PurpleAir $PM_{2.5}$ performance across the U.S.

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Webinar with project partners

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Introductions

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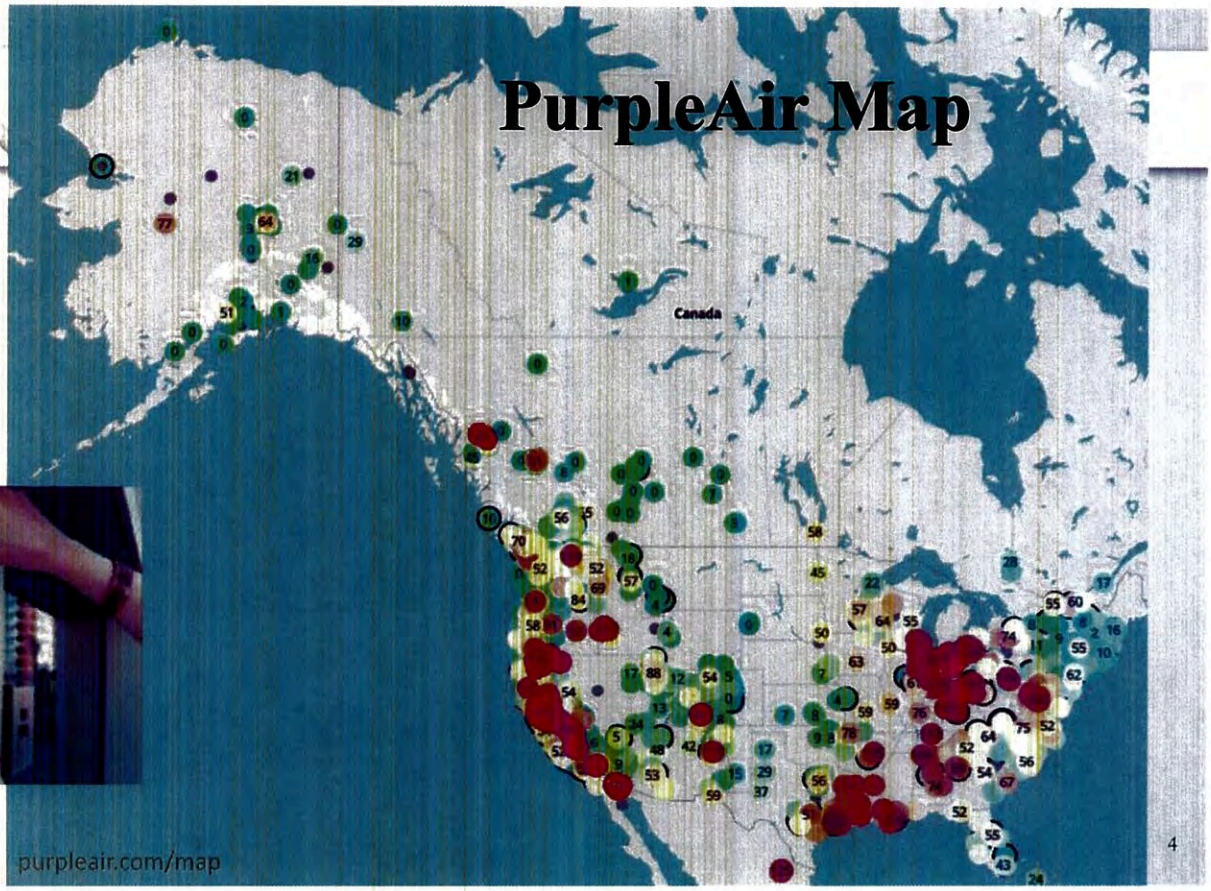
Overview

- Background
- Goals
- Methods
  - Dataset
  - Quality assurance methods
  - Correction methods
- Results
  - Error
  - Reported Air Quality Index (AQI) values
  - Results by state
- Conclusions
- Next Steps

PurpleAir Map

- Cost: ~$250
- 1,000's deployed worldwide



Goal

To develop a correction that can improve PurpleAir $PM_{2.5}$ measurements across the U.S.

- To be used by PurpleAir and/or various users (local agencies, community groups, exposure scientists)

Balance:

- Broad applicability
- Simplicity of use
- Best correction method

Dataset

All sensors collocated by air monitoring agencies (Thank you!)

- Communicating with all partner agencies to ensure collocation and to glean additional details on sensor siting
- **Note:** This removes some of the uncertainty associated with using PurpleAir data as usually you cannot confirm they are correctly located on the map

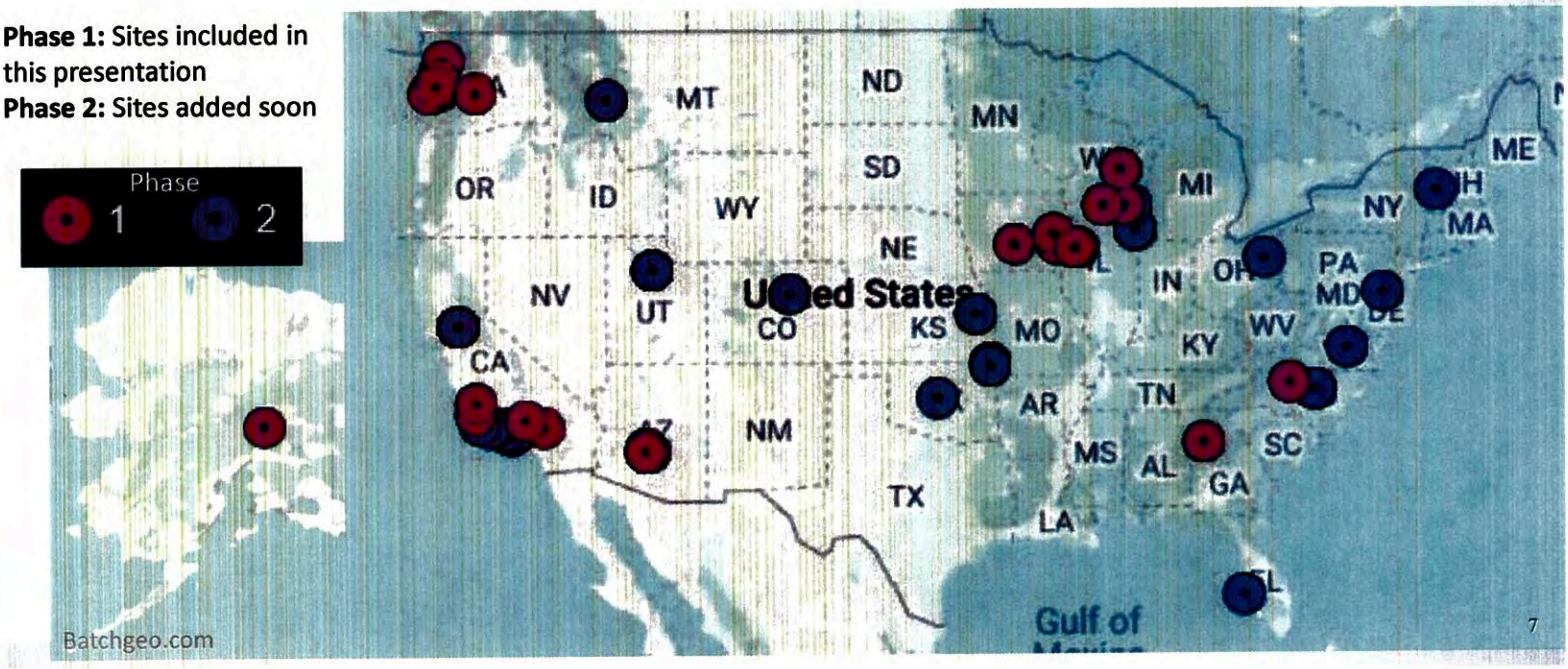
24-hour averaged Federal Equivalent Method (FEM) and Federal Reference Method (FRM) data downloaded from Air Quality System (AQS)

