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CAIRSENSE Study:

Real-world evaluation of low cost sensors in Denver, Colorado

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2. **U.S. EPA Region 8**
3. **U.S. EPA Region 4**
4. **Colorado Department of Public Health and Environment**
5. **U.S. EPA Region 1**
6. **Jacobs Technology Inc.**

Foreword

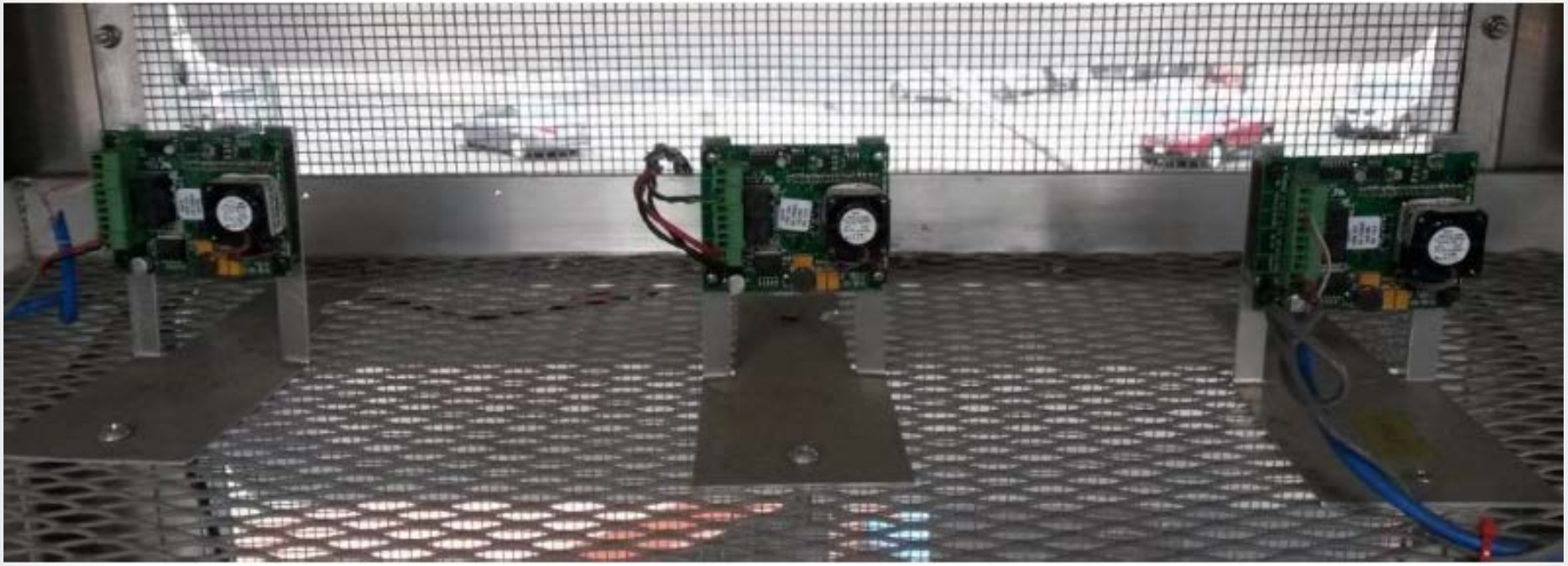
- The goal of this presentation is to give information on the following topics:
  - Description of selected low-cost sensors and sensor types
  - Performance evaluation of low-cost sensors
  - Challenges in performing sensor evaluation

  This presentation is to the public and would be useful for a technical individuals wanting to use sensors for research or interpret sensor data.

CAIRSENSE-Denver Overview

- **Objectives:**
  1. **Evaluate long term performance and comparability of nine different low-cost sensors against regulatory monitors**
  2. **Evaluate sensor performance in high altitude, low humidity, and low temperature**
- **Low cost sensors (<$2500) are a rapidly developing industry with little real world evaluation**
- **Data collected from September 2015 to February 2016**
- **Follow-up to a similar study in Atlanta, GA**

O_3 Sensor -Aeroqual SM-50 ($350)



- Uses an electrochemical sensor
- Uses EPA developed external data logger

NO_2 + O_3 Sensor - Cairpol Cairclip ($1500)

- **Measures combined O_3 + NO_2 using an electrochemical sensor**
- **Data stored on external data logger**

PM Sensors – Light Scattering

TSI AirAssure
($1000)

AirCasting AirBeam
($250)

AirViz Speck ($150)

Shinyei PMS-SYS-1
($1000)

PM Sensors – Laser Particle Counters

Alphasense OPC-N2
($500)

TZOA PM Research Sensor
($600)

Dylos DC-1100/DC-1100 Pro
($200-260)

Consumer Marketing

Denver Monitoring Site

Regulatory Monitors:

- Teledyne 400E O_3 Monitor
- Teledyne T500U NO_2 Analyzer
- GRIMM EDM 180 Dust Monitor

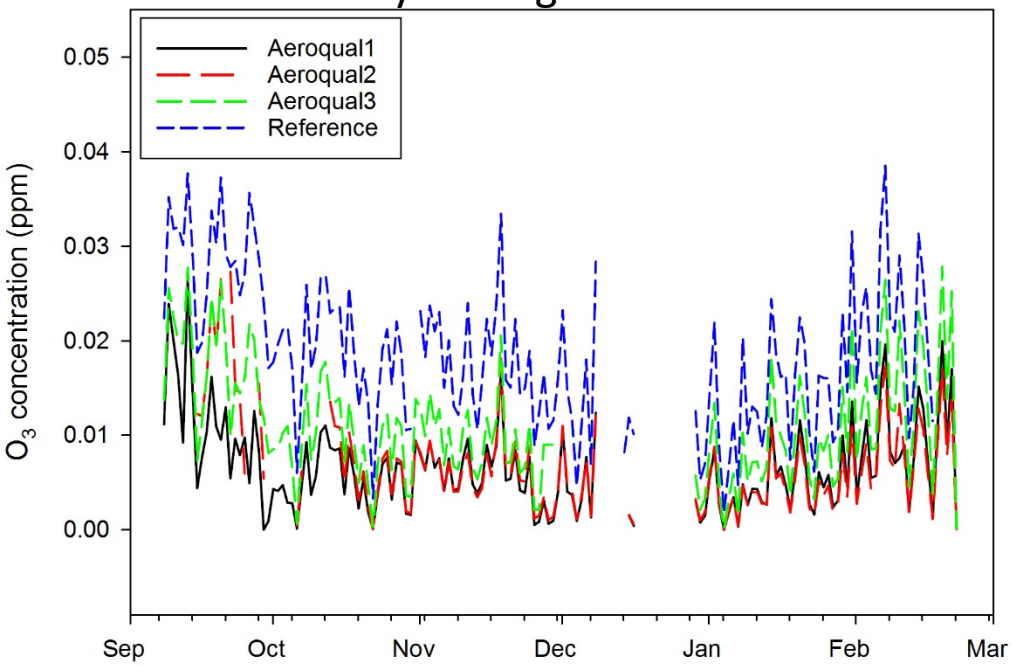
Sensor Deployment

Evaluation Challenges

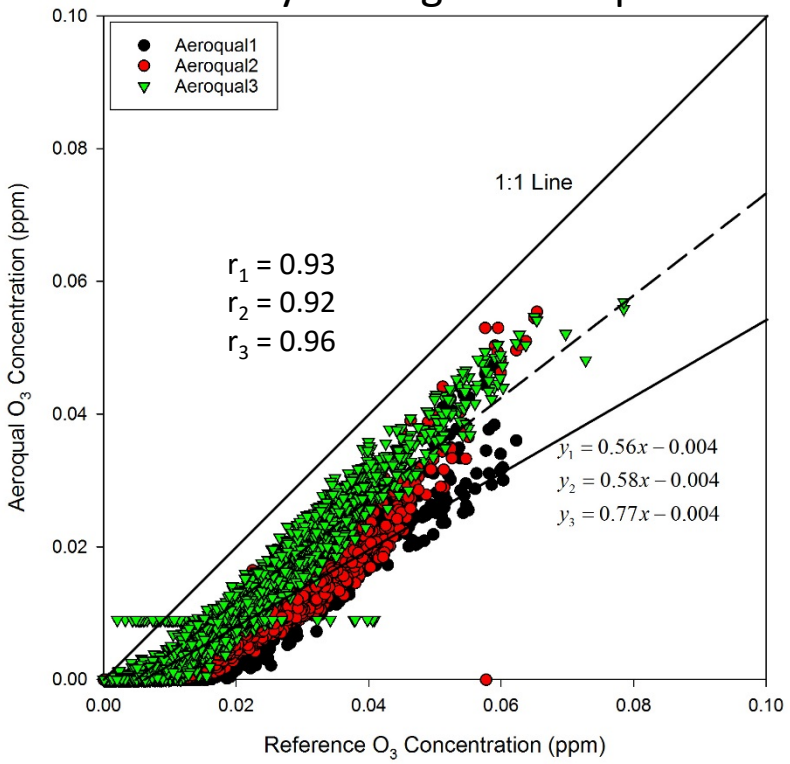
- **Data logging**
  - Many sensors had no internal data logging – required connection to EPA built data loggers or laptops
  - Some sensors had cloud based data storage, but this capability was removed for data security
- **Data processing**
  - Multiple different data output formats
  - Different time series formats (daylight, standard, elapsed time)
  - Large amounts of 1-minute data to be processed (used, 5 minute, 1 and 12 hour, and daily averages for comparison)
- **Weather events**

