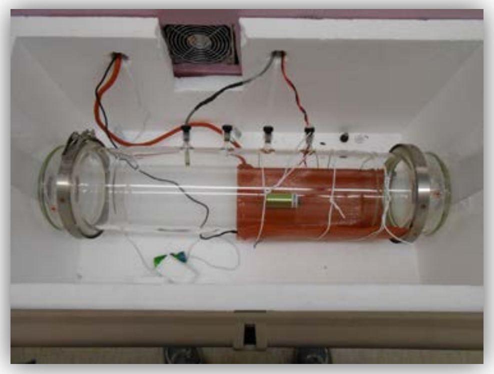


Key Issues

- New technology
- Data logging
- Communications
- Data management
- Cost
- Scale

Evaluation Efforts

- EPA evaluating sensor technology
  - Laboratory and infield evaluations
  - Ozone, NO_2, PM, and VOCs
- Joint Research Center (EU)
  - Evaluation for last 4 years

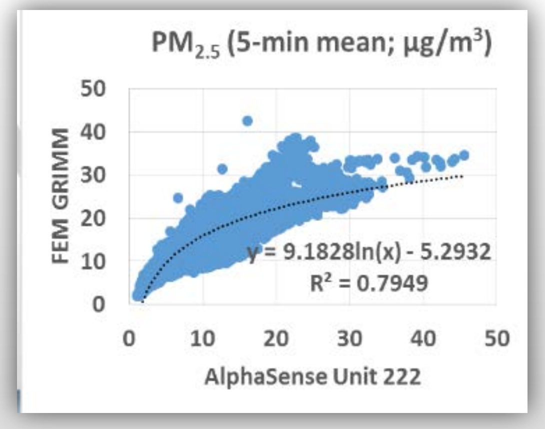


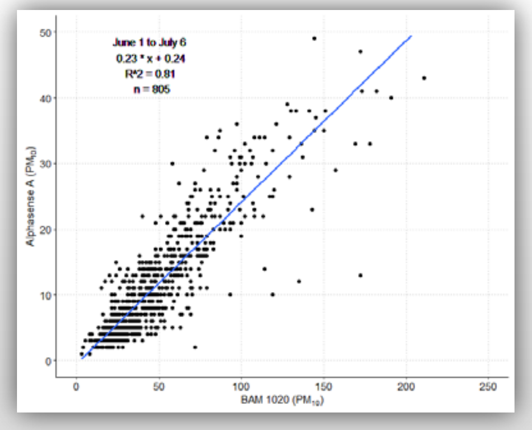
- SCAQMD
  - Air Quality Sensor Performance Evaluation Center (AQ-SPEC)
  - Field and laboratory evaluations
  - Ozone, PM, NO_x, CO, VOCs, H_2S

Results

- Evaluations
  - Compare to FEM reference
- Results
  - VOCs: Needs more work
  - Gases: Some promise for ozone, CO, NO
  - PM: Good results from some sensors