Previous work:

- typically small number of sensors (~<10) in a single region
- some studies not collocated

Collocation sites

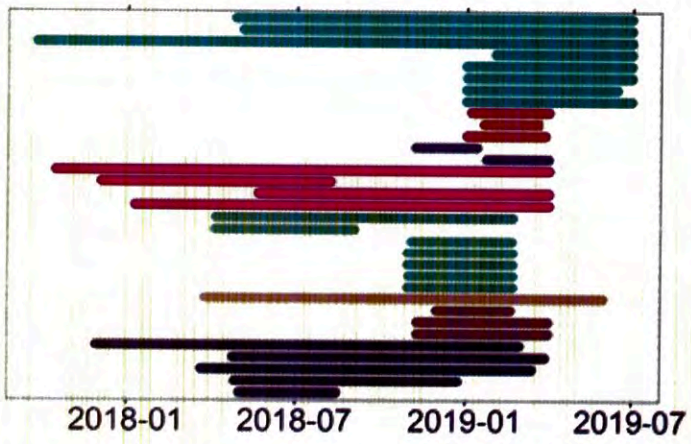
Phase 1: Sites included in this presentation
Phase 2: Sites added soon



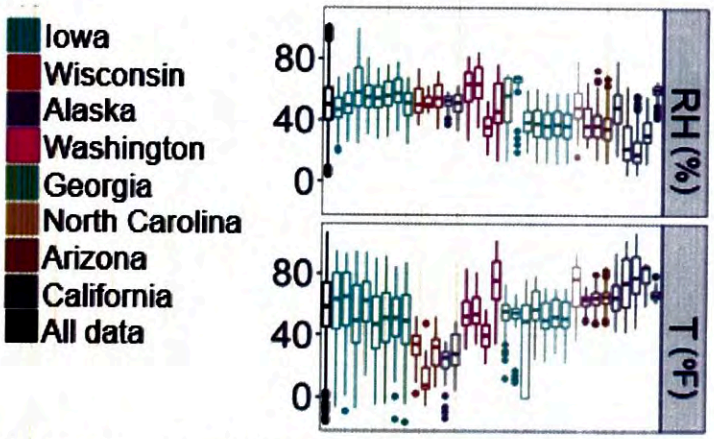
Notes about the dataset

- Primarily online but a few offline
- Public and private sensors
- Operating for different time periods and lengths of time

Dataset time periods



Sensors operated over different time periods from a few months to almost 2 years



24-hr temperature (T) and relative humidity (RH) across sites as measured by the PurpleAir sensors. Some sites ran for a single season resulting in T & RH not representative of the typical annual climate

Cf=1 and Cf=atm corrections

PurpleAir provides PM data with two corrections

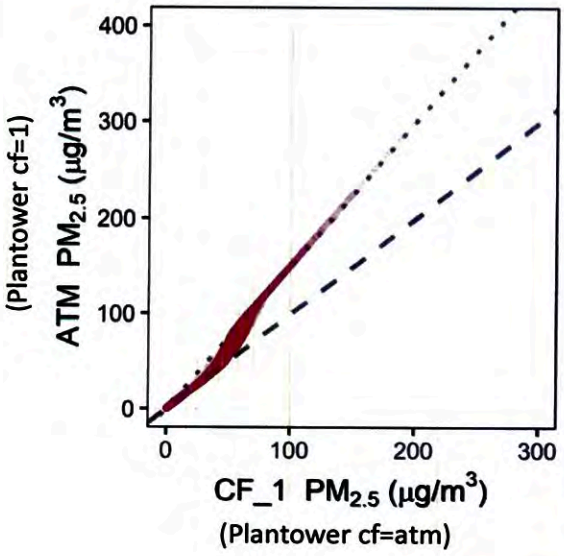
- Displayed on the map: cf=1
  - Plantower cf=atm output
- Also: cf=atm
  - Plantower cf=1 output

Note: since flipped labels were identified, the column names have been flipped in the sensor list output

- A fix may be coming to the other datasets soon

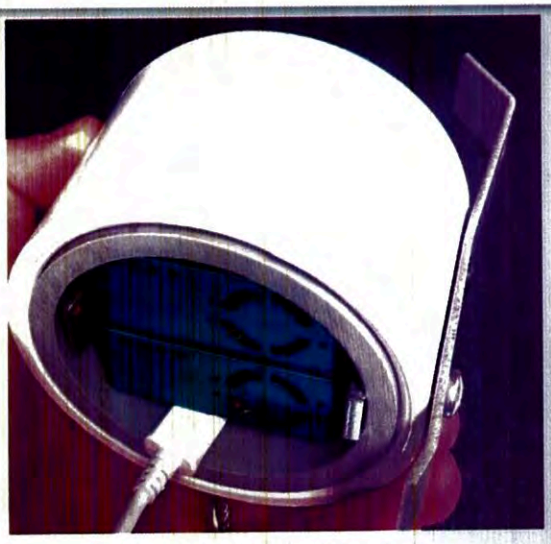
PurpleAir cf=atm selected for this work

- cf=atm R^2=0.65 > cf=1 R^2=0.64



QA: A & B channels

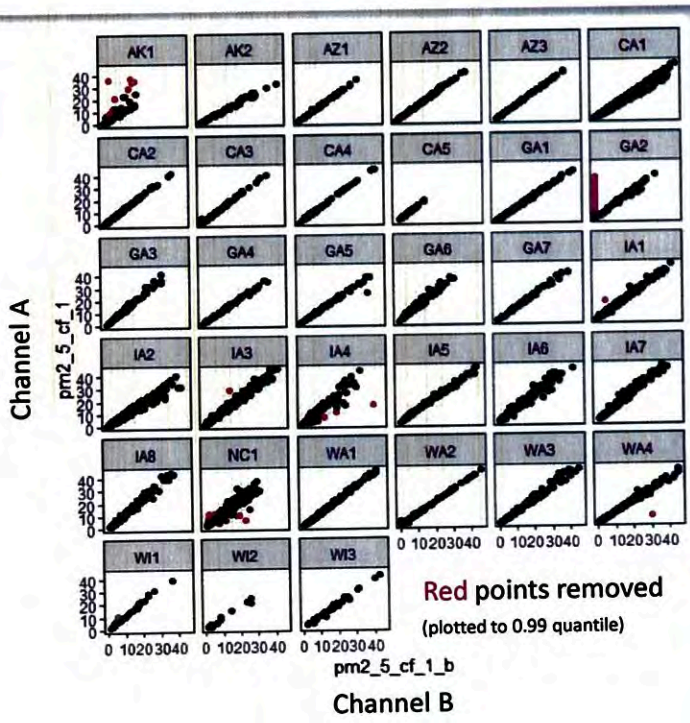
- 2 Plantower PMS5003 (channels A & B)
- Sample for alternating 10-second intervals
- Generate 2-minute averages
  - previously 80-second



PurpleAir underside view

QA steps

- Only 24-hr averages with at least 90% of the data present were used
- Points removed if 24-hr averaged A & B $PM_{2.5}$ differ by:
  - $\geq \pm 5$ µg m^{-3} AND
  - $\geq \pm$ 16 %
    - 2*sd(% error)
  - 2% removed
- A & B channels averaged
  - Slightly improves overall R^2 and confidence on linear regression
  - More important for individual sensors



Equations considered

1. **Raw:** $PM_{2.5}$ = PA (raw PurpleAir $PM_{2.5}$ cf=atm)
2. **Linear:** $PM_{2.5} = a*PA + b$
3. **T & RH:** $PM_{2.5} = a*PA + b*T + c*RH + d$

Units:
$PM_{2.5}$= µg m^{-3}
T=°F
RH=%

Other parameters considered:

- Pressure (not available for all sensors)
- Other T & RH functions
  - Selected equation is more broadly applicable than T*RH*PM
  - Strong nonlinear RH influence not seen in most states
- Size bin data: minimal improvements
- Duration deployed: More data needed from sensors operating ≥ 1 year
- State: Seasonal influences may dominate since <1 year of data in many states

Equations considered

1. **Raw:** $PM_{2.5}$ = PA (raw PurpleAir $PM_{2.5}$ cf=atm)

2. **Linear:** $PM_{2.5} = 0.38*PA + 2.94$, $R^2=0.69$

3. **T & RH:** $PM_{2.5} = 0.39*PA + 0.0024*T - 0.050*RH + 5.19$, $R^2=0.72$

Units:
$PM_{2.5}$= $\mu g\ m^{-3}$
T=°F
RH=%

Statistics used for evaluation

Mean Bias Error (MBE): Accuracy

- The average difference between the PurpleAir and FEM or FRM measurements

Root Mean Square Error (RMSE): Precision

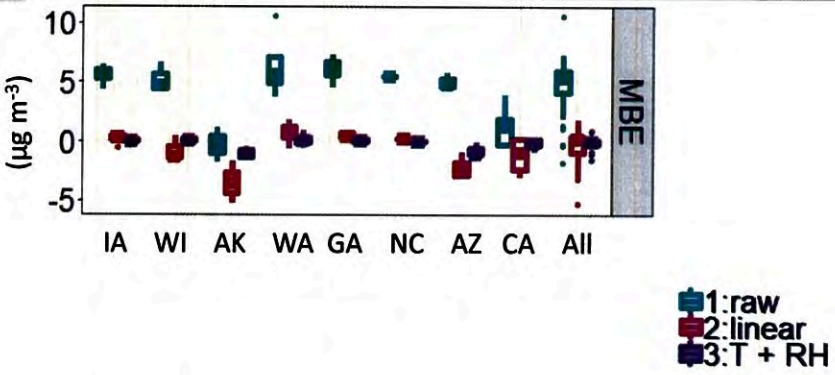
- A measure of the spread between the 24-hr PurpleAir and FEM or FRM measurements
- Since it is squared it penalizes outliers

Spearman correlation: Measure of association

- Similar to pearson correlation or R^2 but for non normally distributed datasets

Results

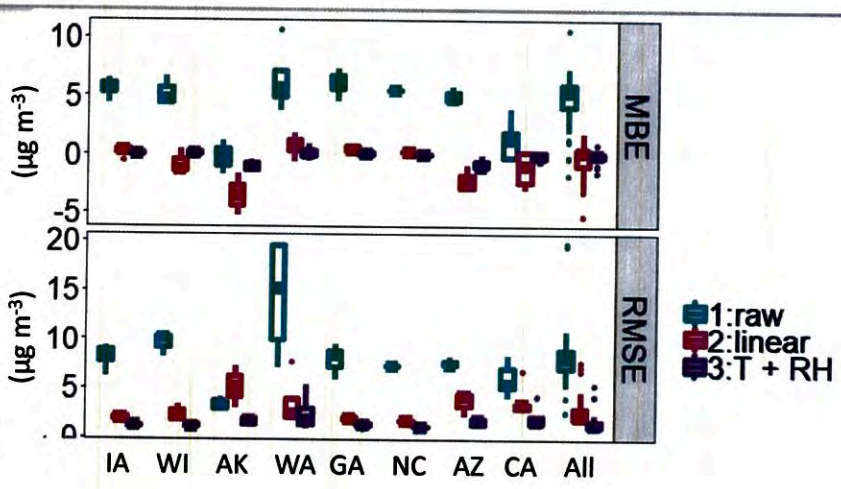
- Linear correction reduces bias (MBE) **except**:
  - AK
- T + RH correction reduces state bias in all states **especially**:
  - AK, CA, AZ



Each point on the boxplot is a single PurpleAir sensor

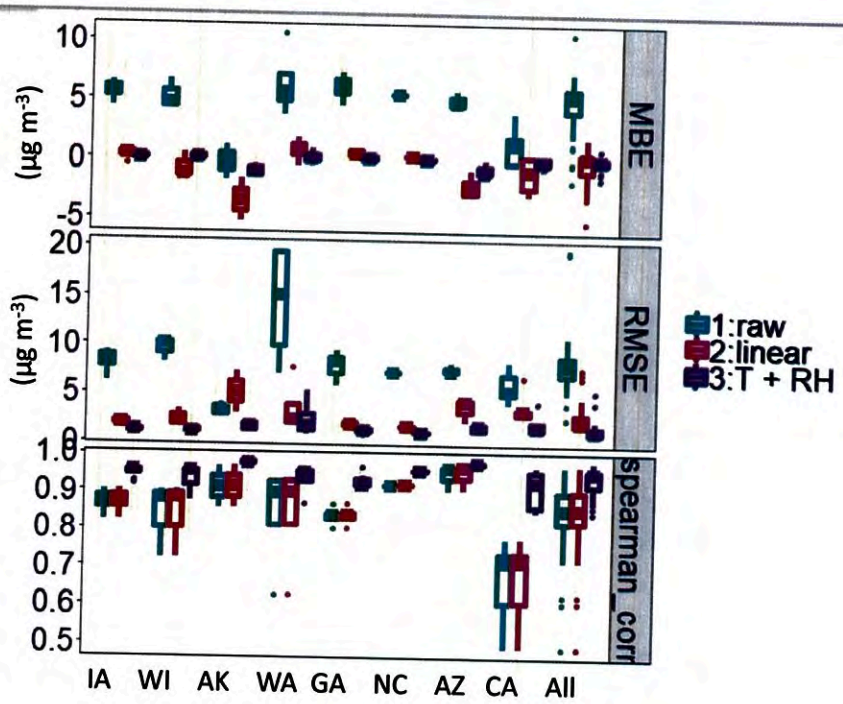
Results

- Linear correction reduces RMSE except:
  - AK
- T + RH correction reduces RMSE in all states

