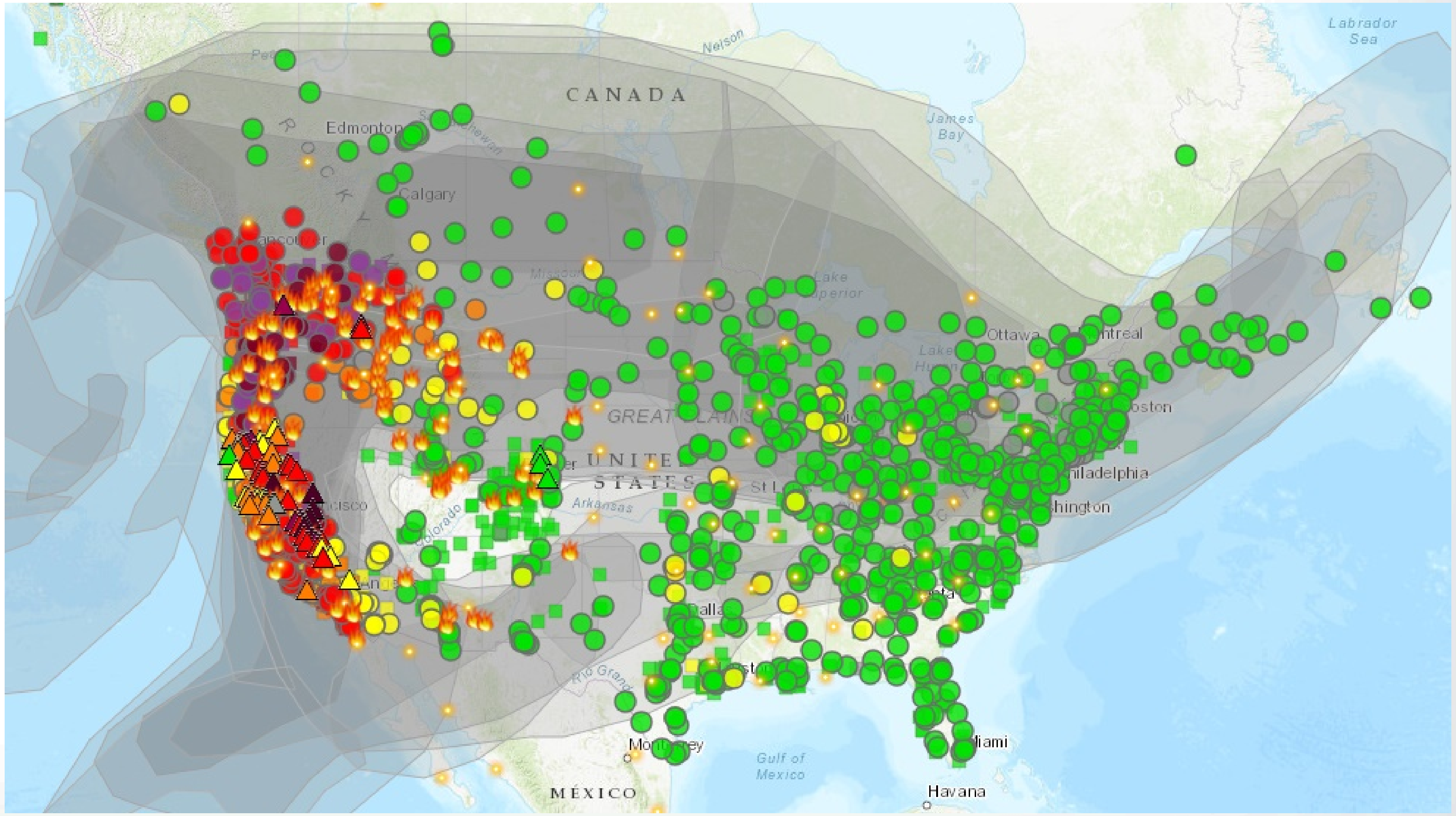
# Air sensors for wildfire smoke:

*PurpleAir, AirNow Fire and Smoke Map, and beyond*

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*Tribal Science Council*
*December 4, 2020*

# Introductions


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# Overview of Today’s Presentation

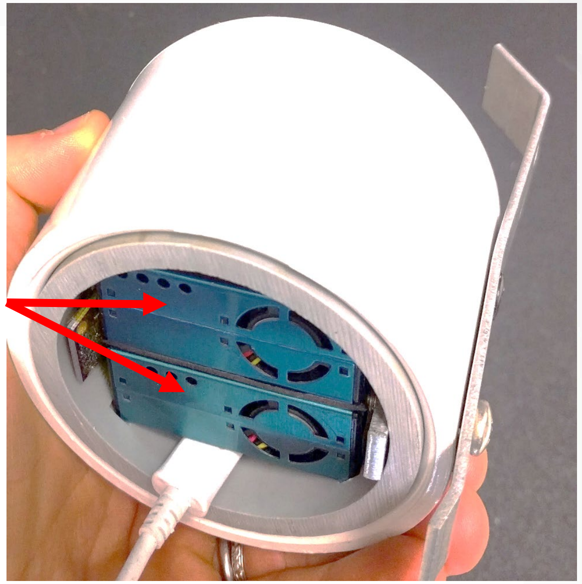
- Primer on PurpleAir Sensors
- Development of a U.S.-wide correction equation for PurpleAir
- Accuracy of the PurpleAir for wildfire smoke
- AirNow Fire and Smoke Map Sensor Data Pilot
- Smoke measurements in remote locations
- ORD/Regional/Tribal collocation project
- Air Sensor Resources

# Primer on PurpleAir Sensors

# Primer on PurpleAir Sensors: Hardware and Outputs

## PurpleAir Data

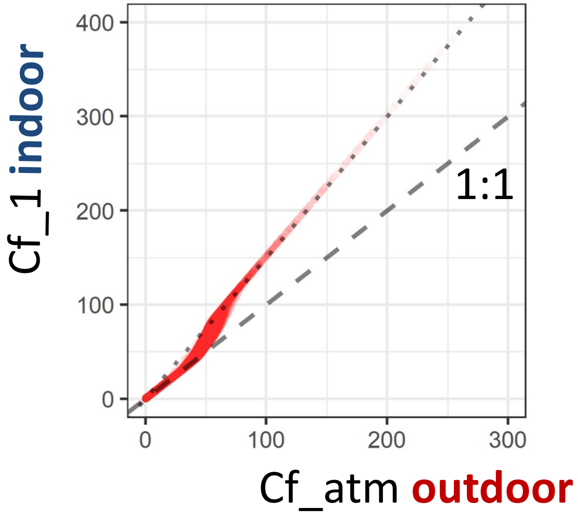
- 2 Plantower PMS5003 PM sensor (channels A & B)
- Channels alternate 10 s sampling intervals
- Reports 2 min averages (previously 80 s)




**PurpleAir underside view**

## PurpleAir Data Outputs

- Particle count by size
- $PM_1$, $PM_{2.5}$, $PM_{10}$ with 2 correction factors:
  - **CF=atm "outdoor"** (lower concentrations)
    PurpleAir map **outdoor** sensors
  - **CF=1 "indoor"** (higher concentrations)
    PurpleAir map **indoor** sensors
- ***Internal*** temperature, relative humidity, pressure (BME280 sensor)



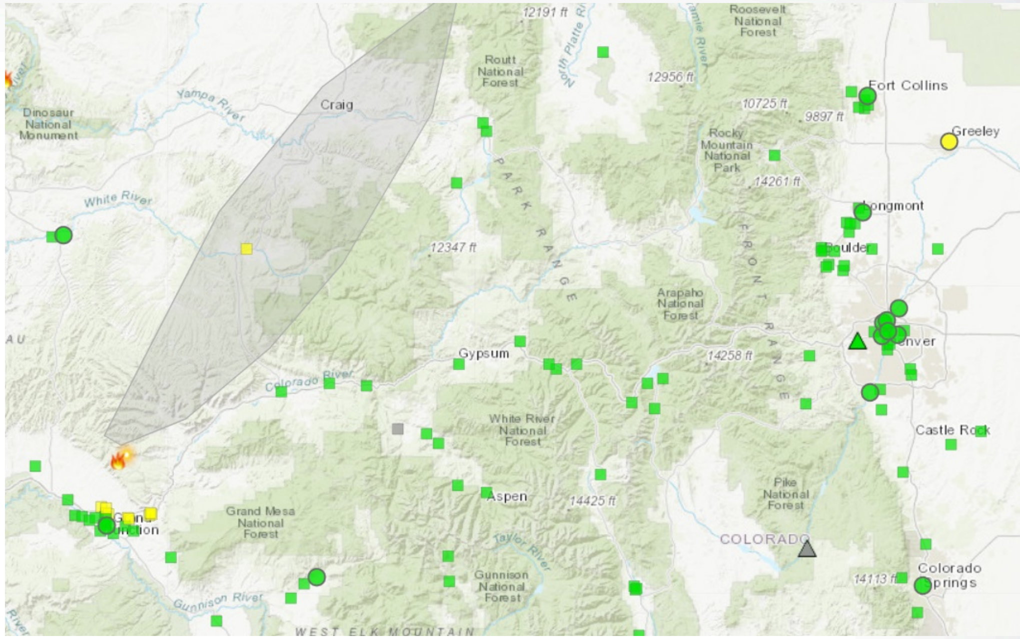

## PurpleAir Data Storage

- Stored locally on a microSD card (PA-II-SD model)
- Streamed to the PurpleAir cloud via wifi
  - Public – displays on the public PurpleAir map
  - Private – displays only when owner logged in

# U.S.-Wide PurpleAir Correction

# Motivation for EPA ORD's work with PurpleAir

- **Air sensors can provide more spatially resolved air quality information**
  - Especially important in rural areas
- **Data is especially helpful in understanding the impact of wildland fire smoke**
  - Variable in time and space due to terrain and meteorology
- **PurpleAir sensors have been widely used by the public and data is reported by media outlets**
- **However, initial studies were typically limited to a few sensors at a single site or region, sometimes not collocated, did not evaluate performance for smoke**




**Additional Information in Remote Mountainous Areas**

*Image source: https://maps.airfire.org/ara/*

*Image source: http://nwcg.gov*

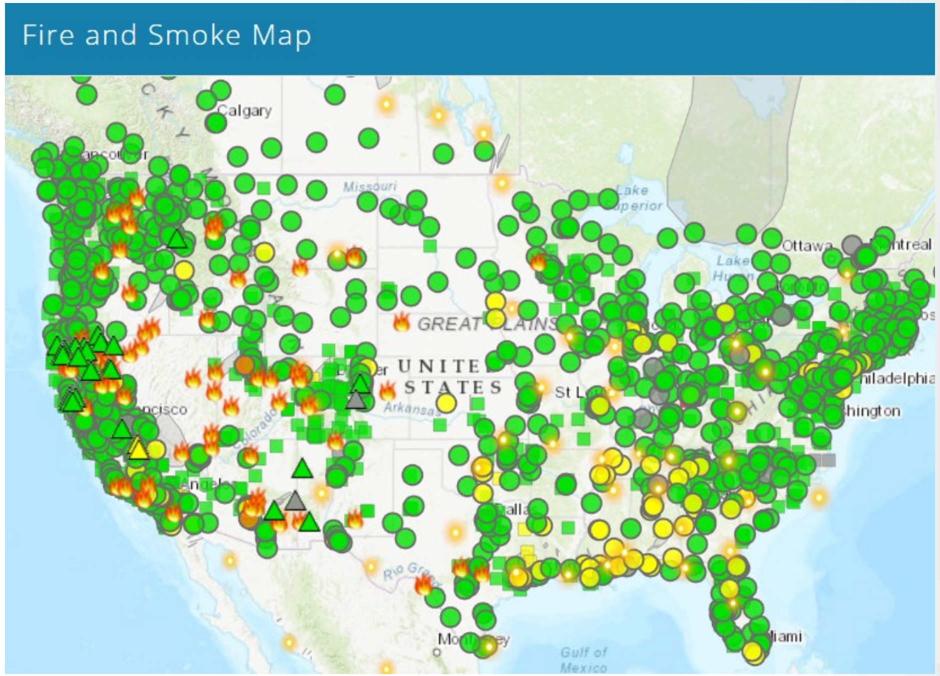
# Goals for U.S.-Wide Correction Work and AirNow Pilot

## Guiding Question

- Is it feasible to use a single correction to improve performance across the U.S.?
    - Use collocations across the country

## Goals

- Balance improved performance with model complexity to avoid overfitting
- Evaluate the performance of the correction for:
    - ambient applications
    - smoke impacted sites
- Use sensors to provide additional data on the AirNow fire map, especially during smoke impacts and where none exists.




**AirNow Fire and Smoke Map**

*Image source: https://maps.airfire.org/ara/*

# Development of the U.S.-Wide Correction Equation for PurpleAir Sensor Data

# Data Sources for this work

Secondary data collected independently by air monitoring agencies and provided to EPA

PurpleAir sensors provided by EPA

Long Term Performance Project (and LTPP+*)

**Team:** EPA ORD, partner local air agencies
**Objective:** Evaluate multiple sensors across the U.S. (LTPP+ PurpleAir only)

**24-hr U.S.-Wide Correction Development**

**Method:** collocations with FEM and FRM measurements
**Objective:** Build a correction equation that improves PurpleAir performance across the U.S.

*LTPP+ = In addition to 7 locations outfitted with multiple sensor types, a few additional collocations sites were established with JUST PurpleAir sensors

# Description of Collocation Sites


Collocation sites across the U.S.

## Collocation Dataset:

- 50 sensors at 39 sites across 16 states
- Range of meteorological conditions and particle types/sizes
- Sensor data collection began at different times with the earliest beginning in late 2017

## Reference monitors:

- Operated and maintained by state, local, and tribal (SLT) agencies with their own approved monitoring plans and QA/QC protocols

## Site characteristics:

- Regulatory monitoring sites characterized as urban and neighborhood sites with no clear hyperlocal sources

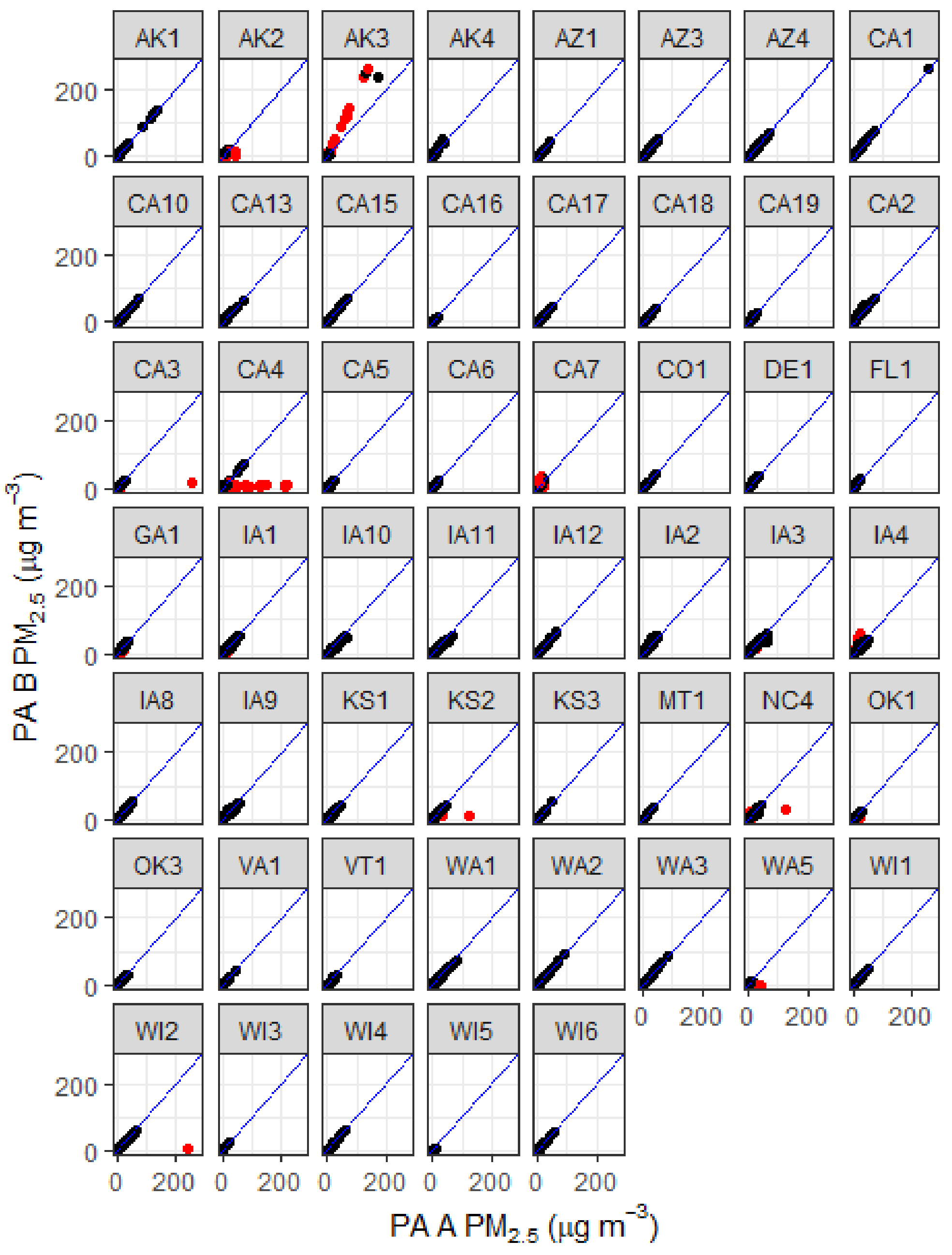
## Collocation characteristics:

- PurpleAir sensors were located at regulatory sites and typically placed within 10m horizontal distance and 1m vertical distance of regulatory monitor, away from flow obstructions and trees
- Sites identification
  - Identified publicly available sensors within 50m of a reference monitor and contacted agencies to verify these as ‘true collocations’

# PurpleAir U.S.-Wide Correction: Data Cleaning

- Agreement between A and B channels provides confidence in measurements
- Points removed if 24-hr averaged A & B $PM_{2.5}$ differed by
  - $\geq \pm$ 5 µg $m^{-3}$ AND
  - $\geq \pm$ 62% (95% Confidence interval on % error)
- 2% of points of full dataset excluded
- 19/53 sensors had at least 1 point removed (36%)
- A & B channels averaged to increase certainty

Red points removed



# PurpleAir U.S.-Wide Correction: Equation selection

- Considered the following parameters onboard the PurpleAir using 24-hr averages:
  - $PM_{2.5}$
    - $PM_{2.5}$ cf_1
    - $PM_{2.5}$ cf_atm
    - Binned counts (calculated values, not true counts)
      - $B_{>0.3}$, $B_{>0.5}$, $B_{>1.0}$, $B_{>2.5}$, $B_{>5.0}$, $B_{>10.0}$
  - Environmental parameters
    - Temperature (T), Relative Humidity (RH), Calculated Dewpoint (D)
- Compared performance of a variety of equation forms
  - Built and tested on independent datasets

# PurpleAir U.S.-Wide Correction: Selected Model

## Resulting Correction Equation

**$PM_{2.5}$ corrected= 0.524*[$PurpleAir_{CF=1;\ avgAB}$] - 0.0852*RH + 5.72**

- $PM_{2.5}$ = ($\mu g\ m^{-3}$)
- RH = Relative Humidity (%)
- $PA_{cf=1;\ avgAB}$ = PurpleAir higher correction factor data averaged from the A and B channels