Aeroqual – O_3

Daily Average Time Series

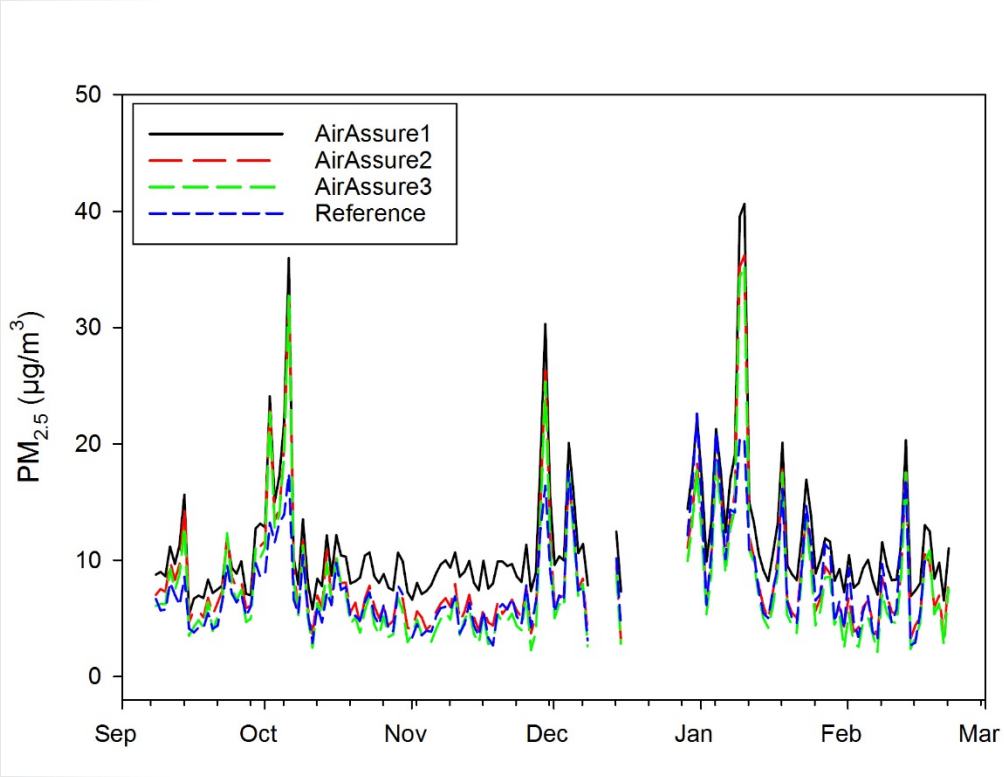


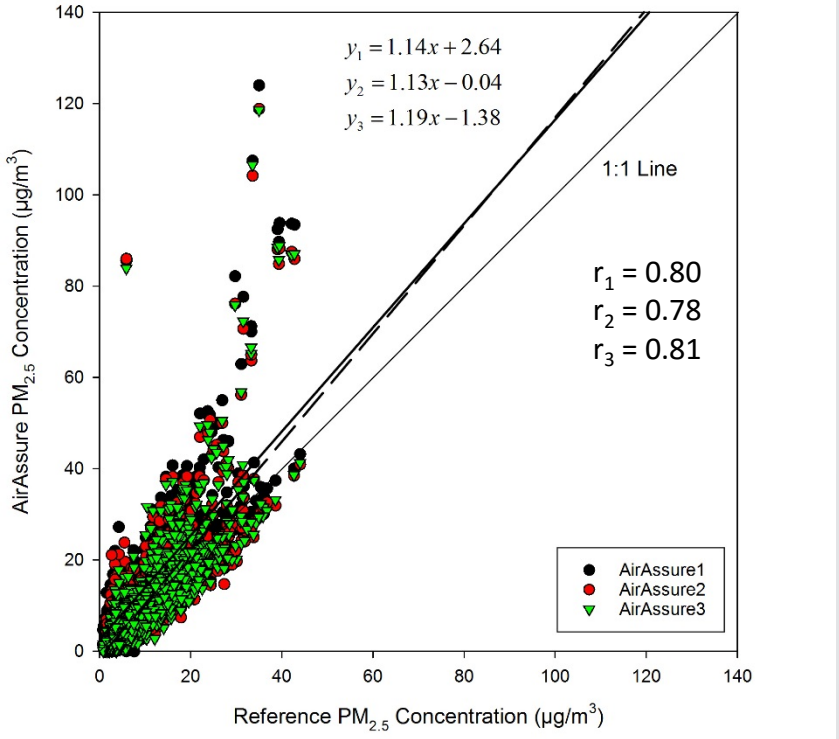
Hourly Average Scatterplot



- Initial lab audit had 1:1 ratio
- Underreports regulatory monitor O_3
- Consistent across seasons
- Strong correlation to regulatory monitor