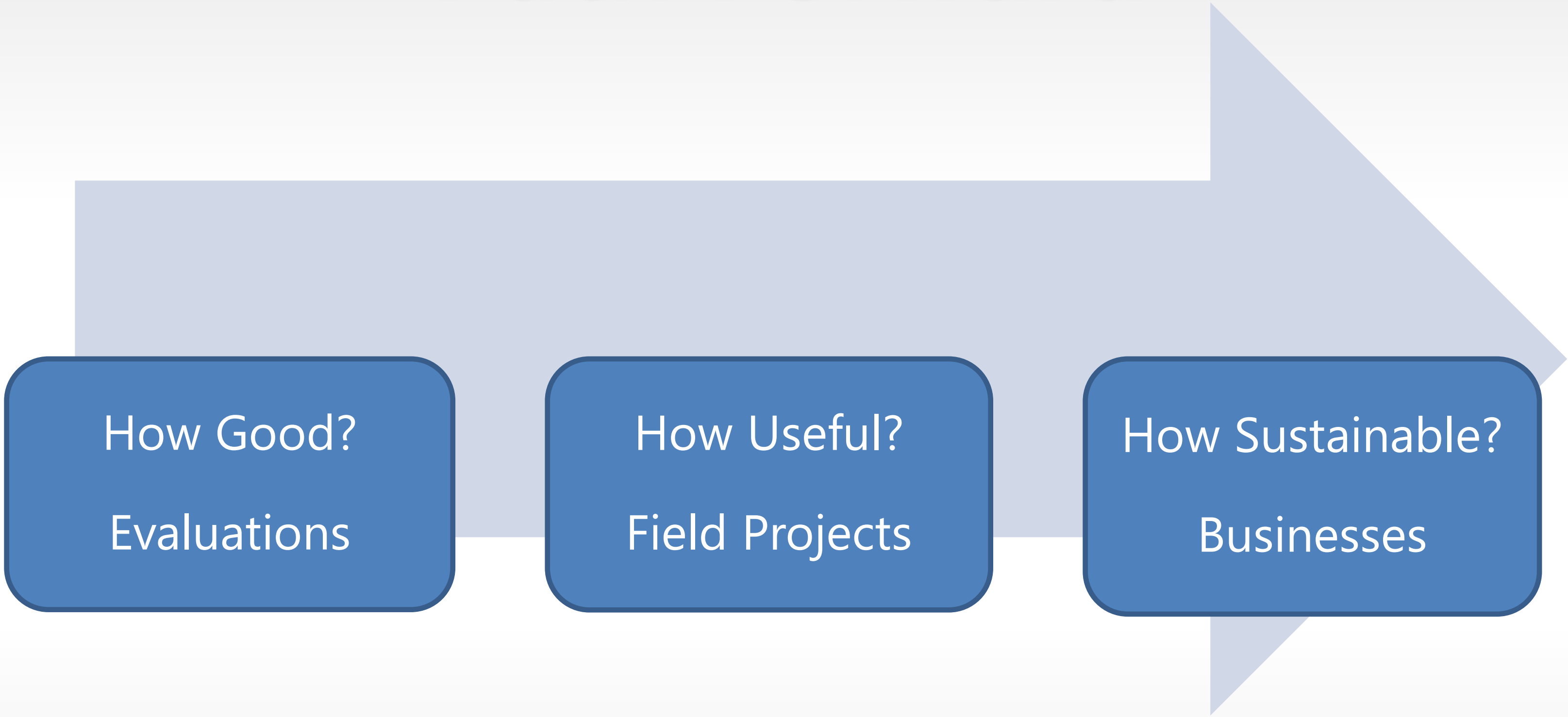
$PM_{2.5}$
5-min average
r^2=0.78





PM_{10}
1-hr average
r^2=0.81

Path Forward



✓ | In progress | ?

1. Study – Coal Dust (PM_{10})

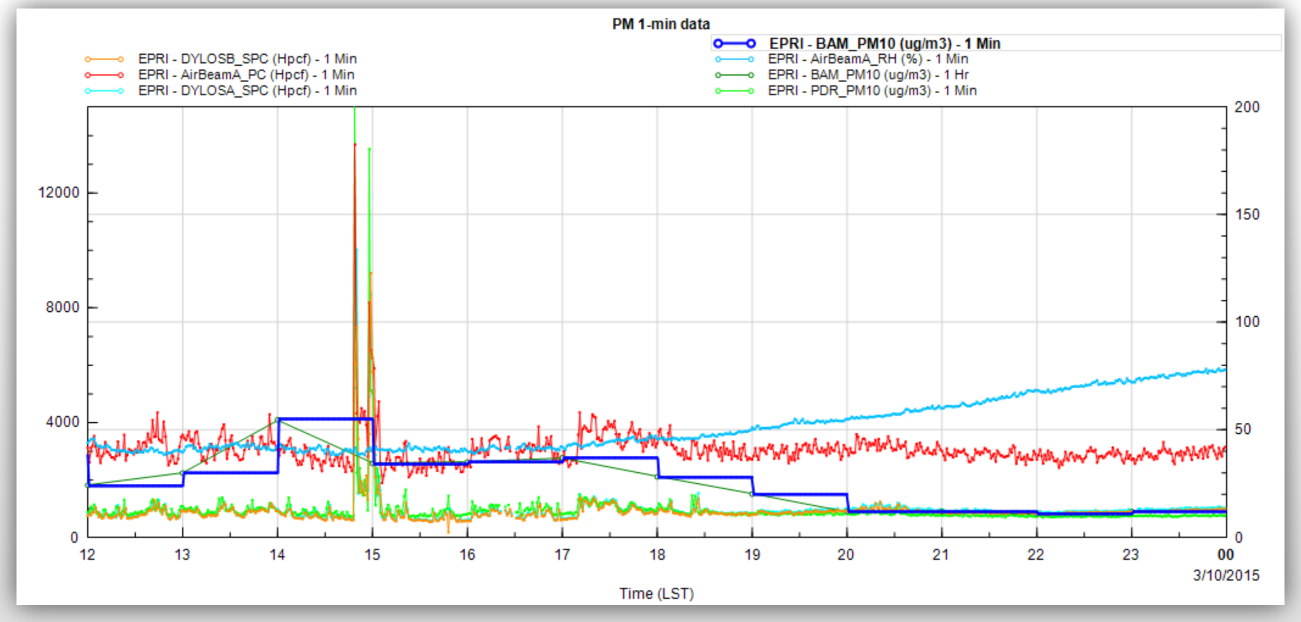
- Objectives
  - Determine whether sensors can detect and quantify fugitive PM_{10} from coal piles
  - Identify sensor limitations and technical challenges
- Study
  - 2-month study in warm climate
  - Weather station

