ORD SPEAR Program: Air Quality Sensors

CASTNET Monitoring Meeting
Thursday, September 26th, 2019
RTP, NC

U.S. EPA Office of Research and Development
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EPA Sensor Performance, Evaluation, and Application Research (SPEAR) Program

- **Project Goals**

  Discover, evaluate, develop, apply, and communicate new and emerging air quality sensor technologies to meet a wide range of stakeholder needs (general public to regulatory officials)

- **Research Questions**

What are the capabilities of emerging technologies and their potential to meet current and future AQ monitoring needs?	How can EPA best support sensor developers and the user community?	What other data and technologies are needed to help understand and interpret sensor data?	How can EPA apply the knowledge gained to issues of concern to EPA and our clients, partners, and stakeholders?

Current State of Sensor Development and Performance

NAAQS

Particulate Matter
- Several Options ($200s to $1000s)
- $PM_{2.5}$: Good correlation but often overpredict
- PM_{10}: Generally not measured well
- Influenced by particle type, temp, and RH

Ozone
- Fewer options ($500s to 1000s)
- Finite lifetimes
- Good accuracy and fairly reliable with collocation

Carbon Monoxide
- Fairly accurate and reliable with collocation
- Must consider concentration range

Nitrogen Dioxide
- Fewer options ($500s to $1000s)
- Highly variable performance
- Strong cross-sensitivities

Sulfur Dioxide
- Difficulty measuring low-concentrations
- Highly variable performance
- Strong cross-sensitivities especially to meteorology

Other

VOCs/ HAPs
- Most measure tVOCs rather than speciated VOCs
- Commonly used for sentinel leak detection
- Strong interest and development work

Ammonia
- Development work occurring
- Price points likely ($5K and up)

Nitric Acid
- No sensors currently available

Black Carbon
- Development work occurring
- Price points currently ~$15K

Other Particle Species/ Sizes
- No speciation sensors currently available
- Ultrafine particle sensors in development

RTP Evaluations

Project Lead: Andrea Clements

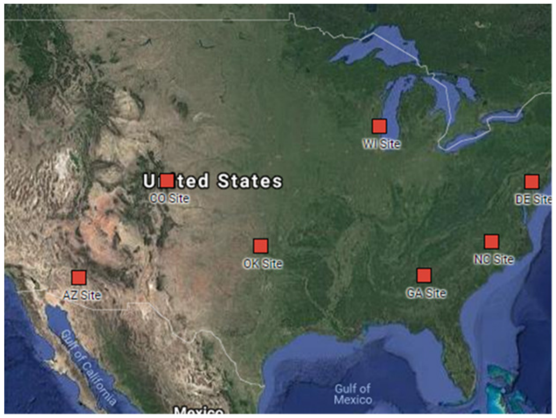
- **Continued effort to evaluate new sensors coming to market**
  - Focus on criteria pollutants but also considering other pollutants (e.g., VOCs, HAPs)
  - Especially interested in products likely to be widely adopted and/or new technologies
- **Select sensors are collocated at the AIRS research site in RTP, NC for 30 days or more**
  - Tested in triplicate to understand sensor variability
  - Data compared to nearby regulatory instruments (FRM/FEM) and meteorological measurements to evaluate performance
- **Results shared on the Air Sensor Toolbox** (www.epa.gov/air-sensor-toolbox)

Long-Term Performance Project (LTPP)

Project Lead: Andrea Clements

Study Design:

- Leverage partnerships with air monitoring agencies to test sensors in a variety of locations for an extended period
- 7 air monitoring stations across the U.S. (NC, GA, DE, AZ, CO, OK, WI)
- 1-year of measurements beginning in July 2019
- Similar reference monitors across sites



Sites across the U.S.

- 6 air sensors
- Some PM only, some multipollutant

AQY - Aeroqual

PurpleAir

ARISense - Aerodyne Research

Ramp -SenSit

Maxima - Applied Particle Technology

Clarity Node - Clarity Movement Co.

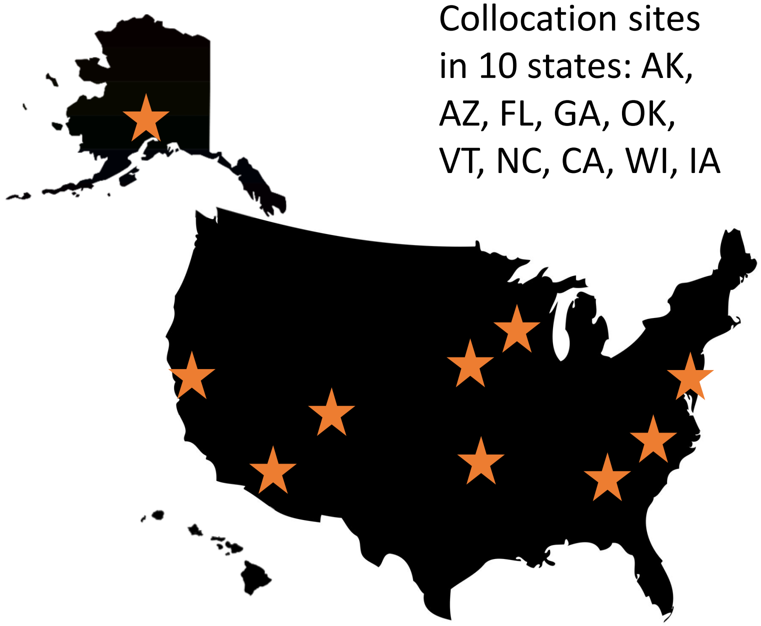
Image sources: www.aerodyne.com/products/arisense; www.purpleair.com/; www.aeroqual.com/product/aqy-micro-air-quality-station; https://clarity.io/solution

LTPP – U.S. Performance PurpleAir

Design:
- Leverage projects already underway by air monitoring agencies
- 12 partner air monitoring agencies and ~50 collocated Purple Air sensors across the U.S.