## Reasoning:

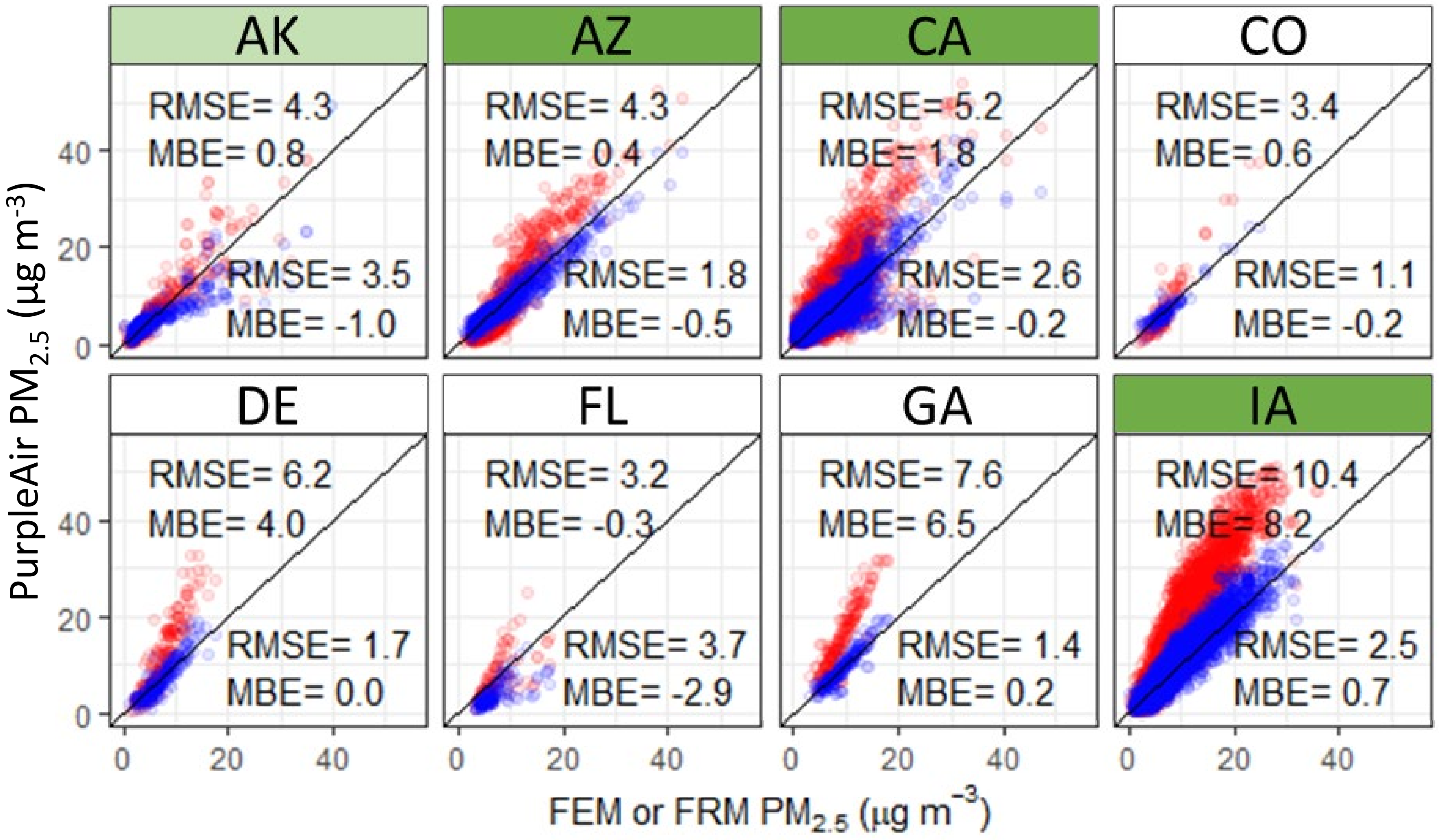
- A less complex model is less likely to over fit the data

More details on this work can be found on the air sensor toolbox:
https://www.epa.gov/air-sensor-toolbox/technical-approaches-sensor-data-airnow-fire-and-smoke-map

# PurpleAir U.S.-Wide Correction: Performance by State

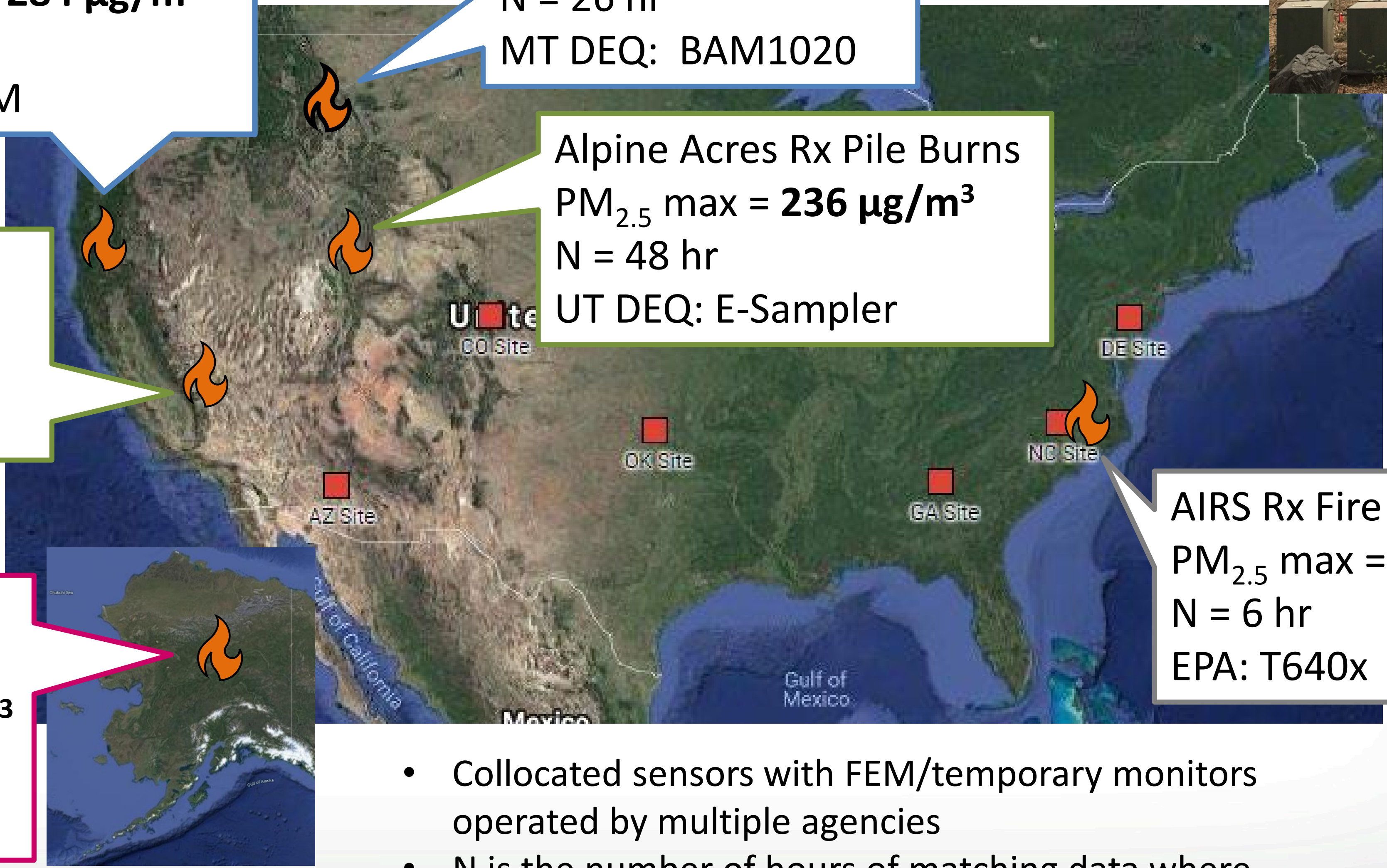
- State bias typically within 2 µg $m^{-3}$
- RMSE typically reduced to within 3 µg $m^{-3}$
- Low bias in FL
  - <1 year of data, so may be some seasonal bias
  - More data needed in this region

Data **before correction** and **after correction**
With >1 year of data in **green** (10+months in light green)



# Accuracy of the PurpleAir for wildfire smoke

# Smoke Impacted Datasets




Natchez Wildfire
$PM_{2.5}$ max = **284 µg/m³**
N = 290 hr
CARB: E-BAM

Missoula Rx Fires
$PM_{2.5}$ max = **75 µg/m³**
N = 26 hr
MT DEQ: BAM1020

Alpine Acres Rx Pile Burns
$PM_{2.5}$ max = **236 µg/m³**
N = 48 hr
UT DEQ: E-Sampler

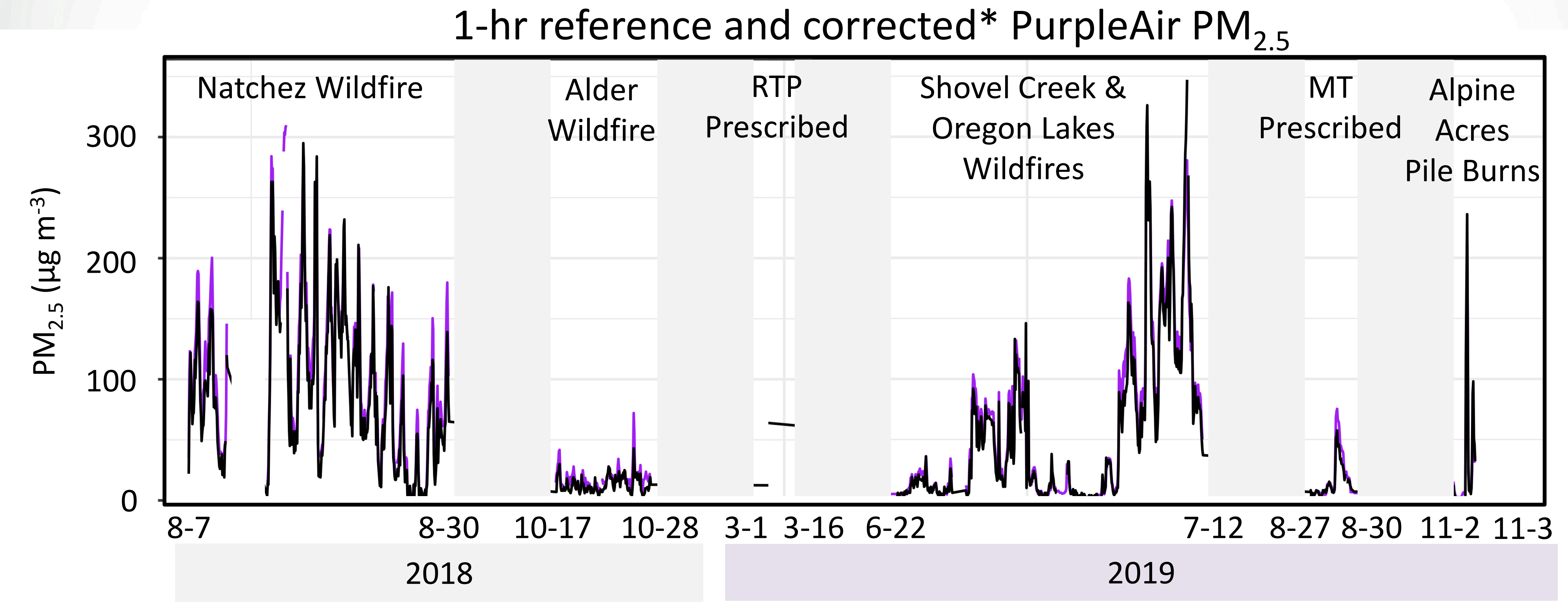
Alder Wildfire
$PM_{2.5}$ max = **32 µg/m³**
N = 64 hr
USFS: BAM 1020

AIRS Rx Fire
$PM_{2.5}$ max = **40 µg/m³**
N = 6 hr
EPA: T640x

Shovel Creek/Oregon Lakes Wildfires
$PM_{2.5}$ max = **200 µg/m³**
N = 290 hr
ADEC: BAM 1020

- Collocated sensors with FEM/temporary monitors operated by multiple agencies
- N is the number of hours of matching data where reference > 12 µg $m^{-3}$

# Smoke Impacted Time Series

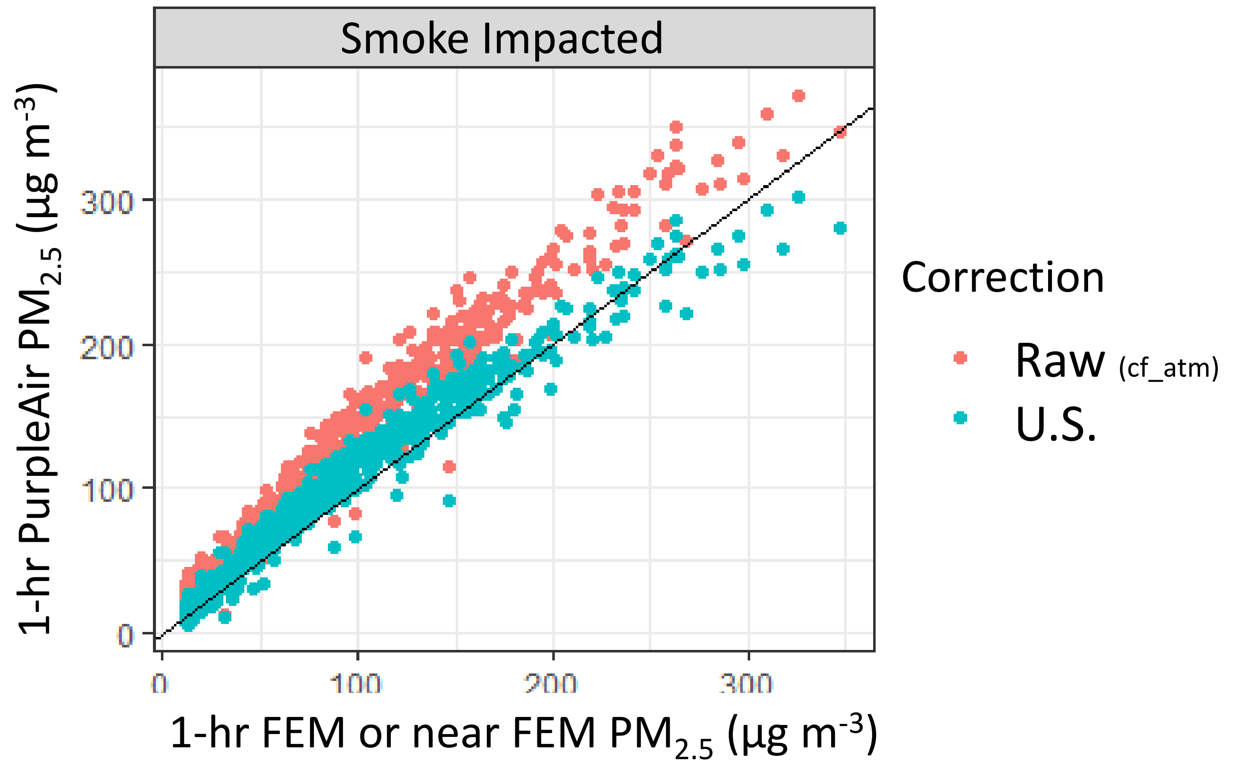



* Using the PurpleAir U.S.-wide correction

# 1-hr U.S.-Wide Correction Equation Performance

| Correction | type | cf | Equation | MBE* µg $m^{-3}$ (%) |
|---|---|---|---|---|
| U.S. | U.S. ambient | 1 | PAx0.524 - 0.0852xRH + 5.72 | 6.4 (12%) |
| None | n/a | atm | none | 30.2 (38%) |

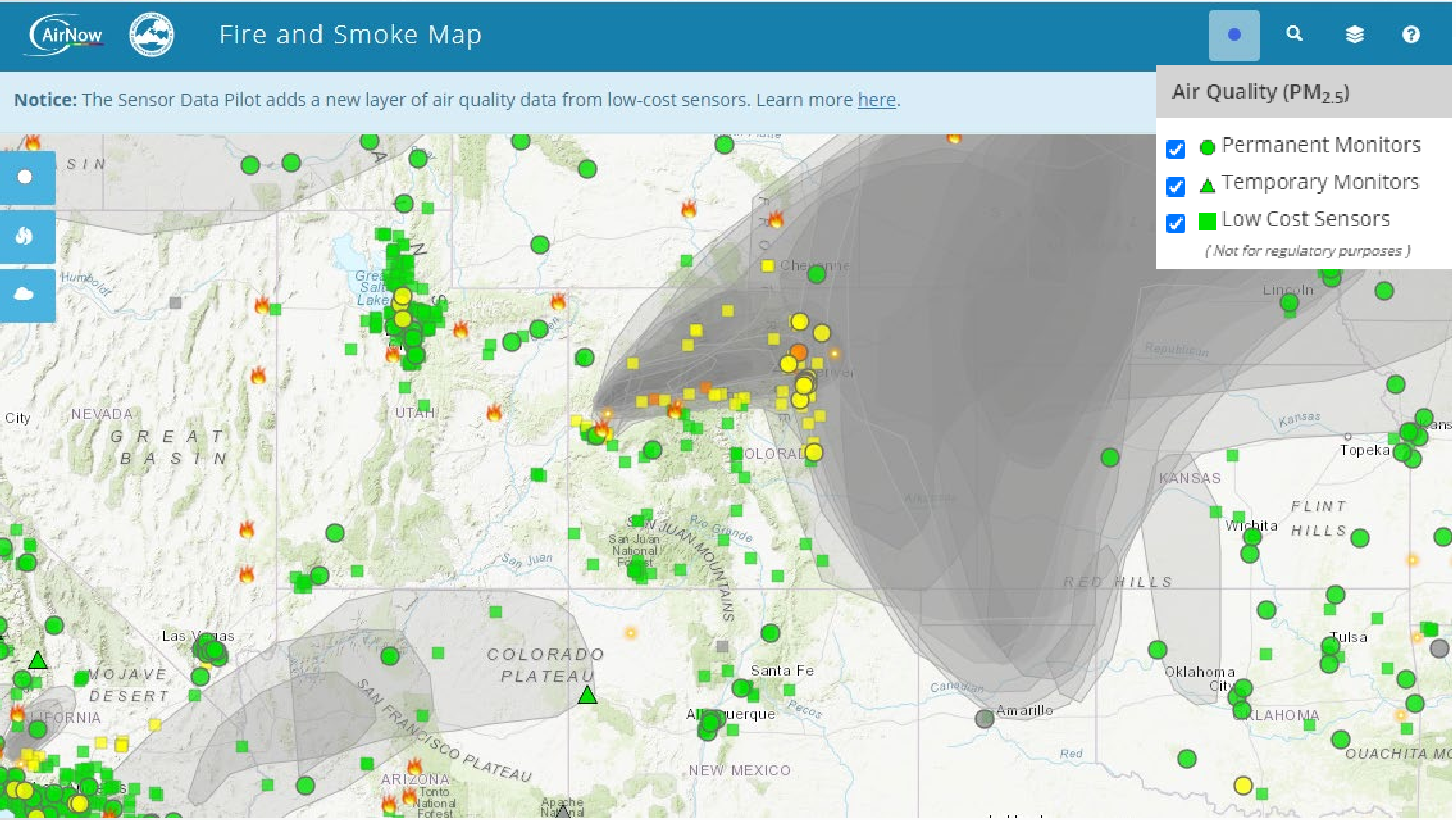
U.S.-wide correction reduces error from raw data currently display on PurpleAir map