Equipment	
Reference Instrument	MetOne BAM-1020 PM_{10} Thermo PDR-1500
Sensors	Dylos AirBeam

Sponsor: Electric Power Research Institute (EPRI)

1. Results – Coal Dust (PM_{10})

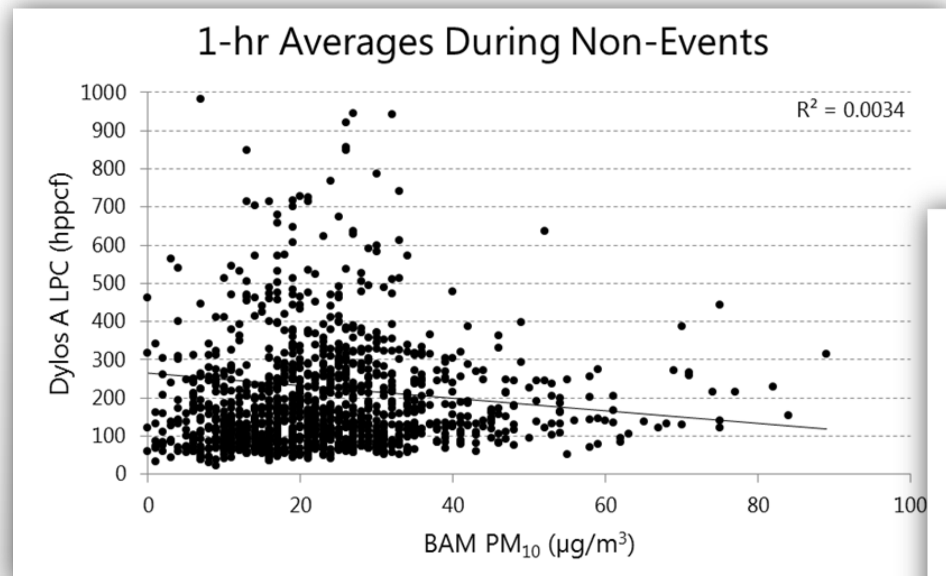
- 17 events were identified
  - Short in duration (a few minutes)
  - Concentrations were 2–5 times higher than background
- 37 of 1,392 hours (2.7%) were impacted by windblown dust events

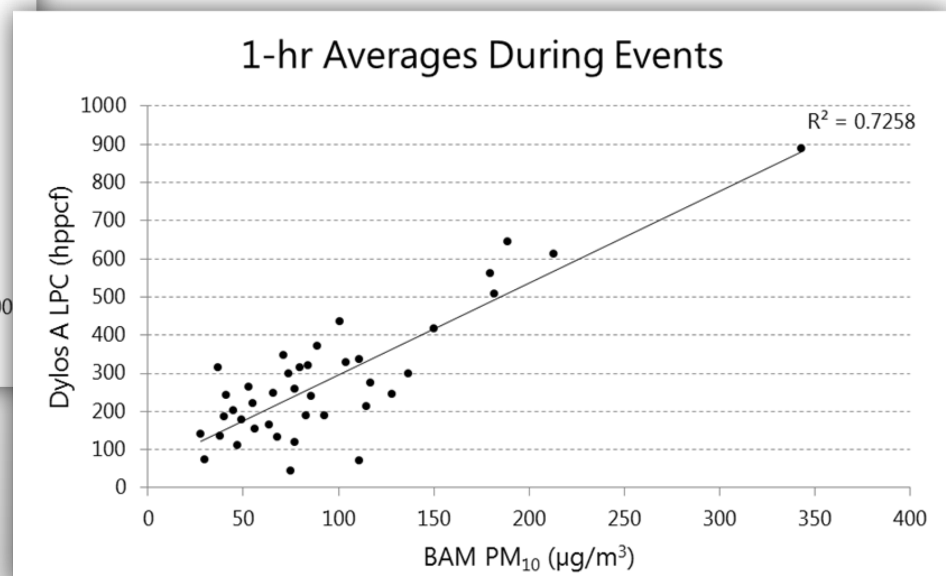


Sponsor: Electric Power Research Institute (EPRI)