Objectives:
- Draw broader conclusions about the performance
- Explore methods of Quality Assurance (QA) and adjusting data from distributed sensors

Preliminary findings:
- Good precision between sensors
- Accuracy is variable
    - Slope ~2.1 Atlanta, ~1.7 in RTP, ~1.2 Phoenix



Collocation sites in 10 states: AK, AZ, FL, GA, OK, VT, NC, CA, WI, IA

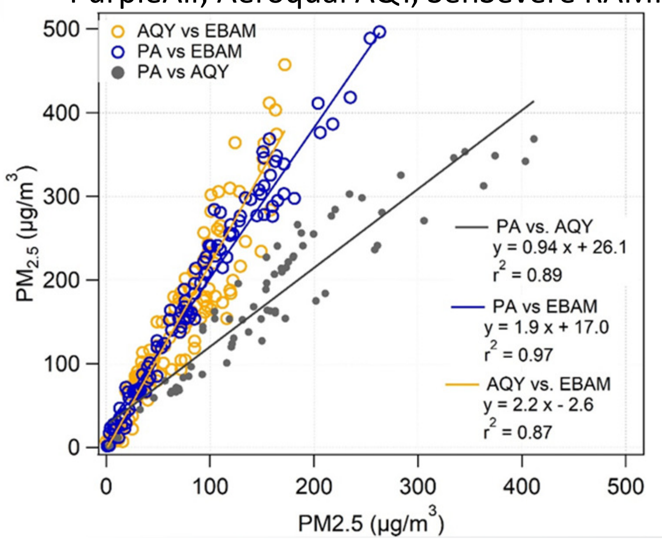
Preliminary results

Wildfire Smoke Applications

Evaluate PM sensors to augment monitoring networks during wildfire smoke events (*Project Lead: Amara Holder)*

- PM sensors were highly correlated ($R^2 > 0.8$) with reference instruments at elevated PM concentrations
- PM sensors generally reported 1.5 – 2X higher than EBAMs at elevated concentrations, but were in better agreement at lower concentrations
- Correction for RH and T improve comparison

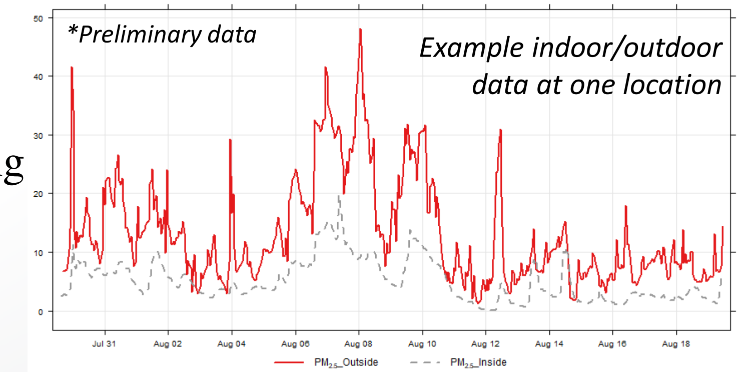
PurpleAir, Aeroqual AQY, SenSevere RAMP



Wildfire Smoke Translational Science Project

(*Science Leads: Amara Holder, Gayle Hagler, Wayne Casio*)

- PM sensors to measure indoor/outdoor pollution concentrations for buildings in Missoula, MT & Hoopa Valley Tribal Reservation, CA
- Mobile monitoring package to map outdoor concentrations, coupling mid-cost $PM_{2.5}$ monitor with GPS, 1-second data resolution
- QA involves collocation with reference monitors and checks on comparison of identical internal sensors for deviations over time.

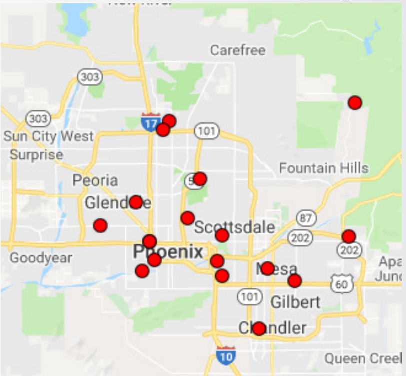


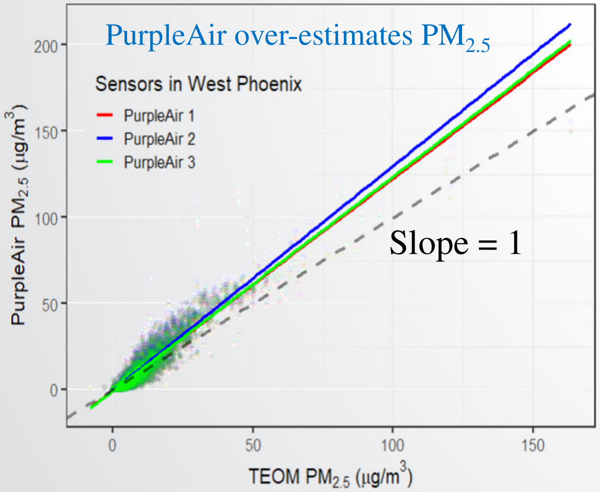
Phoenix as a Testbed for Air Quality Sensors (P-TAQS)

