New Tools For Air Quality Evaluation: Air Quality Sensors

AAPCA Fall Membership Meeting

Monday, August 26th, 2019

Andrea L. Clements, Ph.D.
U.S. EPA Office of Research and Development
clements.andrea@epa.gov

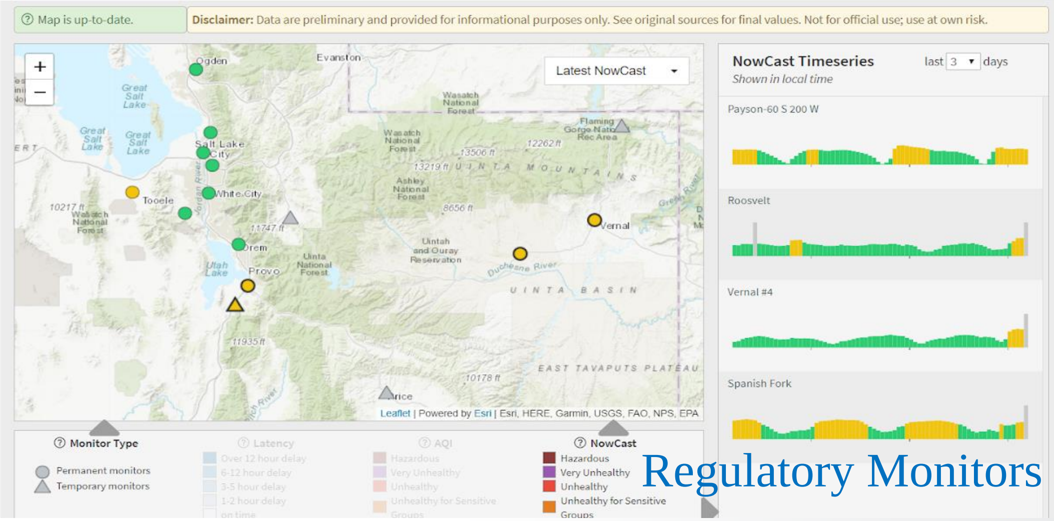
Background

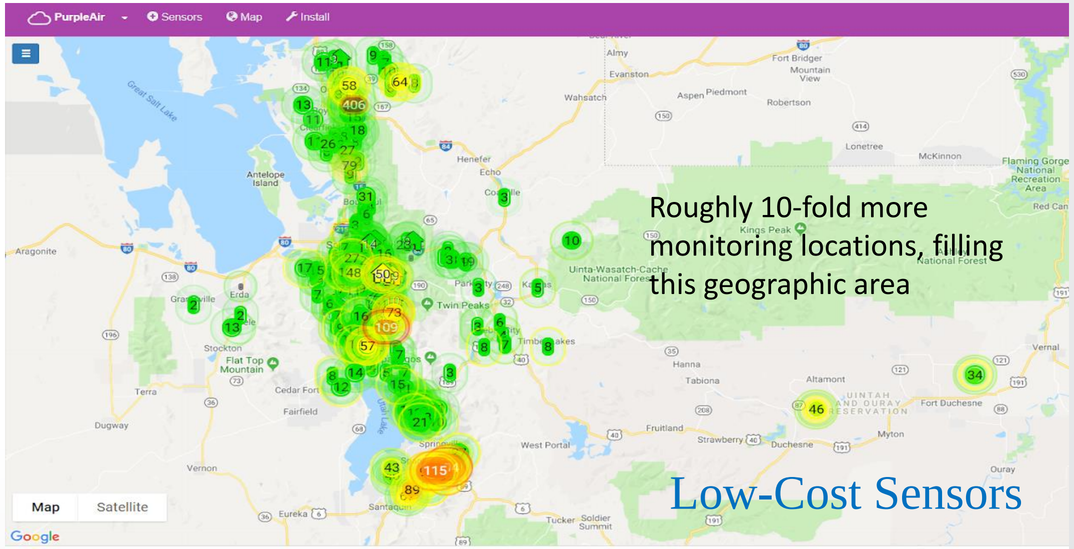
- Technological advances have made it possible to measure air quality with smaller, more portable sensors at lower-cost and in more locations while simultaneously engaging new players.

- Data is more complex with implications for data storage, processing, and data correction before it’s useful for research applications.

Motivation

- Rapid expansion in the use of sensors creates a growing need to understand the data being produced so that agencies are better able to respond.
  - As an example, there are more than 6000 publicly reporting PurpleAir sensors worldwide
  - Outnumber the regulatory monitors
- In some cases, this data is out-competing AirNow for Air Quality information
  - People sometimes believe data they collect themselves over data provided by government
  - Data is geographically closer and perceived to be more representative of local exposure





EPA Research

SPEAR (Sensor Performance, Evaluation and Application Research) Program

- Project Goals
  - Discover, evaluate, develop, apply and communicate new & 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 & future air quality 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 their clients/partners/stakeholders?