1. Results – Coal Dust (PM_{10})

Dylos had good correlation with the BAM for events; weak correlation for all data





2. Study – Winter ($PM_{2.5}$)

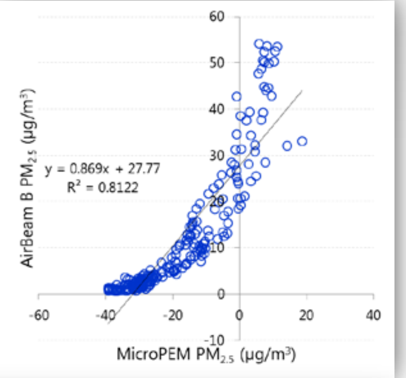
- Objectives
  - Examine the use of low-cost PM sensors for answering questions about Tribal air quality
  - Conduct intercomparison study and mobile sampling
- Study
  - 8-month study in northern Minnesota (Oct-June)
  - Outdoor exposure

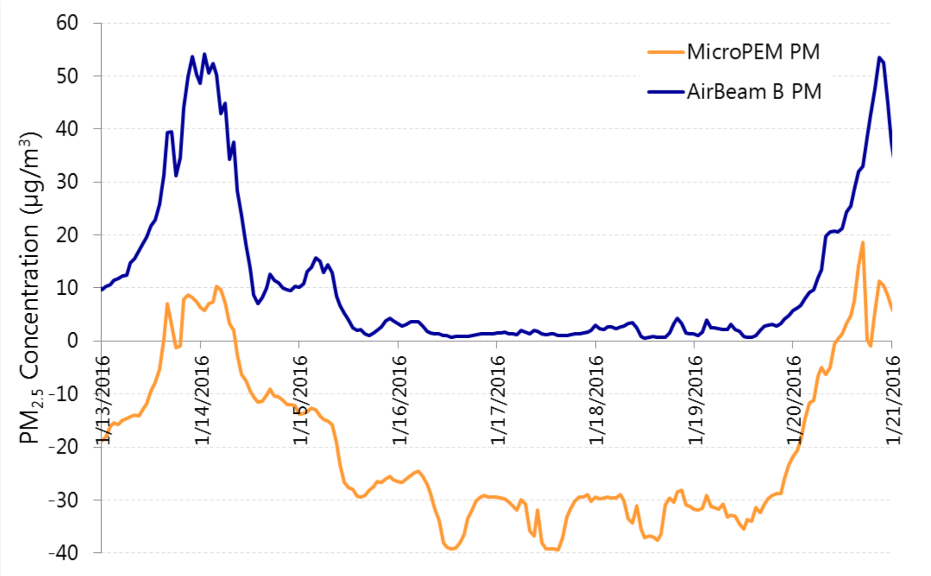
Equipment	
Reference Instrument	FRM – $PM_{2.5}$ (1-in-6 day)
Sensors	AirBeam MicroPEM

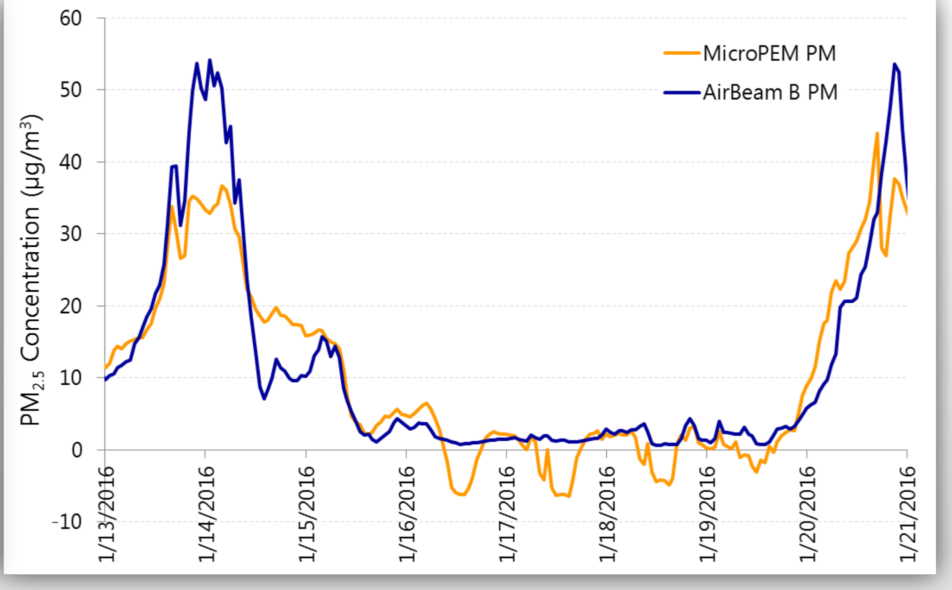
Sponsor: U.S. EPA and Leech Lake Band of Ojibwe