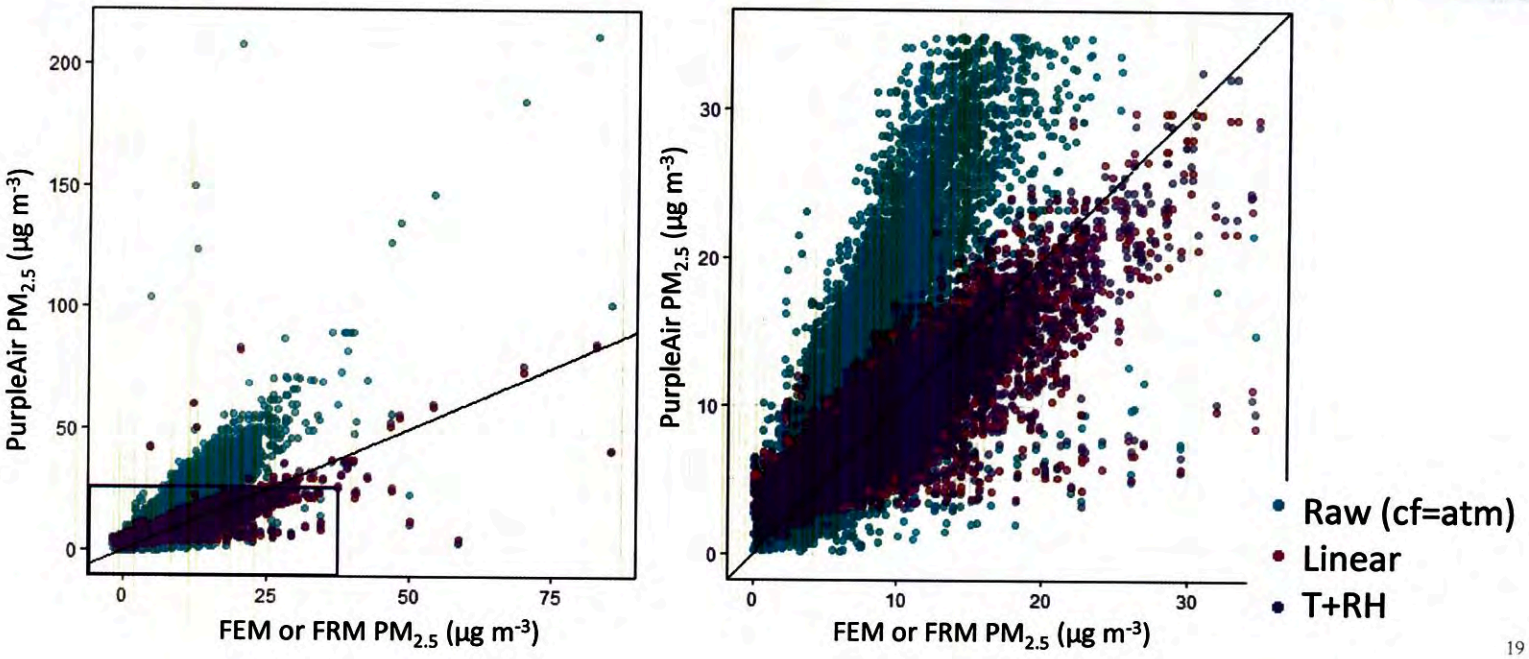


Results

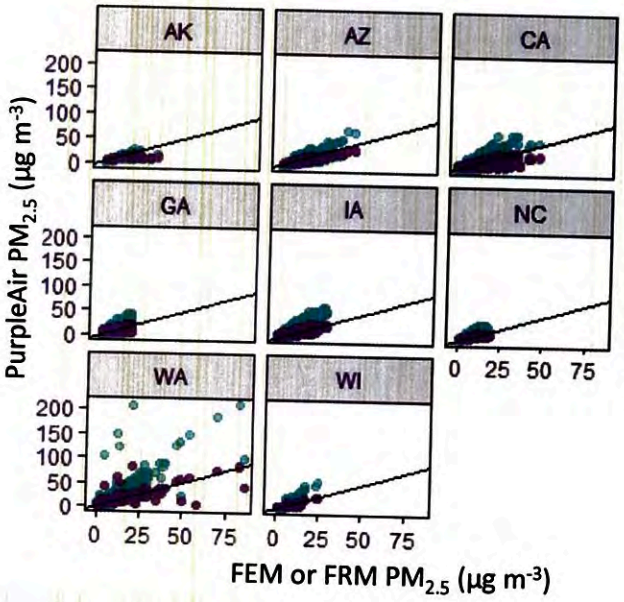
- Spearman correlation improved using T + RH correction in all states

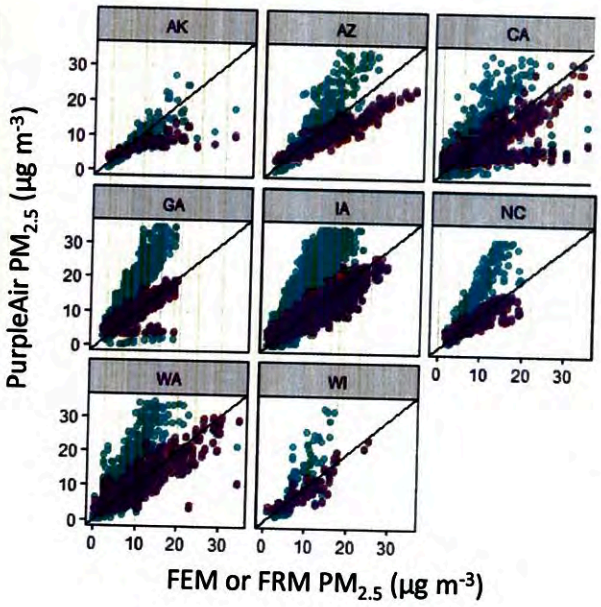


Results


PurpleAir PM2.5 (µg m-3)
FEM or FRM PM2.5 (µg m-3)
0
25
50
75
100
150
200
PurpleAir PM2.5 (µg m-3)
FEM or FRM PM2.5 (µg m-3)
0
10
20
30
Raw (cf=atm)
Linear
T+RH

Results by state



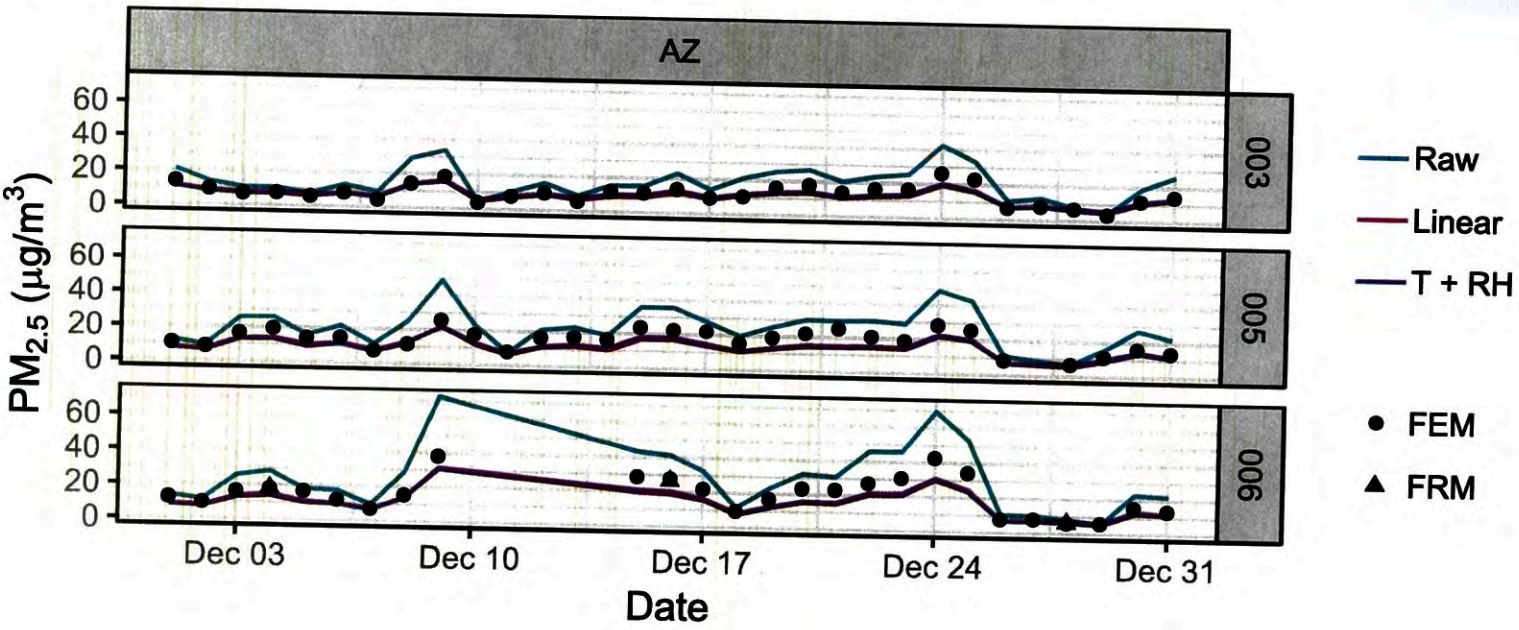


- Raw (cf=atm)
- Linear
- T+RH

- Linear and T+RH very similar
- Does not capture higher concentrations in AK and AZ
- Captures higher concentrations in WA
- 2 prong distribution in CA and GA