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 communicated through the Air Sensor Toolbox (https://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 sensor in a variety of locations for an extended period
- 7 air monitoring stations across the US - NC, GA, DE, AZ, CO, OK, WI
- 1-year of measurements beginning in July 2019
- Similar reference monitors across sites

Sites across the US

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

LTPP - US Performance PurpleAir

Design:

- Leverage projects already underway by air monitoring agencies
- 12 partner air monitoring agencies and ~50 collocated Purple Air sensors across the US

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

Partners from 10 states

Objectives:

- Draw broader conclusions about the performance of Purple Air sensors
  - Different climates
  - Extreme events
- Explore methods of Quality Assuring (QA) and adjusting data from distributed sensors

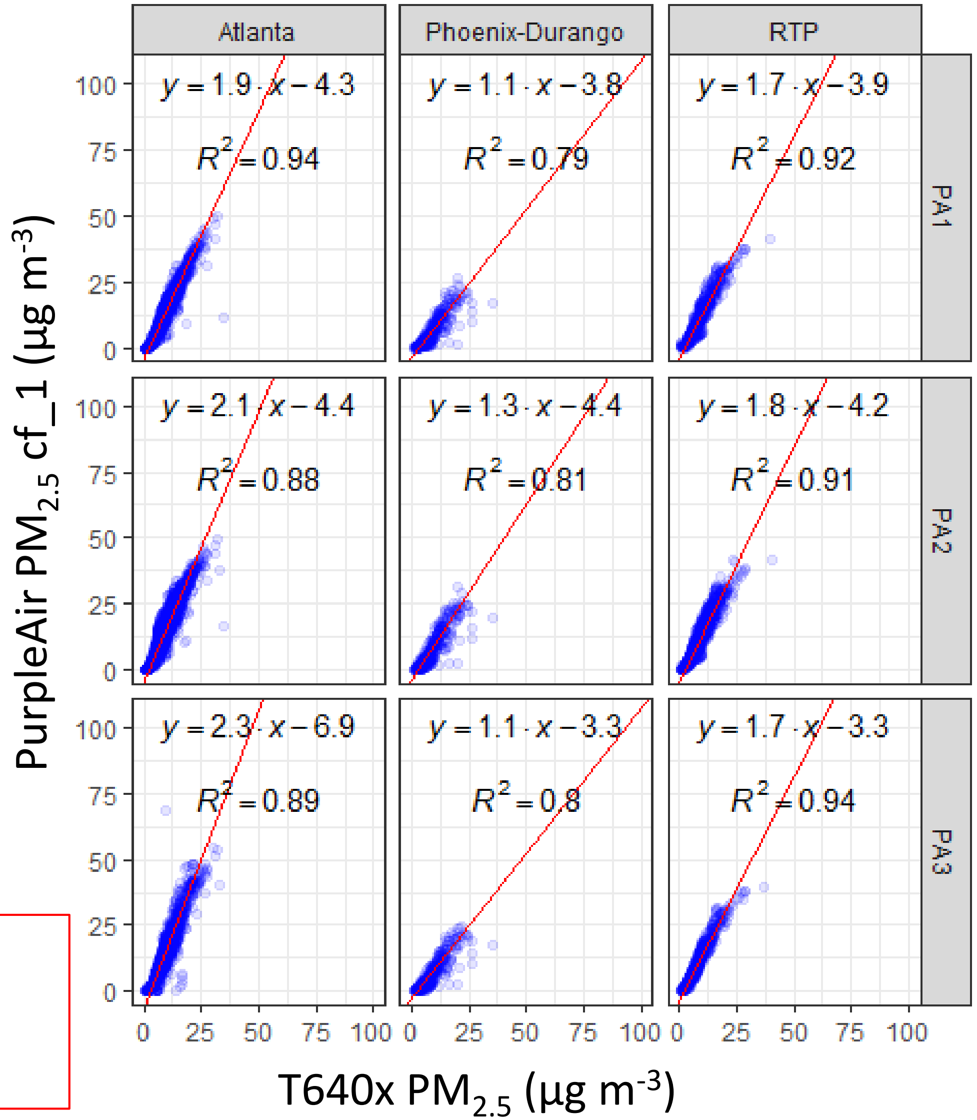
Preliminary results

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

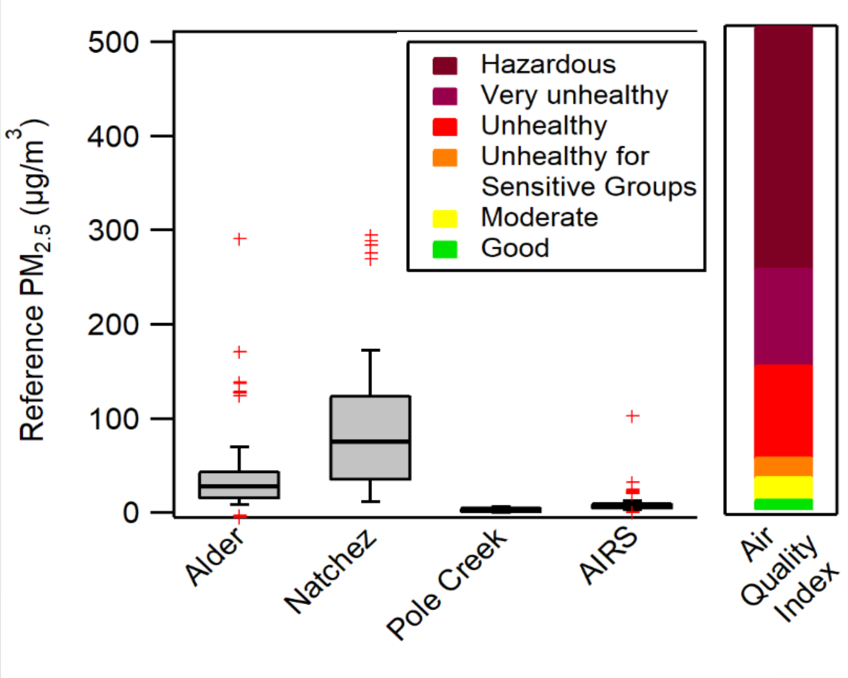
Preliminary results

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)