2. Results – Winter ($PM_{2.5}$)

- The MicroPEM and AirBeam B are well correlated during most time periods between calibration/zeroing
- The MicroPEM was difficult to zero properly and exhibited significant baseline shifts between calibration/zeroing







Sponsor: U.S. EPA and Leech Lake Band of Ojibwe

2. Results – Winter ($PM_{2.5}$)

Good correlations (R^2) between 24-hr sensor measurements on FRM sample days for AirBeam and bias-corrected MicroPEM

	FRM 1	FRM 2	MicroPEM	AirBeam A	AirBeam B
FRM 1	1.00	-	-	-	-
FRM 2	0.93	1.00	-	-	-
MicroPEM	0.01^{uc} 0.96^{bc}	0.01^{uc} 0.89^{bc}	1.00	-	-
AirBeam A	NA	NA	NA	NA	-
AirBeam B	0.83	0.85	0.01^{uc} 0.95^{bc}	NA	1.00

^{uc} Uncorrected MicroPEM $PM_{2.5}$ data
^{bc} Bias-corrected MicroPEM $PM_{2.5}$ is well correlated with the FRMs

Sponsor: U.S. EPA and Leech Lake Band of Ojibwe

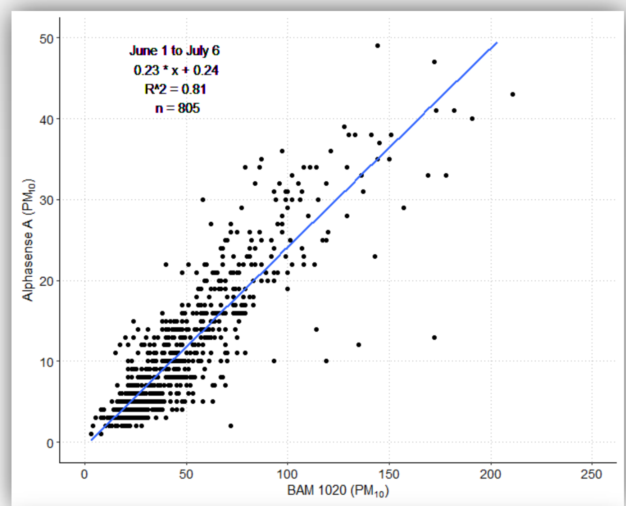
3. Study – Windblown Dust (PM_{10})

- Objectives
  - Can low-cost PM sensors detect dust events?
  - How precise are the sensors?
  - Are they reliable?
  - Can they provide sufficient warning time?
- Study
  - 3-month springtime study
  - School in eastern Santa Barbara County

Equipment	
Reference Instrument	MetOne BAM 1020 (FEM for PM_{10}) GRIMM 11-R (Particle counts) MetOne E-BAM (PM_{10})
Sensors	AirBeam (3 units) Alphasense OPC-N2 (3 units)

Sponsor: Santa Barbara County Air Pollution Control District

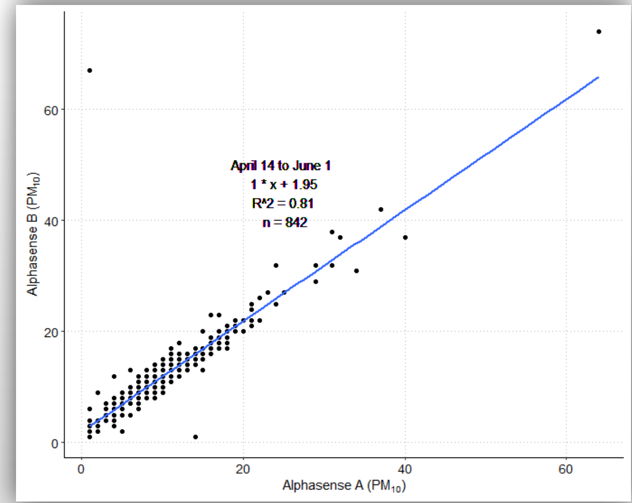
3. Results – Windblown Dust (PM_{10})