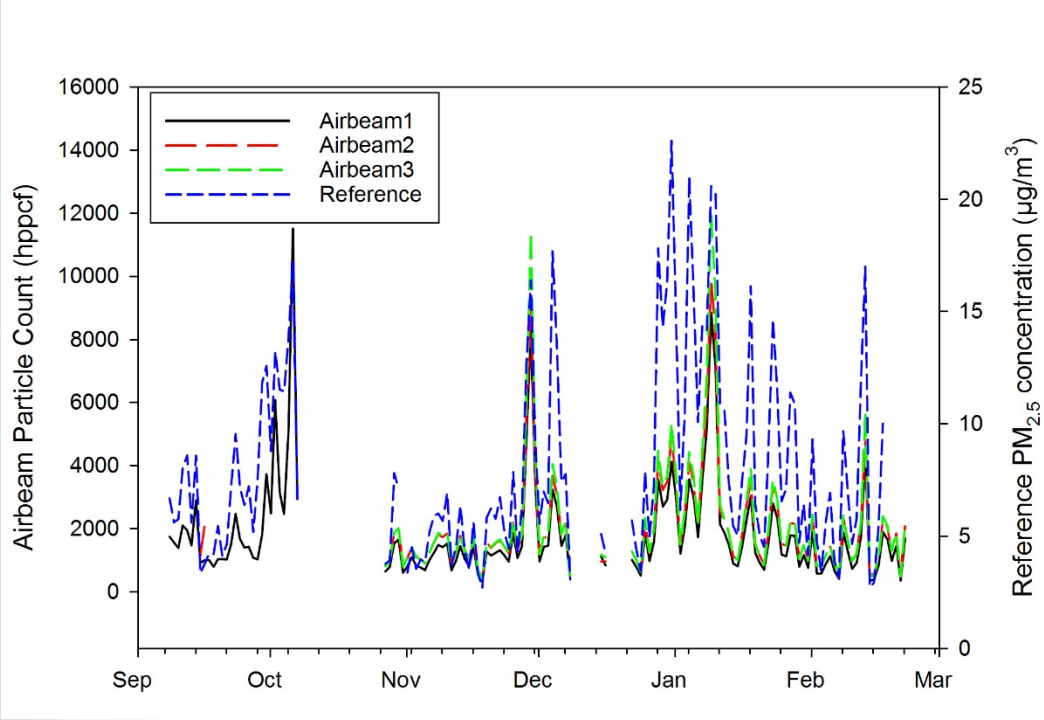
AirAssure – $PM_{2.5}$

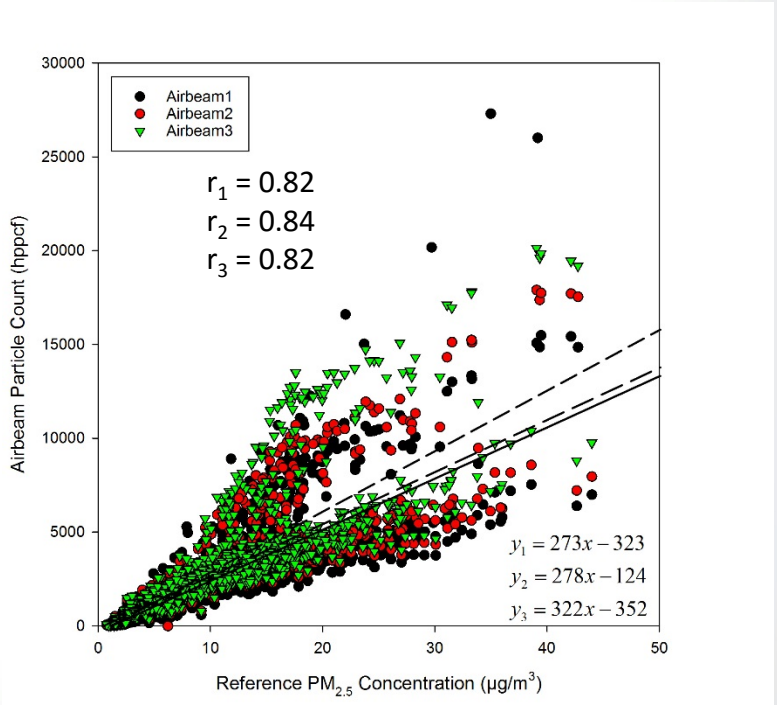




- Few over-responding events
- Strong agreement between units 2 and 3
- Moderate correlation with monitor

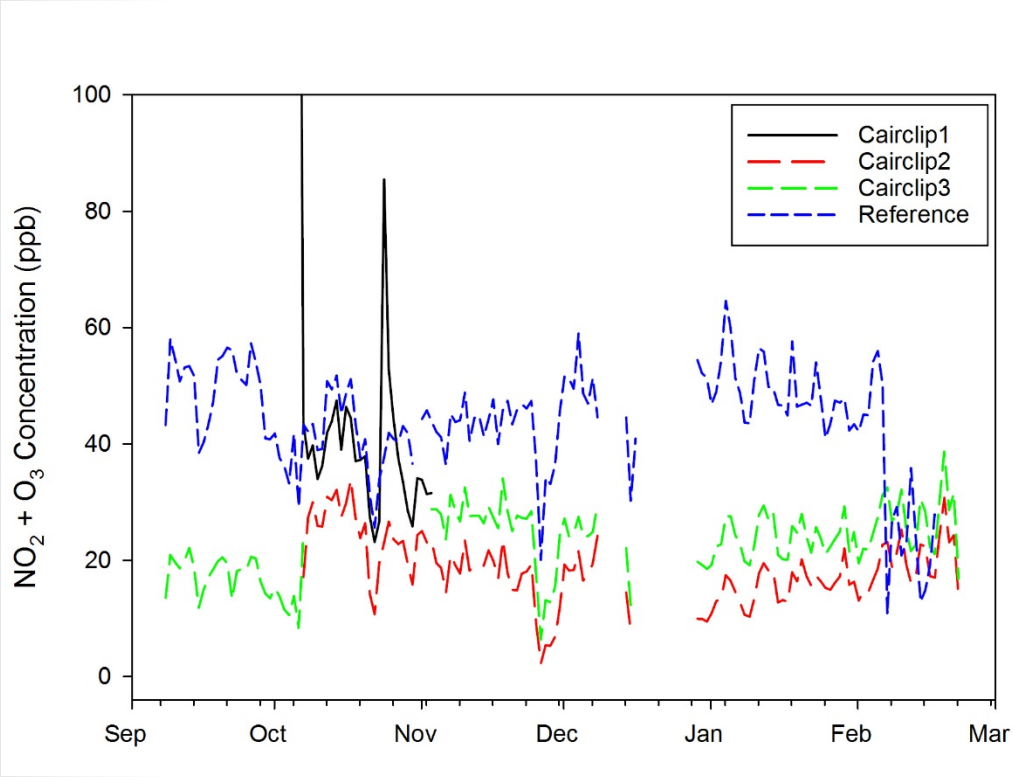
Airbeam – PM

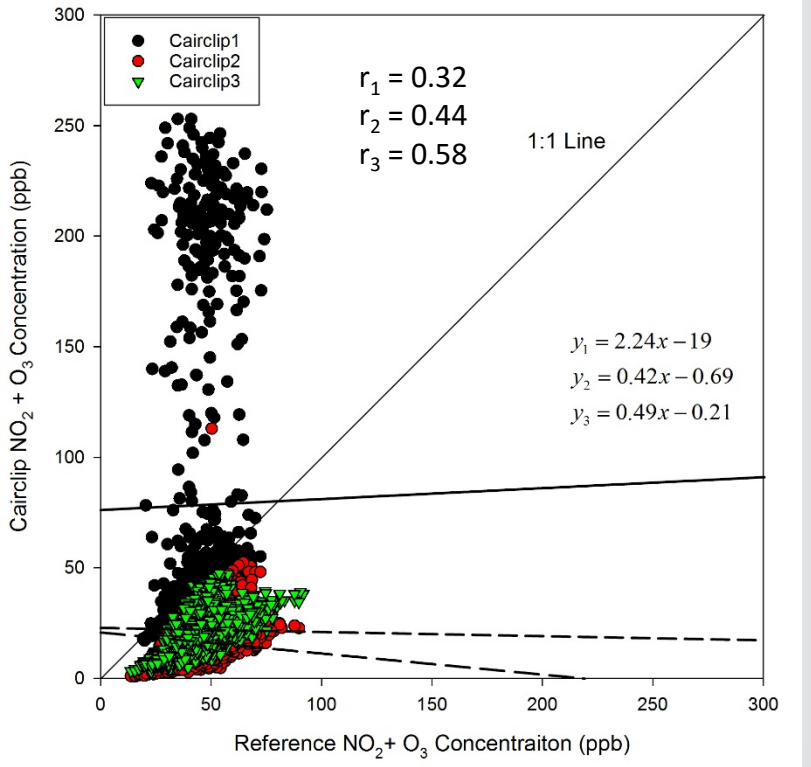




- Under-responds to high events
- Strong agreement between sensors
- Moderate correlation with regulatory monitor