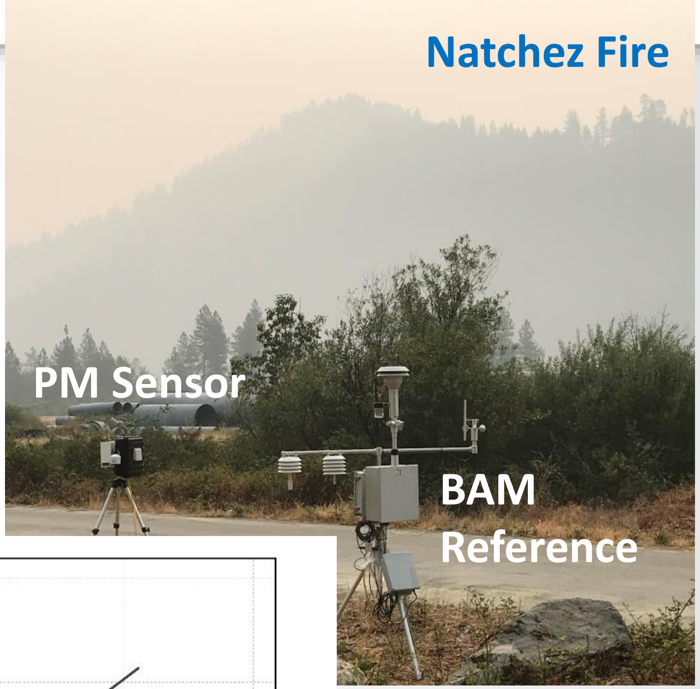


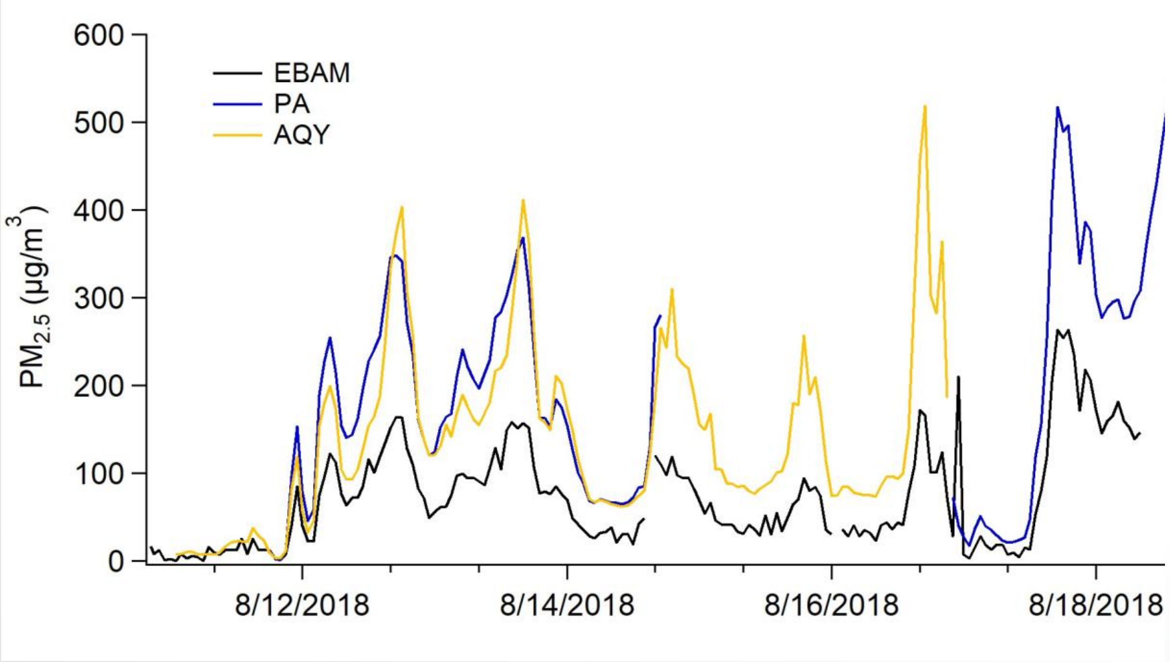
Fire/Measurement Location	Sensors	Reference
EPA ambient monitoring site (RTP, NC)	AQY, PA, RAMP	T640
Natchez Fire (Happy Camp, CA)	AQY, PA	E-BAM
Bald Mt – Pole Creek Fire (Price , UT)	AQY, PA	E-SAMPLER
Alder Fire (Springville, CA)	RAMP	BAM
(Pinehurst, CA)	AQY, PA, RAMP	BAM
(Camp Nelson, CA)	RAMP	E-BAM

