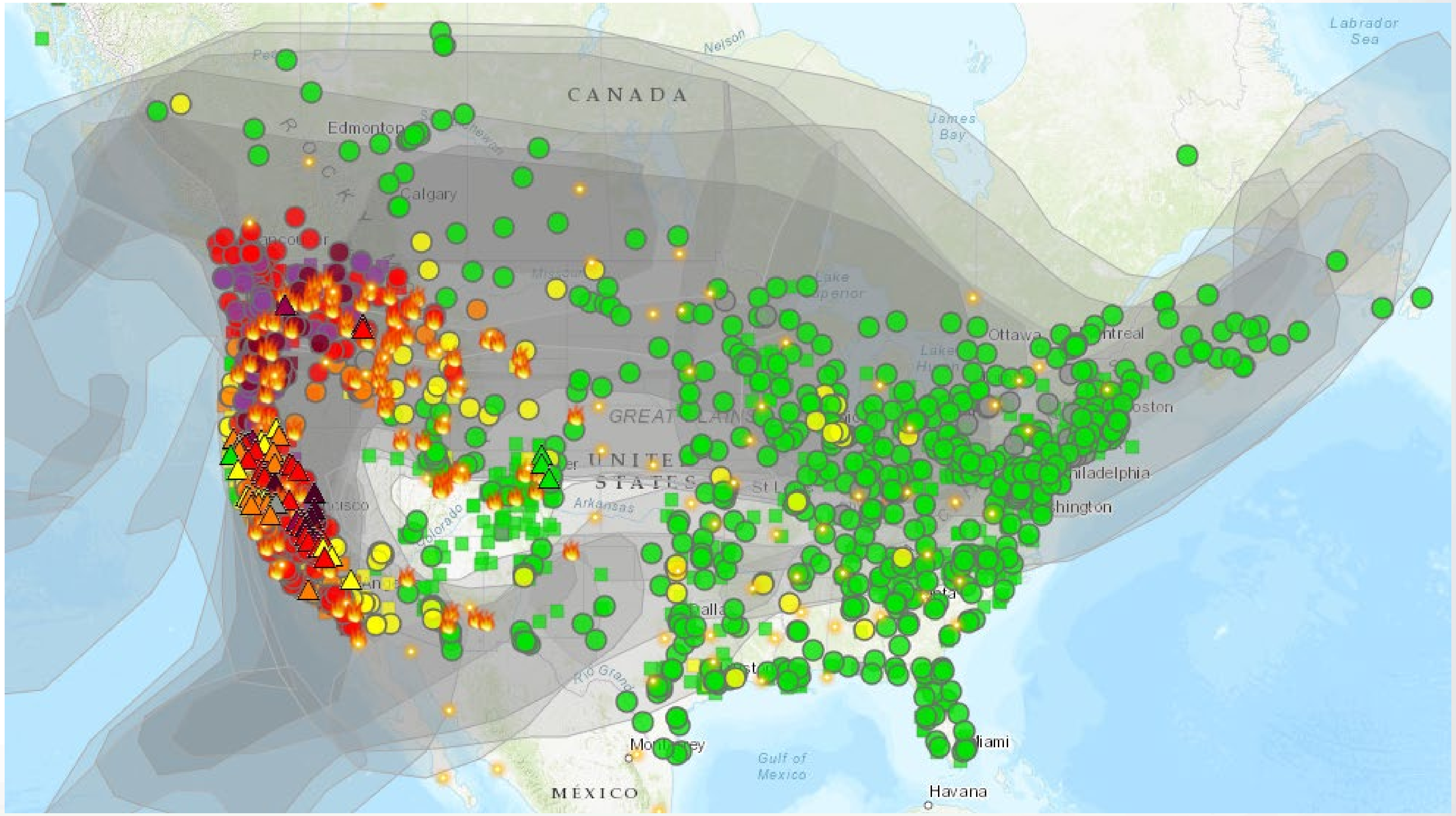
Air sensors:

PurpleAir, AirNow Fire and Smoke Map, and their use internationally



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State Department
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Introductions

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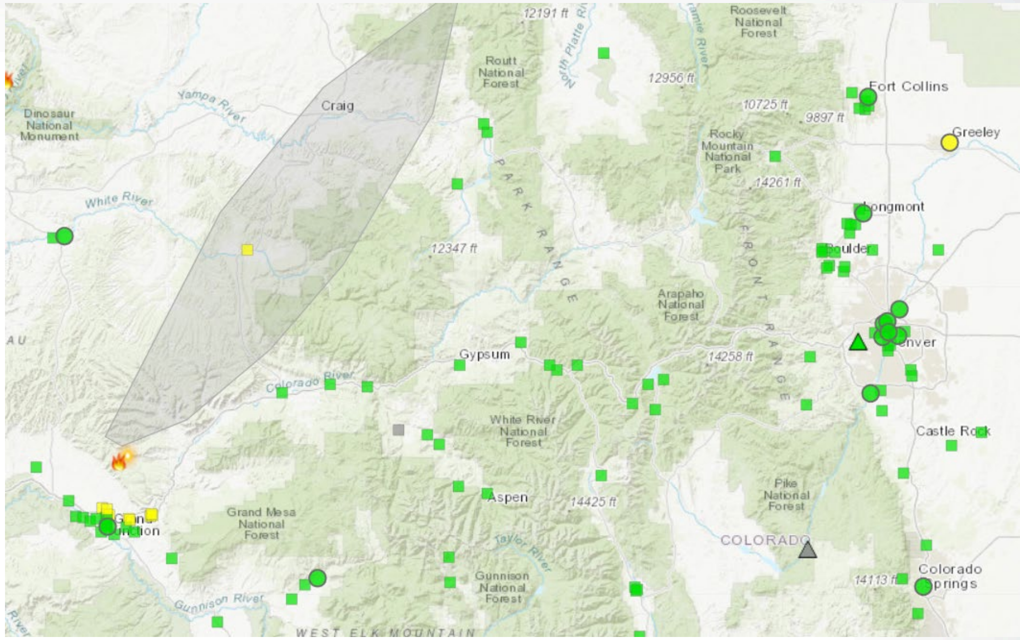
Overview of Today's Presentation

- **Motivation & Background**
- **Development of a U.S.-wide correction equation for PurpleAir & evaluation for smoke**
- **AirNow Fire and Smoke Map Sensor Data Pilot**
- **International PurpleAir performance**
- **Implications for other sensor types**

Motivation for EPA ORD's work with PurpleAir

- Air sensors can provide more spatially resolved air quality information
  - Especially important in rural areas & during smoke impacts
- PurpleAir sensors
  - Widely used by the public and data is reported by media outlets
  - Have been evaluated by air monitoring agencies in the U.S.
- Past work has shown that correction is required
- Is it feasible to use a single correction to improve performance across the U.S.?



Additional Information in Remote Mountainous Areas

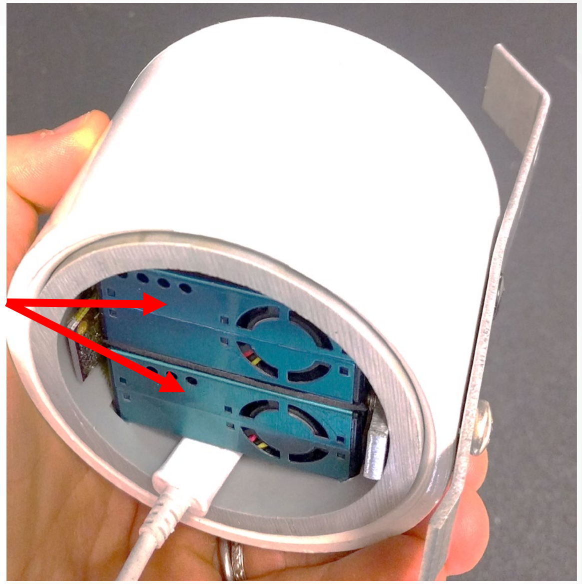
Image source: https://maps.airfire.org/ara/

Image source: http://nwcg.gov

Primer on PurpleAir Sensors: Hardware and Outputs

PurpleAir Data

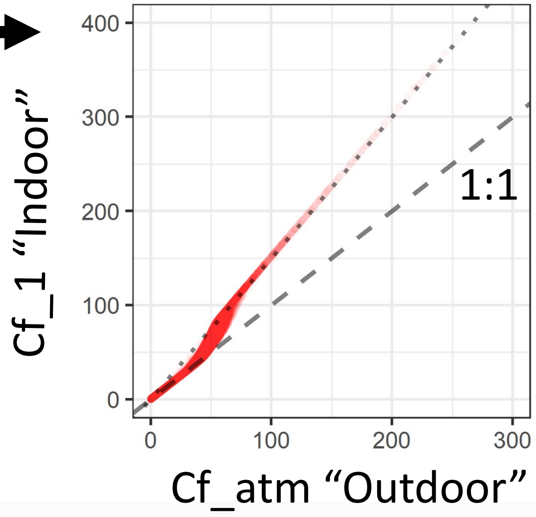
- 2 Plantower PMS5003 PM sensor (channels A & B)
- Channels alternate 10 s sampling intervals
- Reports 2 min averages (previously 80 s)



PurpleAir underside view

PurpleAir Data Outputs

- Particle count by size
- PM_1, $PM_{2.5}$, PM_{10} with 2 correction factors:
    - **CF=atm** (lower concentrations) PurpleAir map **outdoor** sensors
    - **CF=1** (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

Statistics used to Evaluate PurpleAir Sensor Data

- Mean Bias Error (MBE)
  - An estimate of overall error
  - MBE=Average(PurpleAir)-Average(BAM)
- Root Mean Square Error (RMSE)
  - An estimate of hourly error
  - Penalizes outliers

Development & Evaluation 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

Team: EPA ORD, partner local air agencies

Objective: Evaluate multiple sensors across the U.S.

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.