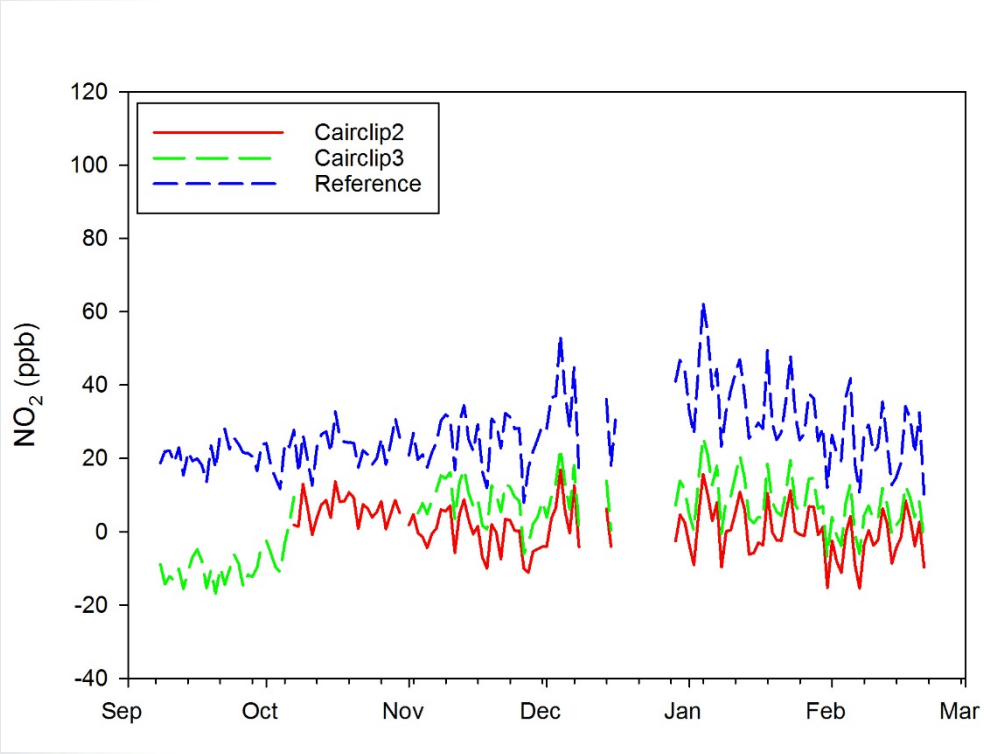
Cairlip – O_3+NO_2

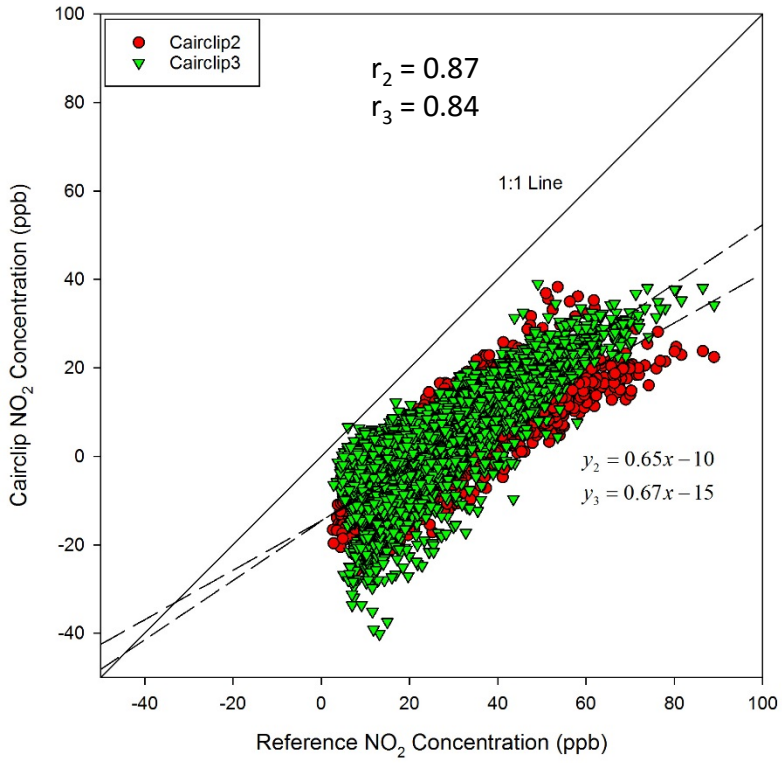




- Cairclip 1 – data transmission issues for entire study
- Cairlips 2 and 3 had data logging and transmissions issues
- The sensors provided excellent calibration response upon return to lab. USB version of this device has not shown data transmission issues. UART version has unknown issue

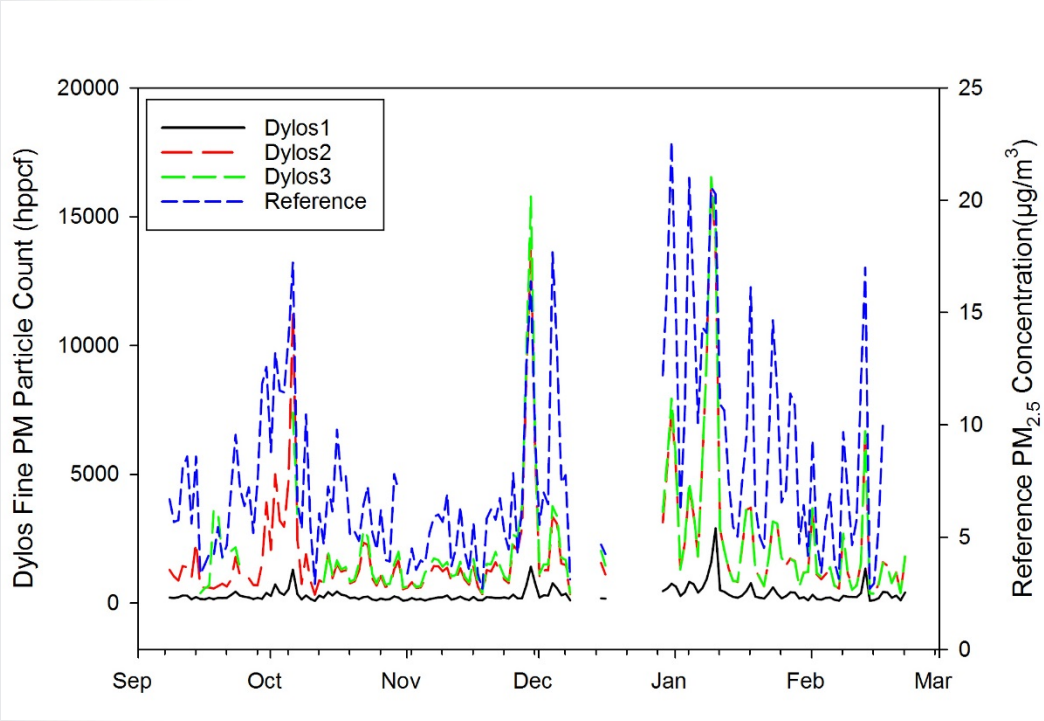
Cairlip – NO_2

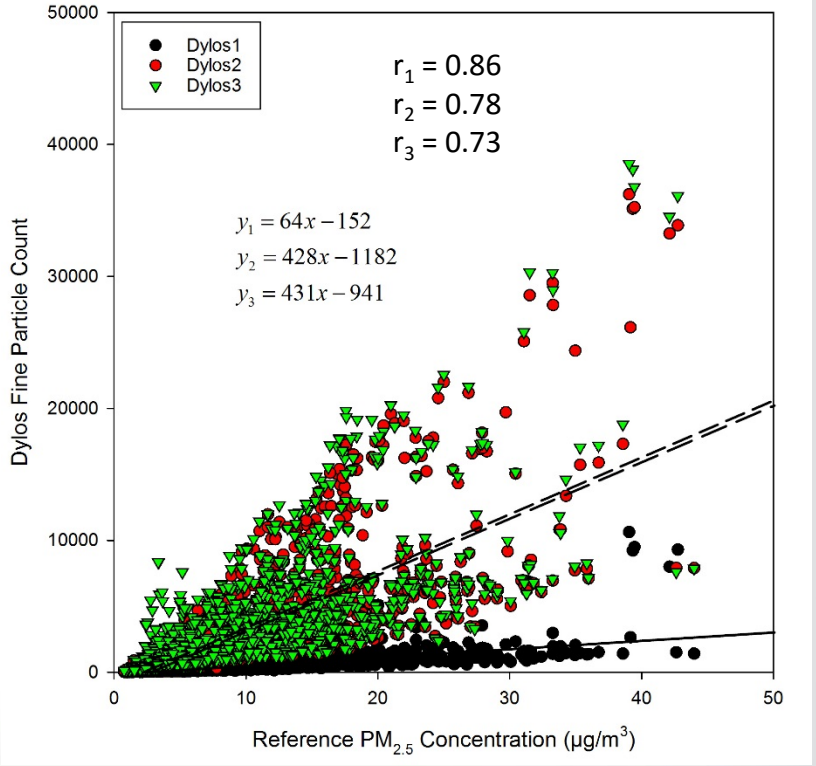




- Subtracted O_3 reference data to evaluate NO_2
- NO_2 results correlate much better with regulatory data
- Cairclip NO_2 underresponds
- Pre- and post- sampling laboratory audit showed 1:1 response