* MBE = mean bias error

# AirNow Fire and Smoke Map Sensor Data Pilot

# PurpleAir Add Spatial Variation of Smoke in Areas with Few Monitors




## Map Features:

- Major fire incidents
- Permanent monitors
- Temporary smoke monitors
- PurpleAir sensors
- Satellite hotspots
- Satellite smoke plumes

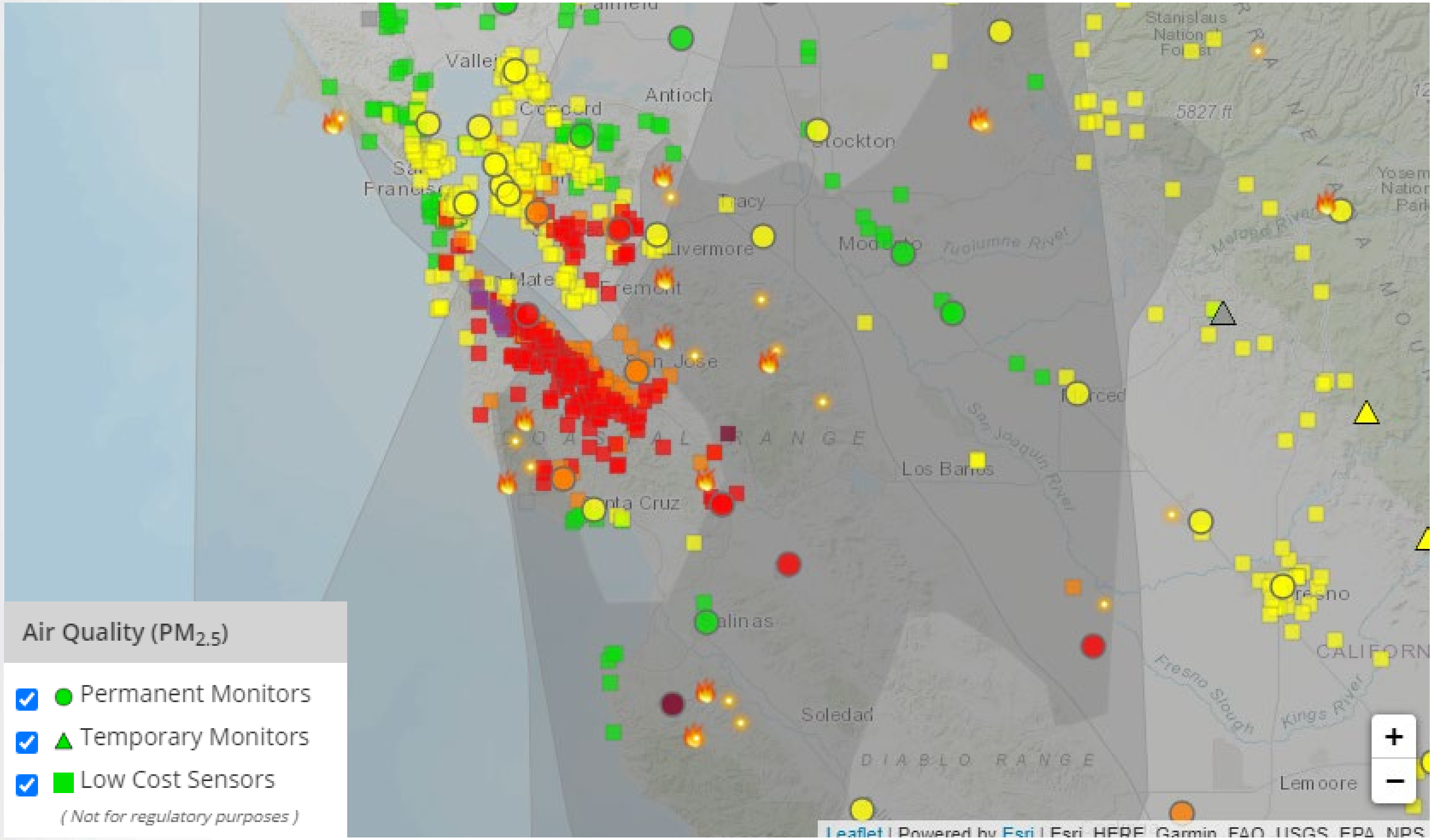
https://fire.airnow.gov/ (8/11/2020)

# AirNow Sensor Data Pilot displays PurpleAir data using the U.S. -Wide Correction

**Steps to applying correction**

1. Average PurpleAir data to 1-hour
   – Exclude if less than 90% complete
2. Clean the data; Remove data when channels differ by ≥ ± 5 μg $m^{-3}$ and ≥ ± 70%
3. Average A & B channels
4. Apply U.S.-wide correction equation to **1-hr data**
5. Apply the Nowcast (weighted 12-hr rolling average)
   – NowCast is used to make 1-hr measurements more similar to the 24-hr measurements that health effects research is based on

# PurpleAir Dense Network Capture High Spatial Variation of Smoke




- Corrected PurpleAir data show similar trends to AirNow monitors
- Dramatic increase of $PM_{2.5}$ observations in some parts of the country
- More ground level measurements demonstrate the limitations of satellites
- There are several considerations for using PurpleAir data

https://fire.airnow.gov/ (8/19/2020)

# Consideration 1: Sensors can fail

- **Most PurpleAir failures are captured by A & B channel cleaning steps.**

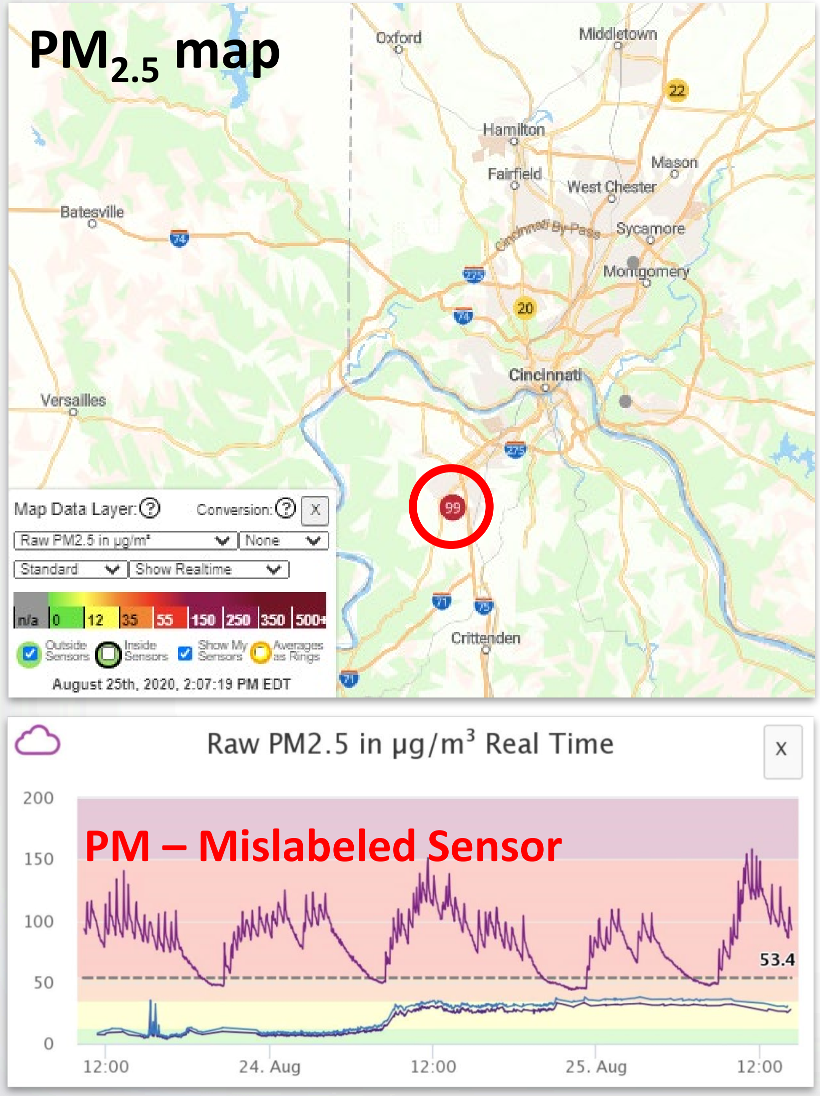
  Mazama Science developed a list of example failure modes that can be found here:
  https://mazamascience.github.io/AirSensor/articles/articles/purpleair_failure_modes.html

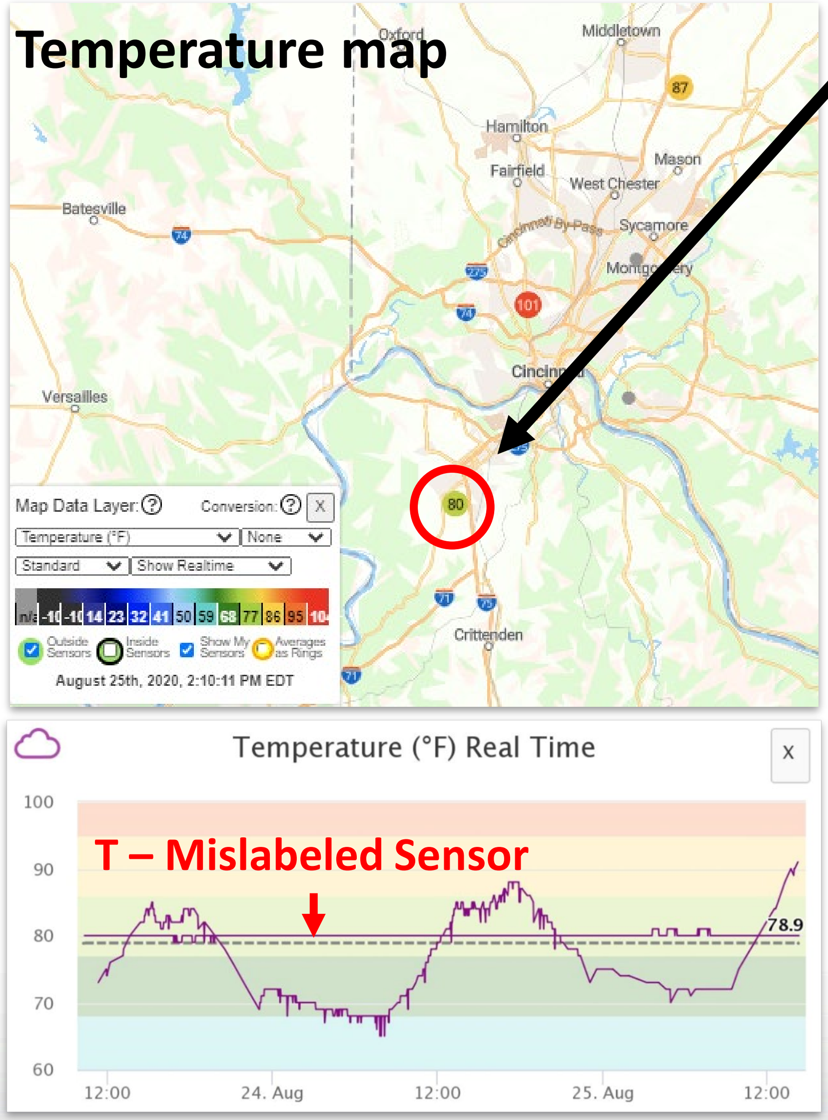
  Briefly:
  - Single channel noise
  - Large jump in single channel data
  - Single channel tracks RH or T
  - Single channel stuck at a number or zero

- **Sensor drift with age is not easy to identify.**

- **Sensor lifespan under different $PM_{2.5}$ concentrations or ambient conditions is still unknown.**

# Consideration 2: Sensors Can Be Mislabeled



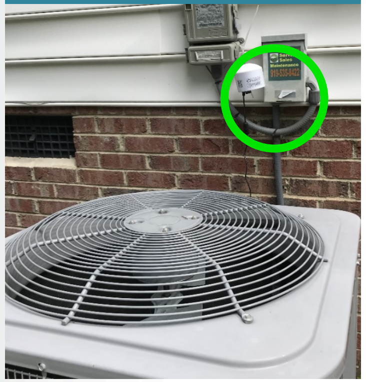

Example of outdoor sensor that disagrees with neighbors

- Compare T and PM from surrounding sensors to identify sensors indoor
- Diurnal trends can be used to identify mislabeled sensors

# Consideration 3: Sensors may be poorly sited

Sensors operated by the public may be poorly sited. We investigated a few suboptimal siting scenarios to identify the impact.

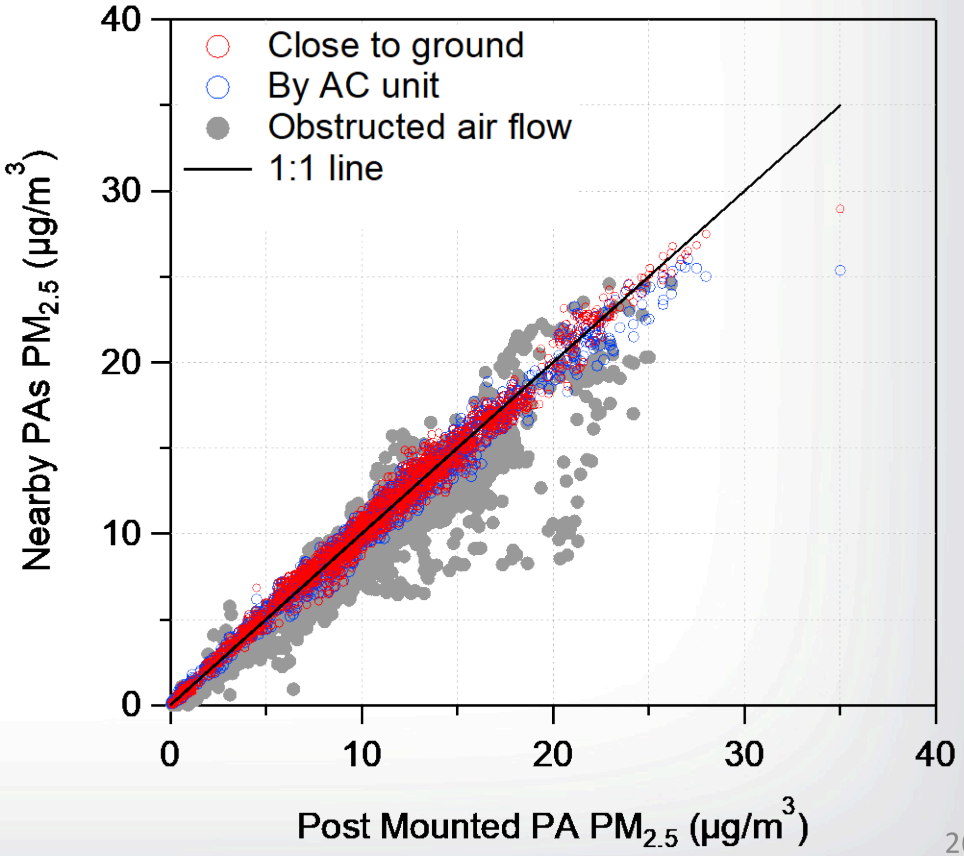
**Next to strong air flow**



**Close to the ground**

**Obstructed air flow**

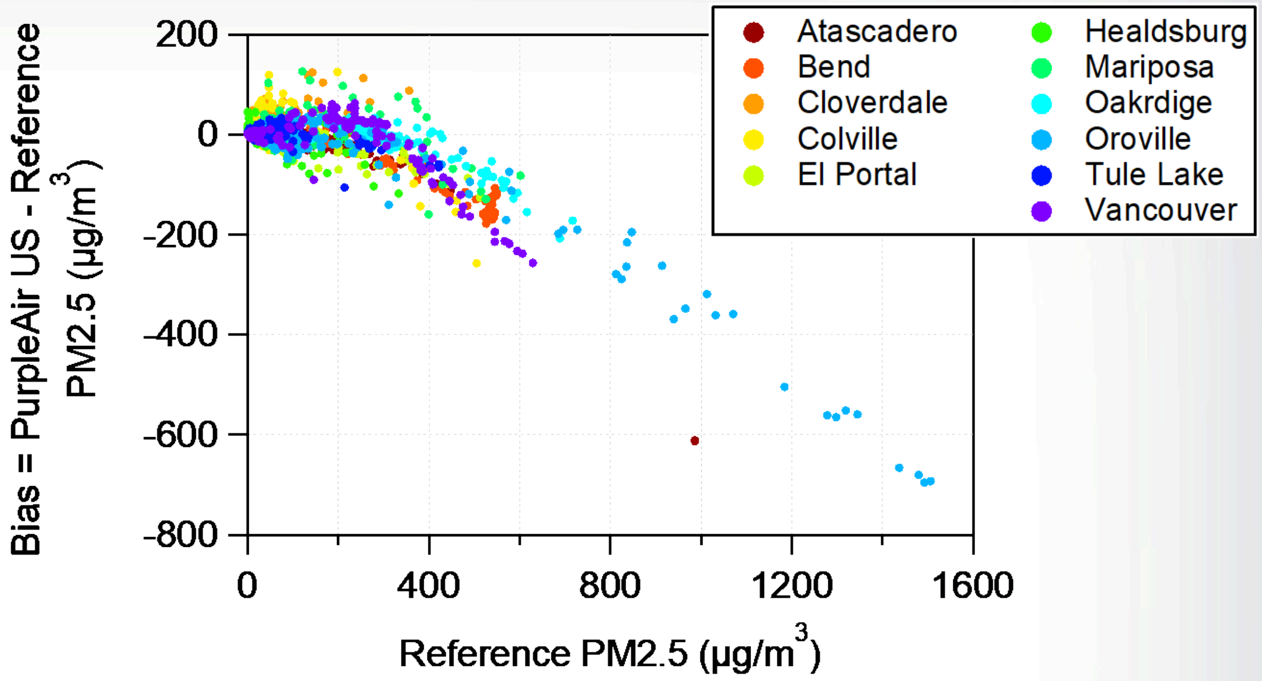
| Siting | Regression | $R^2$ | RMSE ($\mu g\ m^{-3}$) | MAE ($\mu g\ m^{-3}$) |
|---|---|---|---|---|
| Ground | Y = 0.98x +0.31 | 0.98 | 0.69 | 0.53 |
| AC Unit | Y = 0.96x + 0.51 | 0.98 | 0.71 | 0.51 |
| Obstructed | Y = 0.86x + 0.14 | 0.88 | 2.30 | 1.66 |

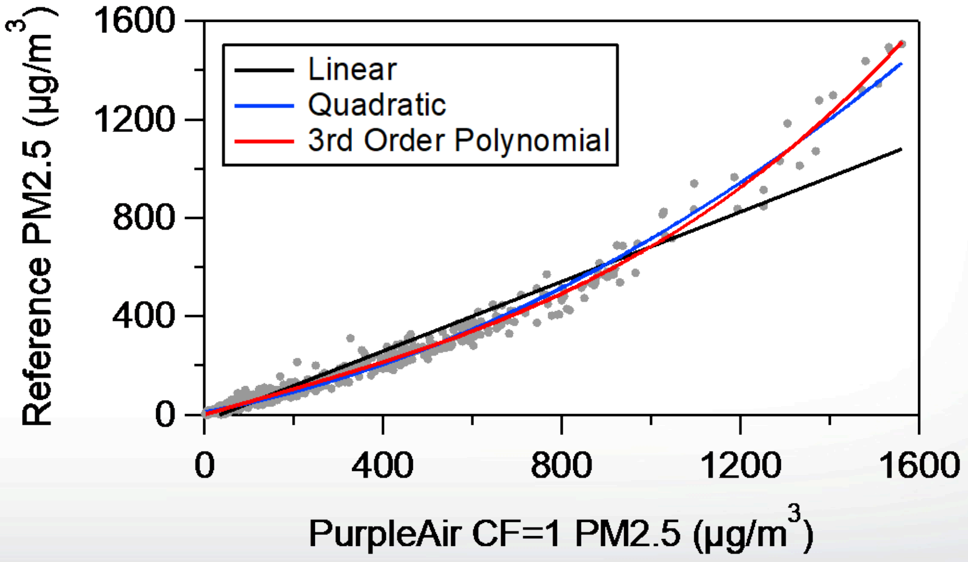



**Most siting scenarios provide acceptable data**

# Consideration 4: Sensors Can Saturate at High Concentrations

- PurpleAir has a linear response up to ~200 µg $m^{-3}$
- Lab studies have shown:
    - Polynomial fit may be better at higher concentrations (Sayahi et al. 2019)
    - PurpleAir stops responding at about 11,000 – 13,000 µg $m^{-3}$, depends upon PM composition and size (Zou et al. 2019)
- New high concentration correction developed from crowdsourced CA and OR wildfire collocated data at ***very high*** concentrations
- We are working to finalize and include an updated equation on the AirNow Fire and Smoke map