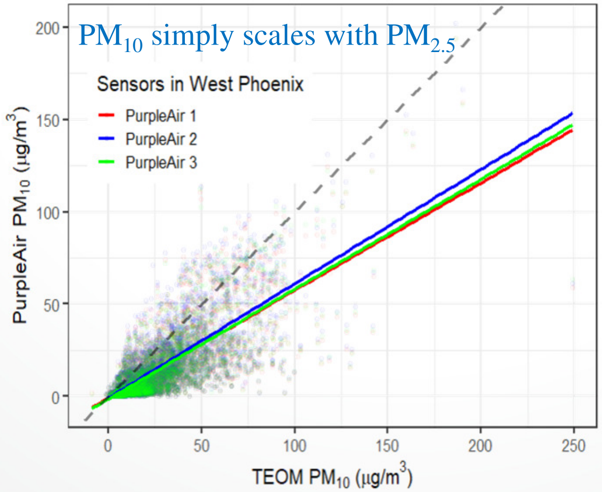
P-TAQS (Nov. 2018 – Mar. 2020)

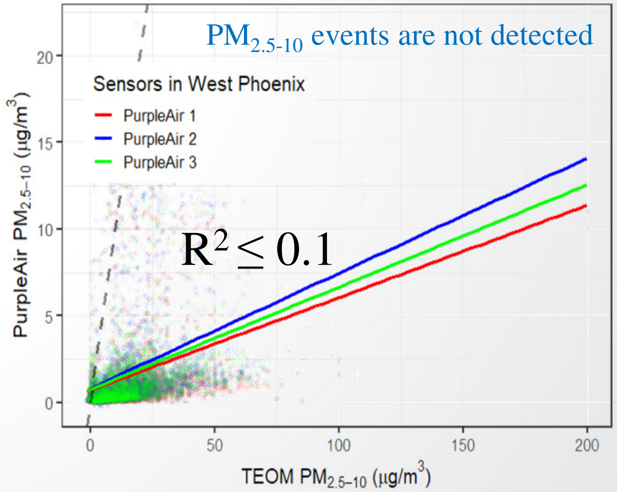
Project Lead: Sue Kimbrough

- Measuring spatial and temporal air pollutant concentrations around the Phoenix metro area
- Use measurements to map the flow of wintertime wood smoke within the area
- Understand the performance of sensors in an arid environment
- Test methods for calibrating a distributed network of sensors









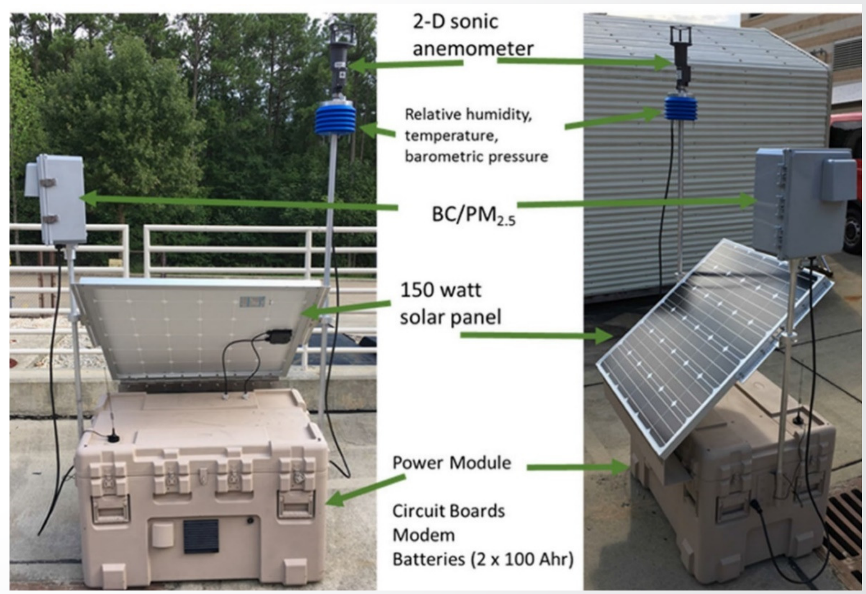
Kansas City Transportation and Local-Scale Air Quality Study (KC-TRAQS)

KC-TRAQS (Oct. 2017 – Nov. 2018)

Project Lead: Sue Kimbrough

- Measuring spatial and temporal air pollutant concentrations in a community near a busy rail-yard facility.
- Combination of stationary sensor measurements, mobile sensor measurements by community scientists, and a mobile monitoring campaign using an instrumented electric vehicle.

Custom built P-Pod
(BC, $PM_{2.5}$, WS/WD, T, RH, P)



Custom built AirMapper
($PM_{2.5}$, CO_2, GPS, noise, T, RH)