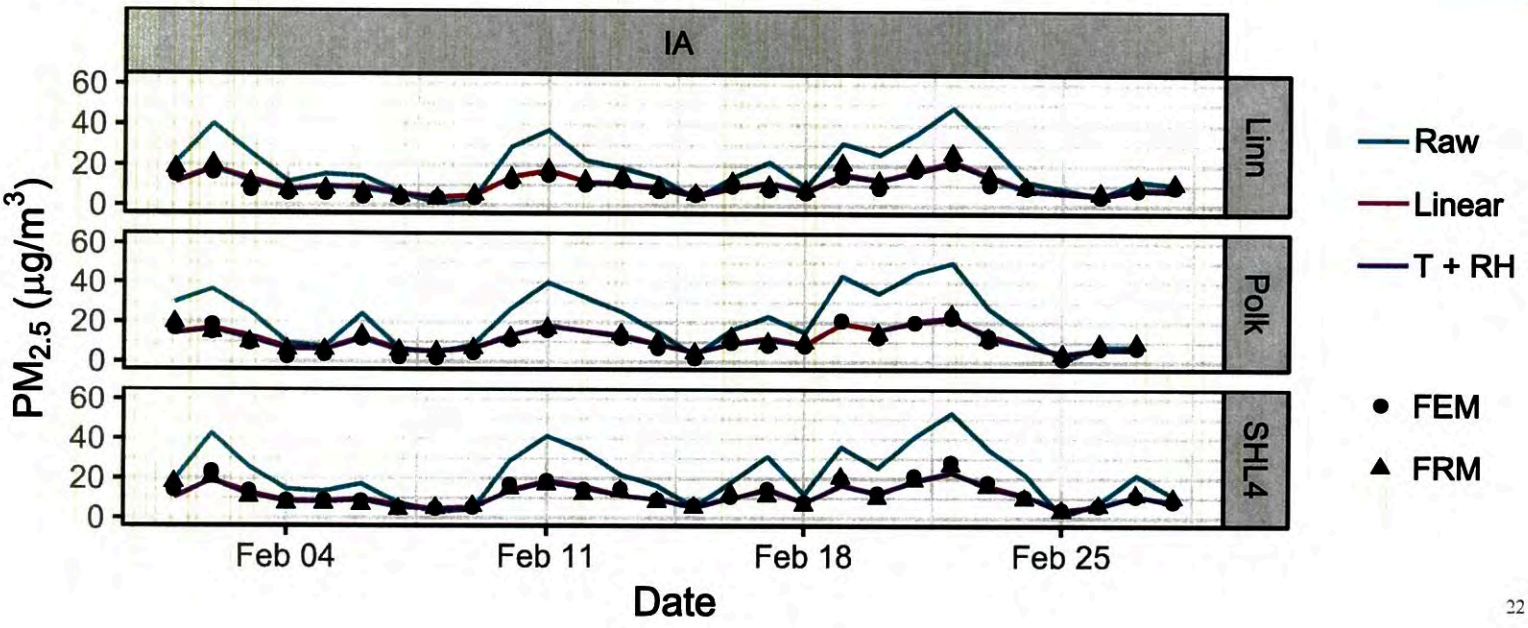
Arizona

3 example sites from Phoenix Arizona



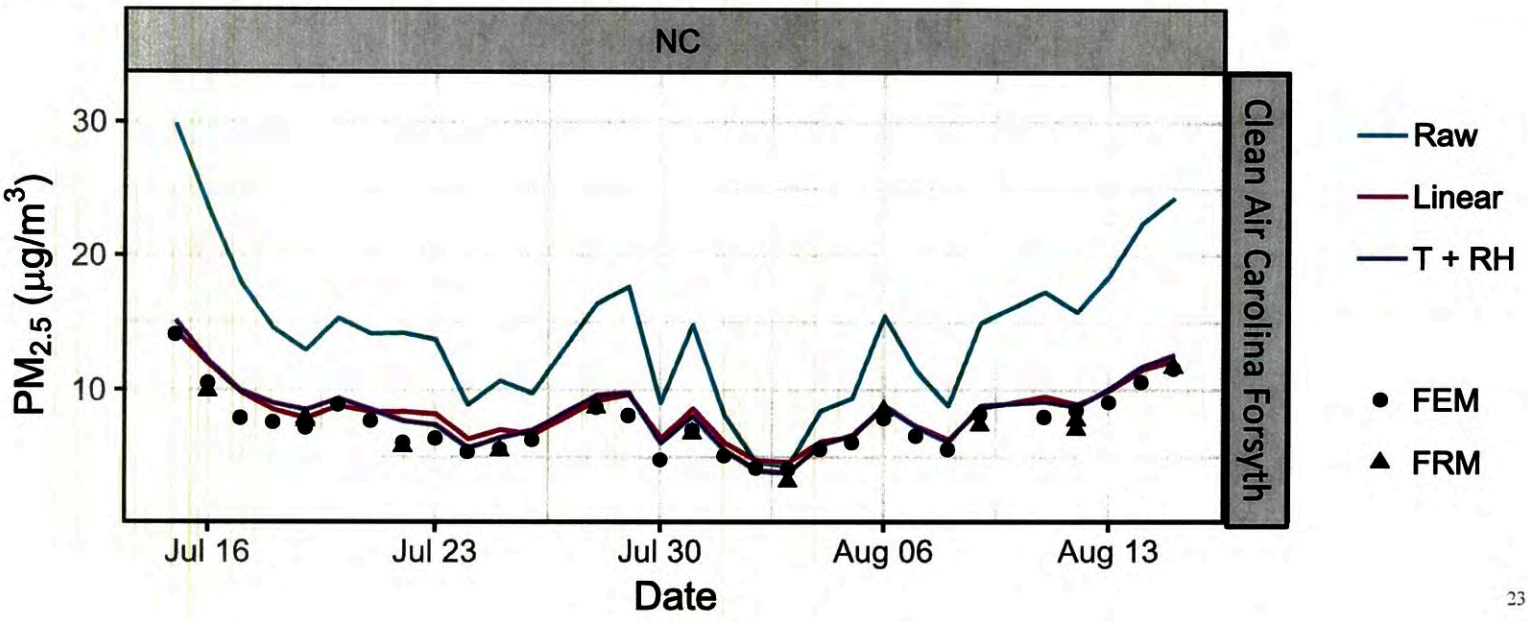
Iowa

3 example sites from Iowa

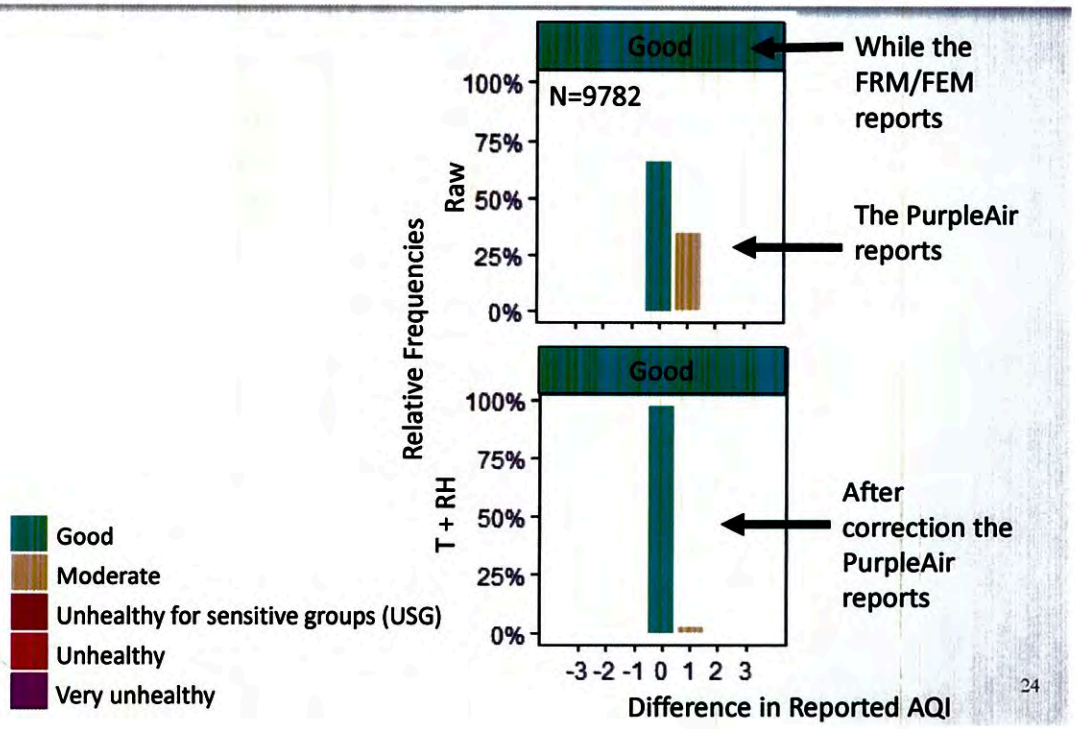


North Carolina

example site from Forsyth County, North Carolina



AQI reporting: Good-Moderate

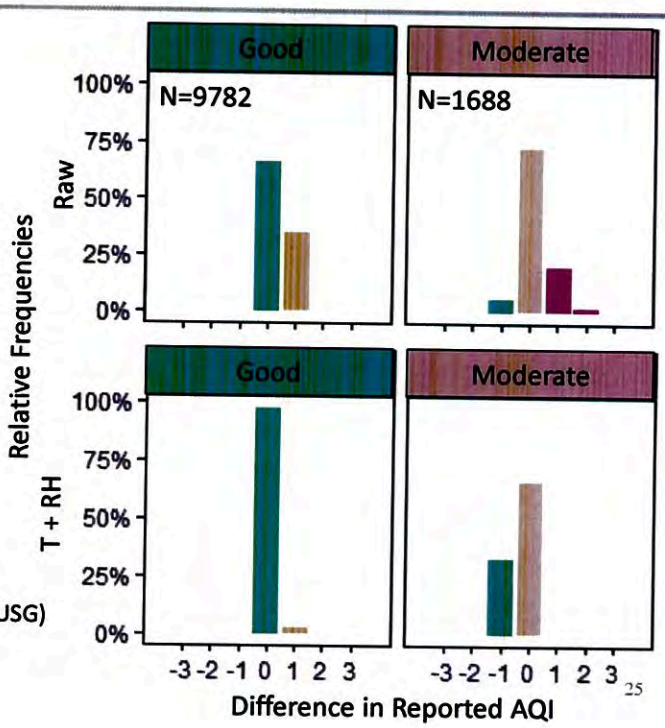


AQI reporting: Good-Moderate

Raw PurpleAir often over reports AQI

- This is important to note as this is what is being displayed and viewed by many of the PurpleAir map

Correcting causes under reporting at moderate AQI

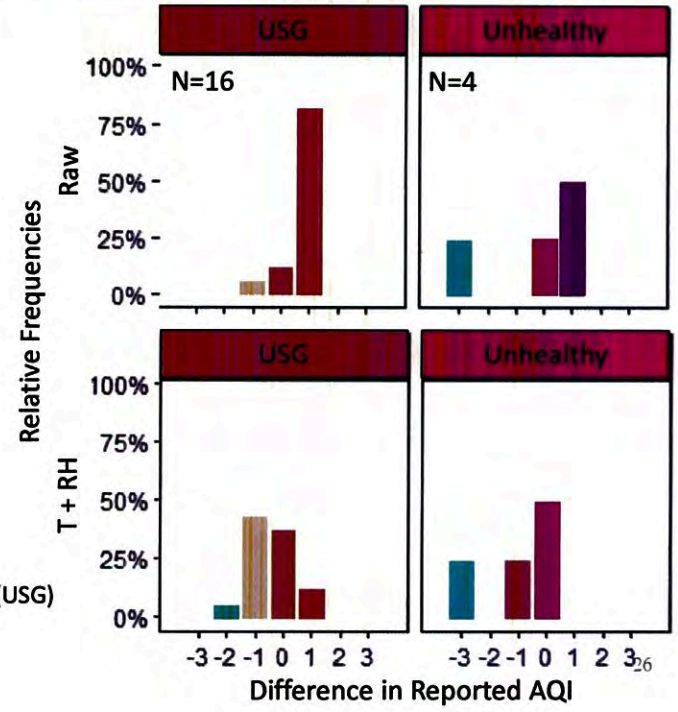


Good
Moderate
Unhealthy for sensitive groups (USG)
Unhealthy
Very unhealthy

AQI reporting: USG-Unhealthy

Limited data at higher AQI

Correction also may contribute to under reporting at higher AQI



- Good
- Moderate
- Unhealthy for sensitive groups (USG)
- Unhealthy
- Very unhealthy

Conclusions

- A U.S. wide correction including T & RH could improve PurpleAir performance in terms of MBE, RMSE, and correlation across the U.S.
- Even a simple linear correction would significantly improve performance in most parts of the U.S.
- Currently PurpleAir often over reports AQI category
- Proposed corrections may not improve higher category AQI reporting
  - Amara Holder (EPA) is specifically exploring performance under wildfire conditions
  - Working to add more high concentration data to improve model performance at high concentration

Limitations:

- Limited high concentration data
- Unknown applicability at shorter time intervals
- Real-world PurpleAir data has additional uncertainty with reported location

Next steps

- Explore additional collocated data provided by partners
- Explore higher time resolutions data (1-hr)
  - Are agencies interested in 2-minute data?
- Further explore performance over time as more sensors operate for 1 year
- Explore data from wildfires
- Explore the long term performance of additional sensor types across the U.S.

Acknowledgements

AK: State of Alaska, Citizens for Clean Air

AZ: Maricopa County Air Quality Department

CA: 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

CO: Colorado Department of Public Health and Environment

DE: Delaware Division of Air Quality

FL: Sarasota County Government

GA: Region 4, Georgia Environmental Protection Division

IA: Iowa Air Quality Bureau

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

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

Questions?