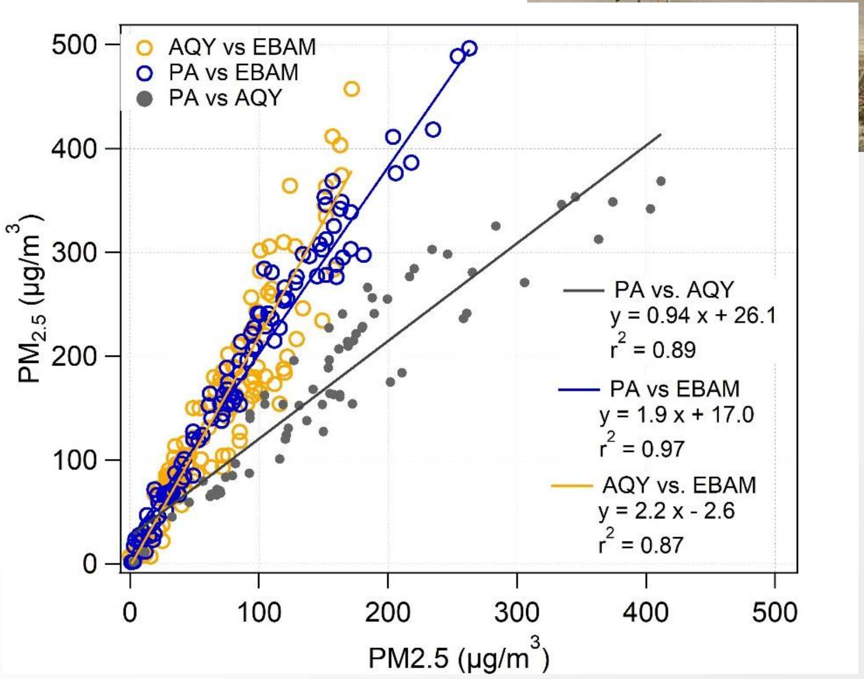
Preliminary results

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 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

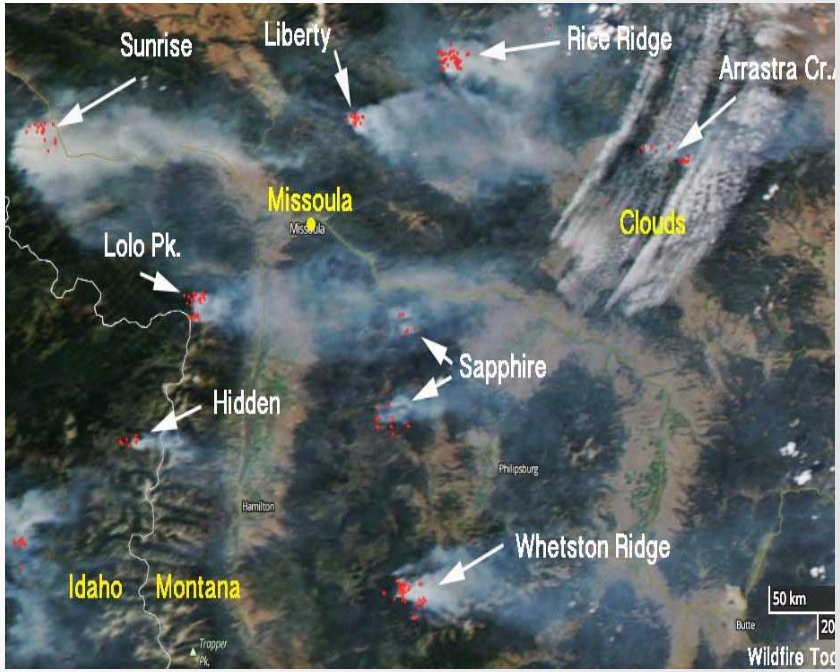
- Two 2019 field campaigns – Missoula, MT & Hoopa Valley, CA with indoor/outdoor measurements and outdoor mapping
- Laboratory testing with portable air cleaners

Science Leads:

Wayne Casio

Gayle Hagler

Amara Holder



Phoenix P-TAQ (Nov. 2018 – Mar. 2020)