PurpleAir

Aeroqual AQY

EPA

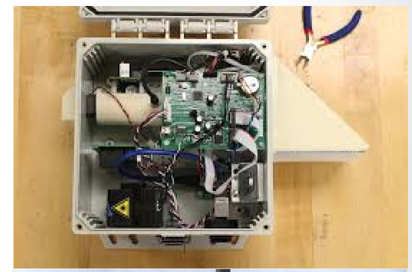
Regional Sensor Loan Program

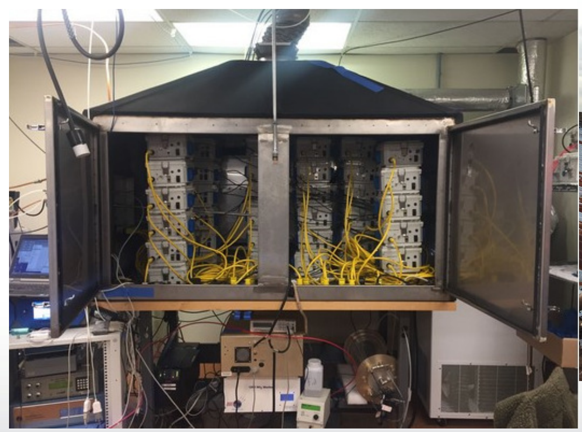
Project Lead:
Andrea Clements

- **Collaboration between ORD and EPA Regions (1, 2, 3, 5, 8)**
  - Procurement of 20 multipollutant sensor devices (AriSense), 7 with solar panels for off-grid application
  - Measurements: CO, NO, NO_2, O_3, CO_2, PM, solar intensity, noise, wind speed, and wind direction

- **Initial sensor performance evaluation work at EPA's RTP site then sensors to be provided to Regions on a rotating basis for targeted projects with local partners**

- **Applications under consideration include**
  - Wintertime PM in mountain valleys
  - Educational outreach with students
  - Measuring near transportation sources





External Collaborations

- **Current Agreements**
  - Cooperative Research and Development Agreement (CRADA) with Aeroqual involving evaluation and application of sensor systems in select field studies
  - CRADA with Aclima involving collaboration on evaluation of ambient mobile monitoring data using higher-end instruments and/or low-cost sensors

EPA Combines Expertise with New Zealand Company to Advance Air Sensor Technologies

Published March 26, 2018

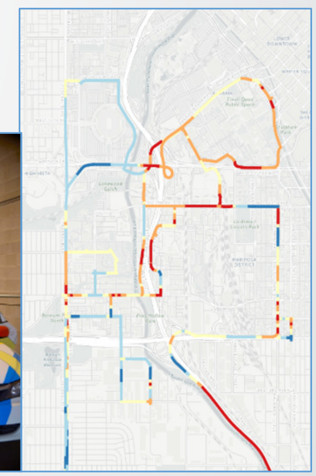
Next Generation Air Monitoring Tools are new technological advances that are increasingly being used by researchers and citizen scientists alike to monitor and measure air quality. Unlike large, stationary federal reference monitors, which allow only a limited group of specialists to use, Next Generation Air Monitoring tools are small, low-cost and portable, engaging a variety of groups to measure pollutants to understand air quality.

While the use of low-cost air sensor technologies continues to rise, the need to accurately characterize air quality remains a challenge. Additionally, there is still a need to understand the performance of sensors over time and to explore potential applications of these emerging technologies.

In November 2017, EPA signed a Cooperative Research and Development Agreement (CRADA) with Aeroqual, a New Zealand-based company specializing in the development of air quality monitoring equipment, with the goal of investigating new applications, methodologies and technologies for the low-cost

Small air sensors like this one can be used by anyone curious about local air quality. Photo credit: Aeroqual.

- **Agreements Under Discussion**
  - Material Transfer Agreement (MTA) with PurpleAir supporting the exchange of air quality sensor data (current and historical)
  - Potential work EPA may pursue
    - Research on quality assurance methods for PA data
    - If methods produce data of sufficient quality, EPA may explore the use of the data in research studies and applications
      - Model evaluation
      - Data fusion
      - Data visualization
      - Development of research and informational applications



Acknowledgments

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- **RTP Evaluations:** *A. Clements, C. Johnson, S. Reece, K. Barkjohn, T. Conner, M. Srivastava, J. Rice, R. Williams*
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- **P-TAQS**: *S. Kimbrough, A. Clements, B. Davis, H. Patel, I. Domsky, R. Pope, I. VonWald, K. Barkjohn, J. Benforado, J. Schaefer, M. Kurpius, R. Evans, G. Hagler, Maricopa County AQD*
- **KC-TRAQS**: *S. Kimbrough, S. Krabbe, R. Baldauf, R. Duvall, M. Hays, P. Barfield, B. Mitchell, B. Wright, R. Snow, J. Faircloth, C. Bailey, C. Croghan, T. Barzyk, V. Isakov, G. Hagler, M. Davis, M. Brown, C. Brown, A. Shields, A. Bhesania, A. Algoe-Eakin, A. Hawkins, N. Feinberg, P. Deshmukh, T. McArthur*
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- **PurpleAir MTA**: *G. Hagler, A. Clements*