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
- Sensors 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

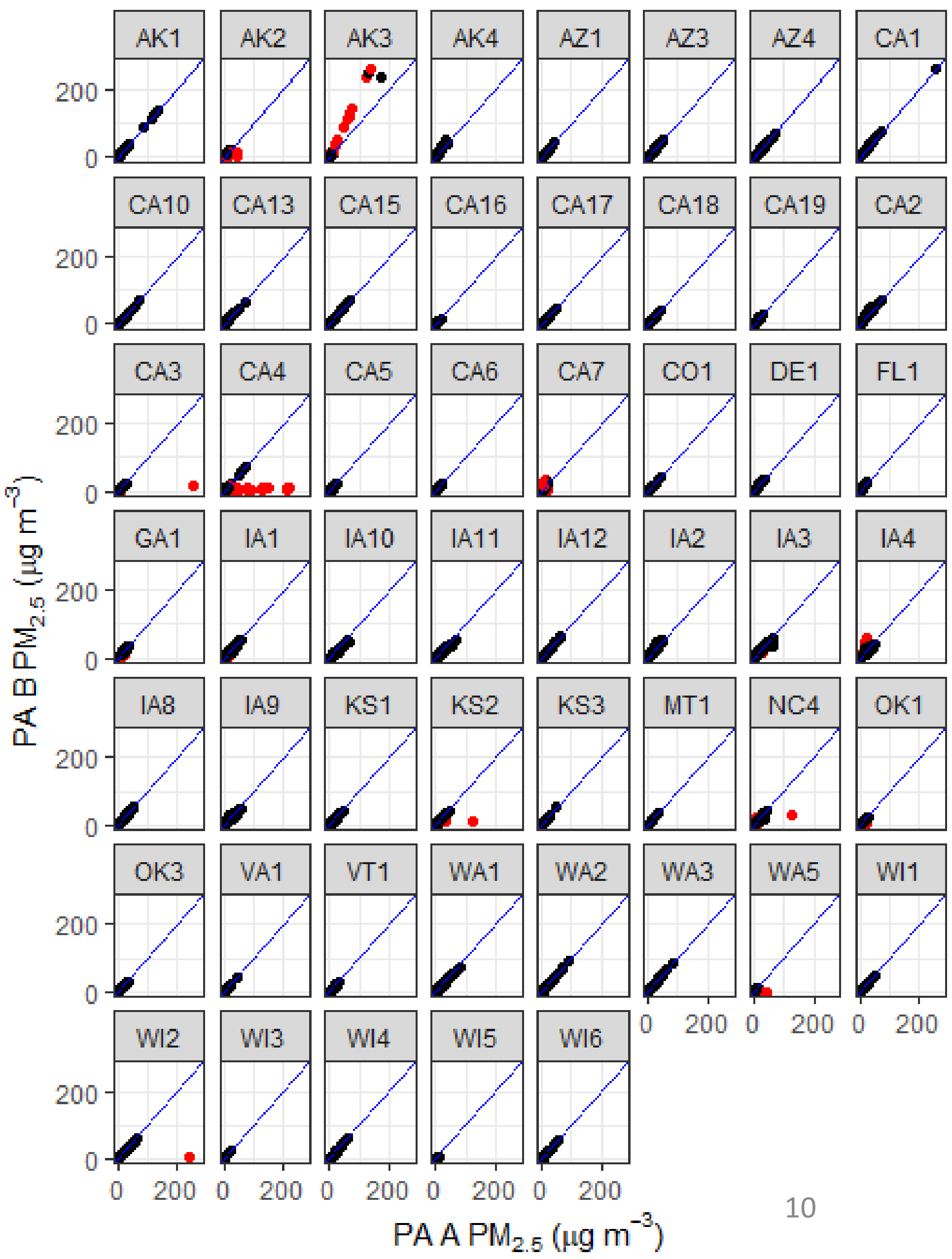
Collocation characteristics:

- PurpleAir sensors were located at regulatory sites and typically placed within 10m horizontal distance and 1m vertical distance of regulatory monitor, away from airflow obstructions and trees
- Sites identification
  - Identified publicly available sensors within 50m of a reference monitor and contacted SLT agencies to verify if these were ‘true’ collocations
  - Other sensors provided by EPA or identified through professional contacts

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 $PM_{2.5}$ channels differed by
  - ≥ ± 5 µg m^{-3} AND
  - ≥ ± 62% (95% Confidence interval on % error [2*standard deviation(% 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 parameters from sensors onboard the PurpleAir
  - $PM_{2.5}$
    - $PM_{2.5}$ 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)
    - Dewpoint (D) [calculated from onboard T and RH]

- 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

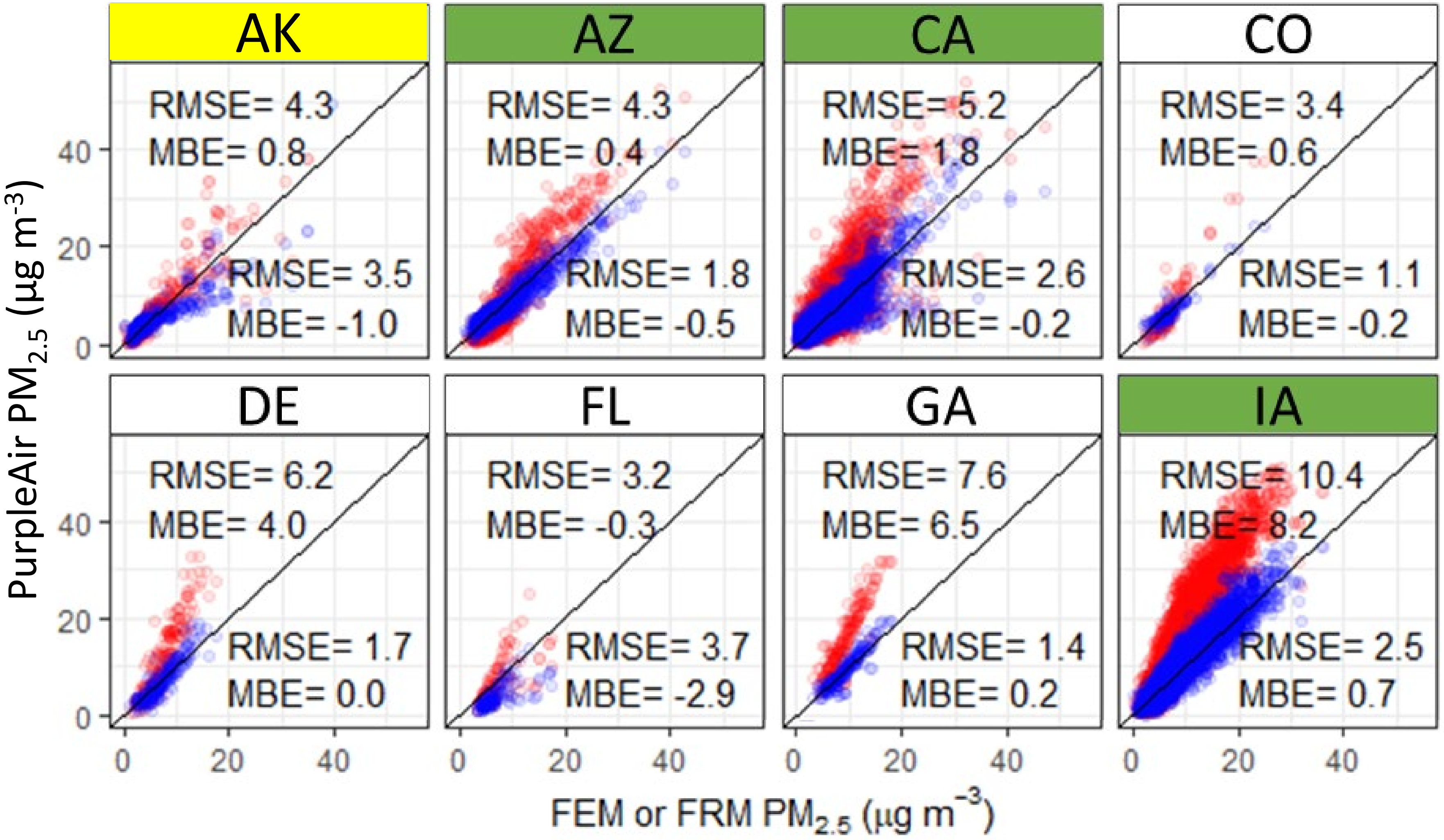
- Air sensor toolbox: https://www.epa.gov/air-sensor-toolbox/technical-approaches-sensor-data-airnow-fire-and-smoke-map
- Atmospheric Measurement Techniques Discussion: https://doi.org/10.5194/amt-2020-413

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 Florida
  - <1 year of data, so may be some seasonal bias
  - More data needed in this region

*Root mean squared error

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



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Also evaluated on Smoke Impacted Datasets (not used to build model)