# Consideration 5: Sensors may not respond the same to all sources

- Sensors respond to PM light scattering
- Large dust particles scatter much less light than small particles per unit mass
- Sensor low bias compared to reference monitors
- **U.S.-wide correction is not applicable to some PM sources**

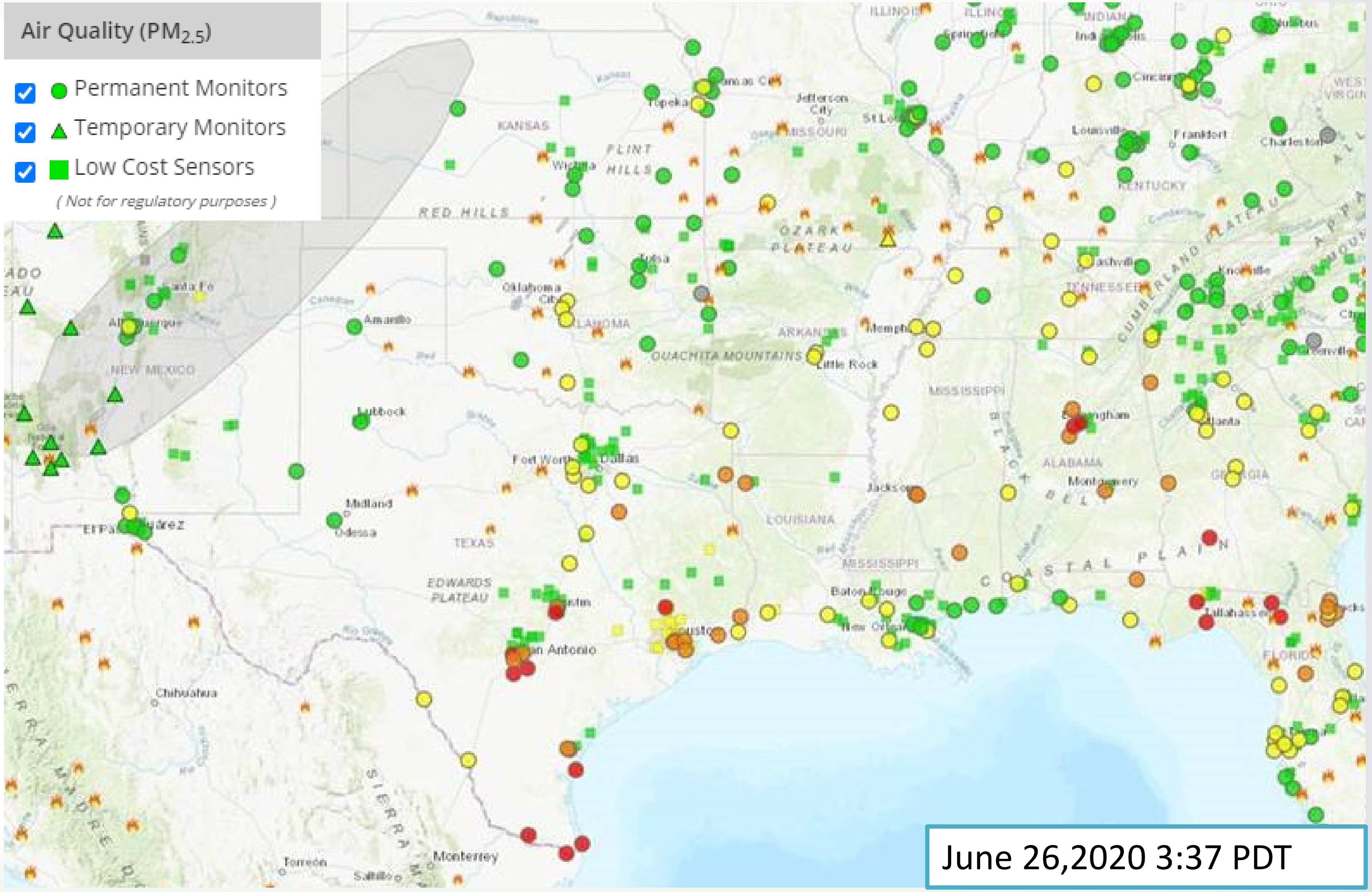



*Image source: Duc Nguyen BAAQMD*

Dec 2020

# Differences between PurpleAir Map and the AirNow Map

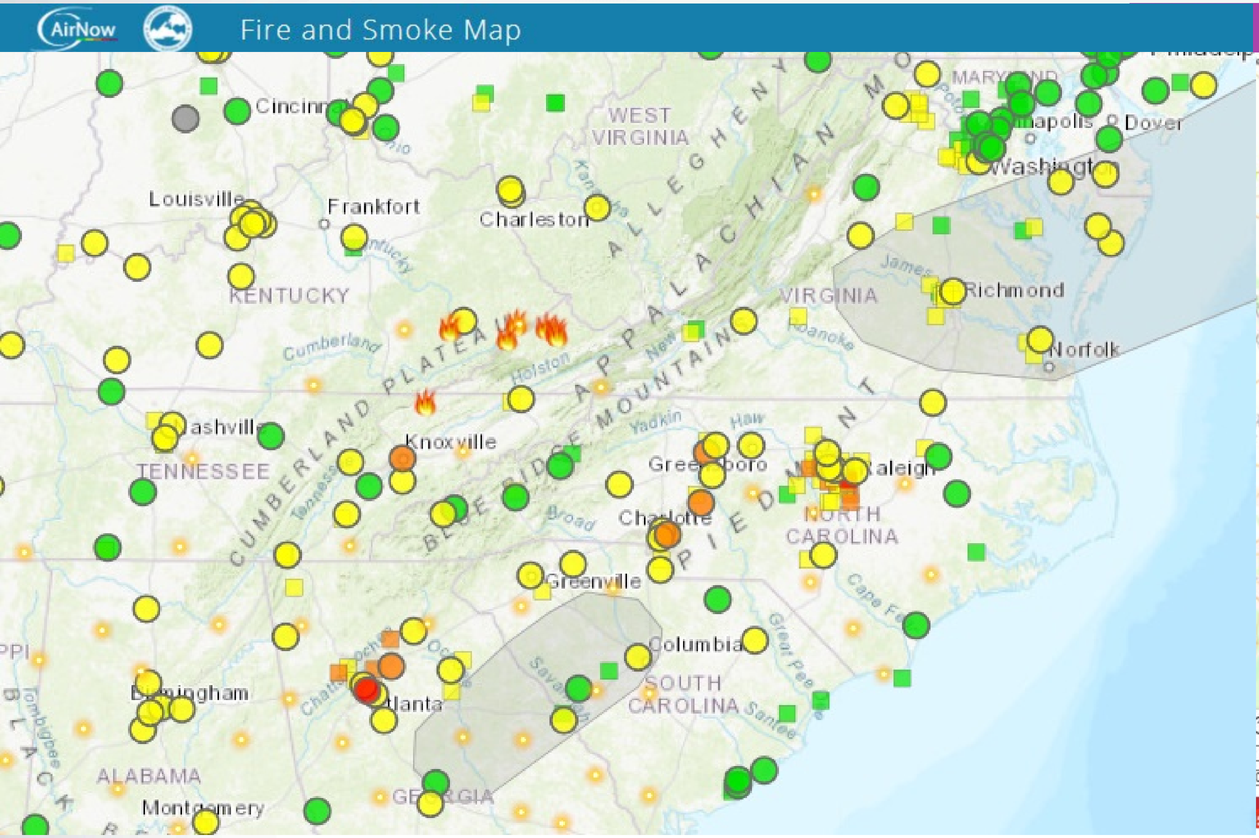
| Source | | Average | Sensors | Air monitors | Pollutant | QA | Outdoor | Indoor |
|---|---|---|---|---|---|---|---|---|
| PurpleAir .com | default | 10-min, modifiable | ✓ | -- | Default: $PM_{2.5}$<br><br>$PM_1$, $PM_{10}$*, Particle counts* | Problematic A or B channels downgraded and hidden | cf_atm | cf_1 |
| | LRAPA or AQ&U | | | | | | | |
| | U.S. EPA correction | 2-min, NOT modifiable | | | | | cf_1 | cf_1 |
| AirNow | AirNow | NowCast (~3 hr) | | ✓ | $PM_{2.5}$, $O_3$ | Higher quality instrumentation operated by trained field staff | -- | -- |
| | Fire and smoke | NowCast (~3 hr) | ✓ | ✓ | $PM_{2.5}$ | Points removed if A&B differ, Manually flagged sensors removed | cf_1 | Not shown |

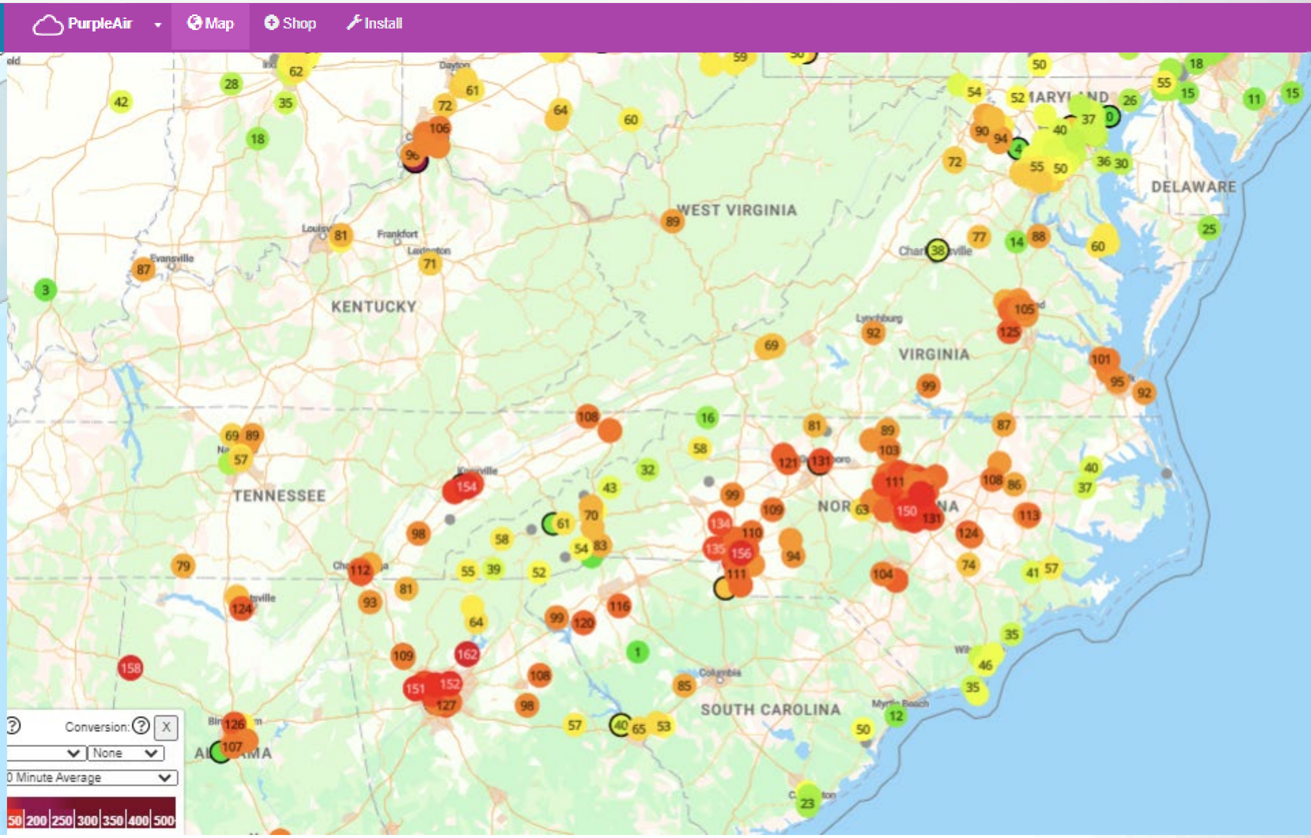
This means if indoor and outdoor $PM_{2.5}$ is the same indoor will read higher

*PurpleAir cannot accurately measure large particles[1,2,3] and does not provide accurate particle counts[4]

[1]Kosmopoulos, et al.: Low-cost sensors for measuring airborne particulate matter: Field evaluation and calibration at a South-Eastern European site, Sci. of The Total Env., 2020.
[2]Kuula et al.: Utilization of scattering and absorption-based particulate matter sensors in the environment impacted by residential wood combustion, Journal of Aerosol Science, 2020.
[3]Robinson, D. L.: Accurate, Low Cost $PM_{2.5}$ Measurements Demonstrate the Large Spatial Variation in Wood Smoke Pollution in Regional Australia and Improve Modeling and Estimates of Health Costs, Atmosphere, 2020.
[4]He, et al.: Performance characteristics of the low-cost Plantower PMS optical sensor, Aerosol Science and Technology, 2020.

# AirNow Fire and Smoke Map VS PurpleAir Map



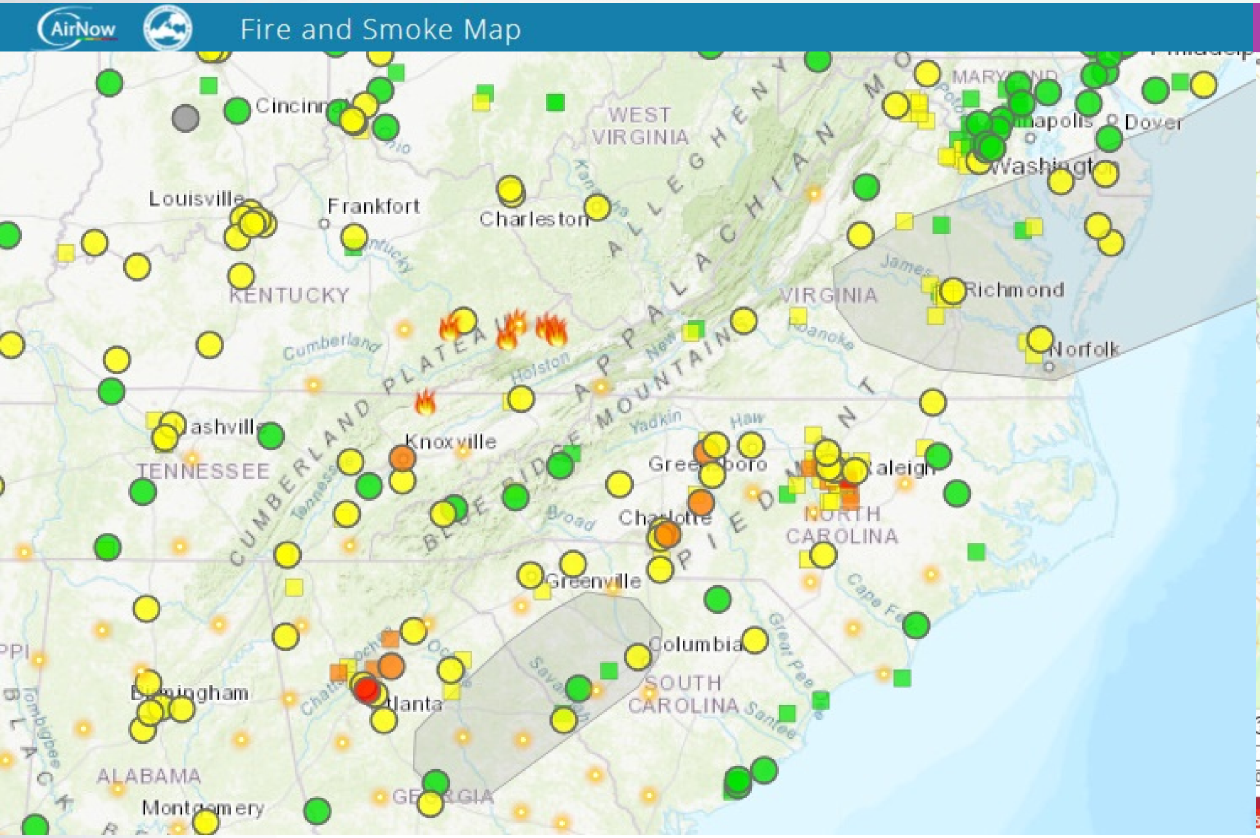



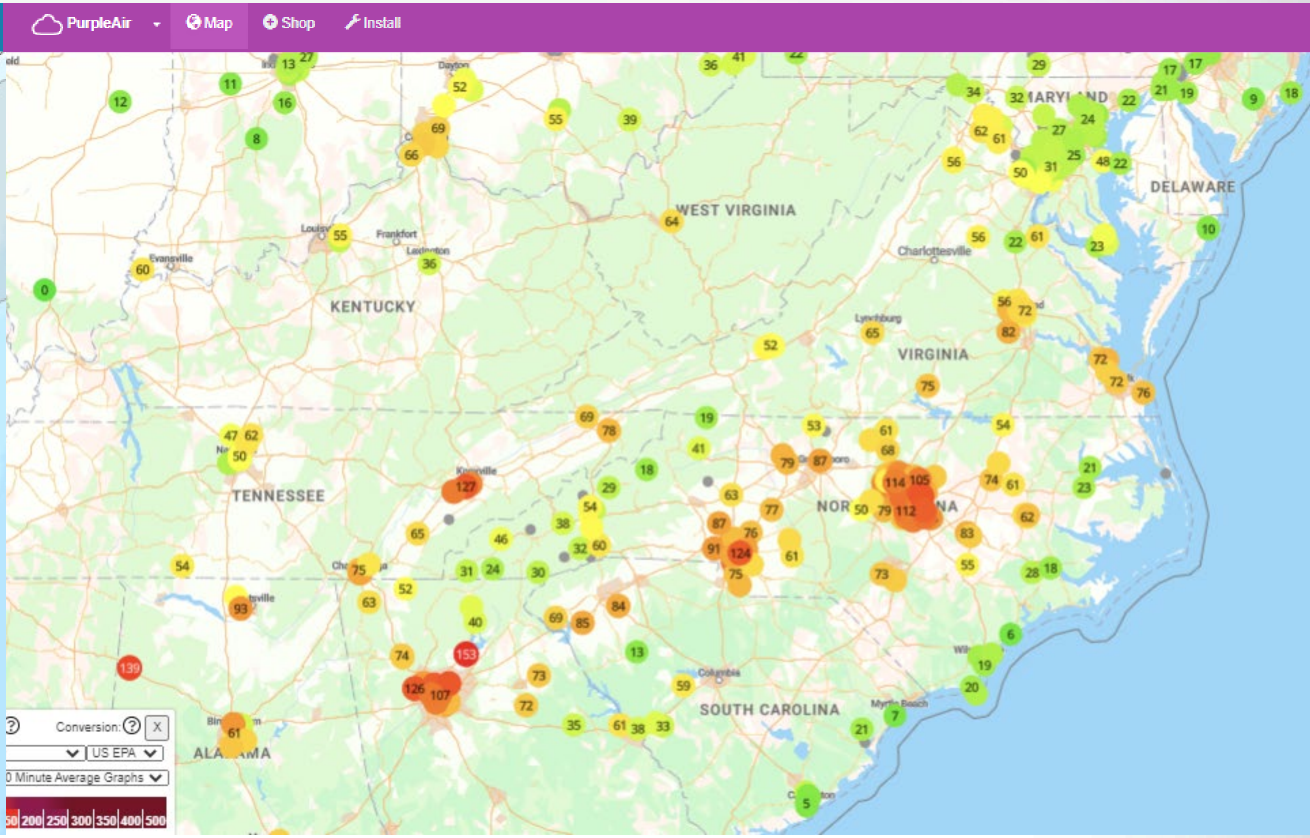

AirNow Fire and Smoke map displays PurpleAir outdoor data that has been cleaned, averaged, and corrected, with the NowCast algorithm applied