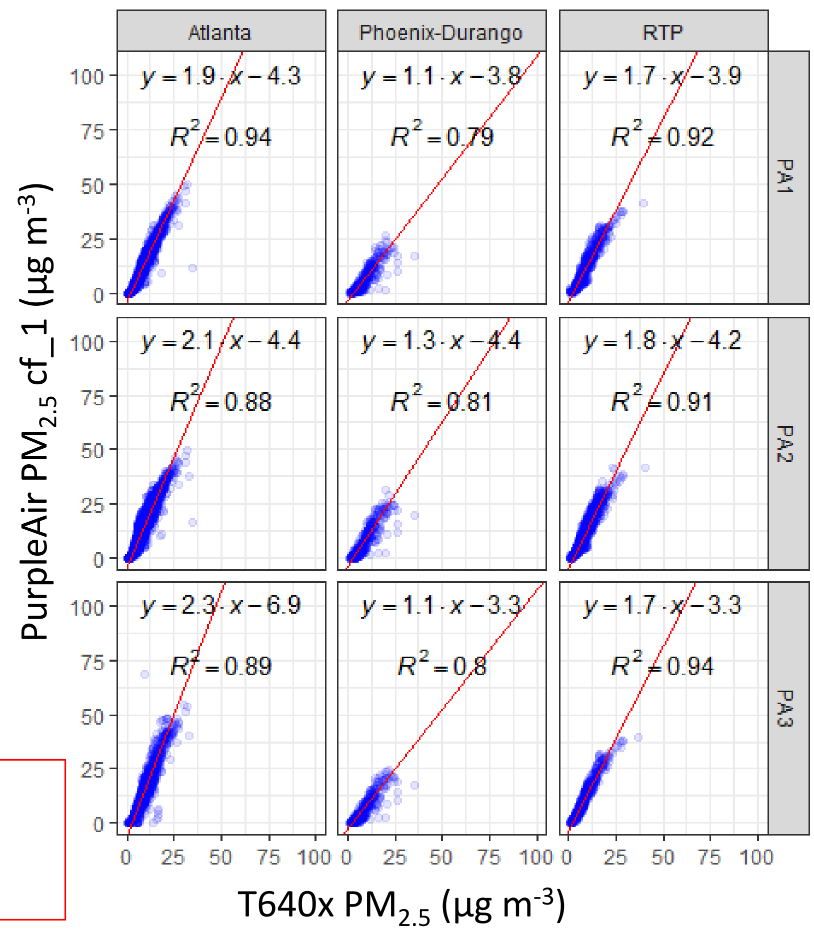
Supplemental Slides

LTPP - US Performance PurpleAir

Preliminary PurpleAir findings

- Good precision between sensors as similar slopes are observed for replicate sensors at same site.
- Accuracy is variable - field collocation is essential as relationships in different parts of the country vary
  - Slope ~2.1 Atlanta
  - Slope ~1.7 in RTP
  - Slope ~1.2 Phoenix

1-hr comparisons across 3 sites



Red line= linear regression

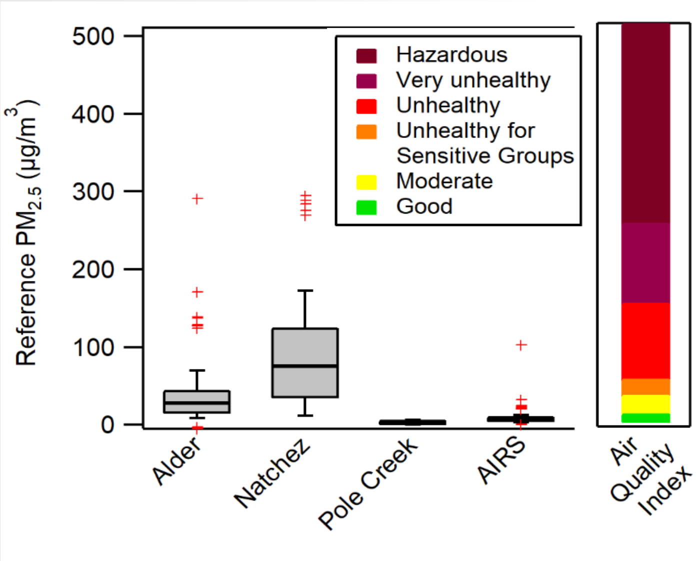
Preliminary results

PM sensors for wildfire smoke

Project Lead: Amara Holder

Evaluated low to mid-cost $PM_{2.5}$ sensors to augment ambient monitoring networks during wildfire smoke events:

- PurpleAir PAII-SD (PM_1, $PM_{2.5}$, PM_{10})
- Aeroqual AQY ($PM_{2.5}$, O_3, NO_2)
- SenSevere RAMP ($PM_{2.5}$, CO, CO_2)