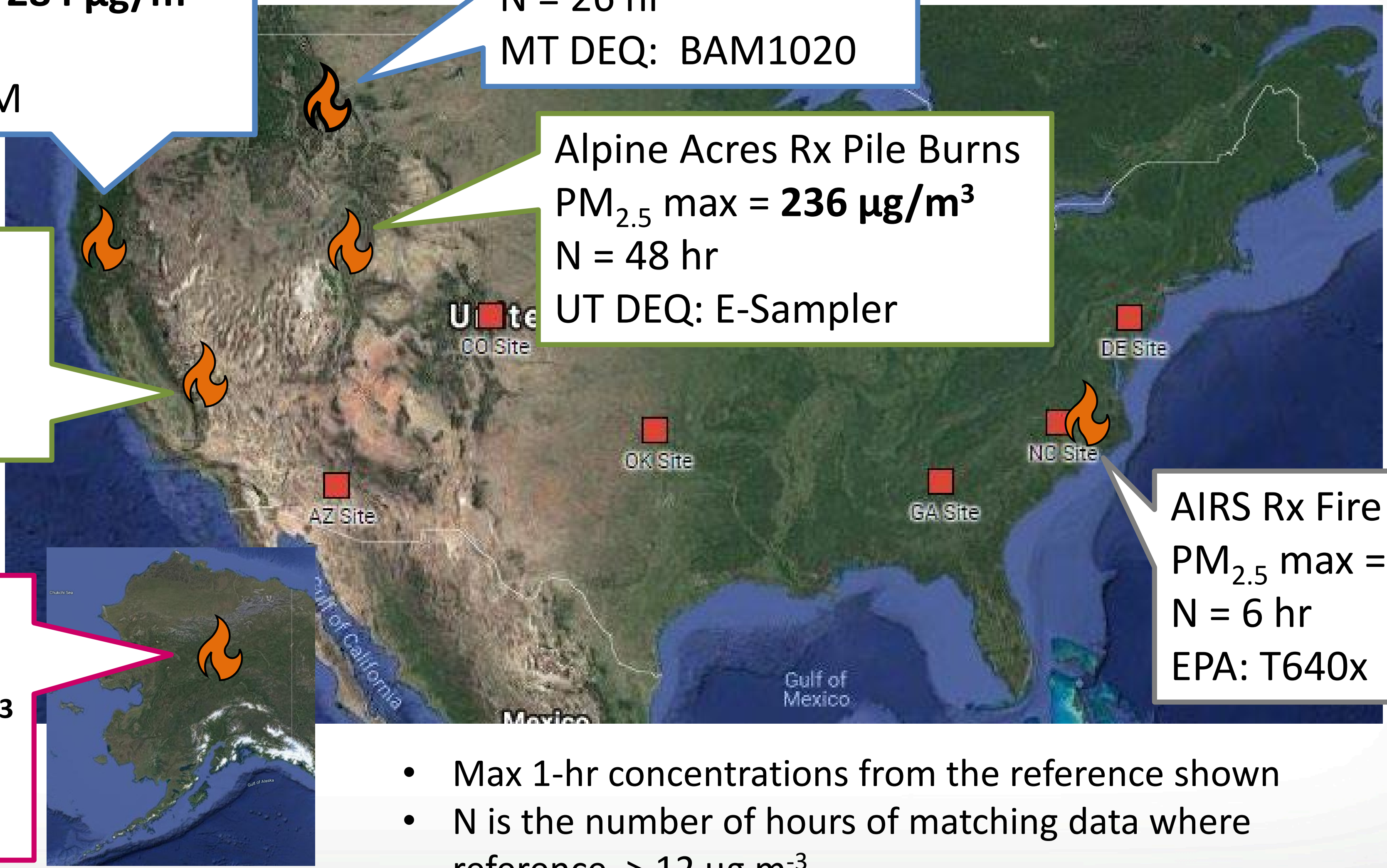
Natchez Wildfire
$PM_{2.5}$ max = **284 µg/m³**
N = 290 hr
CARB: E-BAM

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

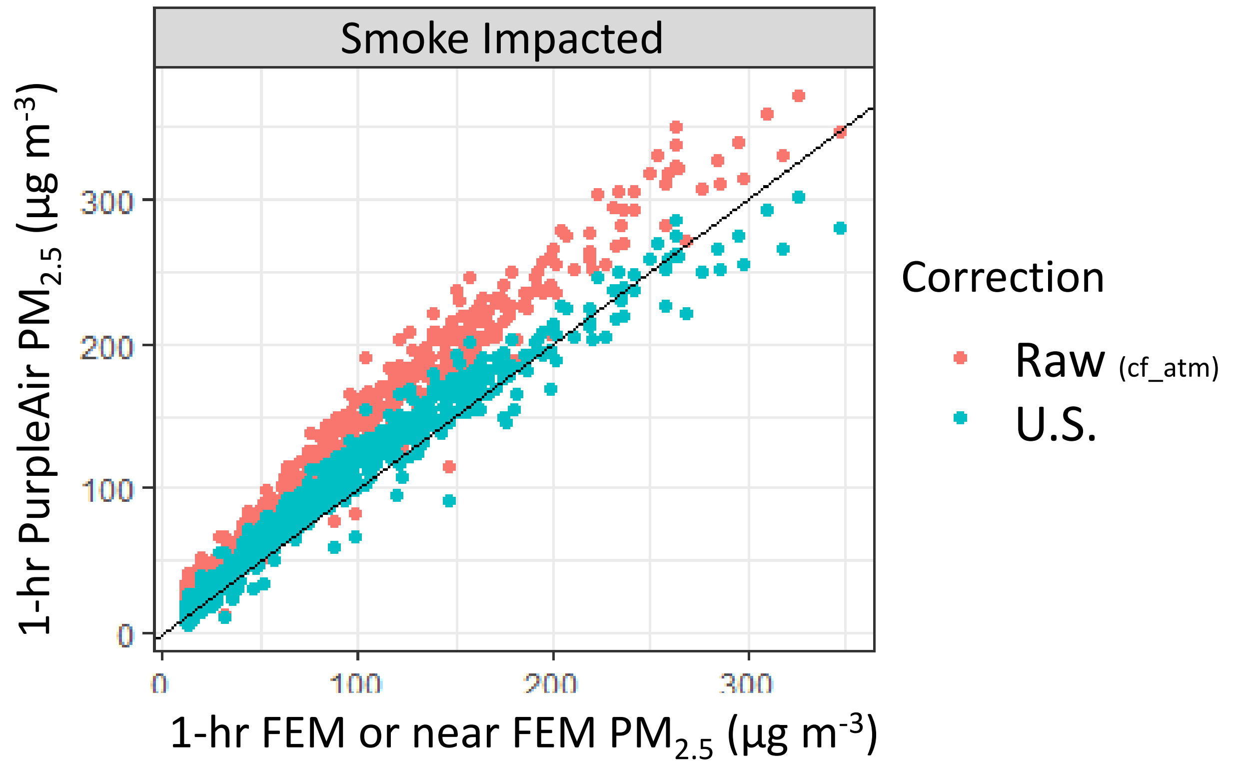
- Max 1-hr concentrations from the reference shown
- N is the number of hours of matching data where reference > 12 µg m^{-3}

Most data from: Holder et al. 2020 https://doi.org/10.3390/s20174796

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

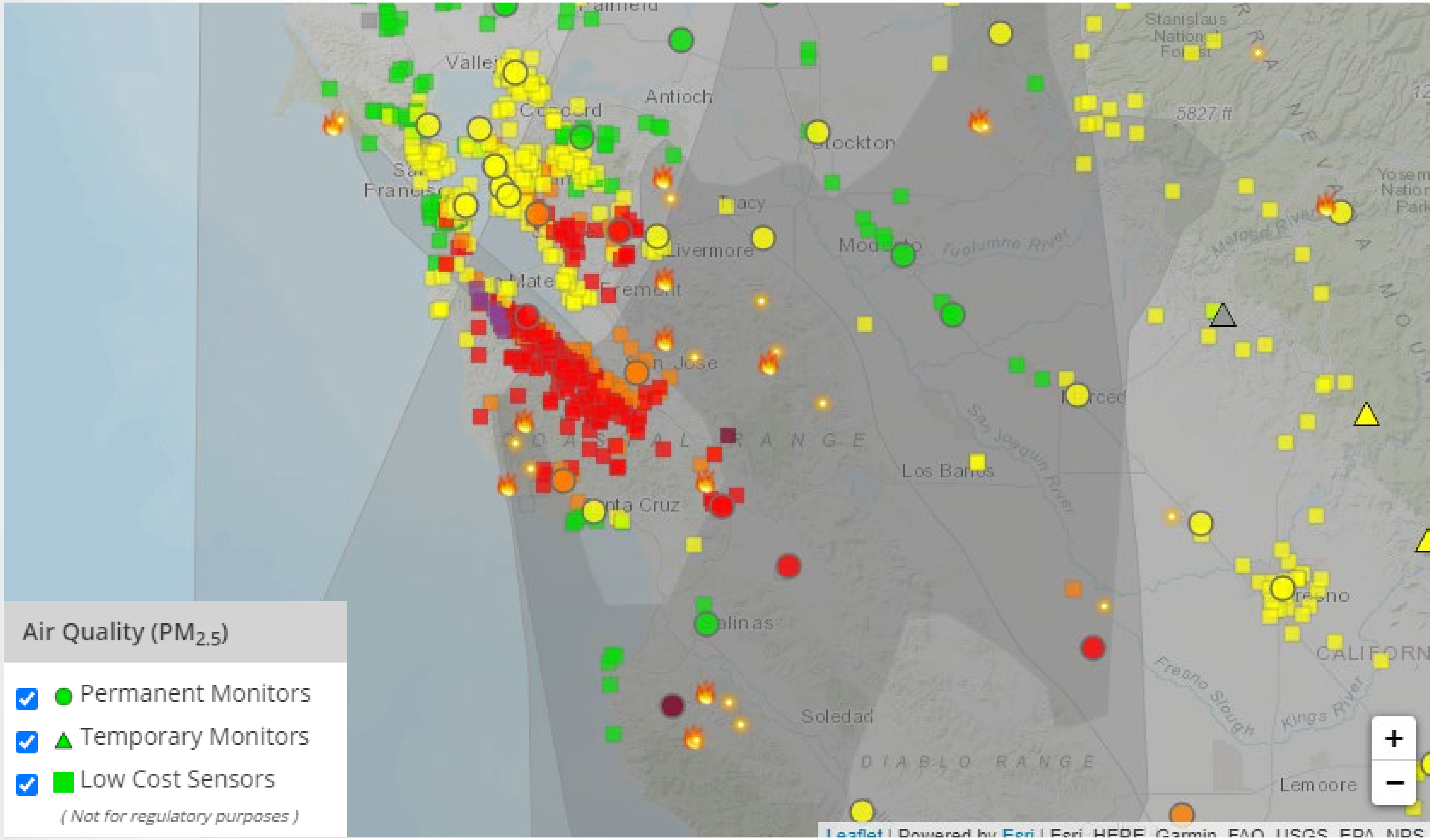
Correction	type	cf	MBE µg m^{-3} (%)
U.S.	U.S. ambient	1	6.4 (12%)
None	N/A	atm	30.2 (38%)