- PurpleAir defaults to indoor (CF=1) and outdoor (CF=atm) sensors 10-minute averaged data
- Sensors with A and B disagreement are displayed behind other sensors

# AirNow Fire and Smoke Map VS PurpleAir Map

Dec 2020

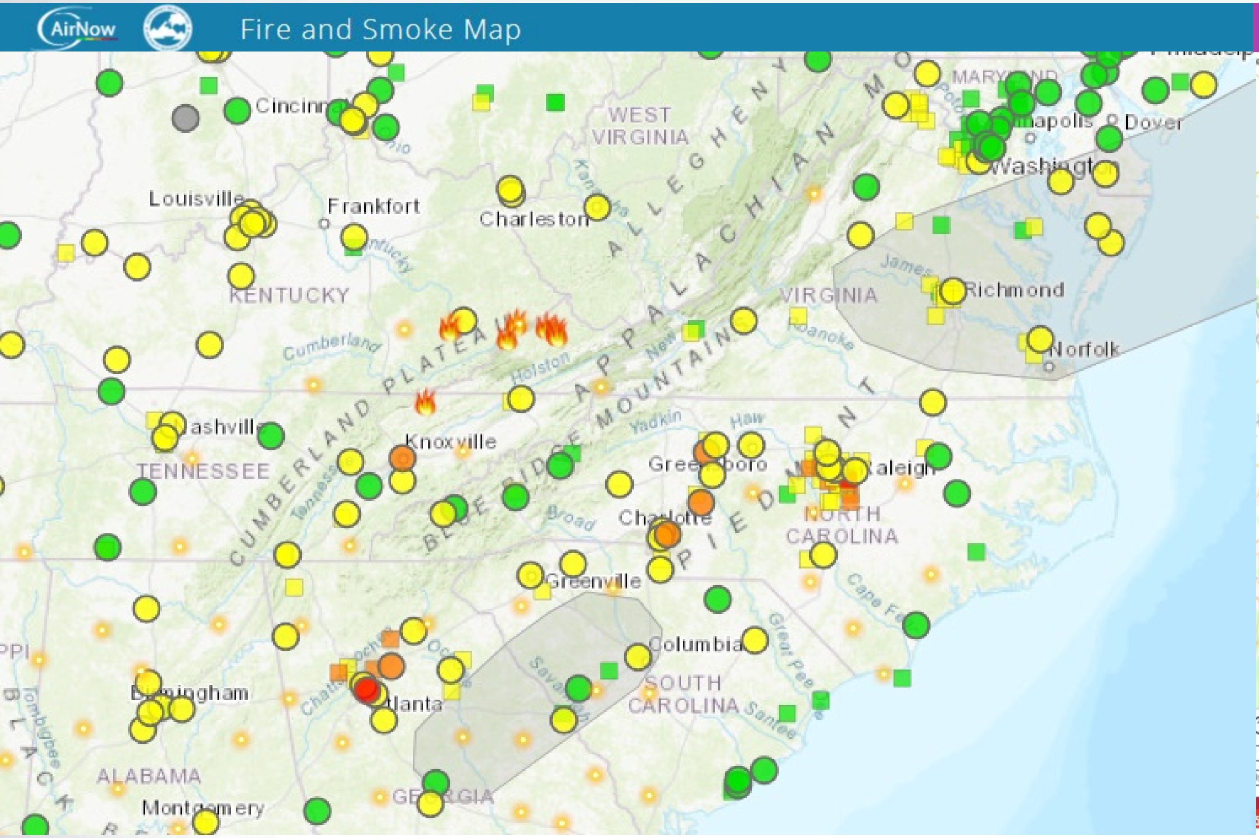


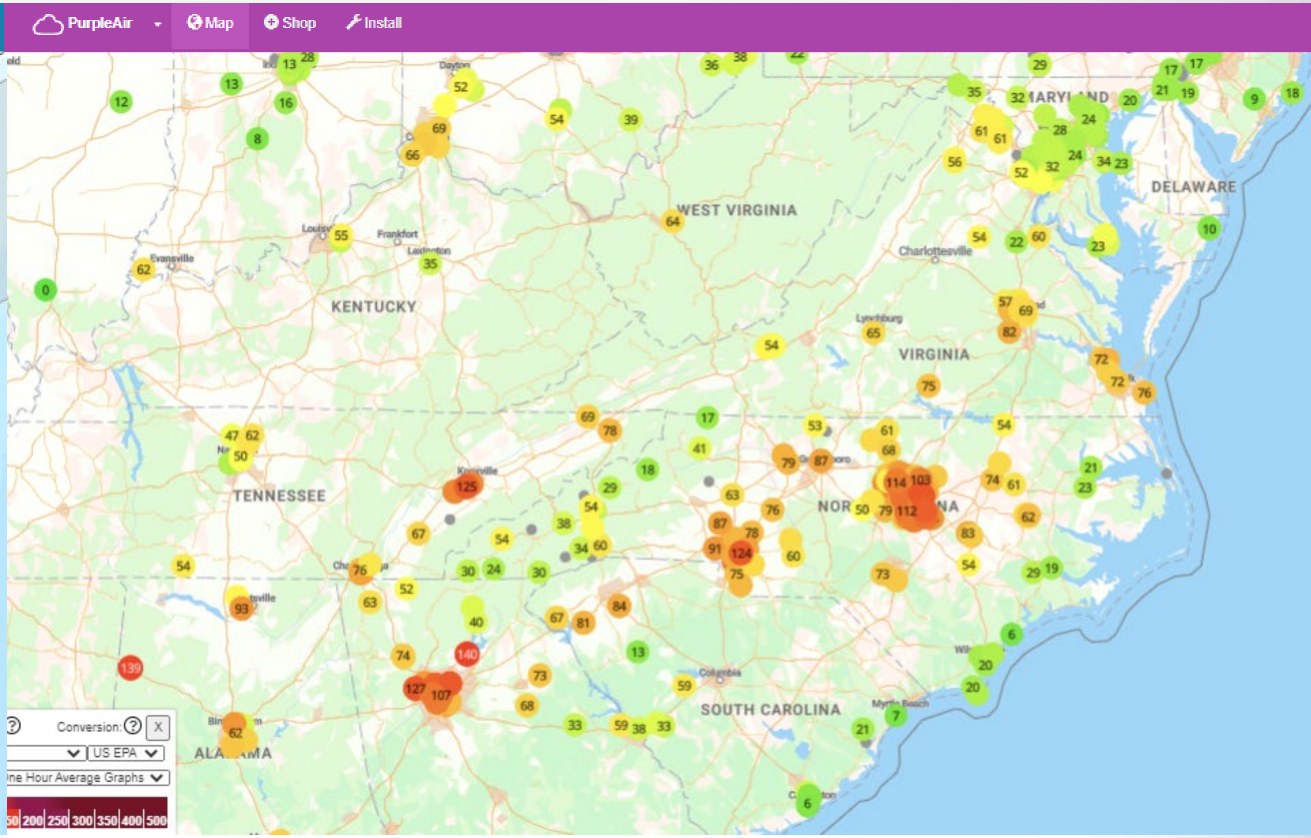




On PuprleAir Map you can select to:

- Remove the indoor sensors
- Use U.S. EPA correction, but it only applies to outdoor sensors and 2-minute data

# AirNow Fire and Smoke Map VS PurpleAir Map




AirNow shows discrete colors corresponding to the AQI categories

**Air Quality Index**

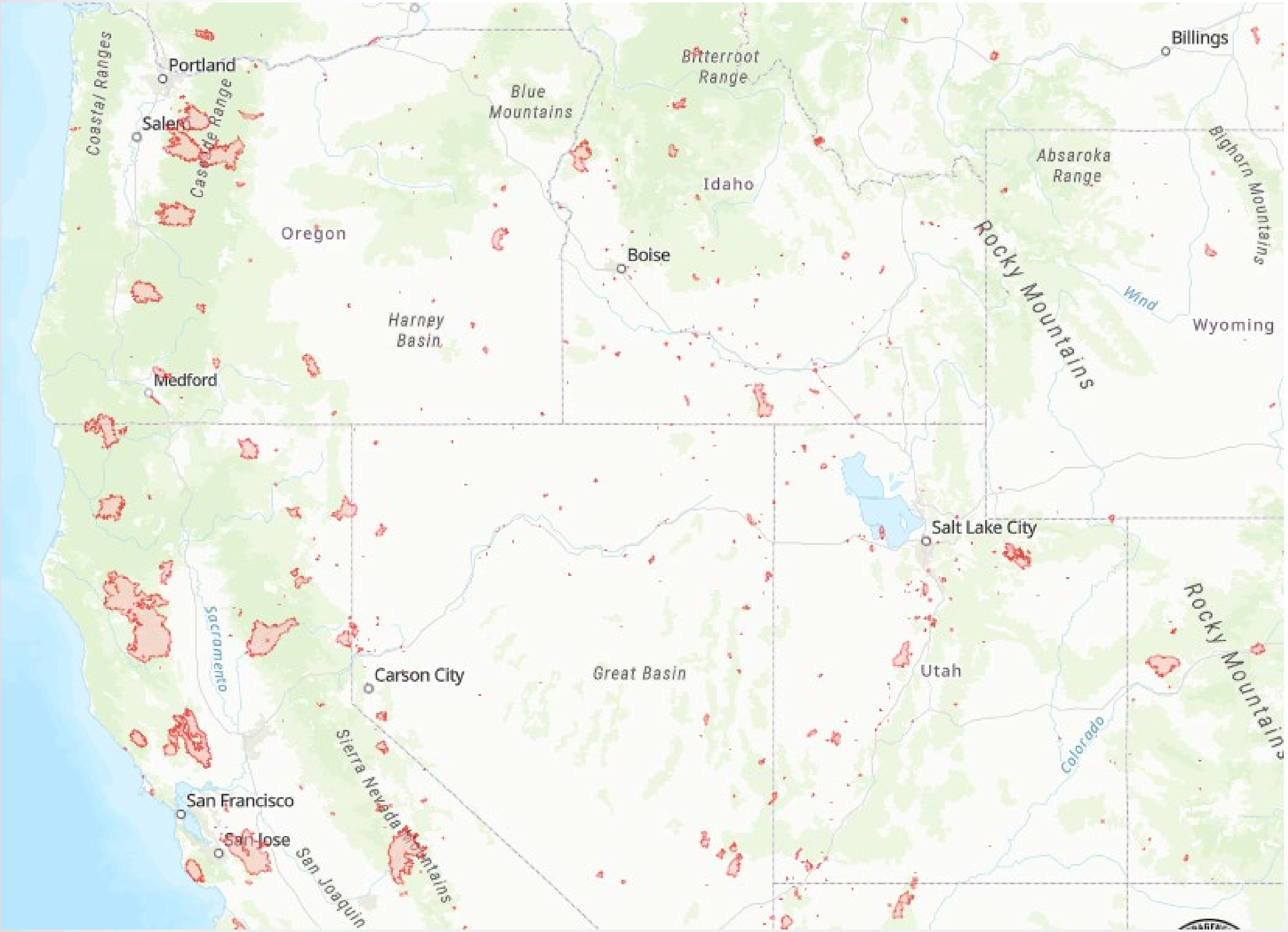
- Good
- Moderate
- Unhealthy for Sensitive Groups
- Unhealthy
- Very Unhealthy
- Hazardous
- No Data

PurpleAir displays a continuous range of colors in between AQI categories

# Smoke measurements in remote locations

# Where are the fires?

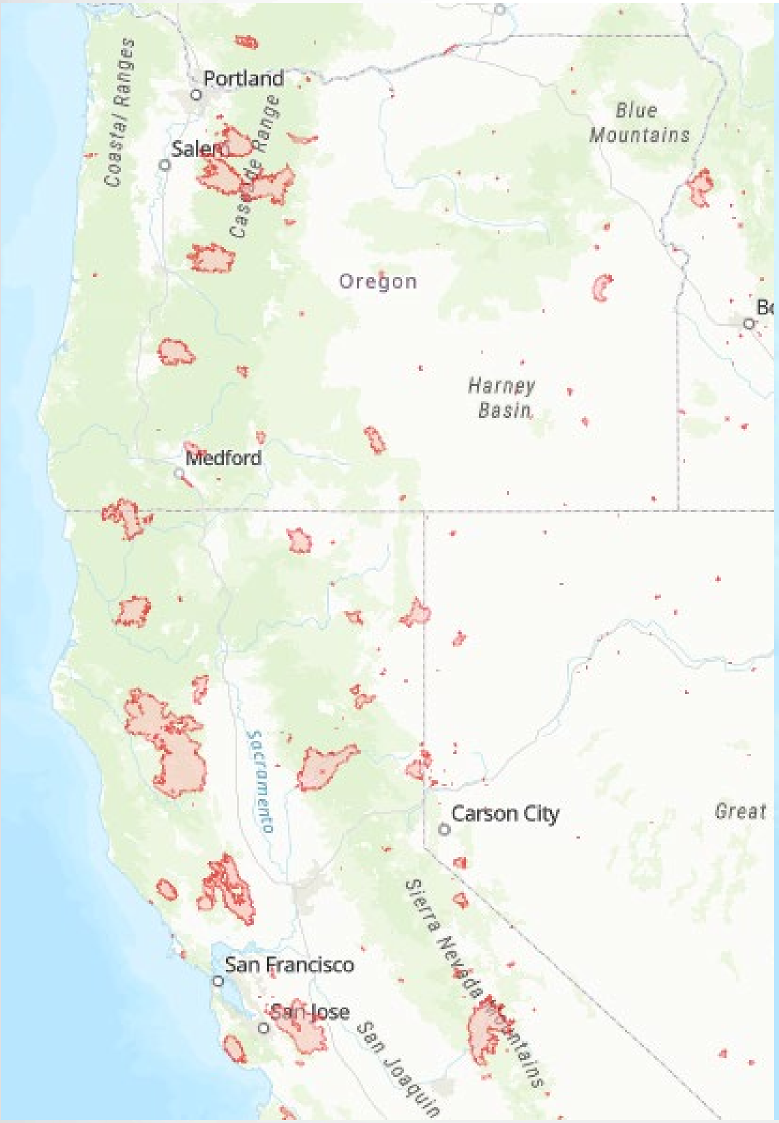
**Burned Area**




https://maps.nwcg.gov/sa/#

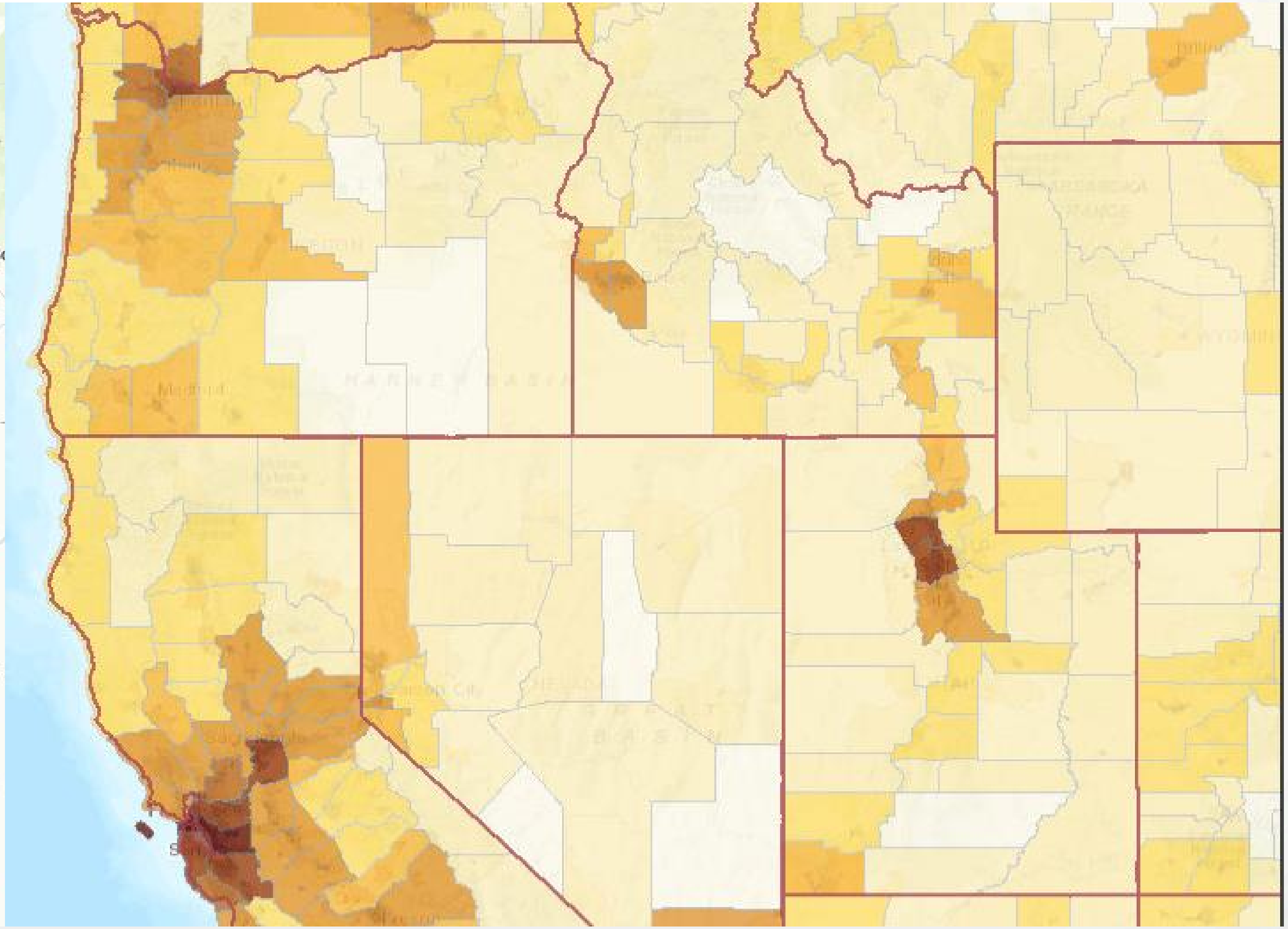
# Where are the people?