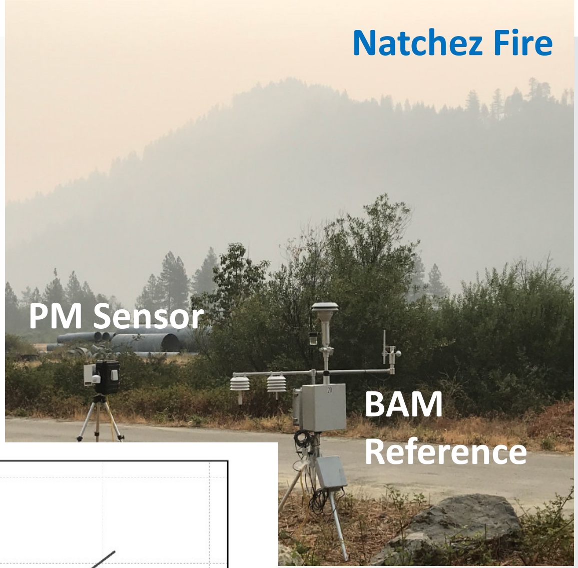


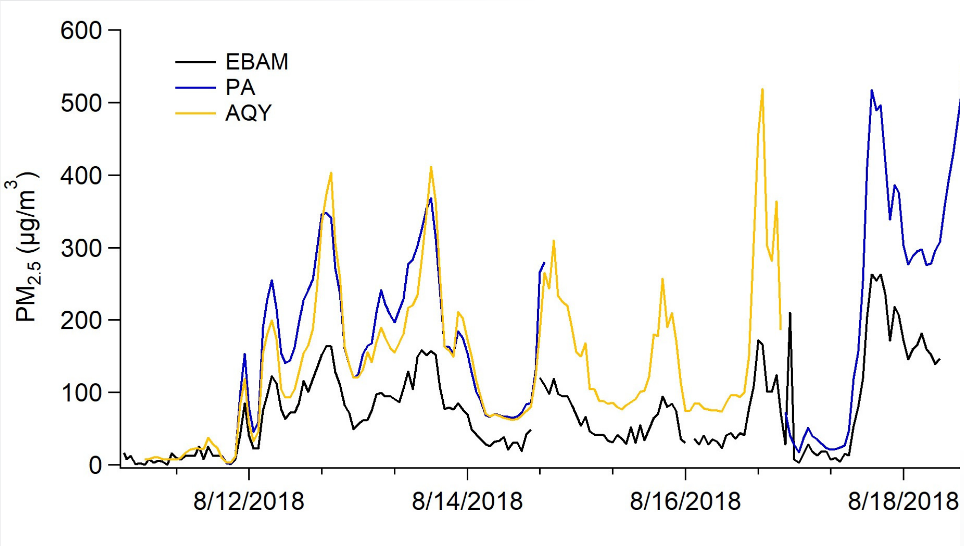
Fire/Measurement Location	Sensors	Reference
EPA ambient monitoring site (RTP, NC)	AQY, PA, RAMP	T640
Natchez Fire (Happy Camp, CA)	AQY, PA	E-BAM
Bald Mt – Pole Creek Fire (Price , UT)	AQY, PA	E-SAMPLER
Alder Fire (Springville, CA)	RAMP	BAM
(Pinehurst, CA)	AQY, PA, RAMP	BAM
(Camp Nelson, CA)	RAMP	E-BAM

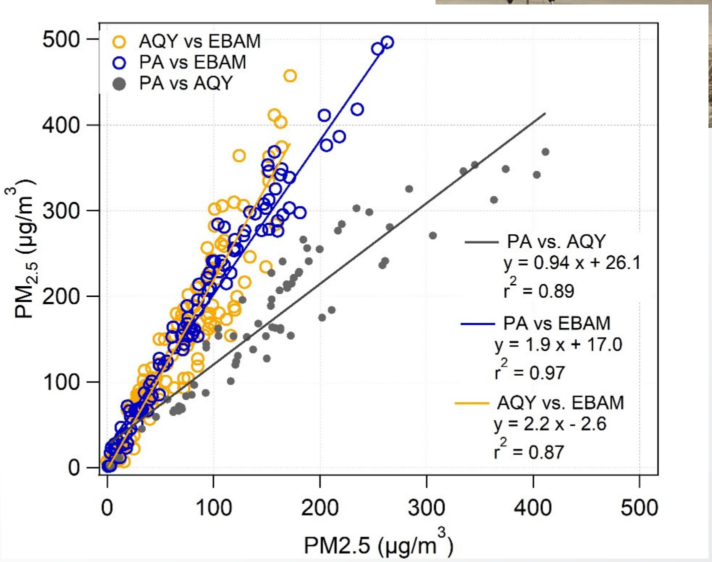
Preliminary results

PM sensors for wildfire smoke

- All PM sensors were highly correlated ($R^2 > 0.8$) with reference instruments at elevated PM concentrations
- PM sensors generally reported 1.5 – 2X higher than EBAMs at elevated concentrations, but were in better agreement at lower concentrations
- Correction for RH and T improve comparison







Preliminary results

Wildfire Smoke Translational Science

- Research study utilizing low-cost $PM_{2.5}$ sensors to conduct screening assessment of indoor/outdoor pollution concentrations at a variety of buildings in two locations affected by wildland fire smoke – Missoula, MT (summer 2019, summer 2020) and Hoopa Valley Tribal Reservation, CA (fall 2019 to summer 2020)
- Mobile monitoring package also utilized to map outdoor concentrations, coupling mid-cost $PM_{2.5}$ monitor with GPS, 1 second data resolution
- QA involves collocation with reference monitors and algorithm checks on comparison of identical internal sensors for deviations over time.

Science Leads:

Wayne Cascio

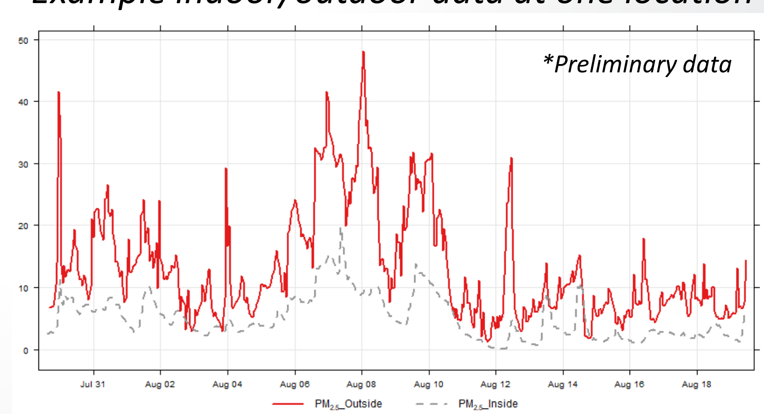
Gayle Hagler

Amara Holder

Prototype mobile system

Sensor collocation

Example indoor/outdoor data at one location



Preliminary results

Wildfire Smoke Translational Science

Research Questions

- What interventions are effective for reducing wildland fire smoke exposures and risks?
- How is public health impacted by different levels and durations of exposures?
- What science is available to support recommendations for communities to develop clean air spaces in larger buildings?
- How effective are portable air cleaners (PACs) during smoke events?
- Are people in community clean air spaces or who have PACs in their homes reducing their exposure/risks to PM2.5?