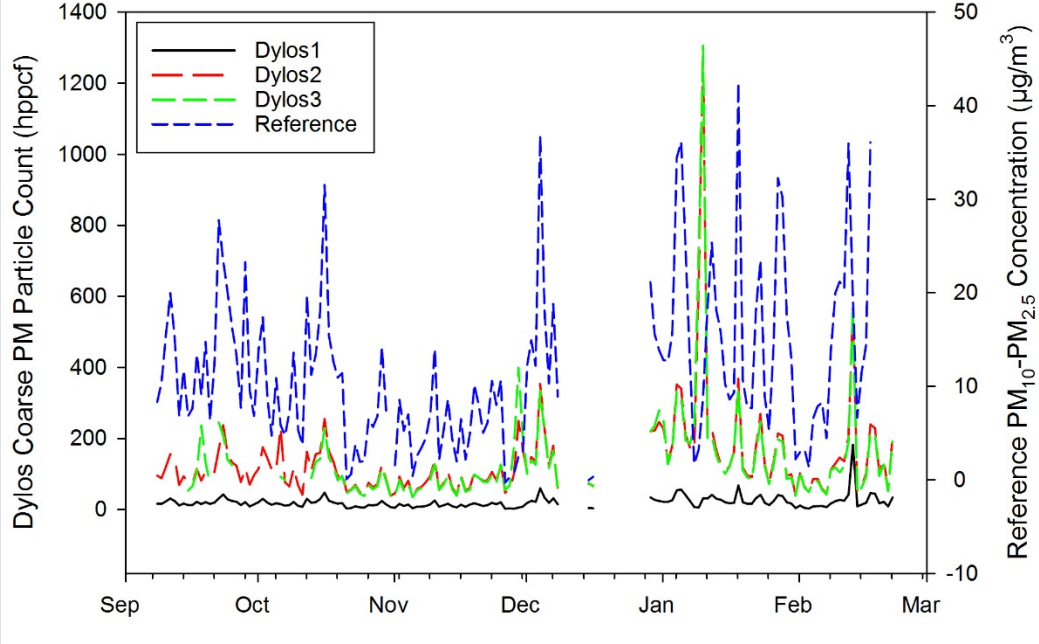
Dylos "Small" Particles

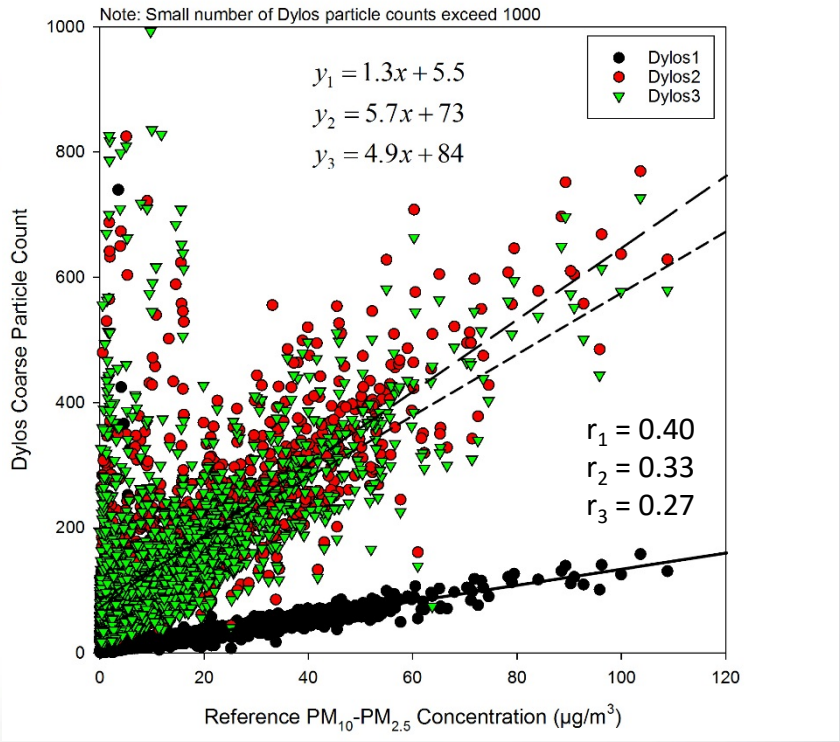




- Units 1 and 2 have good general agreement with regulatory data
- Unit 3 (different model, version 1100) under-responds – less sensitive to particles < 1 µm

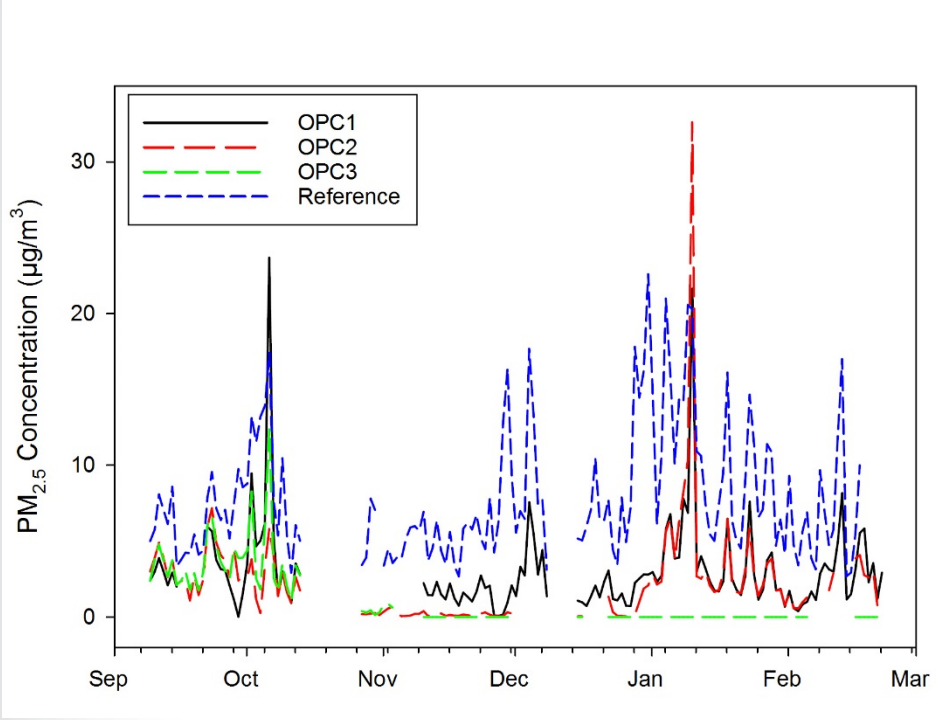
Dylos "Large" Particles

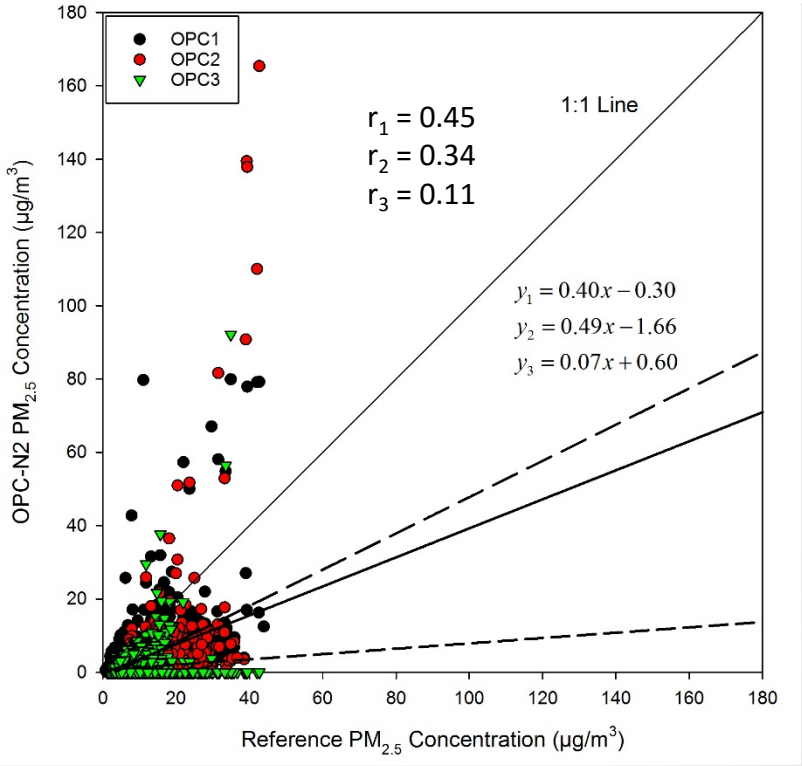




- Units 1 and 2 have good general agreement with SoC (Pro version)
- Unit 3 under-responds – different model (version 1100)
- Not as well correlated with regulatory data as "small" channel