Burned Area




https://maps.nwcg.gov/sa/#

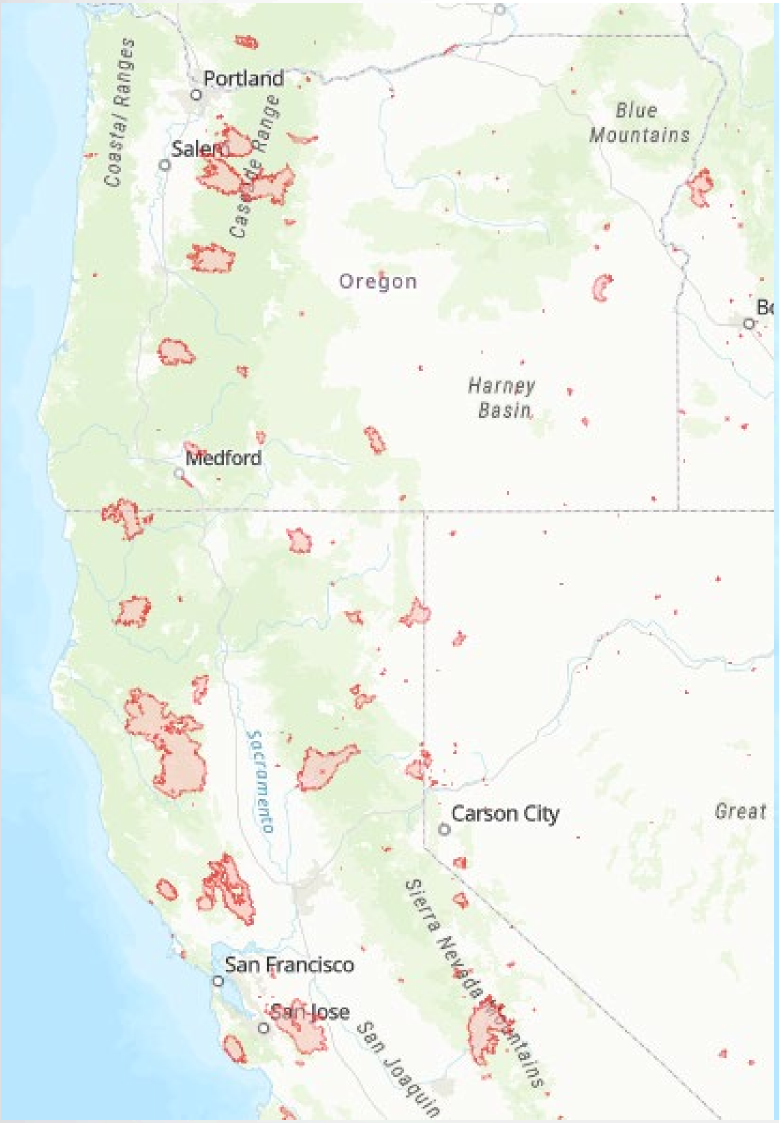
**Populated Area**



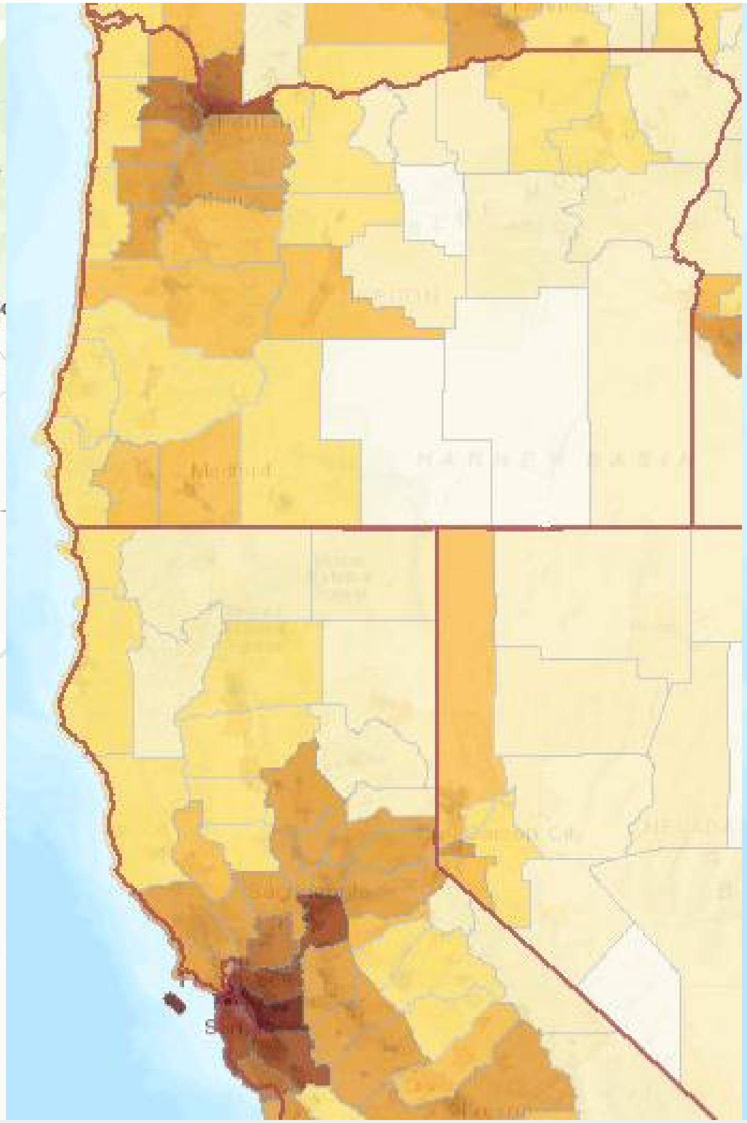
https://www.eia.gov/state/maps.php

# Where are the monitors?

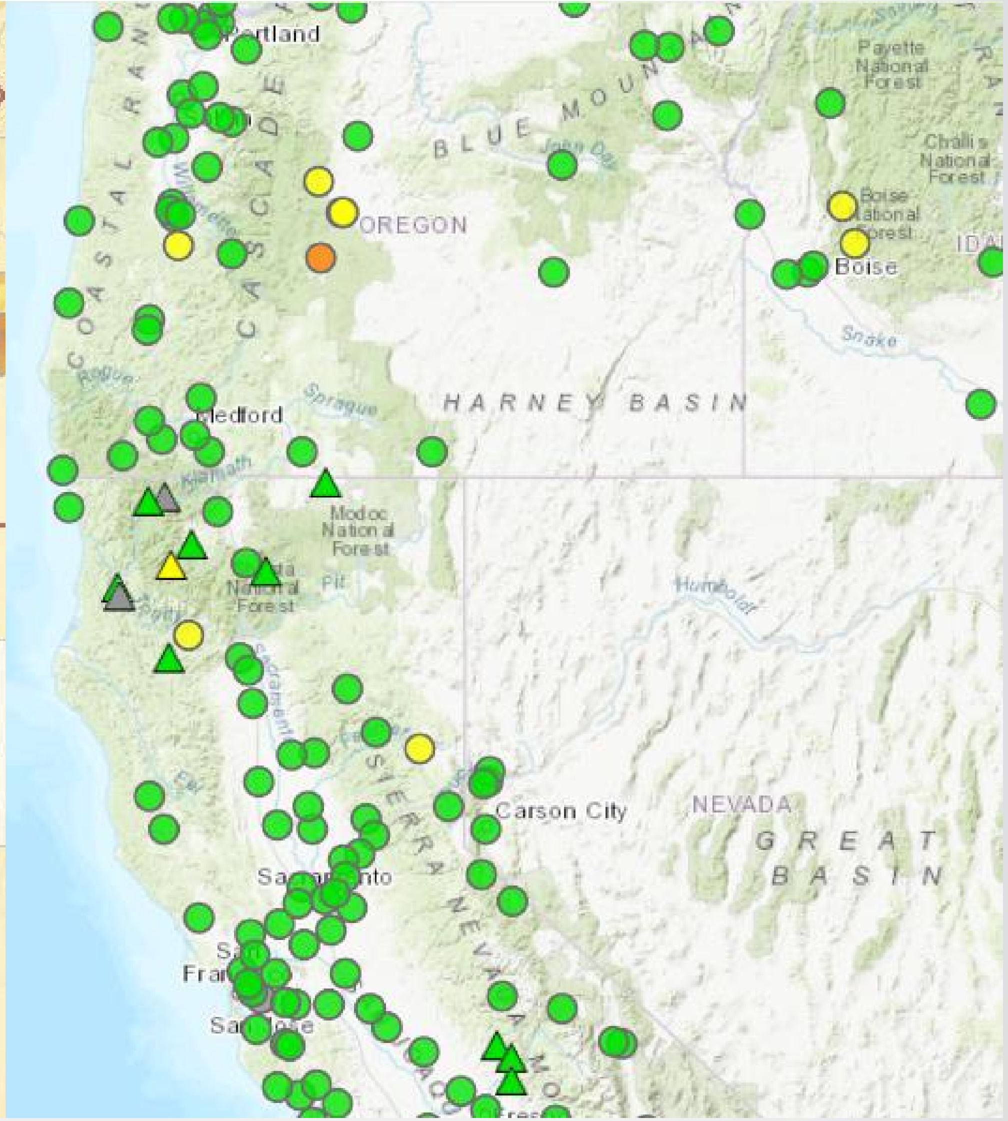
Burned Area




Populated Area



**Monitored Area**



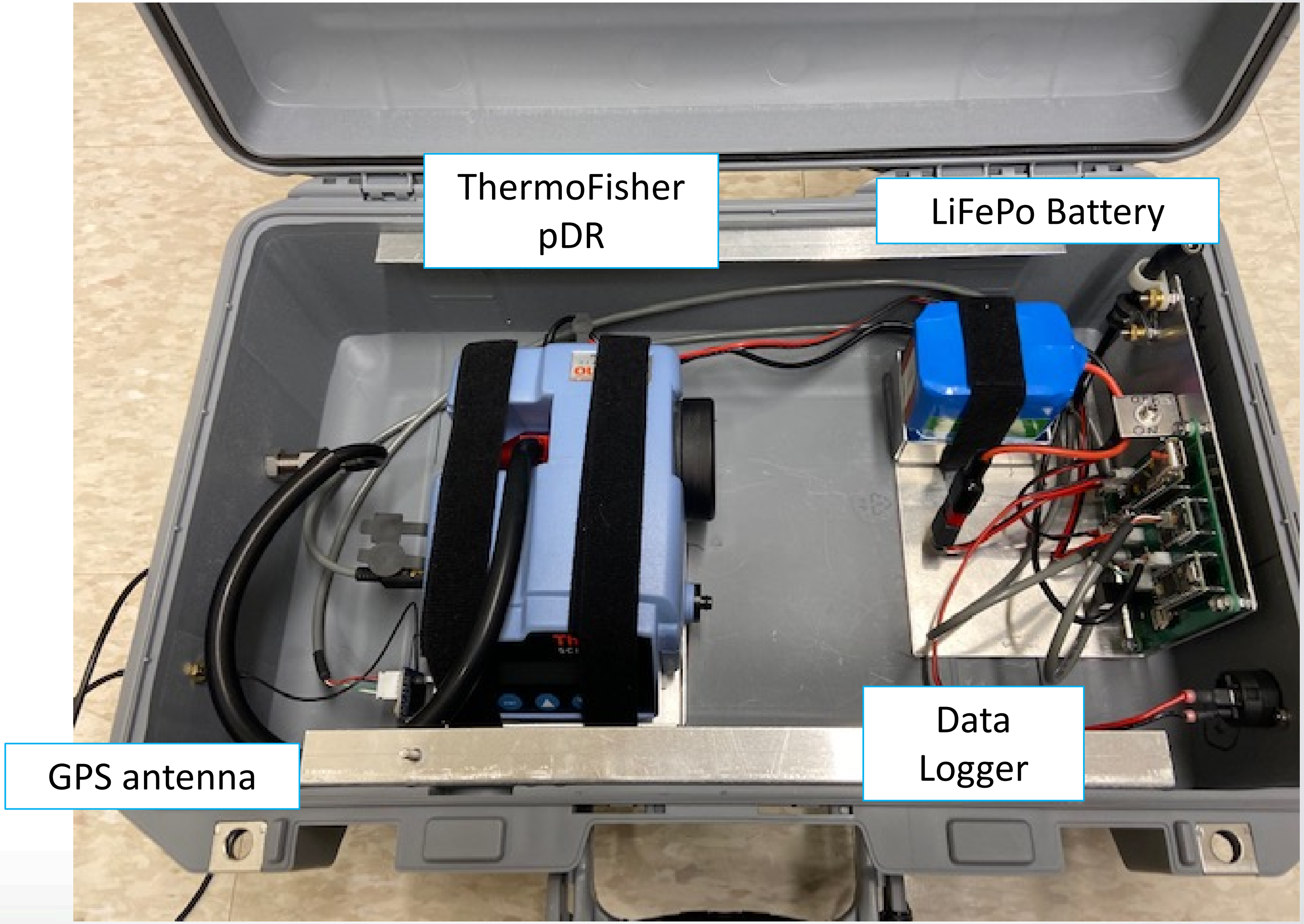

https://maps.nwcg.gov/sa/# https://www.eia.gov/state/maps.php https://fire.airnow.gov/#

# Use a mobile monitor for smoke mapping in remote locations

**Vehicle Add On Mobile Monitor (VAMMS)**

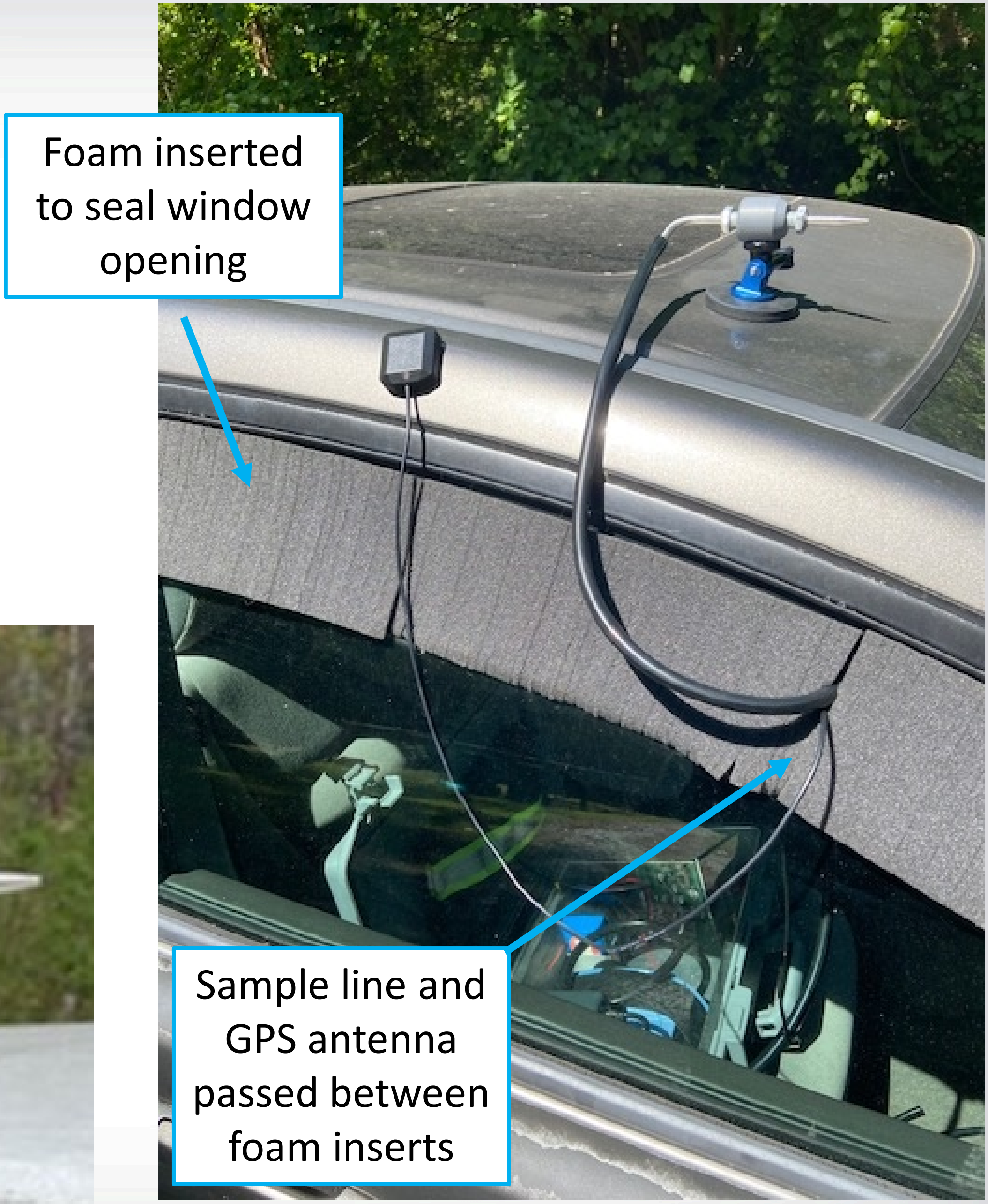
**Design Features**

- Measure at 1 s resolution:
  - Lat, Long, elevation
  - Pressure
  - $PM_{2.5}$
  - Black carbon
- Compact, self-contained, easily shipped for use in any vehicle
- Battery powered for extended use in or outside vehicle without power