Project Design

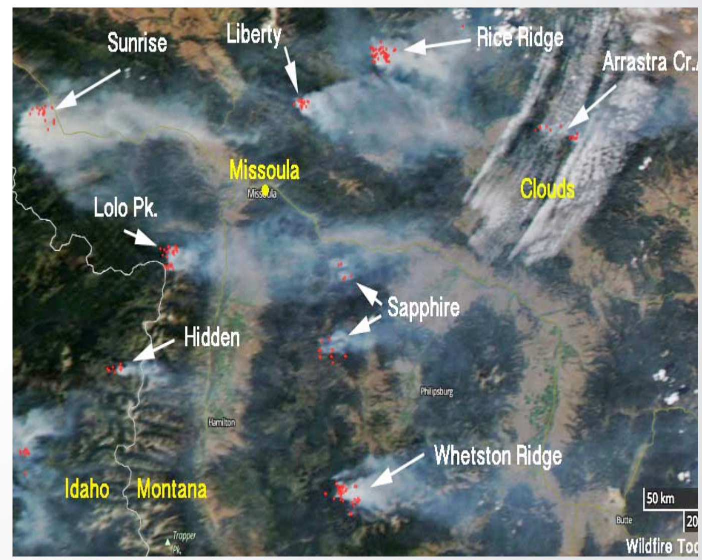
- Two 2019 field campaigns – Missoula, MT & Hoopa Valley, CA with indoor/outdoor measurements and outdoor mapping
- Laboratory testing with portable air cleaners

Science Leads:

Wayne Casio

Gayle Hagler

Amara Holder



Phoenix P-TAQ (Nov. 2018 – Mar. 2020)

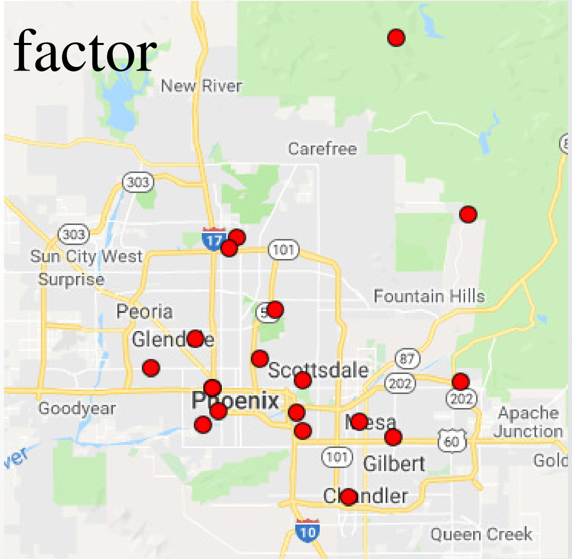
Project Lead: Sue Kimbrough

Phase 1 – Pilot (Nov. 2018 - May 2019)

- Study PurpleAir performance in unique, arid environment
  - Low humidity, high temperature, and high PM_{10} concentrations
- Evaluate sensor performance against collocated reference monitors
- Sensor degradation, reproducibility, and local correction factor

Phase 2 – (May 2019-Mar. 2020)

- Is PurpleAir suitable to supplement monitor network?
- Calibration of non-collocated PurpleAir sensors
- Optimal density and use of PurpleAir sensors