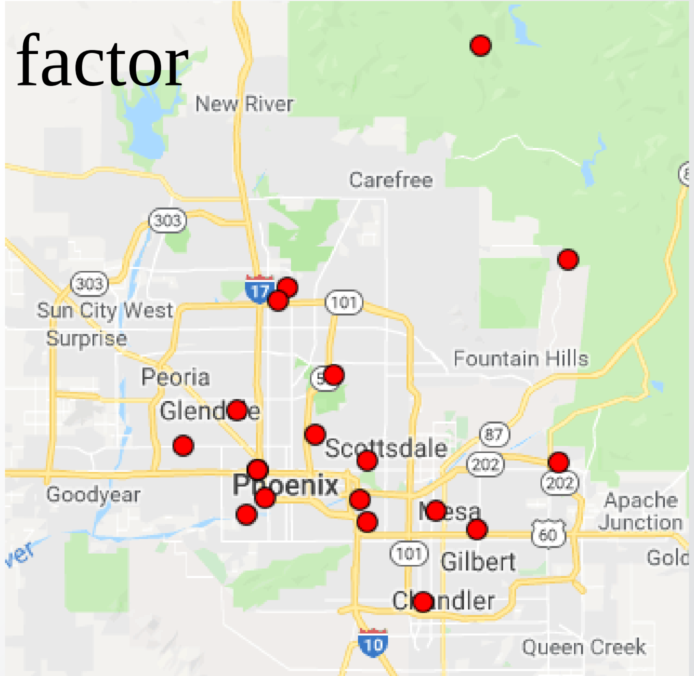
Project Lead: Sue Kimbrough

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

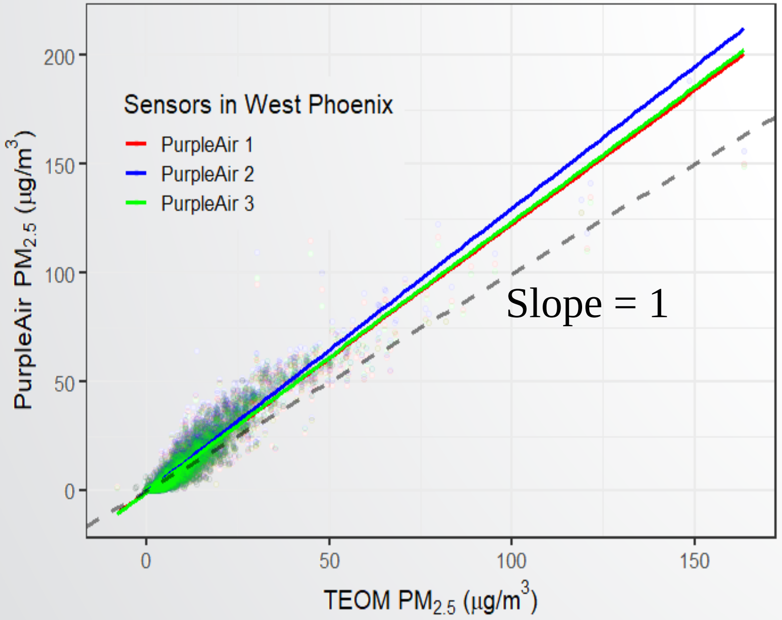


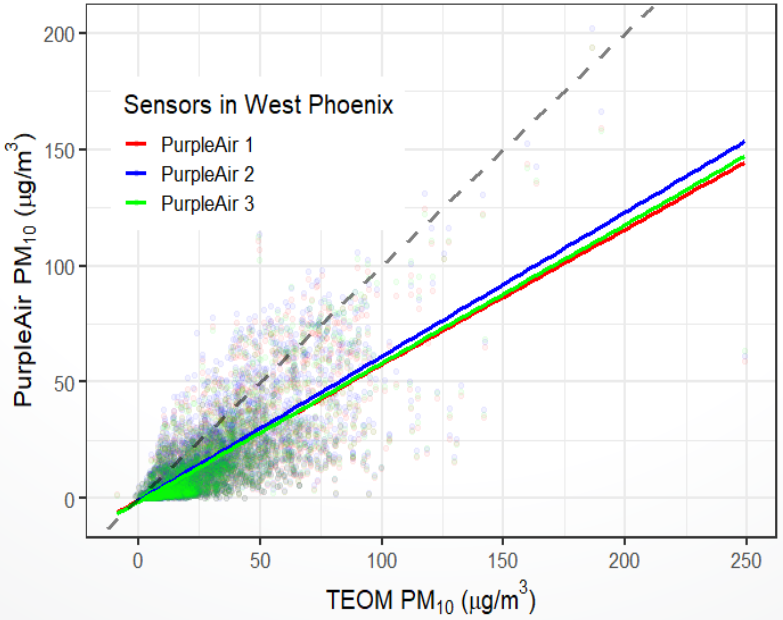
Preliminary results

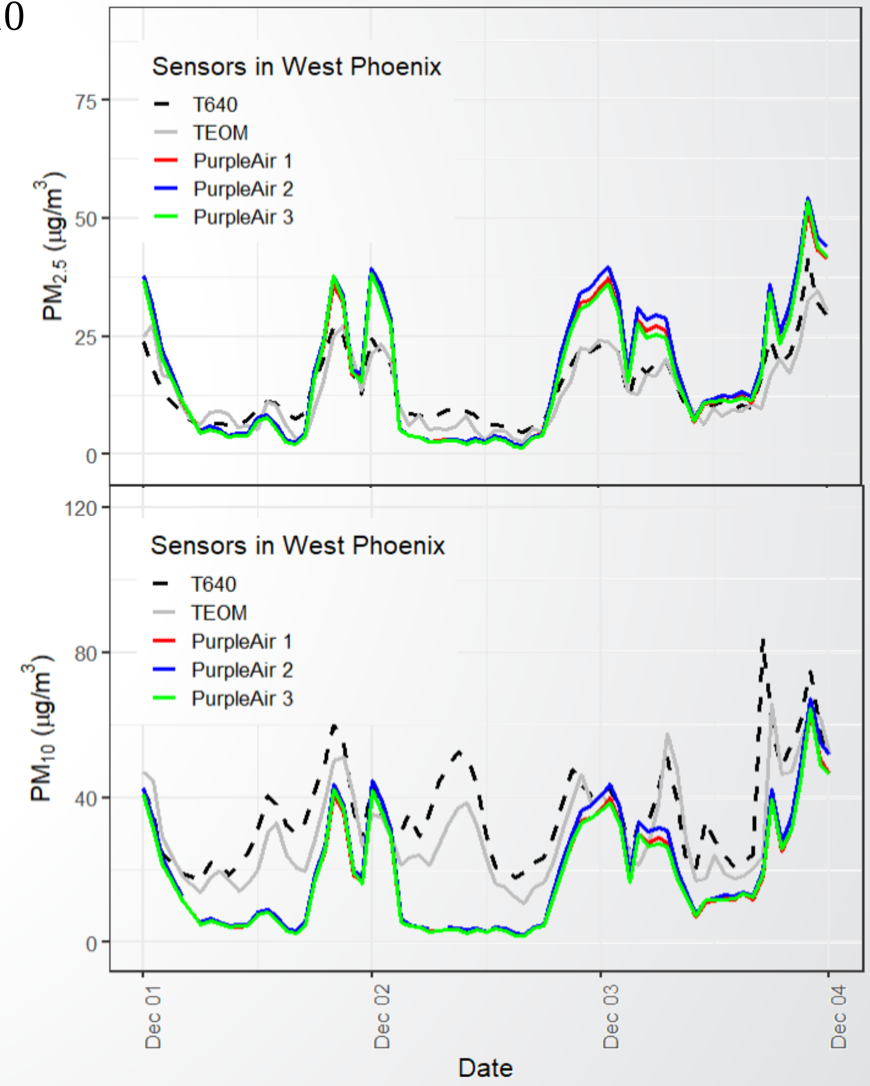
P-TAQ Pilot (Nov. 2018 – Apr. 2019)