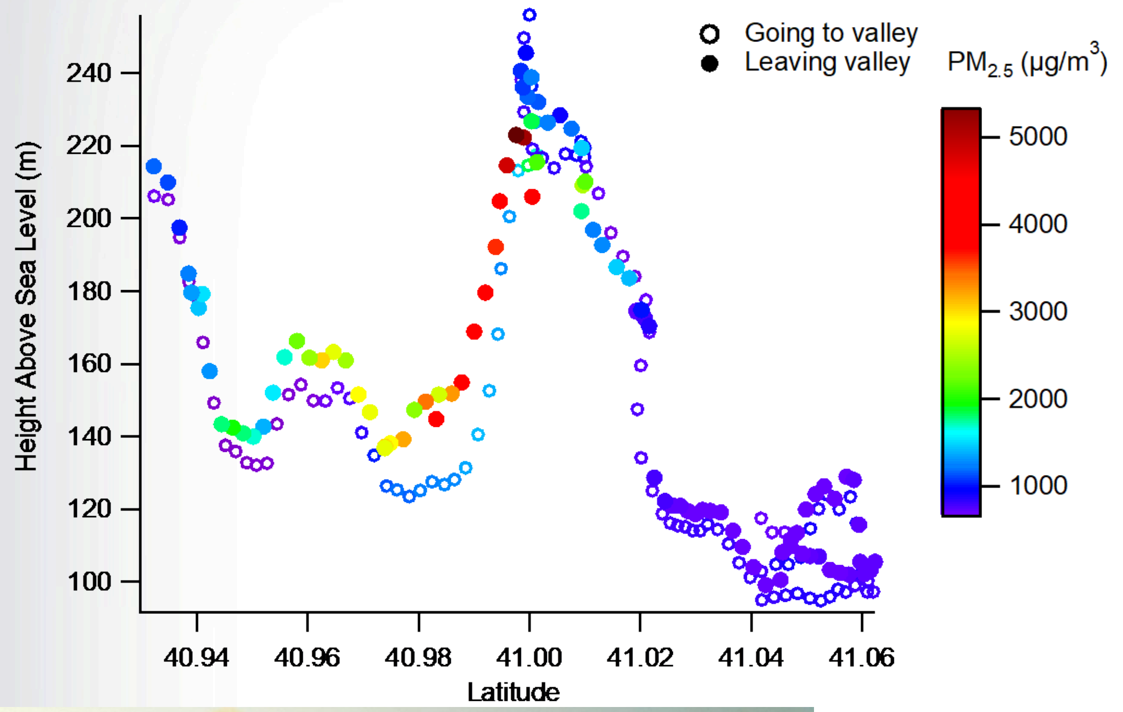


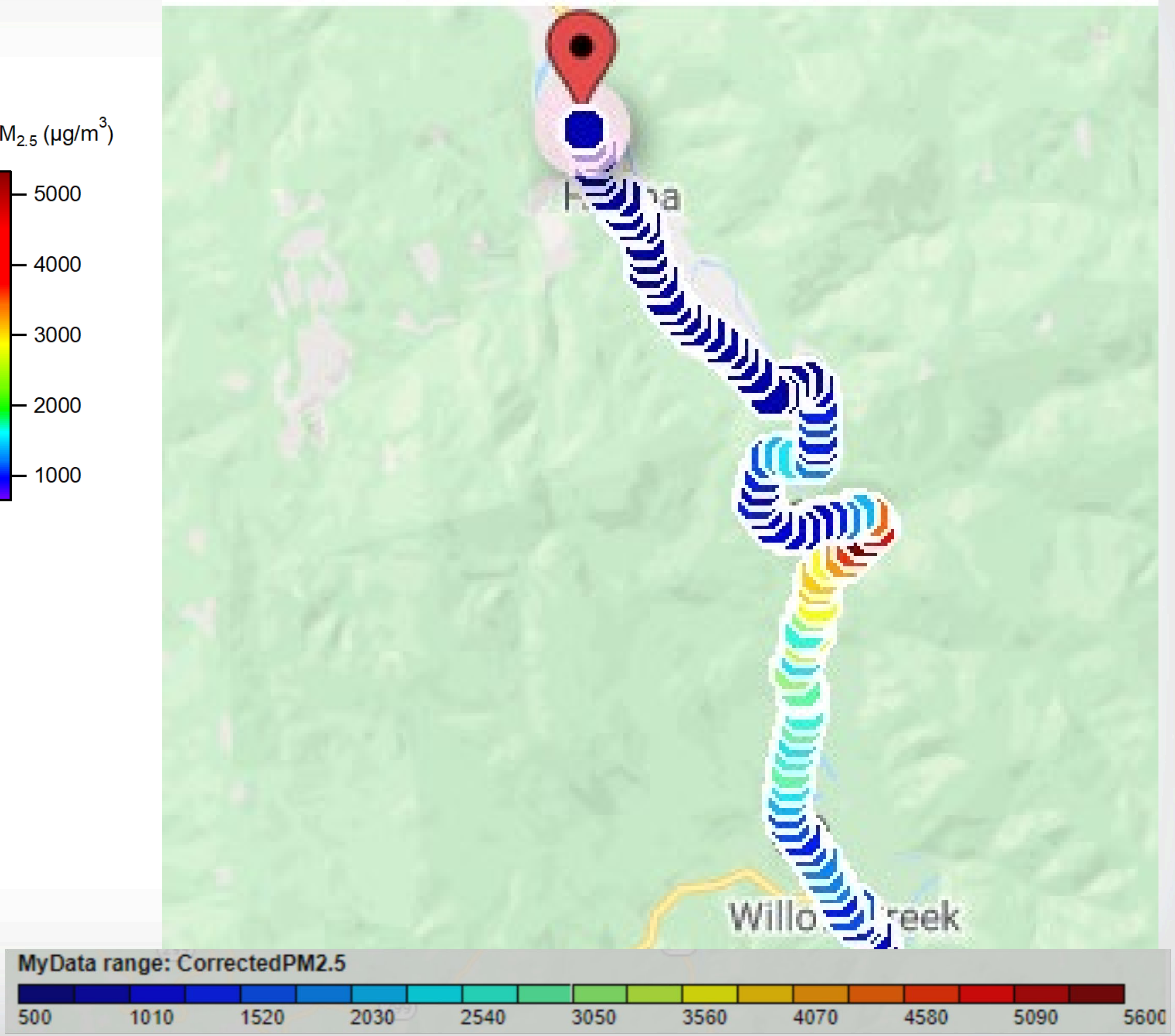
# Isokinetic probe mounted on vehicle

- Ambient PM is sampled through an isokinetic probe (@ 25 mph)
- A magnetic mount provides an easy install on any vehicle
- Foam passthrough allows tubing and GPS antenna into the car – while keeping smoke out
- **Improved passthrough under development**



# Wildfire Example: Red Salmon Complex, California October 2020



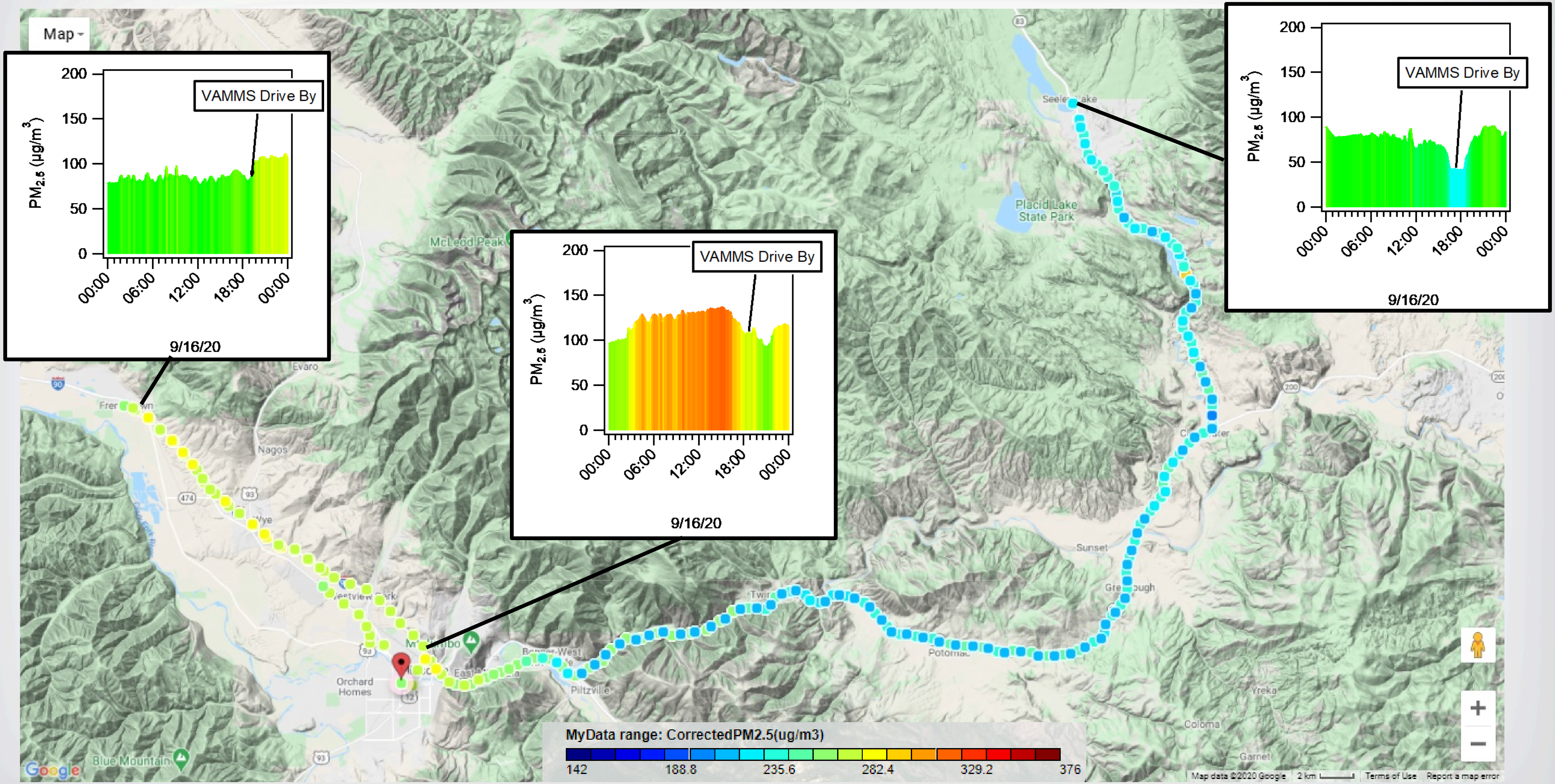



# Temporary smoke monitor for remote locations

**Design Features**

- Use a PurpleAir sensor to measure $PM_{2.5}$ at high time resolution, valid up to 1.5 $mg/m^3$
- Compact and lightweight for hiking deployment
- Solar-battery for weeks to months operation without power
- Weather resistant setup
- Online data through cellular/satellite communication

# Aged Wildfire Smoke Example: Missoula September 2020



# Regional/Tribal Collocation Project

# ORD/Regional/Tribal Collocation Shelter Project

## Issue

- Data from most air sensors are not directly comparable to regulatory data out-of-the-box.
- Sensors must be collocated to better understand performance and to develop correction equations.
- Most monitoring locations do not have infrastructure to support community science collocations.

## Approach

- Build and deploy a number of collocations shelters at regulatory monitoring sites across the county.
- Release a design document for future builds.

## Anticipated Outcomes

- Agencies and community groups can collocate air sensors and use this data to improve the quality of the data collected from subsequent projects.

**Currently seeking motivated partners**

**Contact: Ryan Brown <brown.ryan@epa.gov>**

# Acknowledgements

**AK:** State of Alaska, Citizens for Clean Air

**AZ:** Maricopa County Air Quality Department

**CA:** Hoopa Valley Tribe, San Luis Obispo County Air Pollution Control District, Mojave Desert Air Quality Management District, Antelope Valley Air Quality Managment District, California Air Resources Board, Santa Barbara County Air Pollution Control District, Air Quality Sensor Performance Evaluation Center, Ventura County Air Pollution Control District, Bay Area Air Quality Management District

**CO:** Colorado Department of Public Health and Environment

**DE:** Delaware Division of Air Quality

**FL:** Sarasota County Government

**GA:** EPA Region 4, Georgia Environmental Protection Division

**IA:** Iowa Department of Natural Resources, Polk and Linn County Local Programs, and the State Hygienic Laboratory at the University of Iowa

**MT:** Missoula County, Montana Department of Environmental Quality

**NC:** Forsyth County Office of Environmental Assistance & Protection, Clean Air Carolina, UNC Charlotte, North Carolina Department of Environmental Quality

**OH:** Akron Regional Air Quality Management District

**OK:** Quapaw Nation, Oklahoma Department of Environmental Quality

**UT:** University of Utah, Utah Department of Environmental Quality

**VA:** Virginia Department of Environmental Quality

**VT:** State of Vermont

**WA:** Washington Department of Ecology, Puget Sound Clean Air Agency

**WI:** Wisconsin Department of Natural Resources

**Federal:** Forest Service, Wildland Fire Air Quality Response Program, National Park Service, EPA Region 9, EPA Region 10, Lauren Maghran, Ed Brunson, Mike McGown, Sam Frederick, Brett Gantt, Ian Vonwald, Heidi Vreeland, Gayle Hagler

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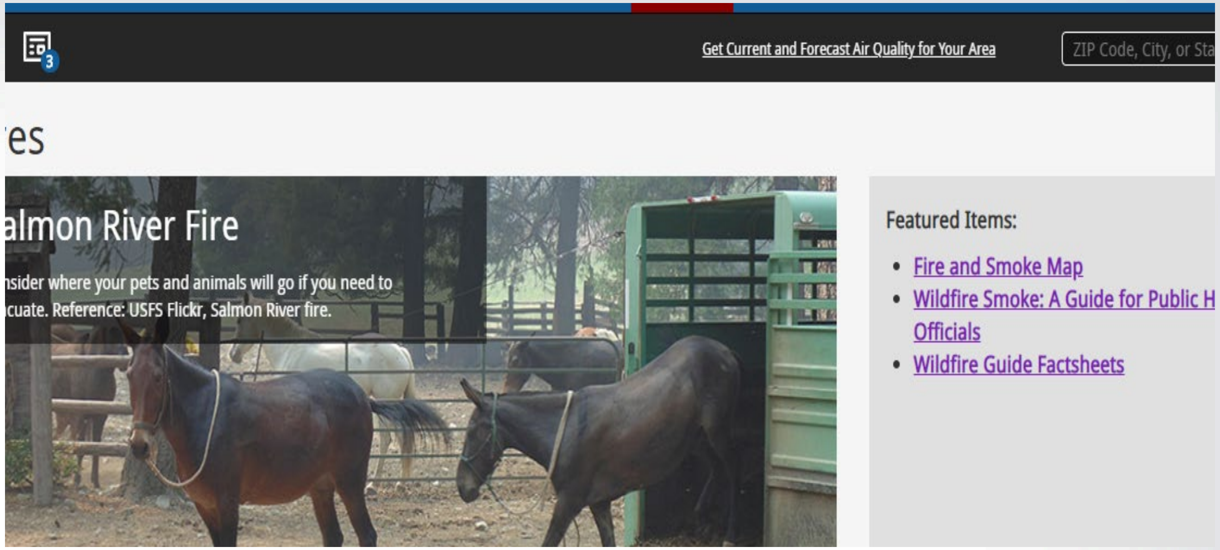
# Wildfire Smoke Resources

### AirNow Fire Page

https://www.airnow.gov/fires/

- AirNow fire and smoke map
- Factsheets
- Current Smoke Advisories
- Smoke Ready Toolbox
- Wildfire Smoke Guide for Public Health Officials
- For questions about AirNow Sensor Data Pilot Contact: Sensordatapilot@epa.gov

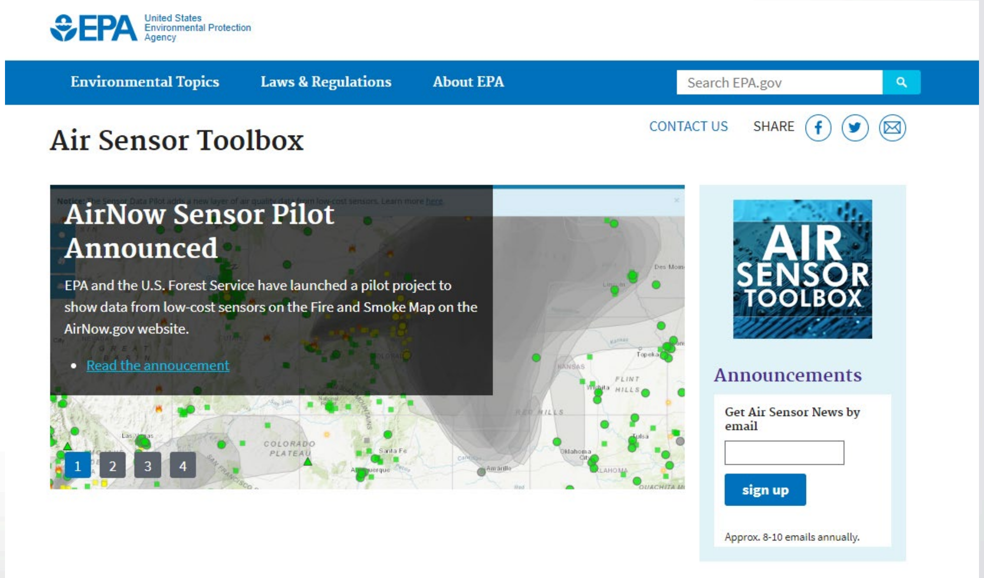



# Air Sensor Resources

### Air Sensor Toolbox

http://www.epa.gov/air-sensor-toolbox

- Air Sensor Guidebook
- Air Sensor Loan Programs
- Sensor Evaluation Results
- Current and Past Research
- Technical Information about U.S.-Wide Correction



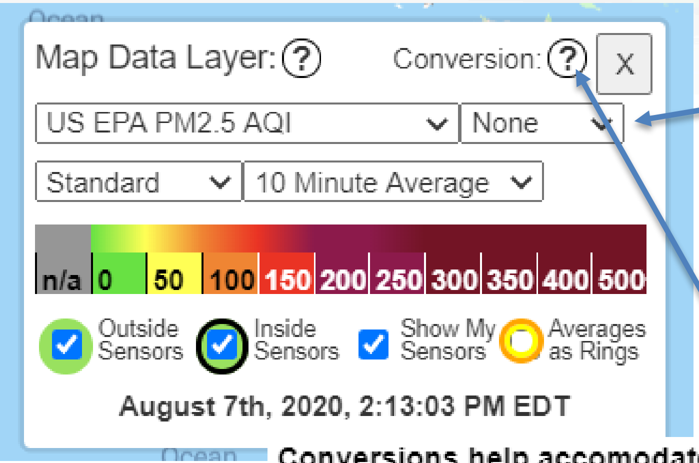
# Supplemental Slides

# Primer on PurpleAir Sensors: Online Conversions

**PurpleAir's Map allows users to view data sensor data in multiple ways:**

- The first drop-down menu can be used to select what data is displayed.
  - The default is the "US EPA PM2.5 AQI"
    - 10-min average converted by U.S. AQI scale
  - Data can be viewed with different time averages.

- Three conversion factors can be applied to data on the map (not downloaded)
  - **"US EPA"** Development discussed in this presentation
  - **"AQ and U"** was developed by U. Utah during wintertime in Salt Lake City
  - **"LRAPA"** was developed by Lane Regional Air Protection Agency for woodsmoke dominated times




**Conversions can be applied with this drop-down.**

**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

# Motivation for EPA ORD’s work with PurpleAir

- Much work exists in the literature about the performance of PurpleAir sensors
- However, studies are typically limited to a few PurpleAir sensors in a single site or region and sometimes sensors are not collocated


**Feenstra, et al. 2019.** 'Performance evaluation of twelve low-cost $PM_{2.5}$ sensors at an ambient air monitoring site’, *Atmospheric Environment*, 216: 116946.

**Gupta, et al. 2018.** 'Impact of California Fires on Local and Regional Air Quality: The Role of a Low-Cost Sensor Network and Satellite Observations', *GeoHealth*, 2: 172-81.

**Kim et al. 2019.** 'Evaluation of Performance of Inexpensive Laser Based $PM_{2.5}$ Sensor Monitors for Typical Indoor and Outdoor Hotspots of South Korea', *Applied Sciences*, 9: 1947.

**Magi et al. 2019.** 'Evaluation of $PM_{2.5}$ measured in an urban setting using a low-cost optical particle counter and a Federal Equivalent Method Beta Attenuation Monitor', *Aerosol Science and Technology*: 1-13.

**Malings et al. 2019.** 'Fine particle mass monitoring with low-cost sensors: Corrections and long-term performance evaluation', *Aerosol Science and Technology*: 1-15

**Sayahi et al. 2019.** 'Long-term field evaluation of the Plantower PMS low-cost particulate matter sensors', *Environmental Pollution*, 245: 932-40.

**Tryner et al. 2020.** 'Laboratory evaluation of low-cost PurpleAir PM monitors and in-field correction using co-located portable filter samplers', *Atmospheric Environment*, 220: 117067.

**Zou et al. 2019.** ‘Examining the functional range of commercially available low-cost airborne particle sensors and consequences for monitoring of indoor air quality in residences’, Indoor Air: 30(2).