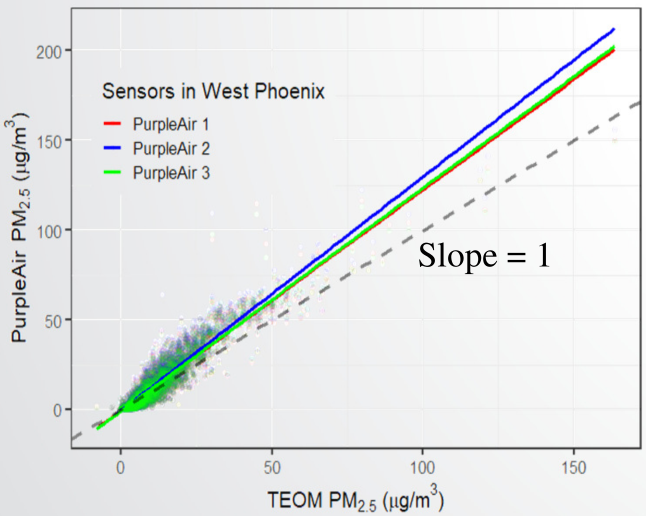


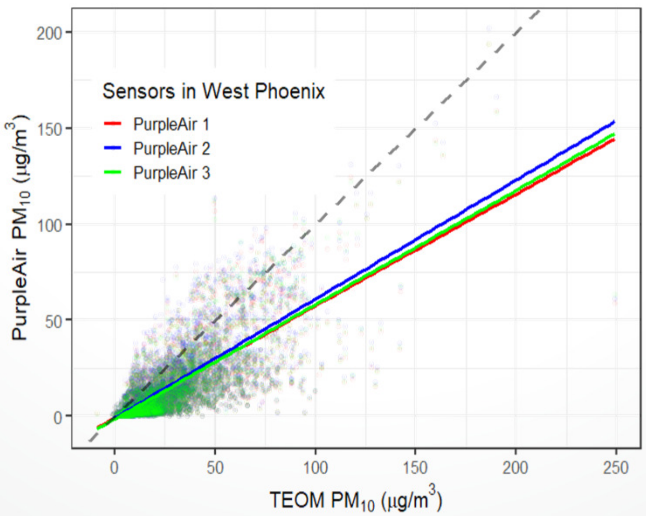
Preliminary results

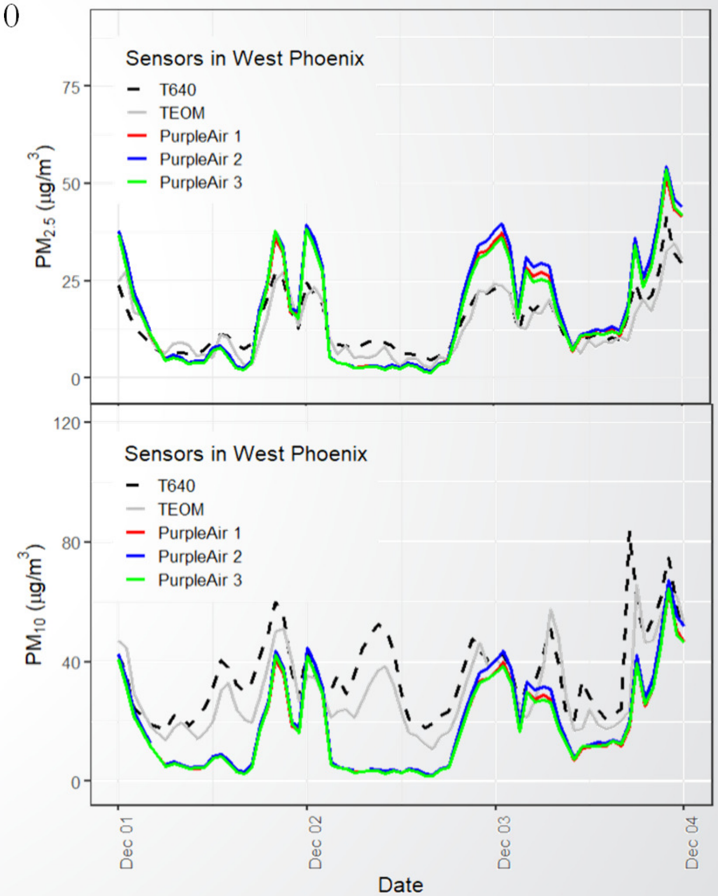
P-TAQ Pilot (Nov. 2018 – Apr. 2019)

- Hourly PurpleAir $PM_{2.5}$ data correlates much better than PM_{10}
- PurpleAir over-estimates $PM_{2.5}$, underestimates PM_{10}

Sensor	$PM_{2.5}$		PM_{10}	
	R^2	Regression	R^2	Regression
PurpleAir 1	0.88	y = 1.2x – 0.5	0.52	y = 0.6x – 0.8
PurpleAir 2	0.88	y = 1.3x - 0.5	0.52	y = 0.6x - 0.7
PurpleAir 3	0.89	y = 1.2x - 0.8	0.54	y = 0.6x – 1.4



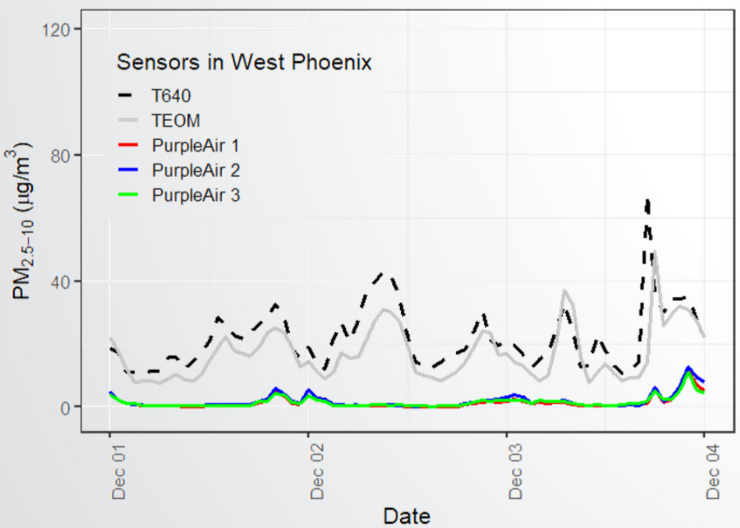


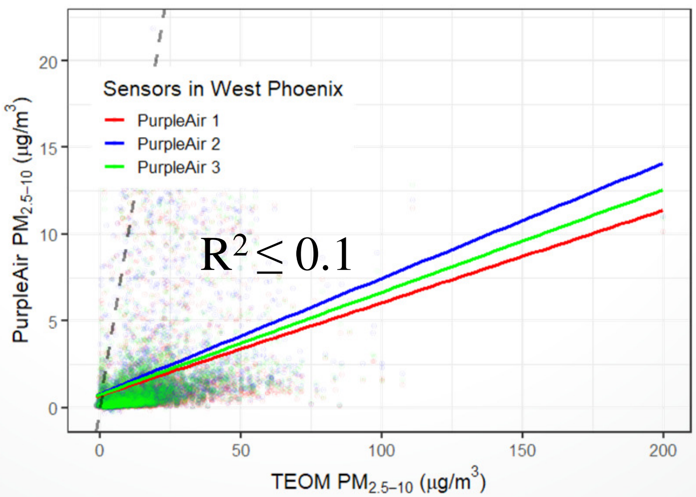


Preliminary results

P-TAQ Pilot (Nov. 2018 – Apr. 2019)

- Hourly PurpleAir $PM_{2.5}$ data correlates much better than PM_{10}
- PurpleAir over-estimates $PM_{2.5}$, underestimates PM_{10}
  - PM_{10} simply scales the $PM_{2.5}$ concentration – not a reliable measurement
  - $PM_{2.5-10}$ events are not detected by PurpleAir





The PurpleAir sensors tested appear to be unreliable for PM_{10}