U.S.-wide correction reduces error from raw data



AirNow Fire and Smoke Map Sensor Data Pilot

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

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

Issues with PurpleAir Sensors and Crowdsourced Data

- Light scattering-based sensors are sensitive to PM optical properties and may not respond the same to all sources (e.g. dust)
- Light scattering-based sensors saturate at high PM concentration
  - ~>250 µg m^{-3} nonlinear correction may be needed
- Air sensors do not have status codes to indicate failures
  - Most failure captured by A & B channel cleaning steps
  - Lifespan unknown, drift hard to identify
- Crowdsourced data may be mislabeled, mislocated, or poorly sited

Frequent sensor data review will be necessary until algorithms are developed to detect malfunctioning, improperly sited, or mislabeled sensors

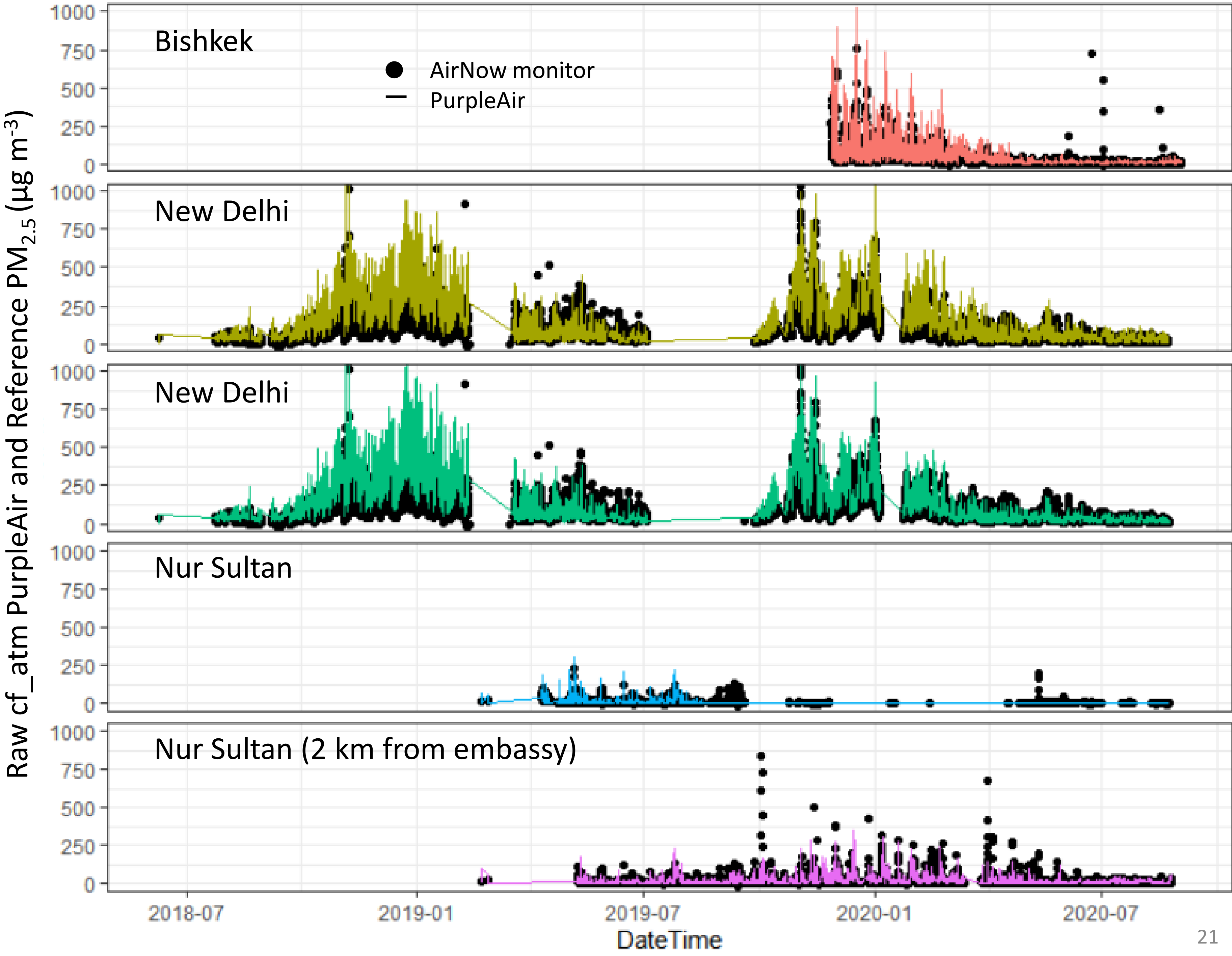
International Performance of PurpleAir Sensors

Background

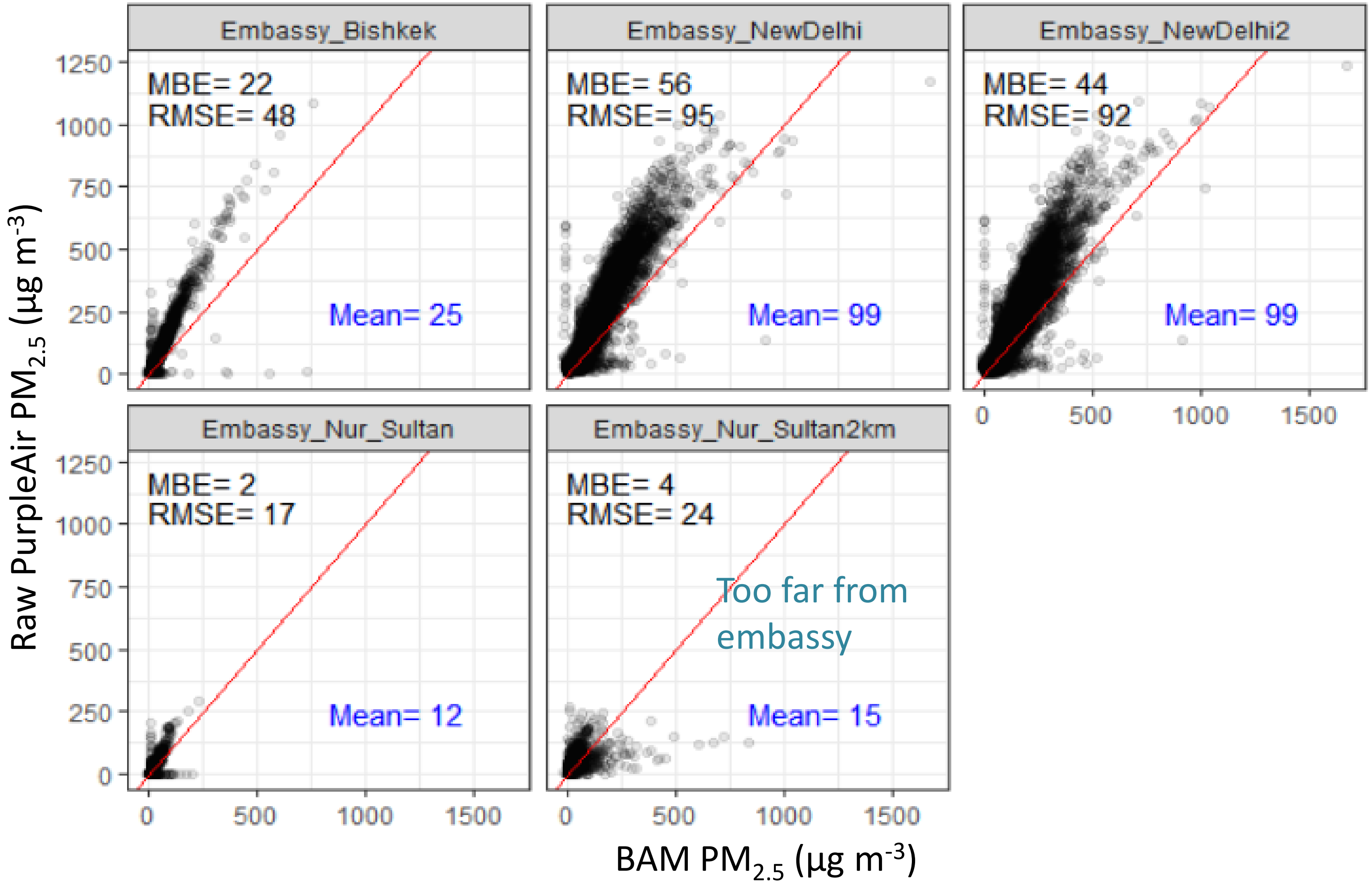
- Is the U.S.-wide correction appropriate for international use?
- PurpleAir sensors collocated with BAMs at U.S. Embassies
  - – Nur Sultan, Kazakhstan
    - One at Embassy & one 2km away
  - – Bishkek, Kyrgyzstan
    - One at embassy
  - – New Delhi, India
    - Two at embassy

Comparison Over Time

- ~1 year+ across sites
- Many large data gaps
- Wide range of concentrations
- Especially high winter concentration in Bishkek and New Delhi