- 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



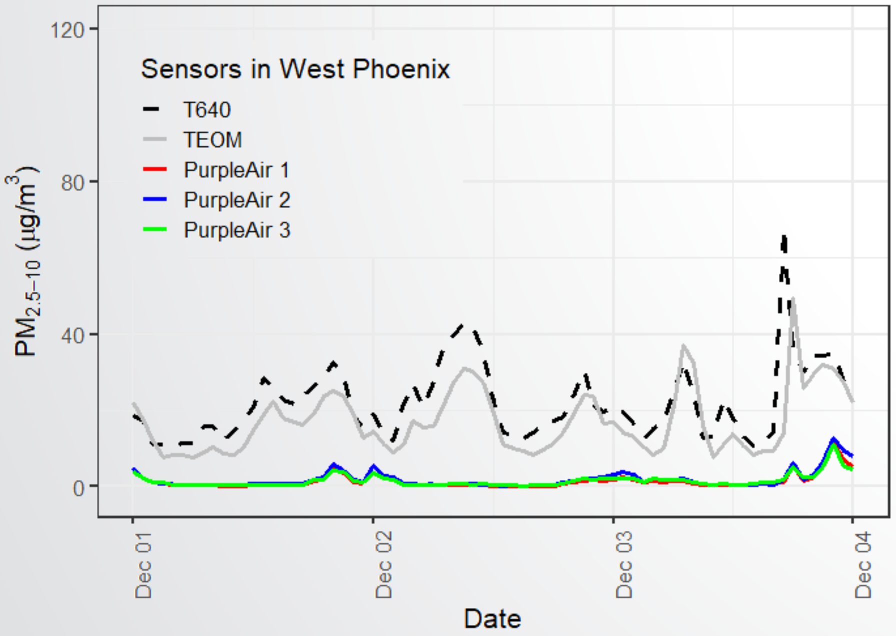


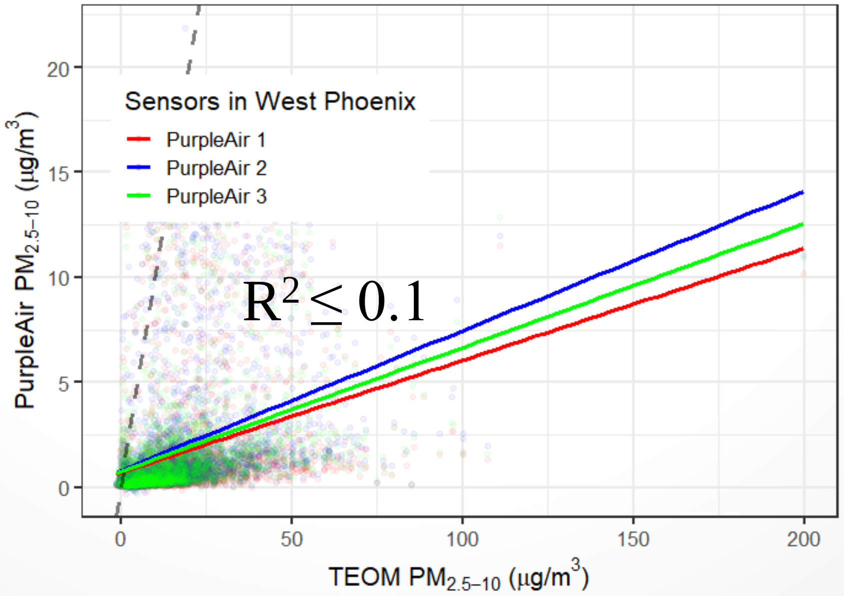


Preliminary results

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
  - $PM_{2.5\text{-}10}$ events are not detected by PurpleAir





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

KC-TRAQS (Oct. 2017 – Nov. 2018)