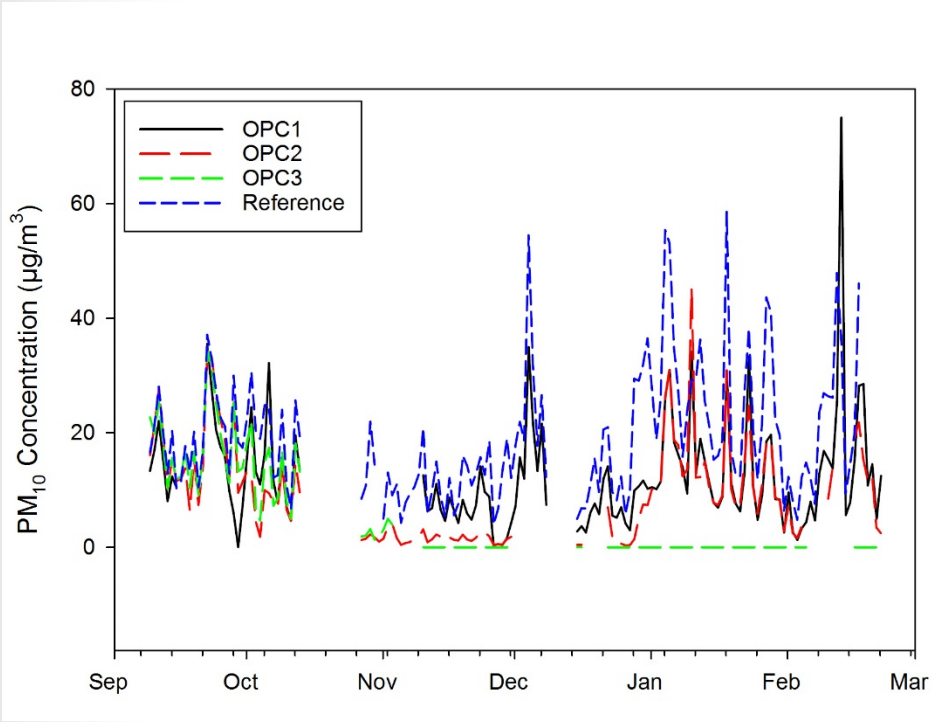
OPC-N2 $PM_{2.5}$

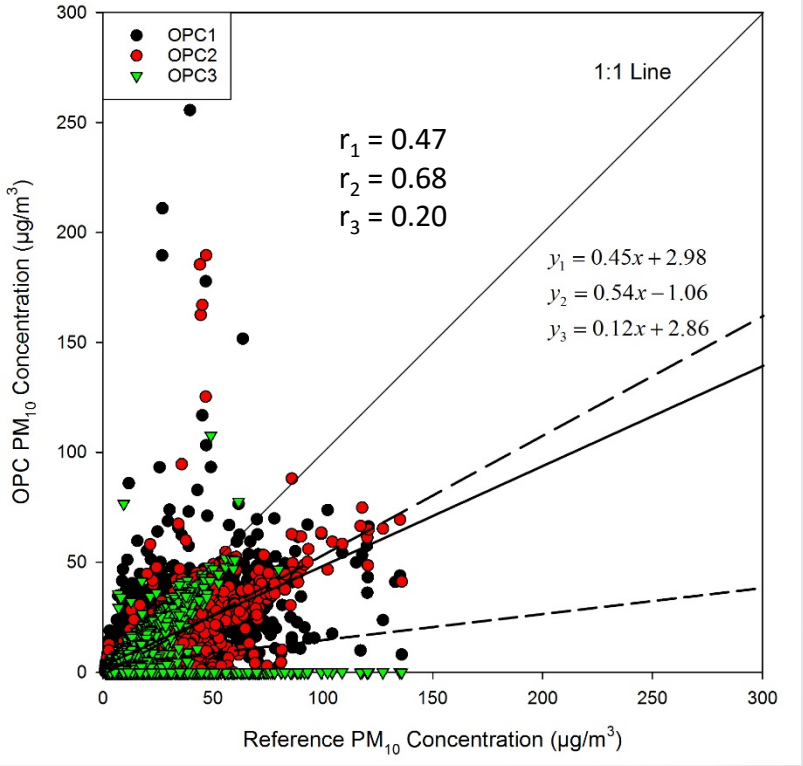




- Units 3 failed in in November
- Units 1 and 2 agree except during Nov-Dec
- Suspect assignment to size bins by manufacturer is mostly an estimation

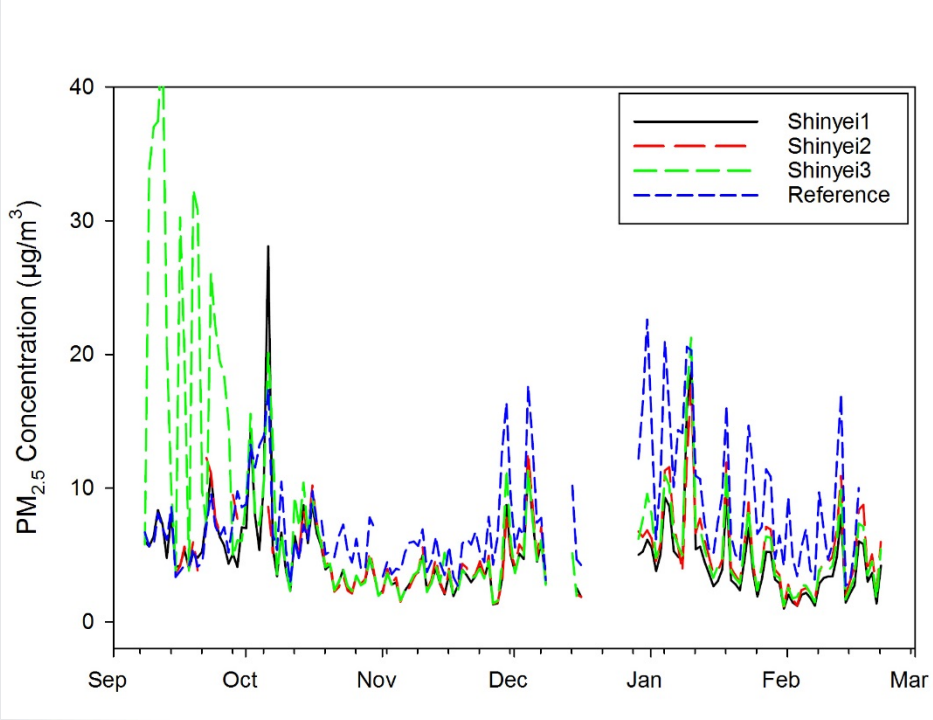
OPC-N2 PM_{10}

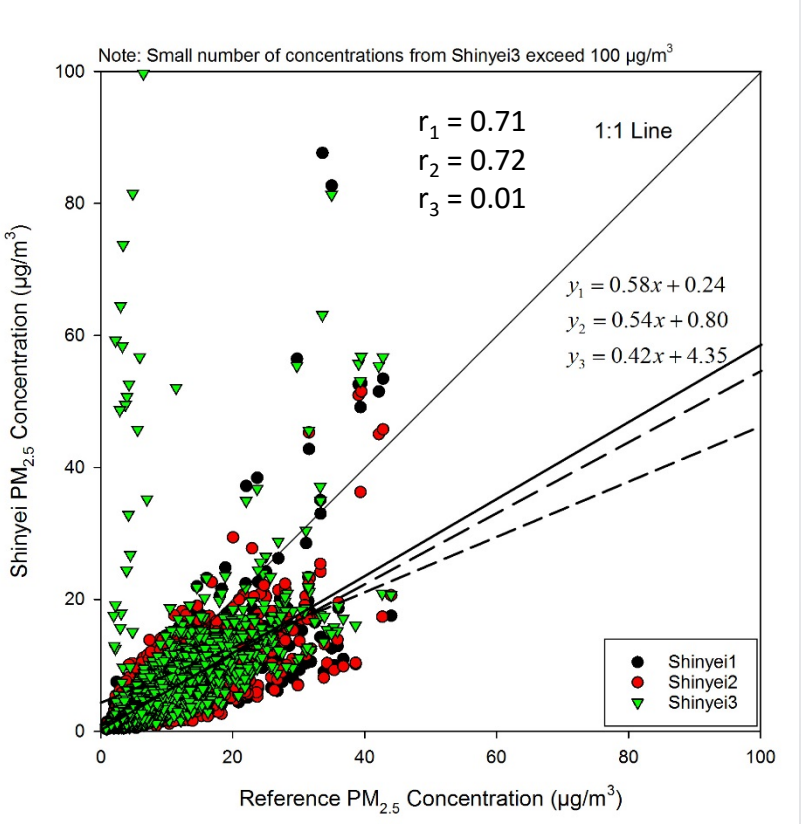




- Units 3 failed in in November
- Units 1 and 2 agree except Nov-Dec
- Better agreement than $PM_{2.5}$
- Suspect assignment to size bins by manufacturer mostly an estimation