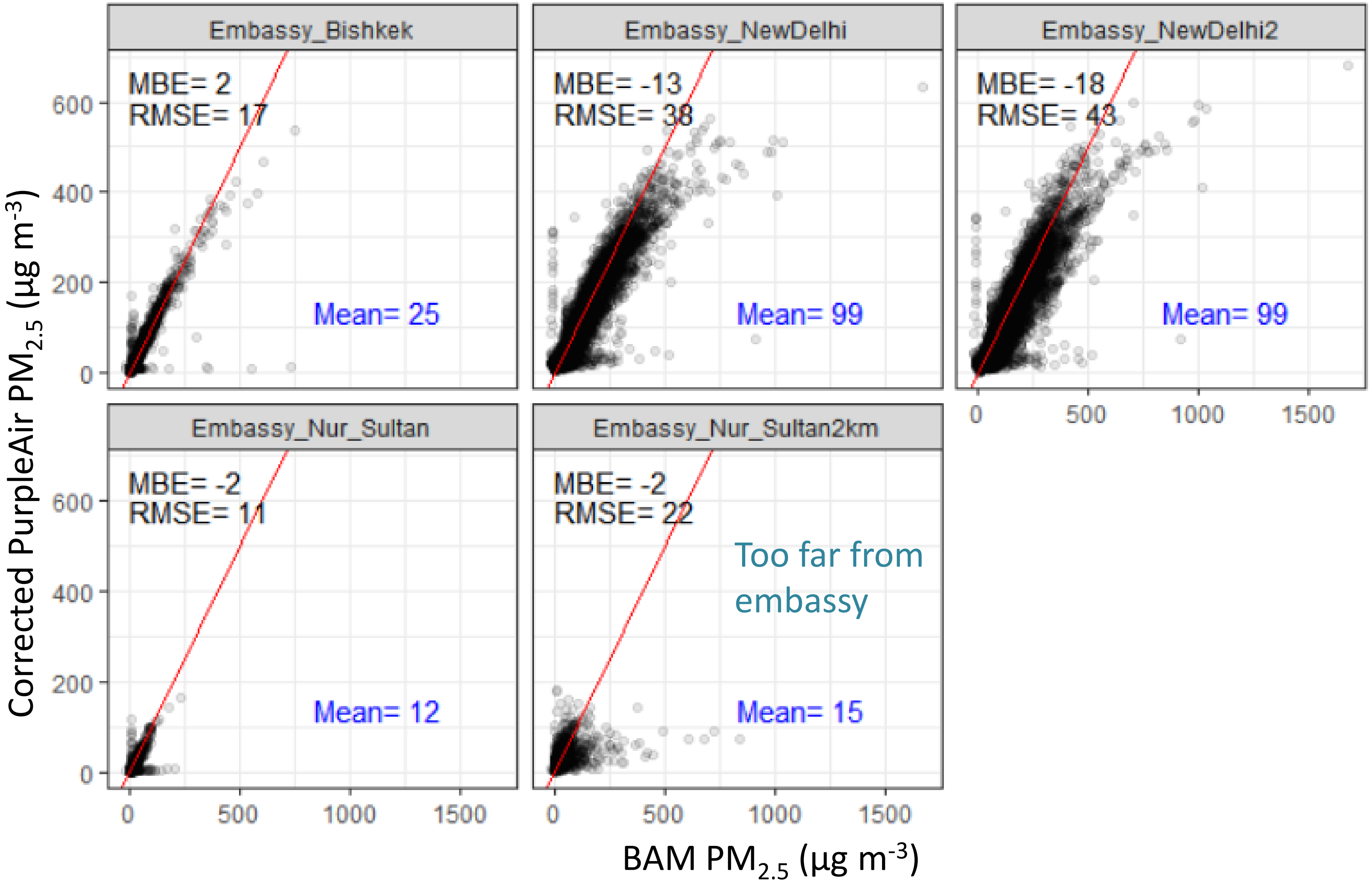


Uncorrected PurpleAir data



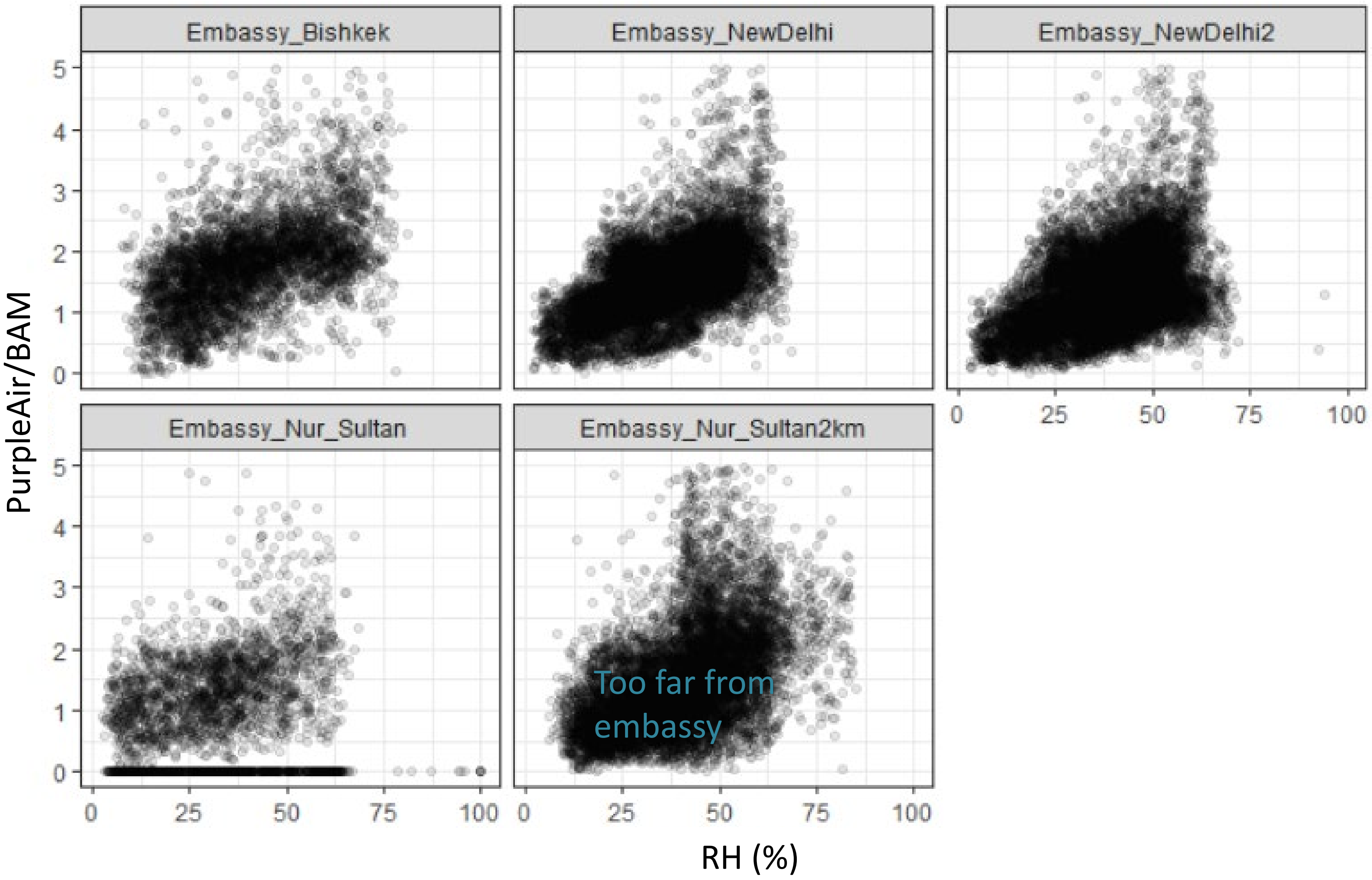
- Raw data that would be reported on PurpleAir.com
- Typically it would overestimate $PM_{2.5}$ concentrations
- The Nur Sultan 2 km away appears to be impacted by local sources
    - More scatter than the sensor at the Embassy but also includes a longer time period

PurpleAir Data Corrected using U.S. Correction Equation



- Applying the U.S. wide correction seems to be a fairly good fit across cities
- Underestimation above ~300 $\mu g\ m^{-3}$
- This is the same behavior we see during extreme 2020 wildfire conditions (~>250 $\mu g\ m^{-3}$)

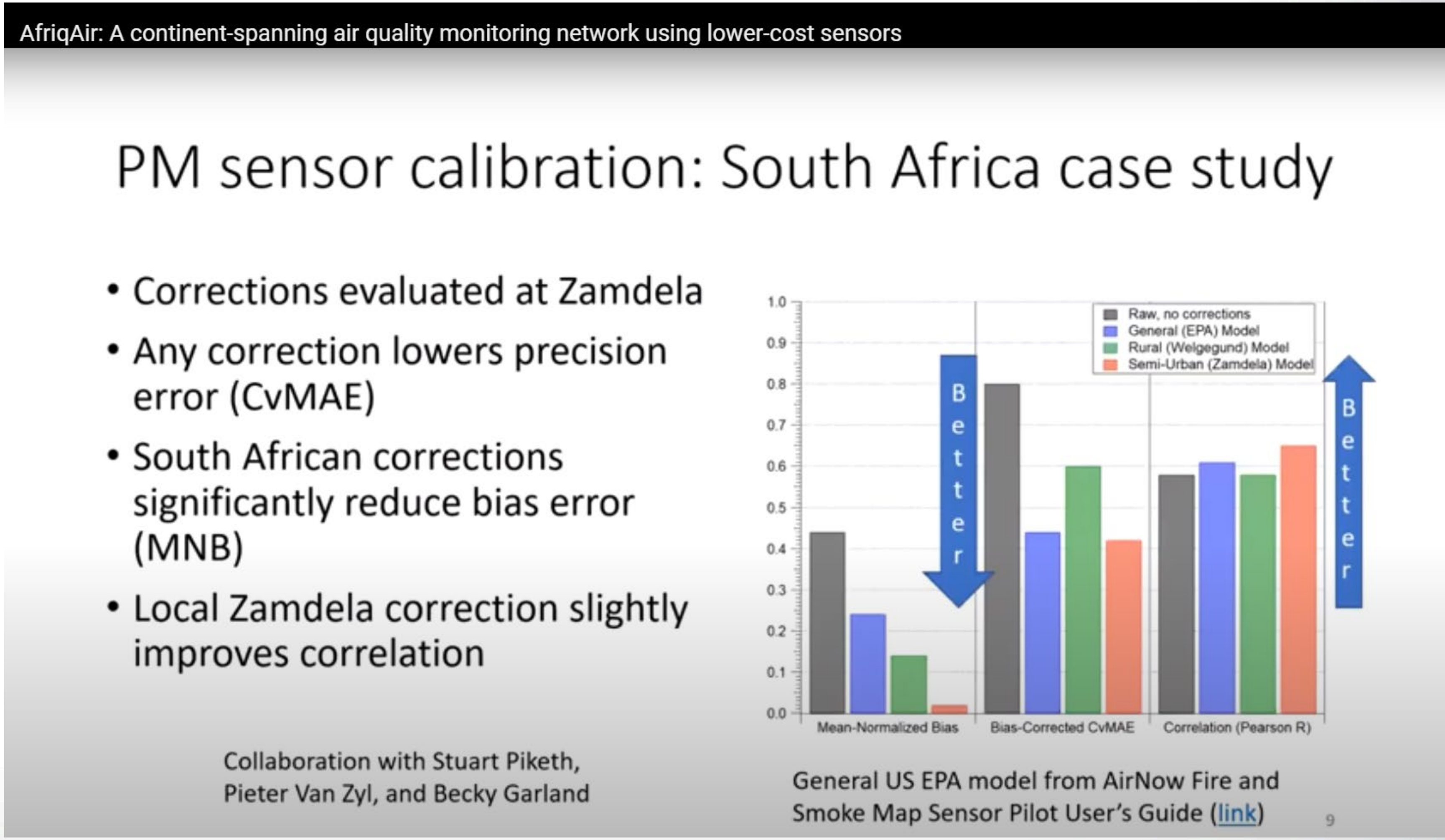
Relative Humidity (RH) Influence on PurpleAir data