# Motivation for EPA ORD's work with PurpleAir

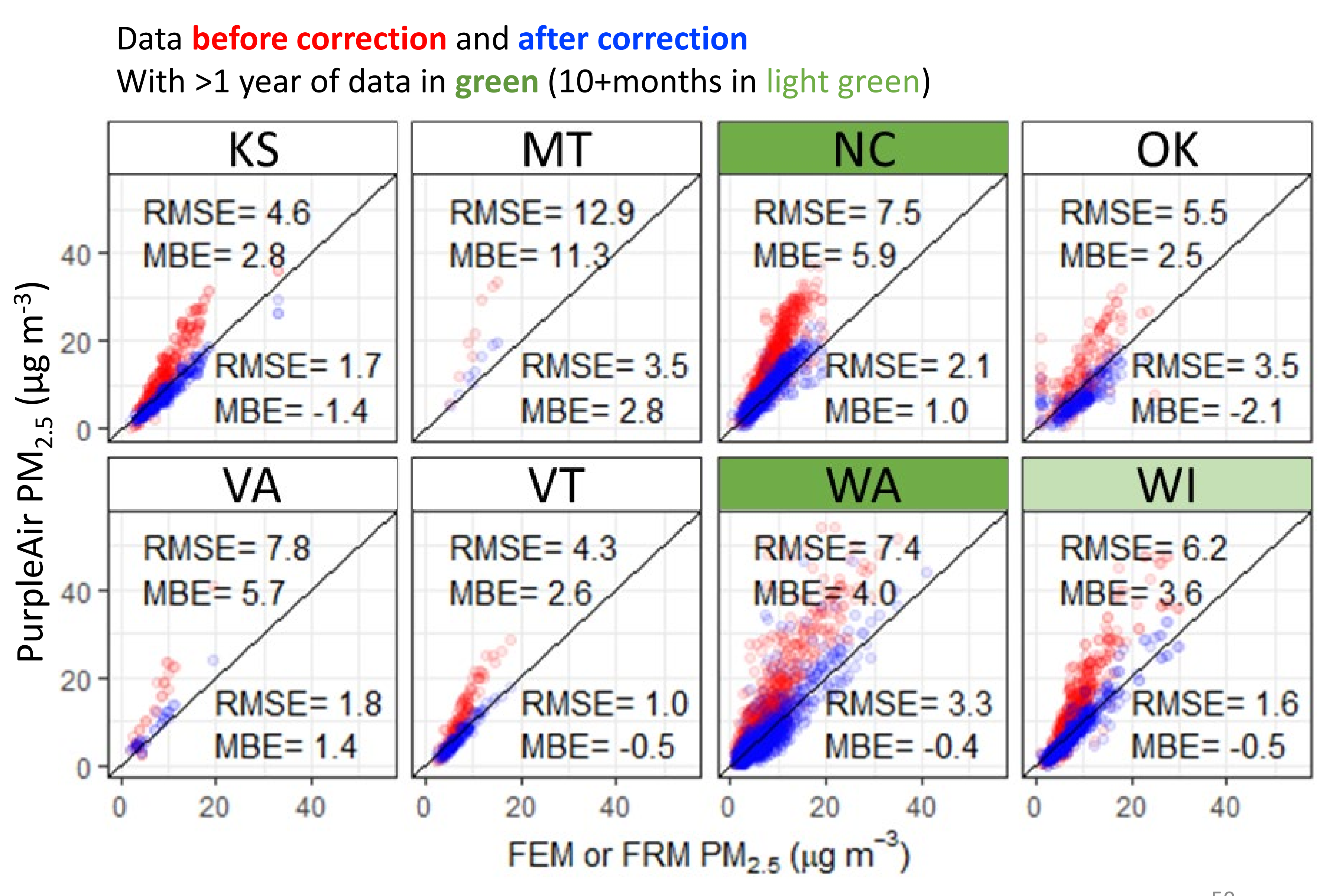
- Some work exists in the literature about the performance of PurpleAir sensors during smoke impacts
- However, these studies are typically limited investigating only smoke
- Most of this literature emerged in late 2019 - 2020
  - **Holder, et al. 2020.** 'Field Evaluation of Low-Cost Particulate Matter Sensors for Measuring Wildfire Smoke', Sensors.
  - **Robinson 2020.** 'Accurate, Low Cost $PM_{2.5}$ Measurements Demonstrate the Large Spatial Variation in Wood Smoke Pollution in Regional Australia and Improve Modeling and Estimates of Health Costs', Atmosphere: 11(8), 856.
  - **Delp and Singer 2020.** 'Wildfire Smoke Adjustment Factors for Low-Cost and Professional $PM_{2.5}$ Monitors with Optical Sensors', Sensors: 20(13) 3683.
  - **Mehadi, et al. 2020.** 'Laboratory and field evaluation of real-time and near real-time $PM_{2.5}$ smoke monitors', *Journal of the Air & Waste Management Association*: 1-22.

# PurpleAir U.S.-Wide Correction: Performance by State

State bias typically within 2 µg $m^{-3}$

RMSE typically reduced to within 3 µg $m^{-3}$

High bias in MT, but only ~1 week of data





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# Description of Smoke Measurements

## Approach:

- Collocate sensors with FEM/temporary smoke monitors
- Operate where $PM_{2.5}$ concentrations were highest
- Capture a range of smoke characteristics, concentrations, and environmental conditions

## Reference monitors provided by external agencies:

- Operated by multiple agencies followed their QA/QC protocols, maintained by their personnel

**Site types:** Fire stations/USFS facilities, monitoring shelters, other

## Collocation characteristics:

- Sensors within 10 m of reference instrument
- In open area without flow obstructions
- Not near trees
- Installed 1.0 – 3 m above ground

## Site characteristics:

- Most were near a roadway, some unpaved
- No hyperlocal sources (e.g. barbecue grills, generators)
- Possible diesel exhaust sources
- Possible smokers

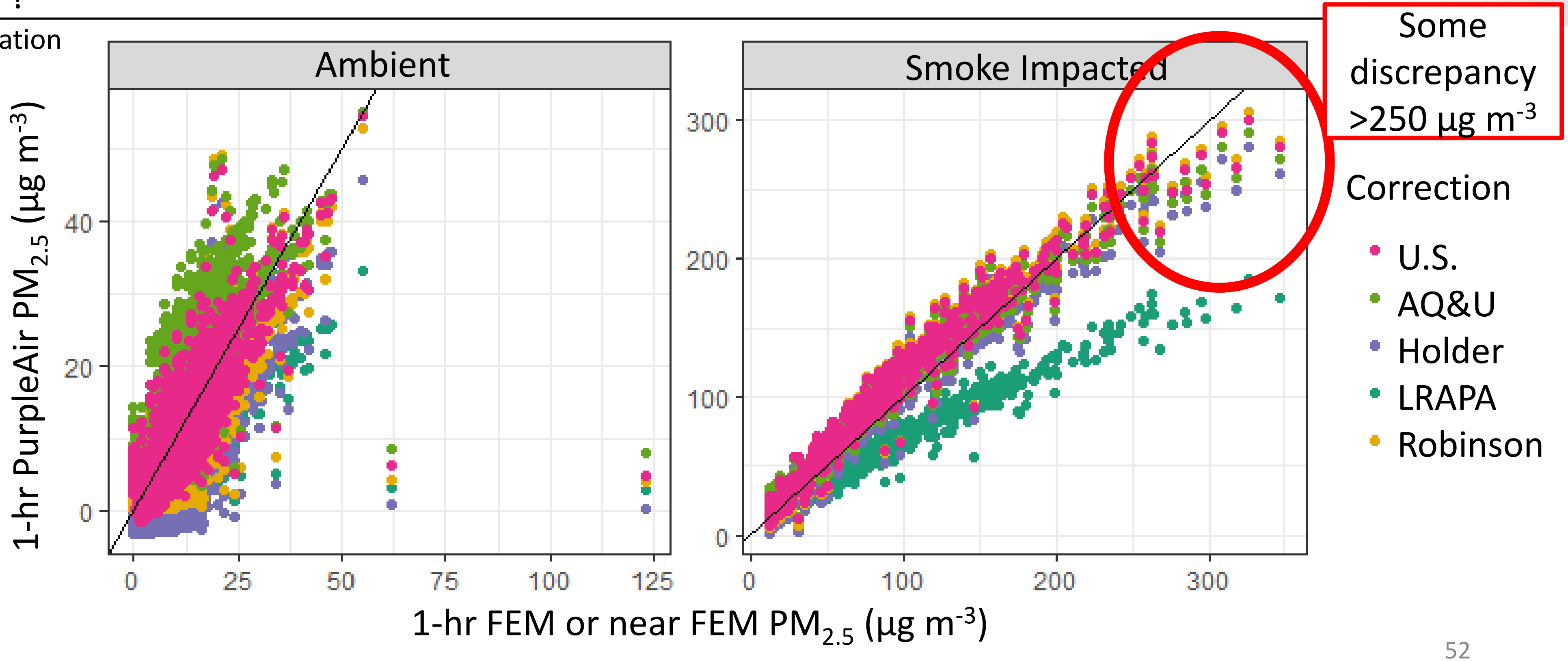
# Comparison of PurpleAir Corrections

| | | | | Ambient | Smoke |
|---|---|---|---|---|---|
| Correction | Type | cf | Equation | MBE μg m$^{-3}$ (%) | MBE μg m$^{-3}$ (%) |
| U.S. | U.S. ambient | 1 | PAx0.52 - 0.085xRH + 5.71 | -1 (11%) | 9 (11%) |
| Holder | Wildfire | 1 | PAx0.51 - 3.21 | -6 (70%) | 0 (1%) |
| LRAPA | Woodsmoke | atm | PAx0.5 - 0.66 | -4 (42%) | -25 (32%) |
| Robinson | Woodsmoke | 1 | PAx0.55 | -2 (27%) | 9 (12%) |
| AQ&U | UT ambient | atm | PAx0.778 + 2.65 | 3 (34%) | 9 (11%) |
| Mehadi | Woodsmoke | ?* | | -- | -- |

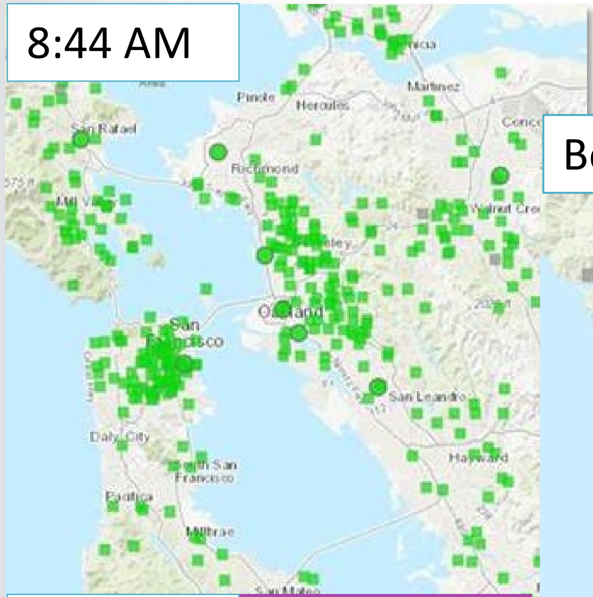
*Not included since uncertain on calculation

Under smoke conditions

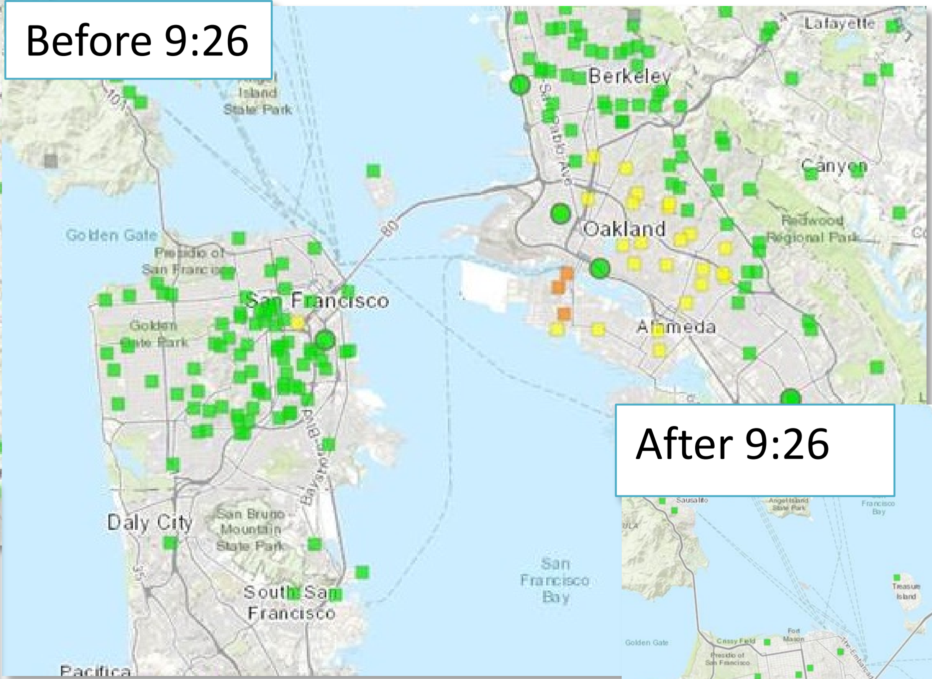
- **Holder correction** reduces most bias
- **U.S., Robinson, & AQ&U** work similarly
- **LRAPA** shows strong underestimation
  - Likely because it was developed on data 0-65 μg m$^{-3}$

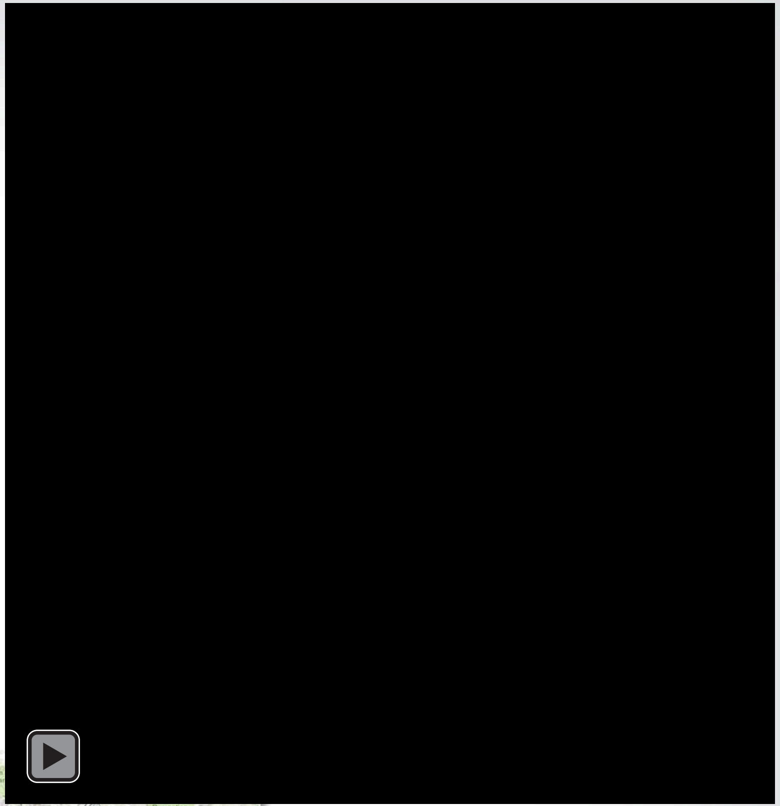


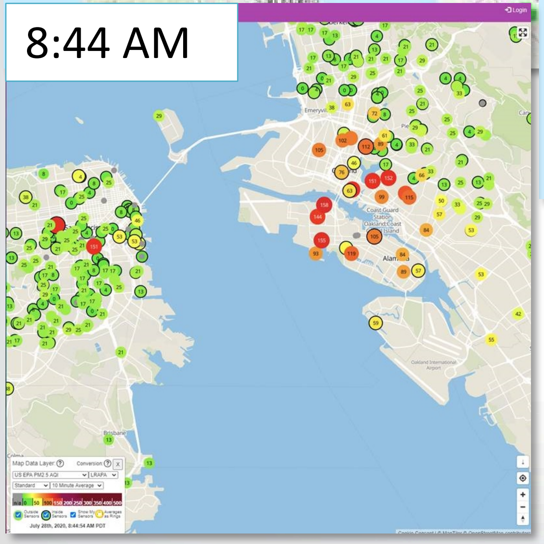
# Impact of NowCast: Example of Rapidly Changing $PM_{2.5}$



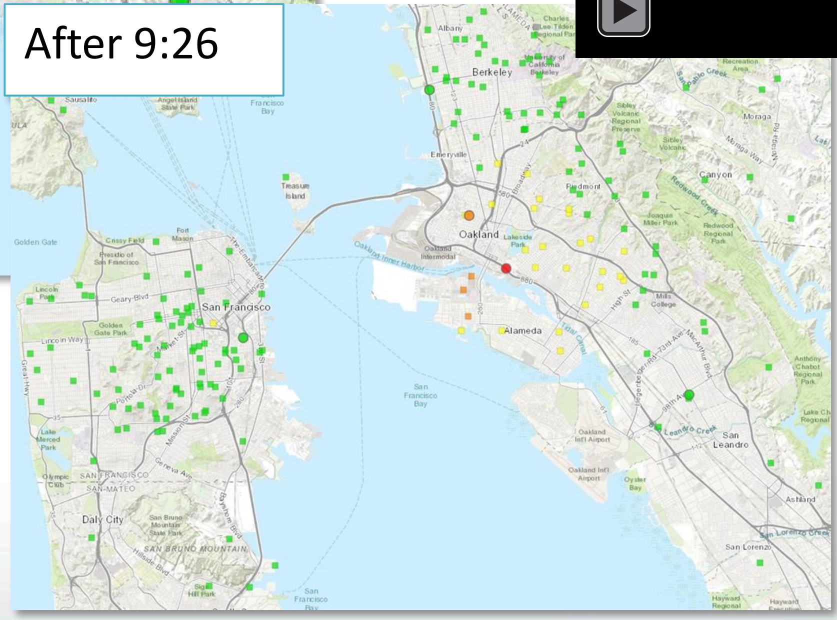

**5 alarm fire in SF quickly spreads smoke across the bay area**






**PurpleAir map reflects smoke plume moving across the area in real-time**



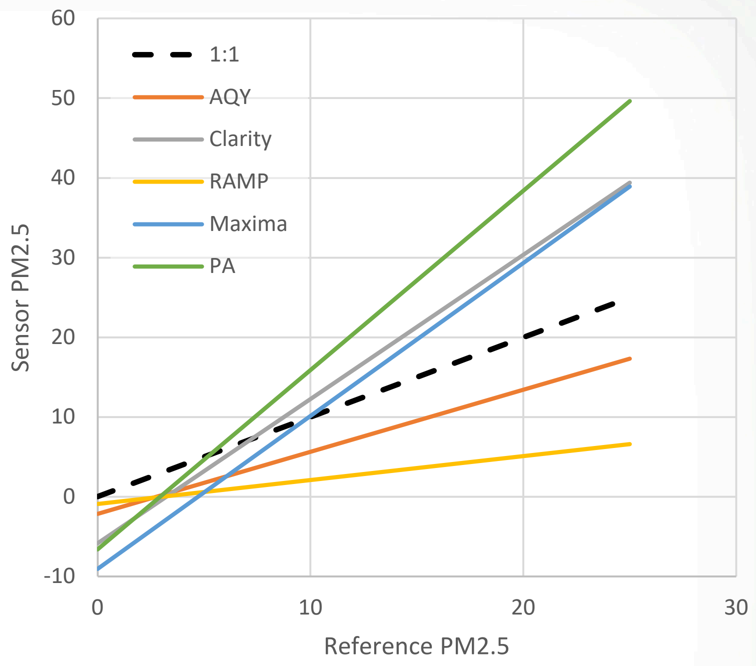

Hourly NowCast data does not reflect rapidly changing air quality resulting in disagreement between AirNow Fire and Smoke map and PurpleAir map

*Source: Duc Nguyen BAAQMD*

# Performance Of All $PM_{2.5}$ Sensors Is Not The Same

- Many PM **sensors show similar trends** when compared to regulatory-grade reference instruments
- **Sensor data must be corrected** to be more comparable
- Cleaning/correction methodology is dependent on make/model
- Sensors with identical sensing units can have different performance
- The degree to which sensors of the same make/model agree with one another (precision) is also variable
- Tight precision is necessary for fleet-wide corrections necessary for large network applications

Corrections for different sensors




1-Hour Averaged $PM_{2.5}$