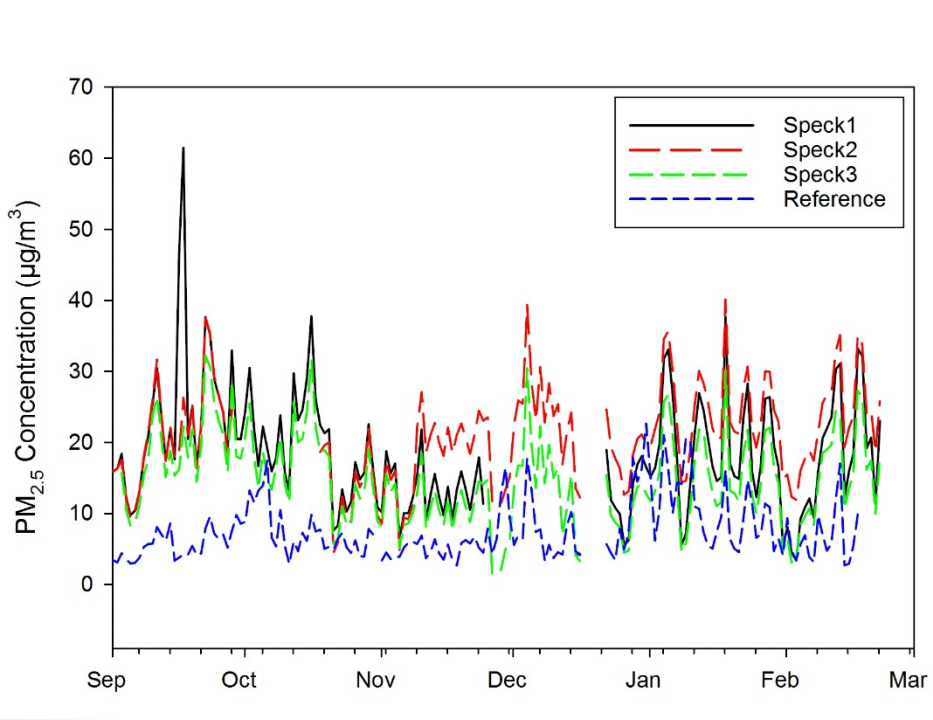
Shinyei PM

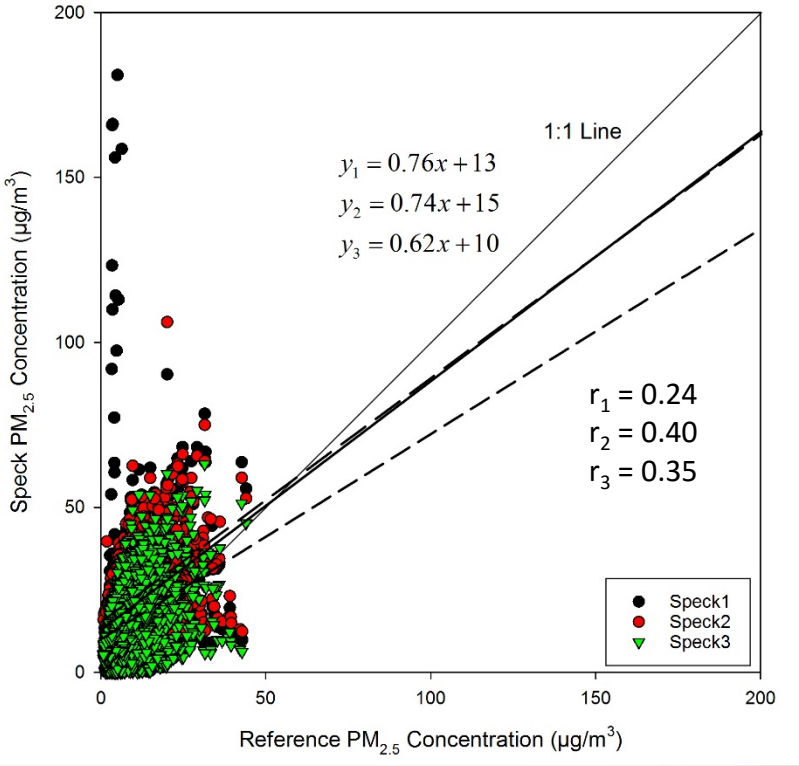




- Unit 3 changed response starting in Oct
- Starting in Oct all units had good agreement with regulatory monitor and each other

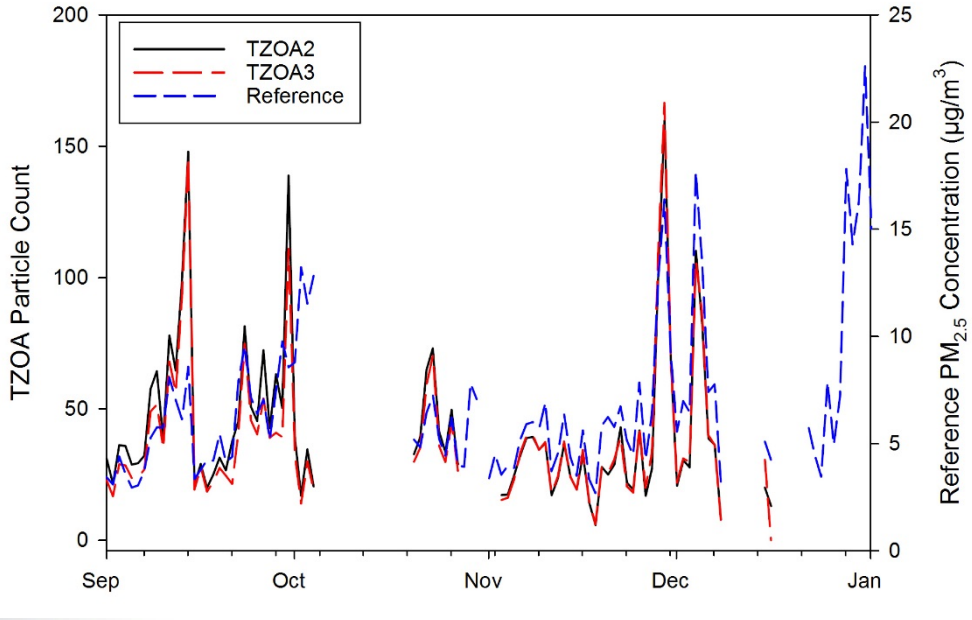
Speck PM

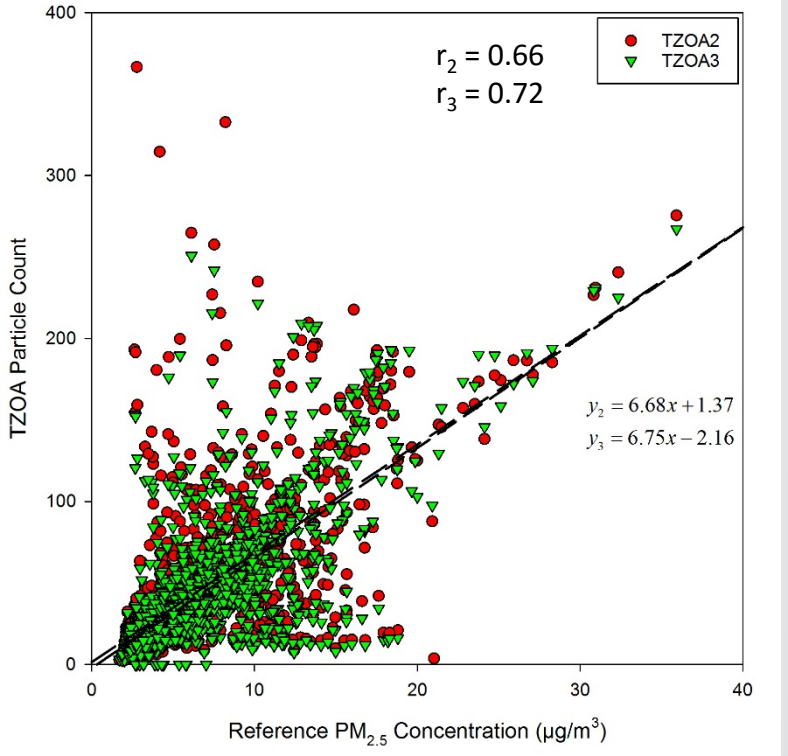




- Units 1 and 2 have good general agreement with regulatory monitor
- Unit 3 under-responds
- This is the third version we have tested and with improved agreement to reference data