- The ratio of sensor/BAM increases at higher RH
- This likely leads to the increased scatter on the previous plots
- Not quite the same pattern across locations

Preliminary Results from South Africa

- ASIC talk: Subramanian et al. 2020
- US EPA correction reduces bias in Zamdela, South Africa (to ~25%)



https://www.youtube.com/watch?v=dJWZNBmNKuw

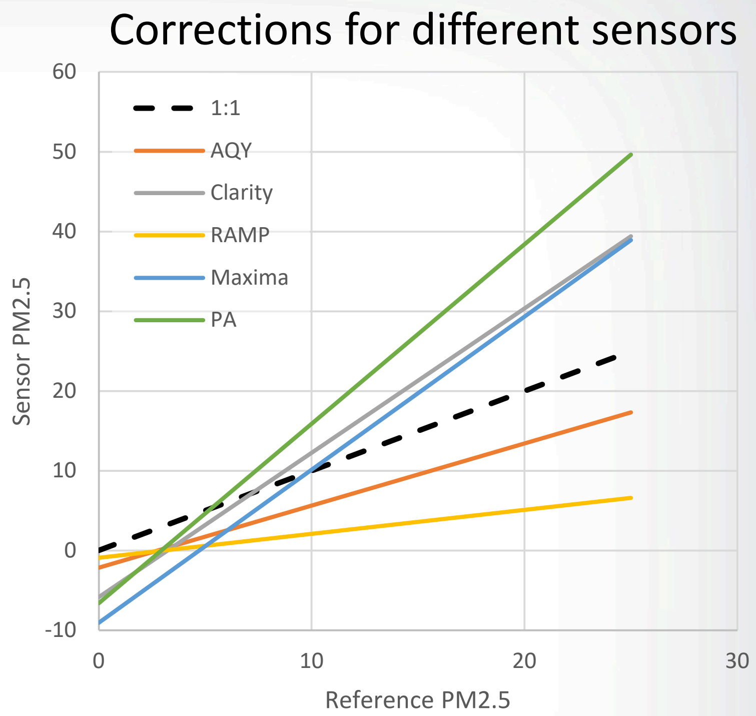
International Conclusion

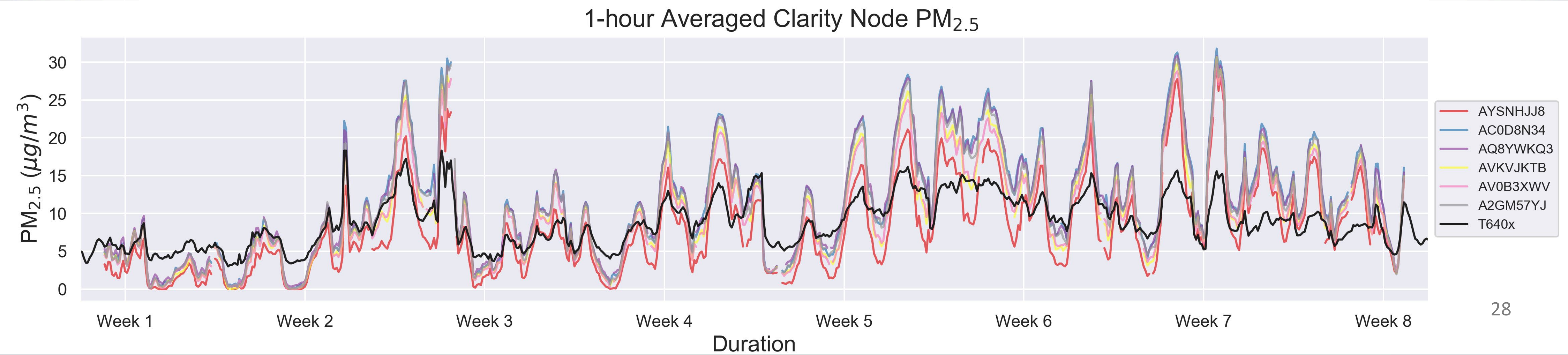
- The U.S. correction improves PurpleAir data accuracy
- Corrected PurpleAirs underestimates $PM_{2.5}$ above ~300 µg m^{-3}
  - We are working on a nonlinear correction for 2020 wildfire smoke in the U.S.
- Sensors read higher when RH is high
  - This could potentially be corrected with a "stronger" RH correction
  - Need to further evaluate if different corrections needed for different cities
- **Limitations:** only 4 cities internationally, limited time periods

Evaluation and Performance of Other Sensor Types
Research Triangle Park, North Carolina

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

- Many PM **sensors show similar trends** to reference instruments
- **Sensor data must be corrected** to be more comparable
  - Dependent on make/model
- Data cleaning methods also dependent on make/model
  - PurpleAir is unique with duplicate PM measurements
- Agreement between sensors of the same make/model (**precision**) is also variable
  - Tight precision is necessary for fleet-wide corrections

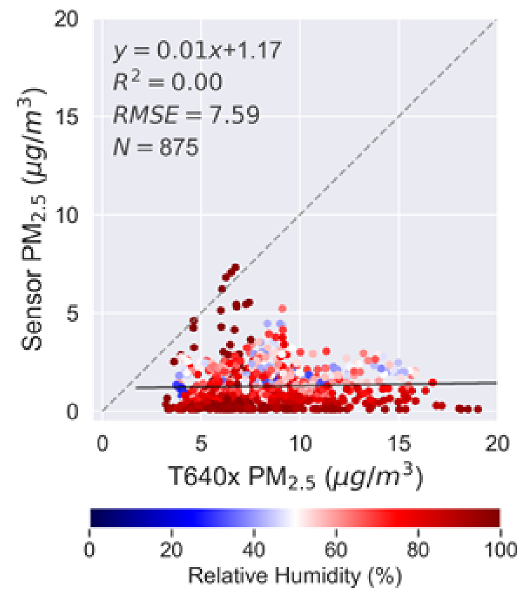




Accuracy for Sensor Types

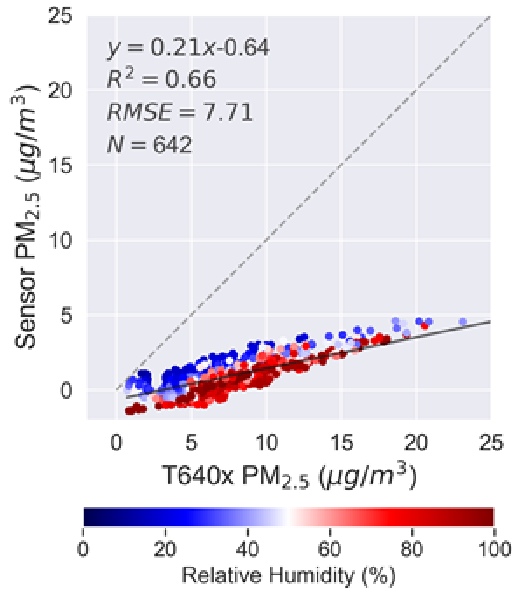
- Wide range of correlation relative to reference monitor concentrations (T640x FEM for $PM_{2.5}$)
- Some models underestimate concentrations while others overestimate

Vaisala AQT420



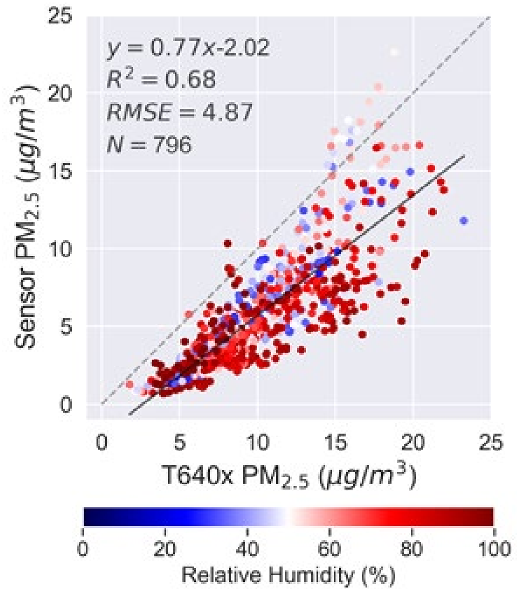
- No correlation with reference

SENSIT RAMP



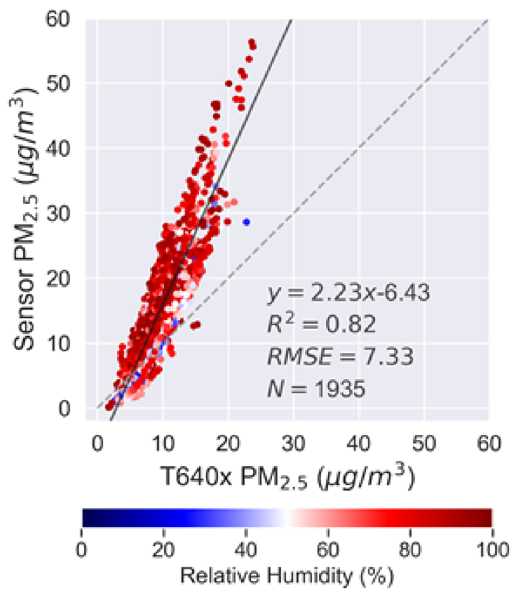
- Moderate correlation
- Underestimates reference by ~80%
- High RH leads to increased underestimation