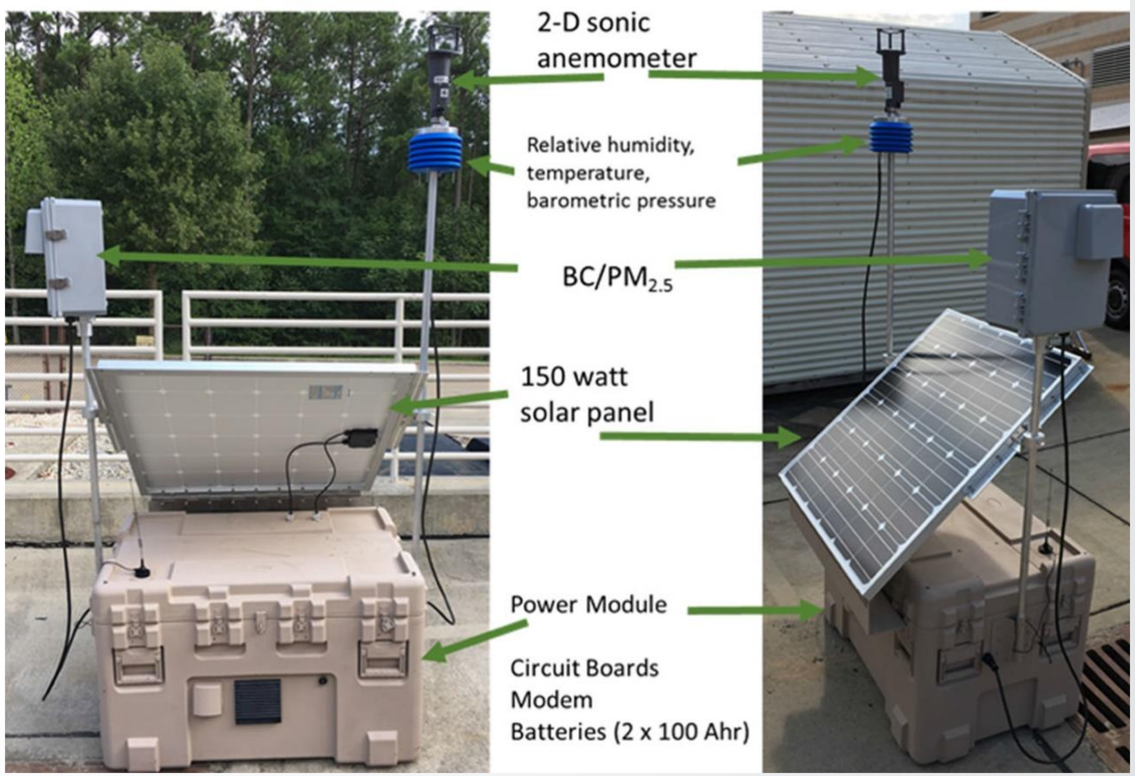
Project Lead: Sue Kimbrough

Kansas City TRansportation and local-scale Air Quality Study (KC-TRAQS)

- Research Questions
  - What is the spatial and temporal extent of local air pollution sources in and around the Argentine (KS) neighborhood?
  - Can the impact of local air pollution sources on the Argentine and surrounding neighborhoods' air quality be identified and quantified?
- Approach
  - A complementary citizen science program using personal sensors and computer modeling tools as a comparison to the field study data;
  - A field study using stationary monitors and mobile measurements to collect black carbon (BC) and $PM_{2.5}$ data to characterize the impact of local air pollution sources.
  - A mobile monitoring campaign using an instrumented electric vehicle and a support vehicle to collect BC, ultrafine particulate (UFP), and nitrogen dioxide (NO_2).
  - A screening model to assess spatial/temporal coverage of measurement sites.

KC-TRAQS (Oct. 2017 – Nov. 2018)

- Sensor Technologies
  - Custom built P-Pod measuring BC (AethLabs MA350) and $PM_{2.5}$ (Alphasense OPC-N2), WS/WD, T, RH, and P
  - Custom built AirMapper measuring $PM_{2.5}$ (Alphasense OPC-N2), CO_2, GPS, accelerometer, noise, T, and RH
  - Commercially available sensors including PurpleAir and Aeroqual AQY

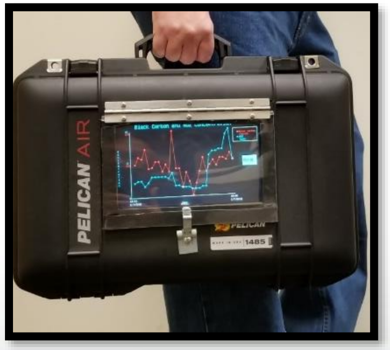


Roadside Vegetation Project

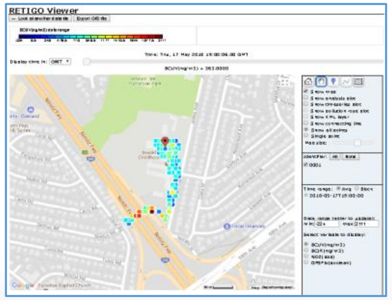
- Collaboration between ORD and EPA Regions (5, 9)
  - Collecting air quality, meteorology, and noise (Detroit only) measurements before and after roadside vegetation planting
  - Assessing benefits for air quality and water runoff control
- Approach
  - Research-grade mobile and fixed monitoring data for UFP, BC, NO_2, CO_2
  - Portable BC and NO_2 sensors
  - Meteorology at multiple heights and locations

Project Lead: Rich Baldauf


“Bird house”



Portable Air Quality Sampler (PAQS)