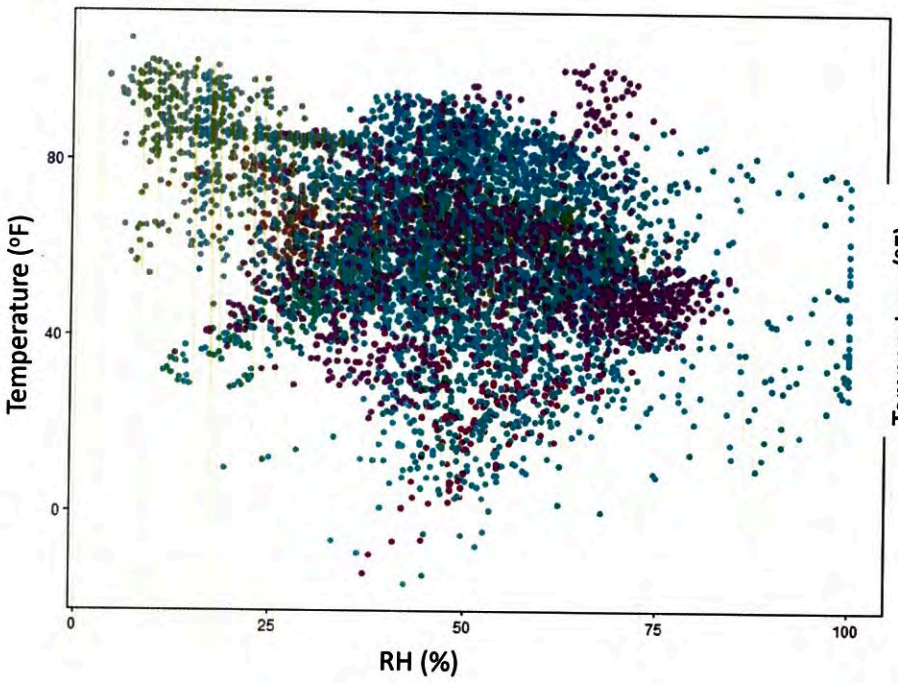
- Contact: Johnson.karoline@epa.gov

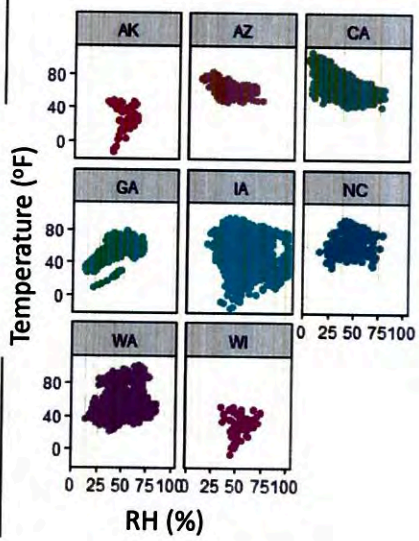
Discussion

Partner agencies: Any initiative or project you would like to discuss?

Extra slides

Dataset: temperature and RH



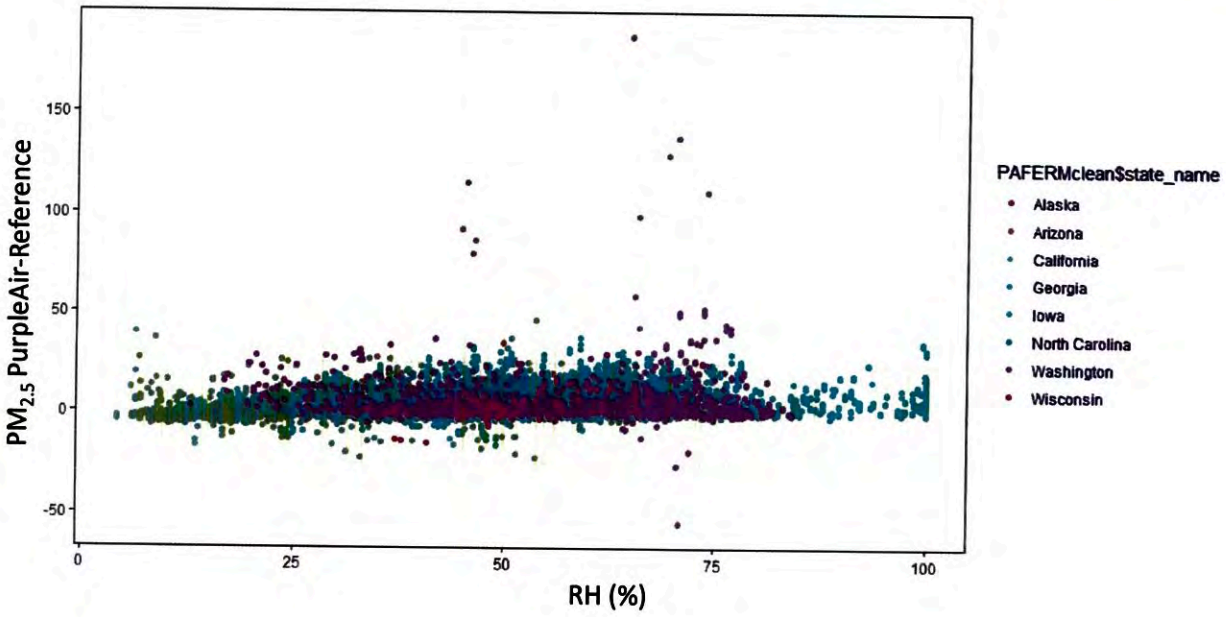


Parameters considered for multilinear regression

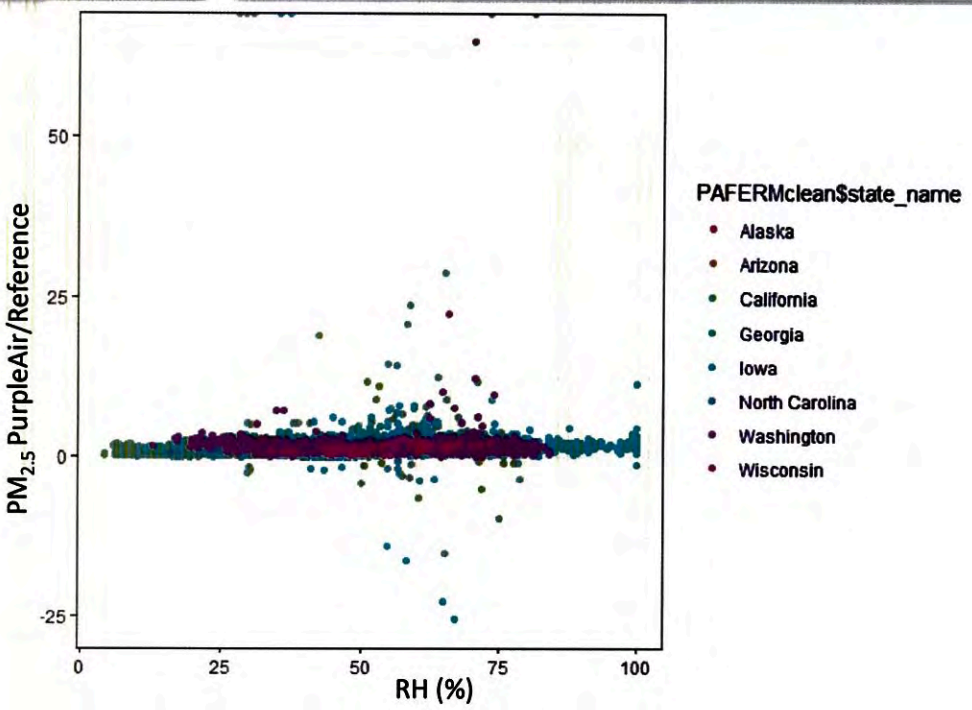
- $PM_{2.5}$ cf=atm and cf=1 channels
  - Cf=atm slightly stronger correlation (cf=1 from Plantower)
- Relative humidity
- Dewpoint
  - RH explained more error
- Temperature
  - T in both °F and K considered but both provide the same results just different coefficients
  - Marginally significant may remove based on results of full dataset (p=0.05)
- Pressure
  - Missing from 22% of the dataset
- Size bin information (reported to reduce detection limit)
  - reduces error <1%
- Duration deployed
  - full dataset suggests intercept decreases by 0.77 $\mu g\ m^{-3}$ after a year of use
- Location (state, region, etc.)
  - Correction less broadly applicable especially since many state datasets do not have all seasons

Only considering parameters available from PurpleAir

RH: sensor-reference

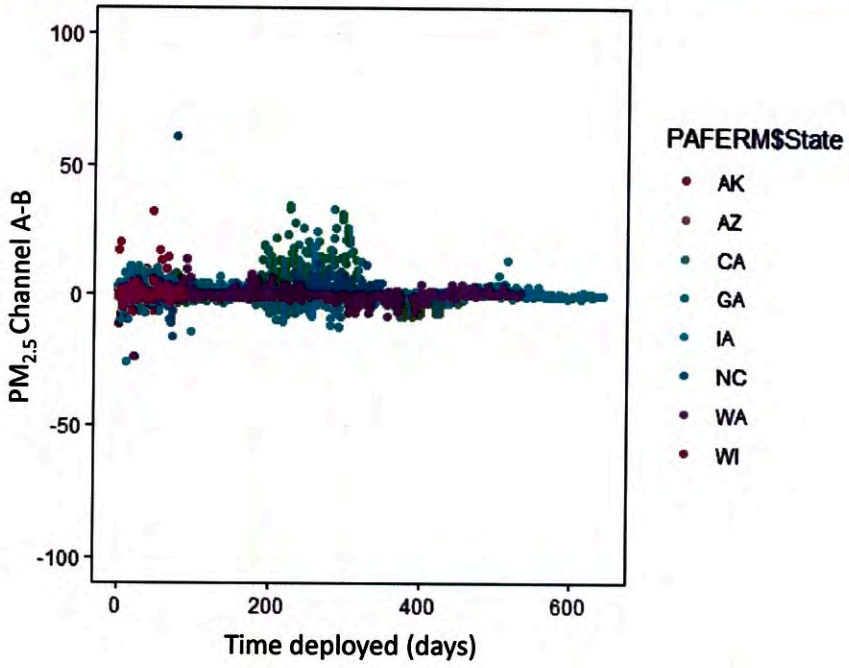


RH: sensor/reference



No distinct pattern between A& B channels over time

- R^2=0 (p=0.02)
- Also no significant relationship time deployed vs. ref-PA difference