Aeroqual AQY



- Moderate correlation
- Underestimates reference by ~20%
- High RH leads to slight increase in underestimation

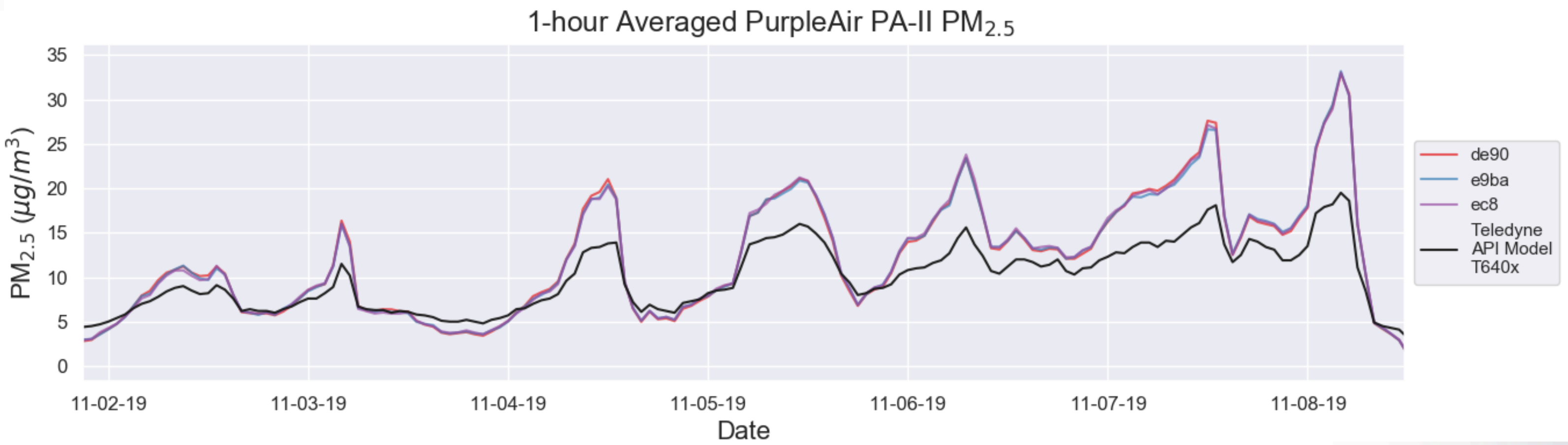
PurpleAir PA-II-SD



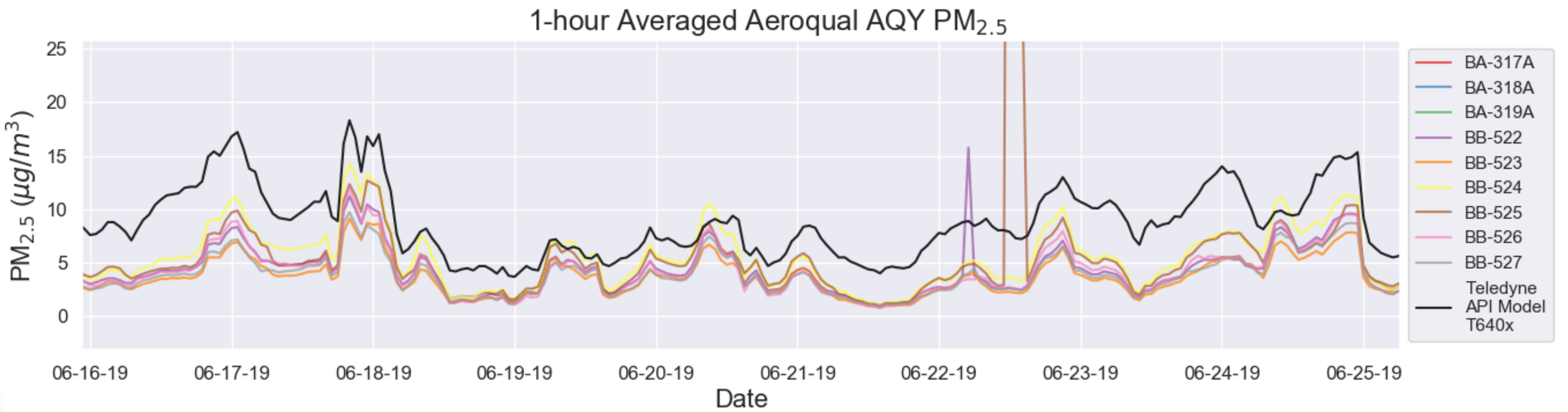
- Strong correlation
- Overestimates reference by ~120%

Precision for Sensor Types

- Some sensors show good agreement among identical units operated at the same time and place
  - **Ex: PurpleAir PA-II shows high precision**



- Other sensors show more spread in measurements
  - **Example: Aeroqual AQY shows lower precision**



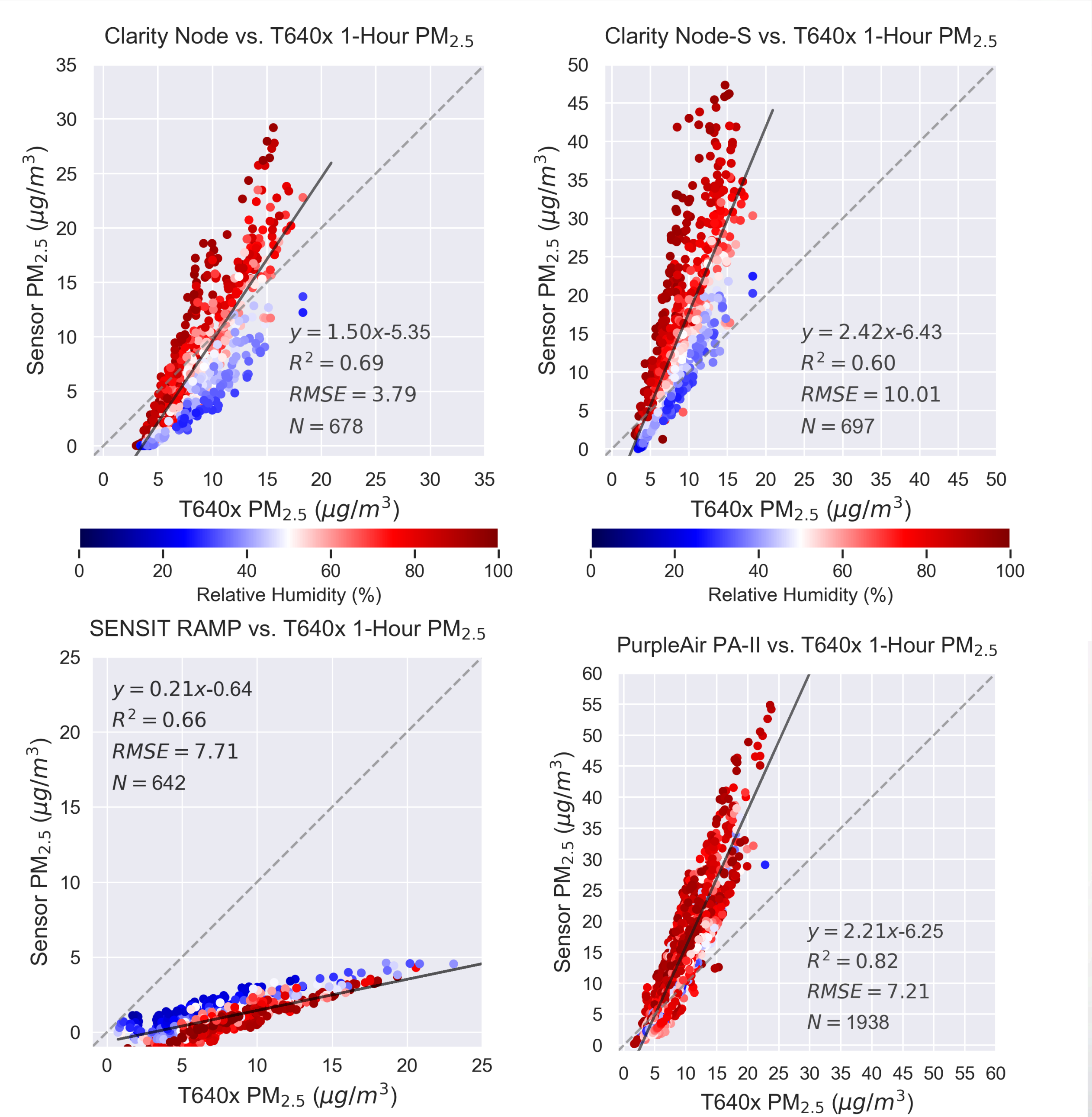
Performance Can Vary for Devices with the Same Internal PM Sensor

Clarity Node (non-solar), Clarity Node-S (solar powered)

- PMS6003 internal PM sensor
- Node-S units exhibit greater overestimation, increased RH influence

Sensit RAMP and PurpleAir PA-II

- PMS 5003 internal PM sensor
- RAMP significantly underestimates while PurpleAir overestimates



Take Home Summary

- Preliminary analysis shows the U.S.-wide PurpleAir correction may also be applicable outside the U.S.
- Other $PM_{2.5}$ sensor networks will require collocation, correction, and an understanding of their performance.
  - Even sensors with similar internal components may not perform the same
- Sensor collocations from more diverse international locations are needed
  - **Request:** More sensor collocations at other sites desirable to understand the performance of PurpleAir Sensors and other sensor
  - **Do you have sensors collocated at international monitoring stations?** We are compiling a list. Contact: johnson.karoline@epa.gov