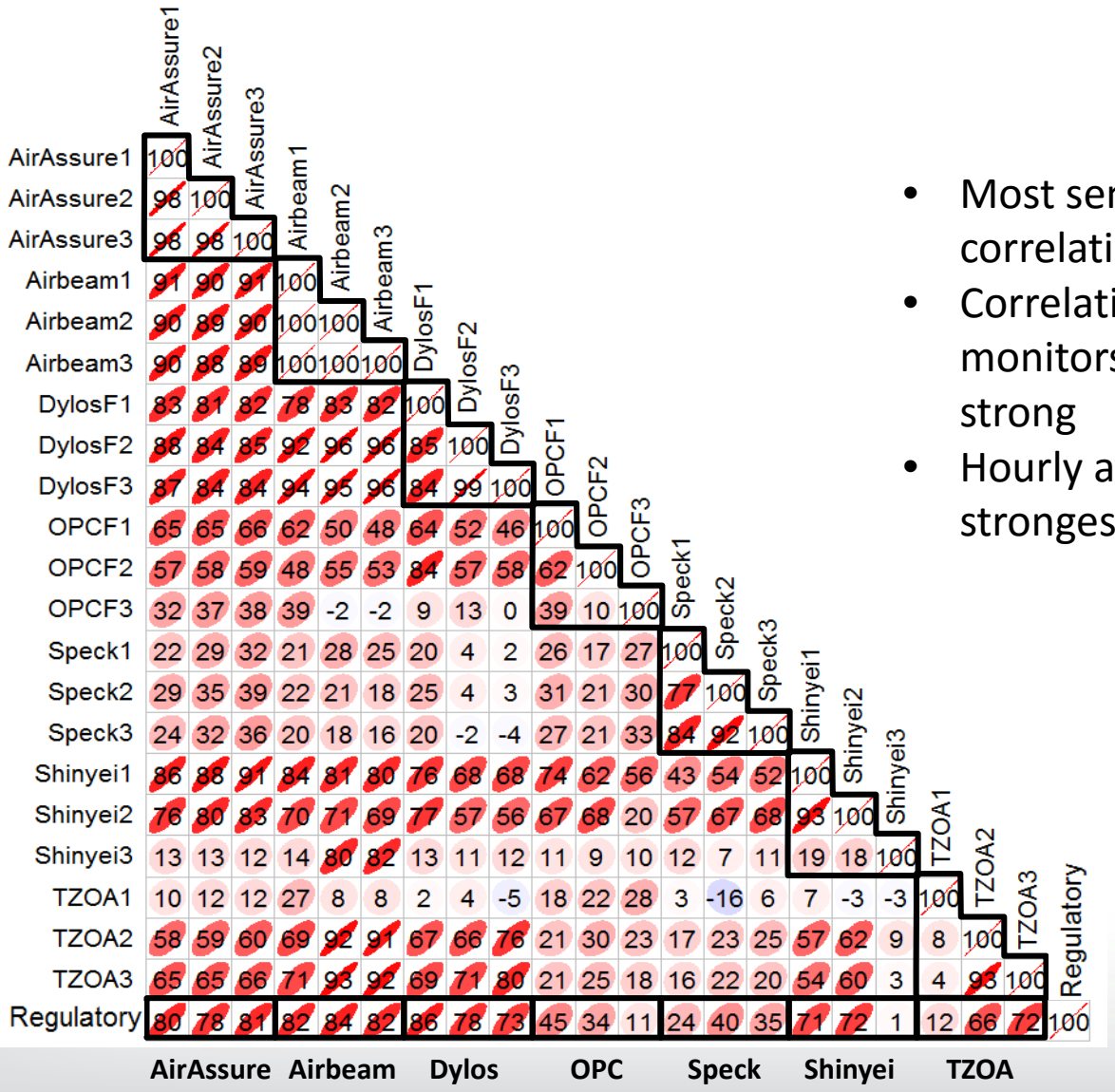
TZOA PM





- Good agreement within units and with regulatory monitor
- Unit 1 never ran properly
- Units failed completely in Dec due to snowfall (not a sensor issue)

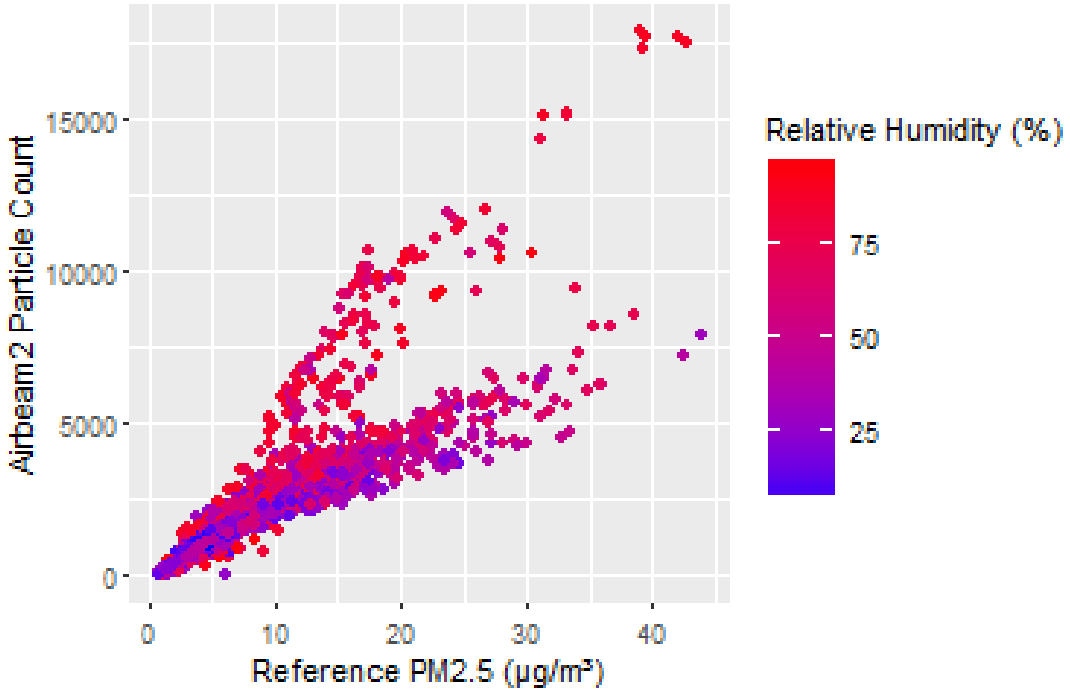
Hourly Average PM Correlations



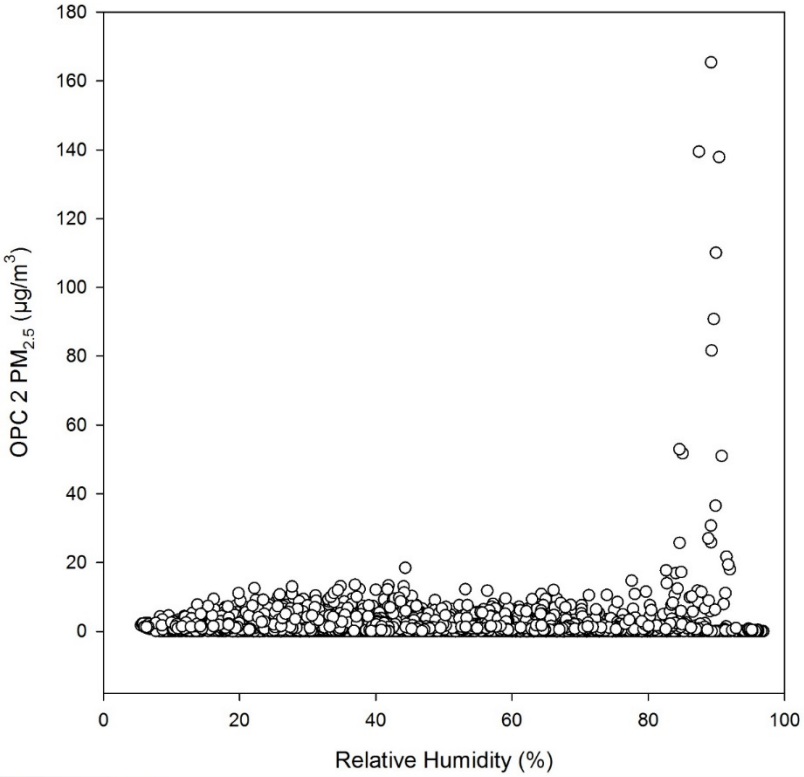
- Most sensors exhibit strong correlation within model types
- Correlations with regulatory monitors range from weak to very strong
- Hourly average values had strongest correlations

Humidity Effects

- Fork with lower particle count has a range of humidities
- Fork with higher particle count also has higher relative humidity
- Similar effect seen in Dylos units 2 and 3



High Humidity Artifacts



- RH appears to impact other PM sensors as well
- The OPC-N2 (shown here) exhibits positive artifacts for PM at high RH

ORD-Region research projects using sensors (FY15-16)

Project	Regional Partner(s)	Measurements	Location
CSAM (Report Complete)	Region 2	PM, NO_2, temperature, humidity – portable stations	Ironbound community, NJ
CitySpace (Under development)	*Region 4 Region 6 Region 7*	*PM – up to 20 stationary nodes*	*Memphis, TN*
AirMapper (Under development)	*Region 5 Region 10*	*PM, noise, temperature, humidity – portable units*	*Chicago, IL Portland, OR*
Puerto Rico EJ (Under development)	*Region 2*	*Tentative: PM, VOCs, NO_2 – portable units*	*Puerto Rico*
AIRS-RTP	*ORD-Externals*	*TZOA, Aeroqual (ozone and NO2), UN sensor Pod, Argonne National Lab Array of Things pod, AQ Eggs, targets of opportunity as they arise*	*RTP, NC*

Sensor Related Resources

Air Sensor
Measure · Learn · Share

Citizen Science Toolbox
EPA

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Online Resources Available at:
www2.epa.gov/air-research/air-sensor-toolbox-citizen-scientists

Air Sensor Guidebook

CSAM Operating Procedures


Mobile Sensors & Applications for Air Pollutants

Citizen Science Air Monitor (CSAM): Quality Assurance Guidelines

Evaluation of Field-deployed Low Cost PM Sensors