Alphasense A vs. BAM

Hourly PM_{10} measurements

$R^2 = 0.81$



Alphasense A vs. Alphasense B

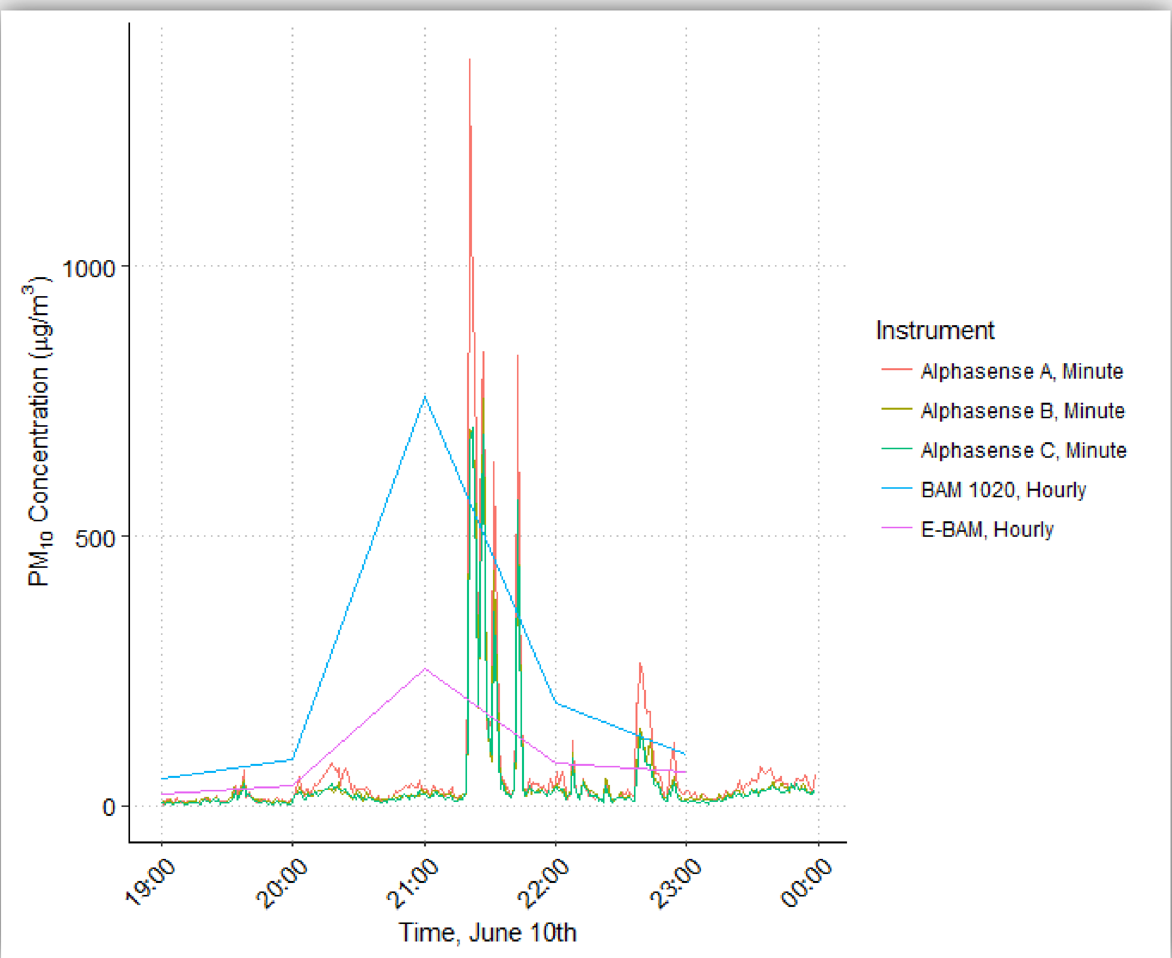
Hourly PM_{10} measurements

$R^2 = 0.81$

BAM = 1*x + 1.95

Sponsor: Santa Barbara County Air Pollution Control District

3. Results – Windblown Dust (PM_{10})



Early Detection

Alphasense A measures a peak at 21:21, for a lead time of 39 minutes over the FEM instrument.

Note: BAM reported at begin hour but not available until after the hour

Sponsor: Santa Barbara County Air Pollution Control District

4. Study – Woodsmoke ($PM_{2.5}$)

- Objectives
  - Use low-cost sensors to provide spatial coverage and engage community
  - Assess the contribution of wood burning to air toxics in Sacramento
- Study
  - Sacramento Metropolitan AQMD project funded by EPA Grant
  - Two existing regulatory monitoring stations, 4 new temporary monitoring sites with FEMs, 9 new sites with low-cost monitors
  - Two-month wintertime study
  - Are certain communities in Sacramento County disproportionately impacted by wood smoke?