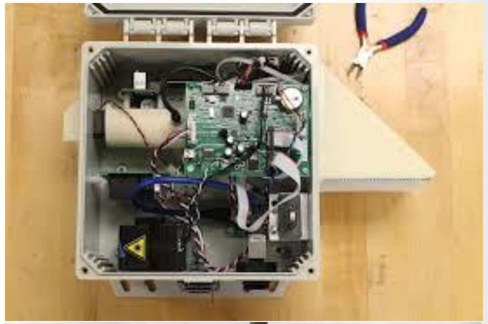


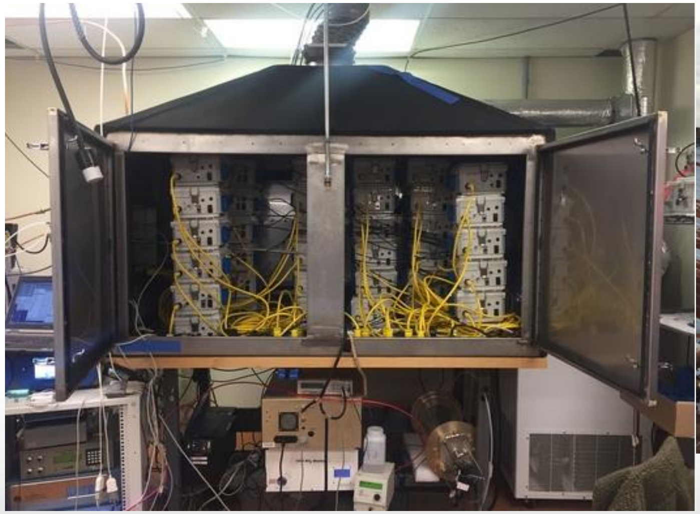
Data explored on RETIGO epa.gov/retigo

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





Library Sensor Loan Program

Project Lead: Andrea Clements

- Collaboration between ORD and EPA Region 9
  - Procurement of 30 low-cost PM sensors (APT) with clip and connectivity for mobile or stationary applications
  - Development of train-the-trainer materials, lessons plans, quick start guide, and a resource list to support the library use and loan
- Approach
  - Library trainers will be given training on air quality and use of sensors
  - Trainers will train additional library staff and conduct outreach programs within their respective library branches
  - Sensors will be loaned to interested community members (e.g., teachers, school groups, community groups, private citizens)
  - Materials will be made publicly available and lessons-learned will be summarized to support future efforts to expand the program to other locales

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

- 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

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

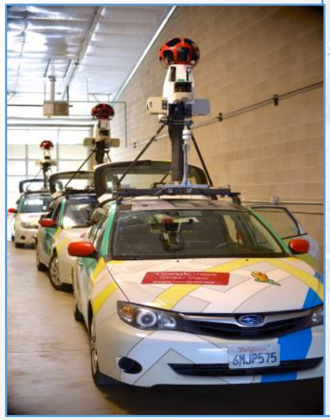
Published March 26, 2018

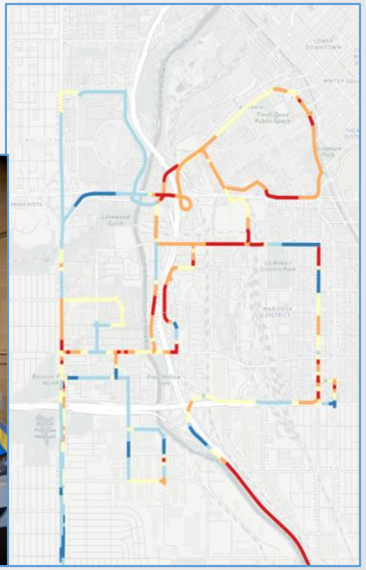
Next Generation Air Monitoring Tools are new technological advances that are increasingly being used by researchers and citizen scientists alike to monitor and measure air quality. Unlike large, stationary federal reference monitors, which allow only a limited group of specialists to use, Next Generation 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.





EPA Grantee Sensor Work

1. **Carnegie Mellon University** - *Democratization of Measurement and Modeling Tools for Community Action on Air Quality, and Improved Spatial Resolution of Air Pollutant Concentrations* – Pittsburgh, Pennsylvania
2. **Kansas State University/University of Memphis** - *Shared Air/Shared Action (SA2): Community Empowerment through Low-cost Air Pollution Monitoring* – Chicago, Illinois
3. **Massachusetts Institute of Technology** - *The Hawaii Island Volcanic Smog Sensor Network (HI-Vog): Tracking Air Quality and Community Engagement near a Major Emissions Hotspot* – Hawai'i Island, Hawaii
4. **Research Triangle Institute** - *Monitoring the Air in Our Community: Engaging Citizens in Research* – Globeville, Elyria Swansea (GES), Denver, Colorado
5. **South Coast Air Quality Management District** - *Engage, Educate, and Empower California Communities on the Use and Applications of "Low-cost" Air Monitoring Sensors* – North, Central, and South California
6. **University of Washington** - *Putting Next Generation Sensors and Scientists in Practice to Reduce Wood Smoke in a Highly Impacted, Multicultural Rural Setting (NextGenSS)* – Yakima Valley, Washington

Acknowledgments

Thanks to all contributors:

- EPA eval: *A. Clements, T. Conner, S. Reece, M. Srivastava, J. Rice, R. Williams*
- LTPP: *A. Clements, K. Barkjohn, I. VonWald, C. Johnson, Maricopa County AQD, Wisconsin DNR, Colorado DPHE, Oklahoma DEQ, Delaware DNR, Georgia DNR, Iowa DNR, San Luis Obispo Country APCD, EPA R4, Sarasota County Government, Quapaw Nation, Vermont DEC, Alaska DEC, Forsyth County OEAP, Mojave Desert AQMD, Antelope Valley AQMD*
- PM Sensors for wildfire: *A. Holder, B. Mitchell, A. Mebust, D. Vallano, L. Maghran, K. Stewart, R. Elleman, M. McGown*
- Wildfire Translational Science: *S. Katz, G. Robarge, W. Cascio, G. Hagler, A. Holder, B. Hassett-Sipple, C. Bagdikian, G. Davison, A. Brown, Missoula City-County Health Department, Climate Smart Missoula, University of Montana, Hoopa Valley Reservation*
- P-TAQ: *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*
- Vegetation: *R. Baldauf*
- Regional Loan: *A. Clements, B. Judge, R. Graham, C. Gross-Davis, M. Fuoco, J. Richard, C. Johnson*
- Library Loan: *A. Clements, R. Duvall, B. Hubbell, A. Kaufman, R. Freed, E. Canteenwala, K. Davidson, P. Pathak, D. Vallano*
- Aeroqual CRADA: *R. Duvall, G. Henshaw*
- Aclima CRADA: *S. Kaushik, A. Whitehill, M. Small, D. Vallano, C. Tucker, S. Caspersen, M. Lunden, B. LaFranchi, A. Singh, C. Blanchard*
- PurpleAir MTA: *G. Hagler, A. Clements*
- STAR Grants: *R. Callan*