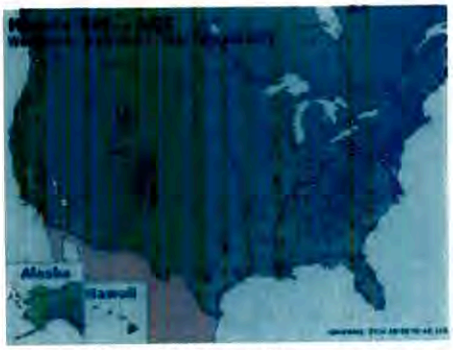
WIKIPEDIA

NowCast (air quality index)

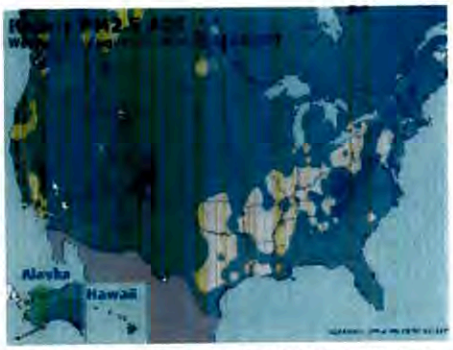
The PM **NowCast** is a weighted average of hourly air monitoring data used by the United States Environmental Protection Agency (USEPA) for real-time reporting of the Air Quality Index (AQI) for PM (PM_{10} or $PM_{2.5}$).

The PM NowCast is computed from the most recent 12 hours of PM monitoring data, but the NowCast weights the most recent hours of data more heavily than an ordinary 12-hour average when pollutant levels are changing. The PM NowCast is used in lieu of a 24-hour average PM concentration in the calculation of the AQI until an entire calendar day of hourly concentrations has been monitored.

The Ozone **NowCast** is an algorithm[1] developed by the USEPA to predict the 8-hour ozone average centered on the current hour from the current 1-hr average ozone data. At each ozone monitoring site, partial least squares regression is used to develop a predictive relationship between the 1-hr and 8-hr averages using the previous 2 weeks of ozone data. USEPA uses the Ozone Nowcast for real time public reporting of the ozone AQI.[1] (https://www.airnow.gov)



$PM_{2.5}$ AQI of US monitors, calculated utilizing NowCast, courtesy US EPA



PM2.5 AQI map, calculated utilizing NowCast, courtesy US EPA

Calculation of the PM NowCast

Let $c_1, c_2, \ldots c_{12}$ represent the hourly PM concentrations for the most recent 12-hour period, with c_1 the most recent hourly value, and let c_{min} and c_{max} represent the minimum and maximum hourly concentration for the 12-hour period.

Define:

$$w^* = 1 - \frac{c_{max} - c_{min}}{c_{max}} = \frac{c_{min}}{c_{max}}$$

and let

$$w = \begin{cases} w^* & \text{if } w^* > \frac{1}{2} \\ \frac{1}{2} & \text{if } w^* \leq \frac{1}{2} \end{cases}$$

With these definitions the PM NowCast[2] is given by:

$$NowCast = \frac{\sum_{i=1}^{12} w^{i-1} c_i}{\sum_{i=1}^{12} w^{i-1}}.$$

For the special case where there is no variability in the hourly values, $c_{min} = c_{max}, w = 1$, and the NowCast reduces to the twelve-hour average:

$$NowCast = \frac{\sum_{i=1}^{12} c_i}{12}.$$

For the special case where w=1/2:

$$NowCast = \frac{c_1 + (\frac{1}{2})c_2 + \ldots + (\frac{1}{2})^{11} c_{12}}{1 + \frac{1}{2} + (\frac{1}{2})^2 + \ldots + (\frac{1}{2})^{11}}$$

But $1/(1-x)=1 + x + x^2 + \ldots, x < 1$, so to a good approximation, when w = 1/2:

$$NowCast = \frac{1}{2}c_1 + (\frac{1}{2})^2 c_2 + \ldots + (\frac{1}{2})^{12} c_{12}$$

Because the most recent hours of data are weighted so heavily in the NowCast when PM levels are changing, EPA does not report the NowCast when data is missing for c_1 or c_2.

Consider a day when the hourly average $PM_{2.5}$ concentration is zero for all hours of the day, except for a single hour from noon to 1 pm, where a monitor records a concentration pulse of 71 micrograms per cubic meter (μg/m^3). According to the equation above, the Nowcast is 71/2 μg/m^3=35.5 μg/m^3 the hour after the pulse, two hours later it is 71/4 μg/m^3=17.8 μg/m^3 and three hours later it is 71/8 μg/m^3= 8.9 μg/m^3. To calculate the corresponding AQI values, each NowCast concentration is substituted into the AQI equation in place of the 24-hour average $PM_{2.5}$ concentration:

$$I = \frac{C - C_{low}}{C_{high} - C_{low}}(I_{high} - I_{low}) + I_{low}$$

where:

I = the AQI,
C = the 24-hour average $PM_{2.5}$ pollutant concentration,
C_{low} = the concentration breakpoint that is ≤ C,
C_{high} = the concentration breakpoint that is ≥ C,
I_{low} = the index breakpoint corresponding to C_{low},
I_{high} = the index breakpoint corresponding to C_{high}.

and:

C_{low}	C_{high}	I_{low}	I_{high}	Category
0	12.0	0	50	Good
12.1	35.4	51	100	Moderate
35.5	55.4	101	150	Unhealthy for Sensitive Groups
55.5	150.4	151	200	Unhealthy
150.5	250.4	201	300	Very Unhealthy
250.5	350.4	301	400	Hazardous
350.5	500.4	401	500	Hazardous

Thus, the three NowCast concentrations correspond to air quality indices[3] of 101, (AQI Color Code Orange, Air Quality: Unhealthy for Sensitive Groups), 63 (AQI Color Code Yellow, Air Quality: Moderate), and 37 (AQI Color Code Green, Air Quality: Good) respectively. After the day is over and all of the hourly data is available, the AQI for the day is calculated from the 24-hr average; 71/24 $\mu g/m^3$= 3.0 $\mu g/m^3$, an AQI of 12 (Color Code Green, Air Quality: Good). EPA has developed a calculator to compute the PM NowCast, AQI, and AQI category and color from the most recent 12 hours of monitoring data.[4]

References

1. *White paper describing EPA Ozone Nowcast Algorithm* (https://github.com/USEPA/O3-Nowcast), U.S. Environmental Protection Agency, 2019-08-05, retrieved 2019-08-07
2. "Computing the NowCast" (http://www.epa.gov/airnow/faq/Nowcast-formula.pptx) (PPTX). US Environmental Protection Agency. Retrieved 25 September 2014.
3. "AQI Calculator: Concentration to AQI" (https://airnow.gov/index.cfm?action=resources.conc_aqi_calc). AirNow. Retrieved 25 September 2014.
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