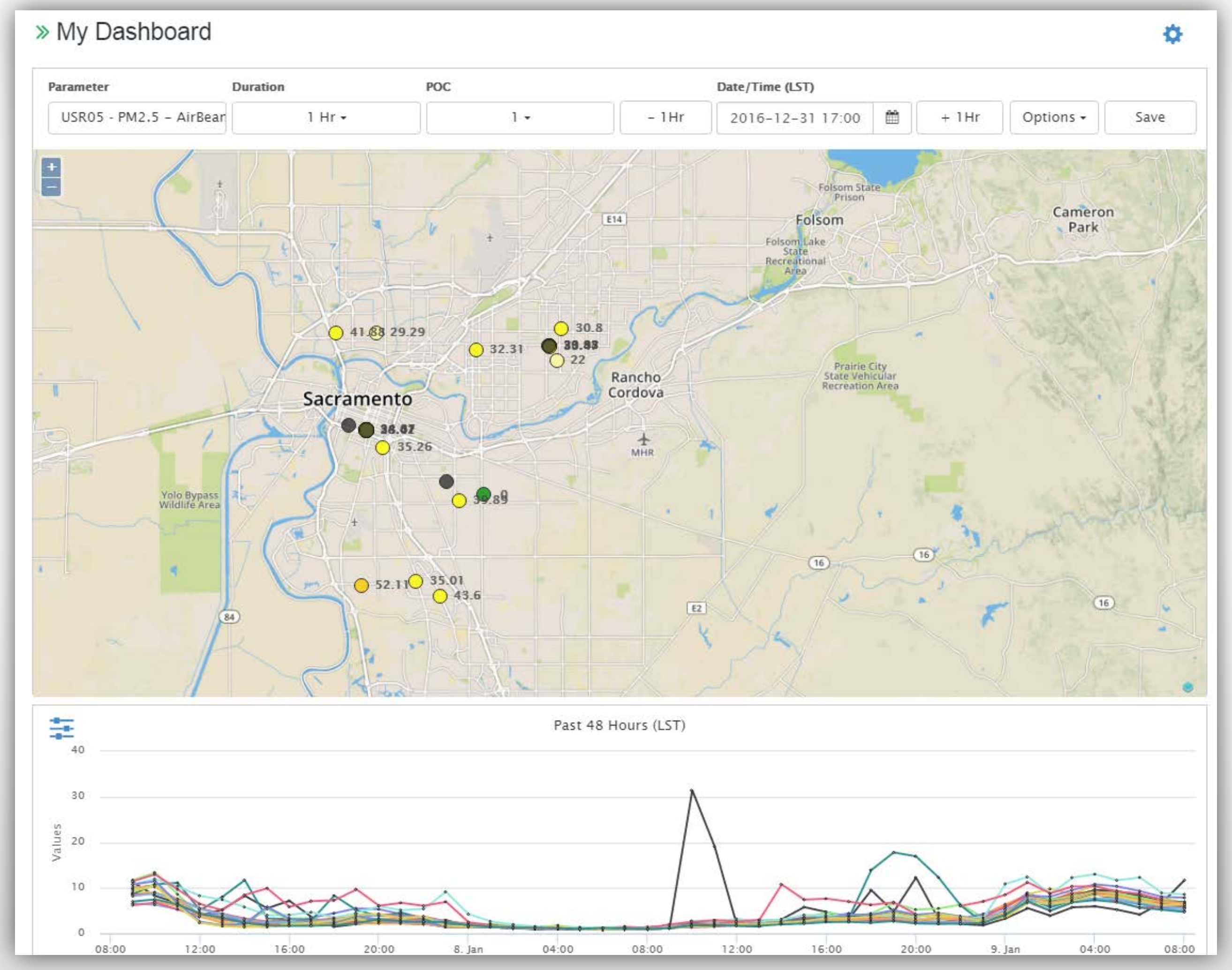
Equipment	
Reference Instrument	MetOne BAM 1020 (FEM for $PM_{2.5}$) Aethalometer (BC)
Sensors	AirBeams

Sponsor: SMAQMD

4. Study – Woodsmoke ($PM_{2.5}$)

Sponsor: SMAQMD

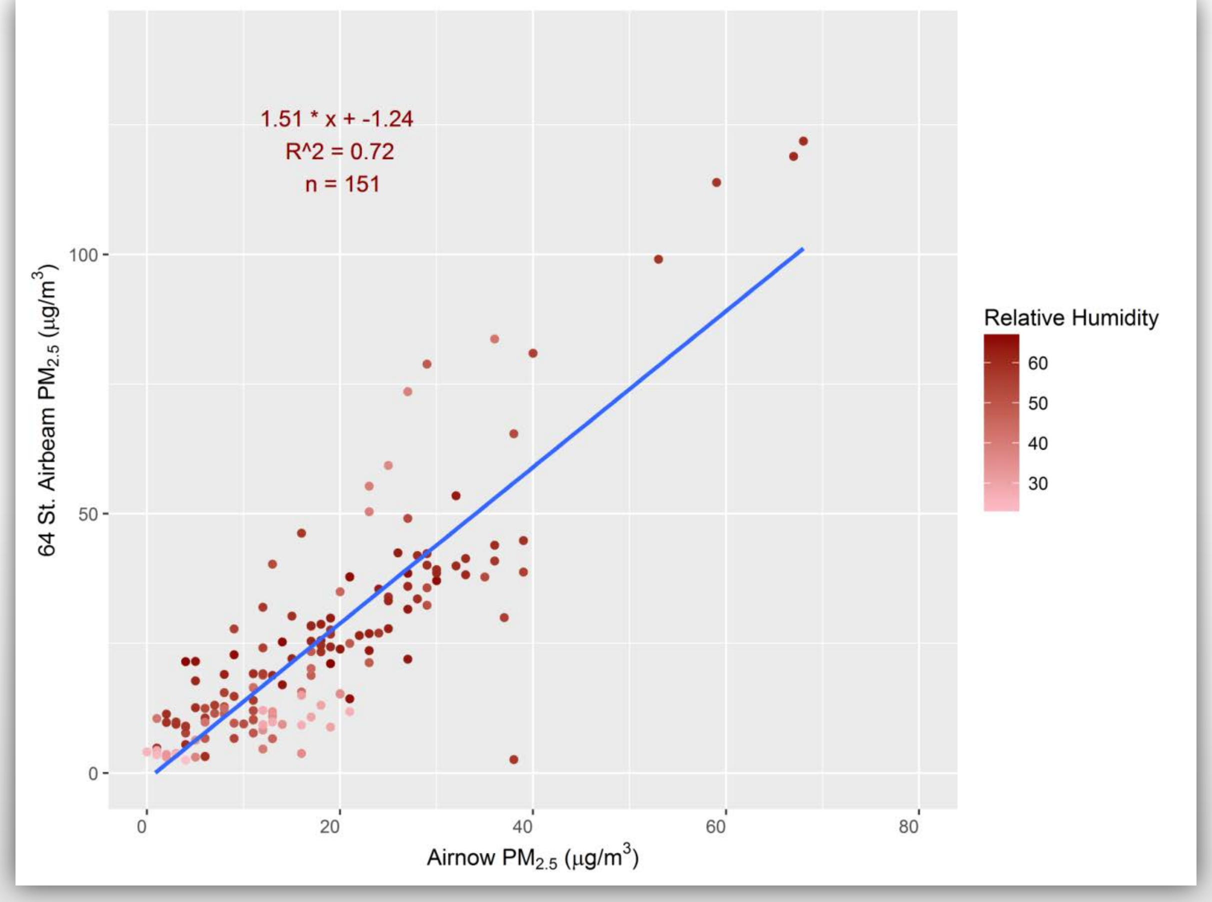
4. Study – Woodsmoke ($PM_{2.5}$)



Sponsor: SMAQMD

4. Study – Woodsmoke ($PM_{2.5}$)

Early exploration of data to understand how well the sensors are doing and how they respond to relative humidity.



Sponsor: SMAQMD

Key Challenges

- New technology
  - Rapid changes; versioning issues with firmware
  - Drift, calibration requirements, and “soiling” issues
  - Hardware issues
  - Unknown lifetime
- Data logging
  - Data acquisition systems don’t always handle sensors
  - Data formats and time standards
- Communications
  - Critical for high data availability
  - More challenging and costly

Key Challenges

- Data management
  - More challenging than FEM instrument (60 to 3600 times more data and more uncertainty)
- Cost
  - Projects cost much more than one sensor
  - Operations and data management are more intense
- Scale
  - 3 sensors vs. 10 sensors vs. 100 sensors
  - Scale affects everything (logistics, data management, reliability, costs)

Path Forward

How Good?	How Useful?	How Sustainable?
Evaluations	Field Projects	Businesses
✓	In progress	?

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