Acknowledgements

Additional resources and details about EPA's work with air sensors
http://www.epa.gov/air-sensor-toolbox

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, State depart

Aeroqual for loaning the AQYs

All field technicians

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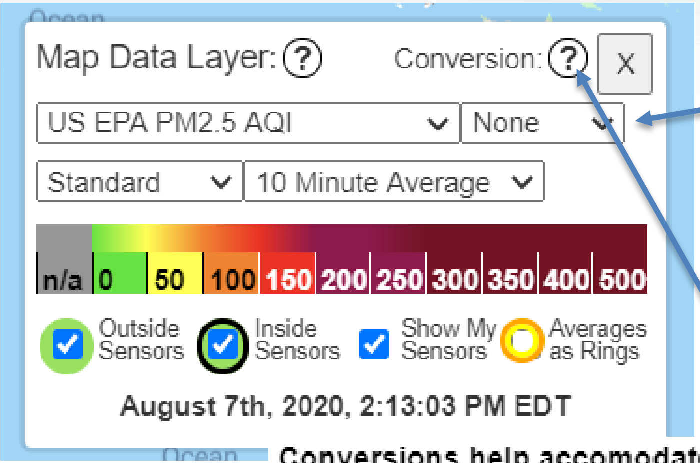
Supplemental Slides

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

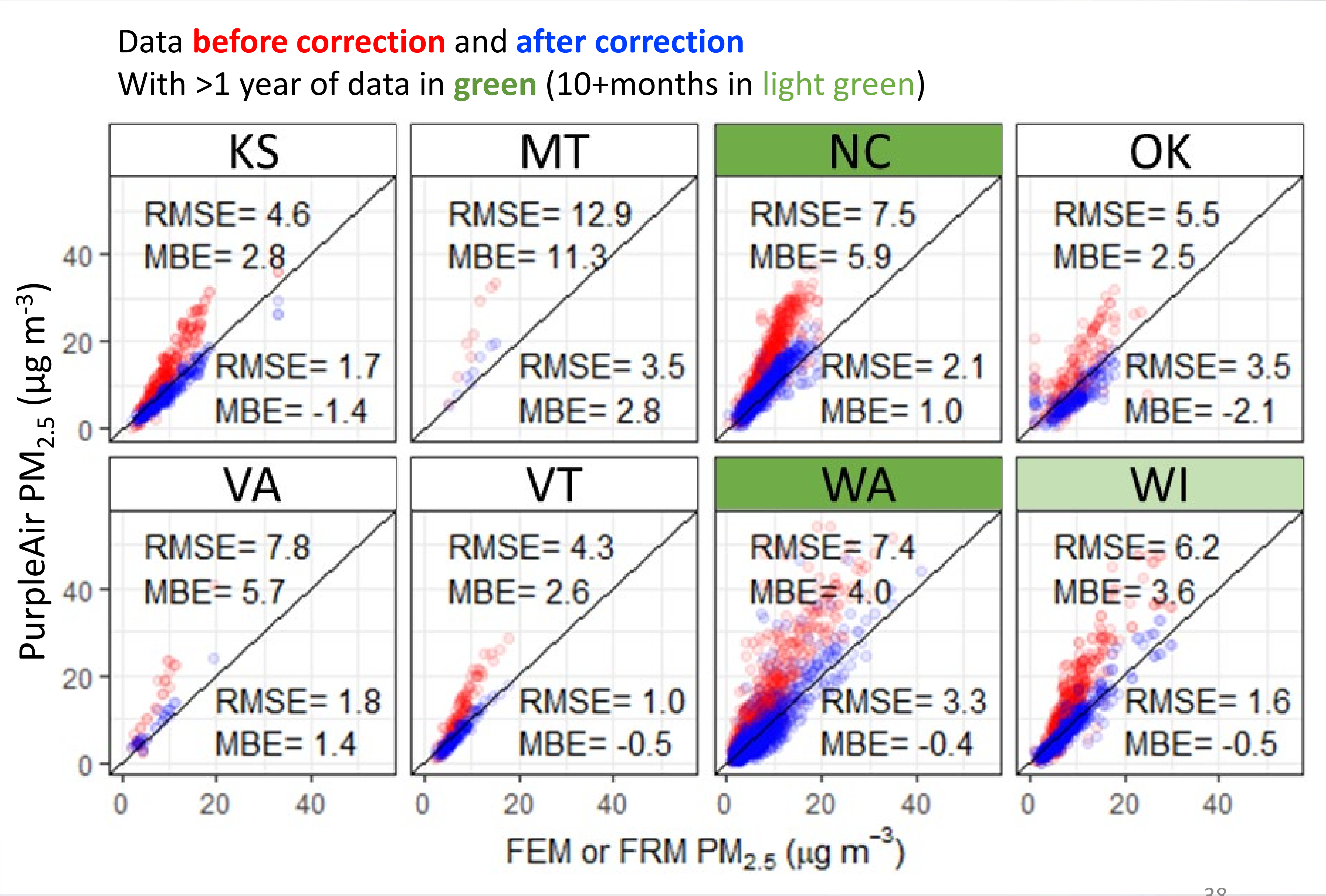
- Some work exists in the literature about the performance of PurpleAir sensors during smoke impacts
- However, these studies are typically limited investigating only smoke
- Most of this literature emerged in late 2019 - 2020
    - **Holder, et al. 2020.** ‘Field Evaluation of Low-Cost Particulate Matter 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

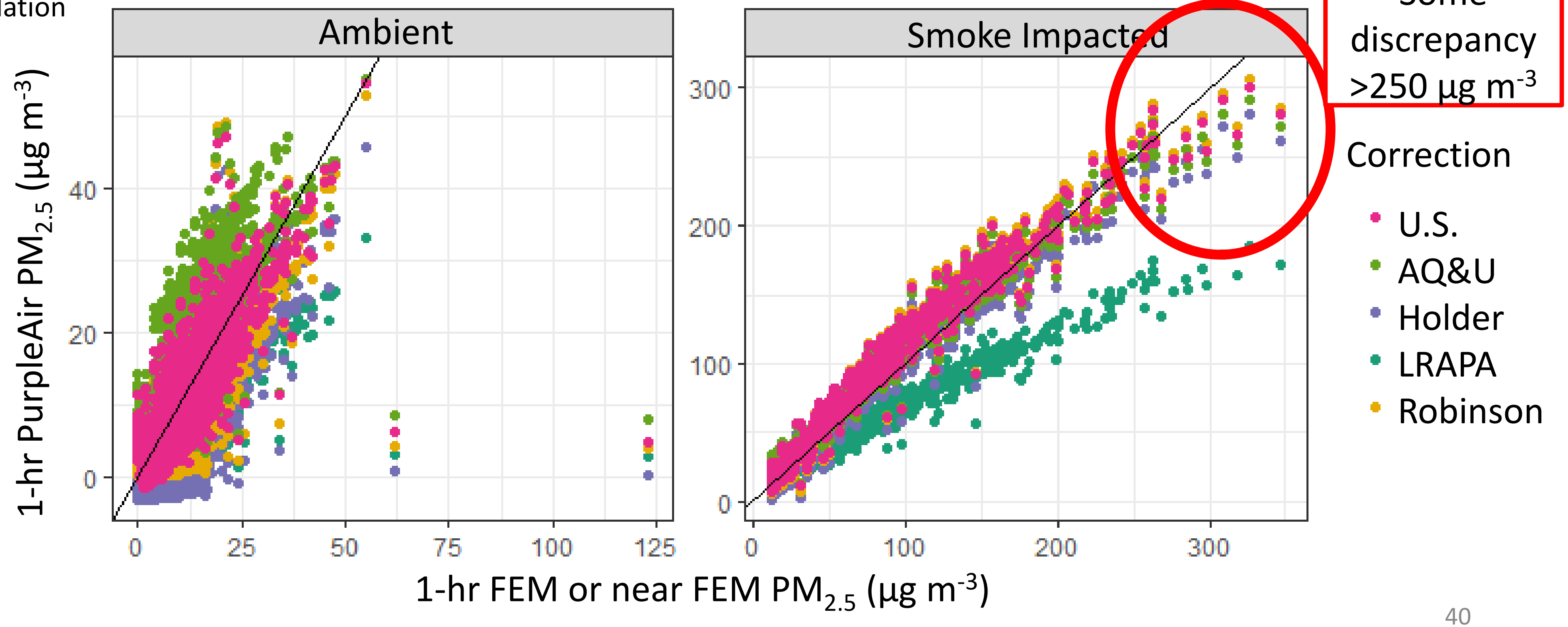
Comparison of PurpleAir Corrections

				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

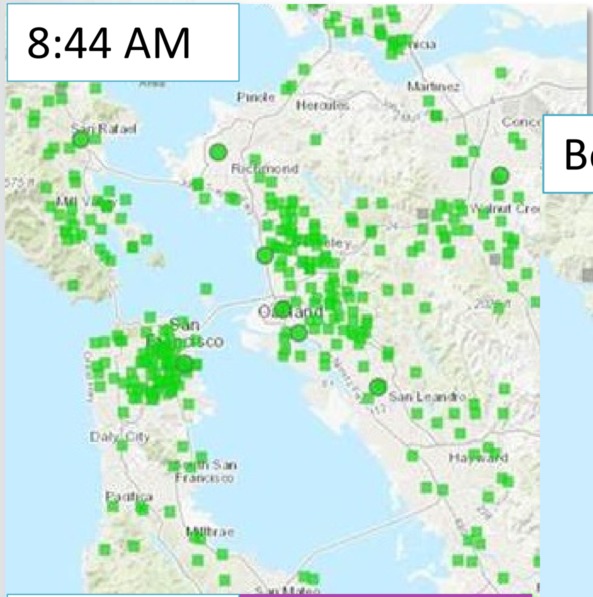
- **Holder correction** reduces most bias
- **U.S., Robinson, & AQ&U** work similarly
- **LRAPA** shows strong underestimation
  - Likely because it was developed on data 0-65 μg m^{-3}



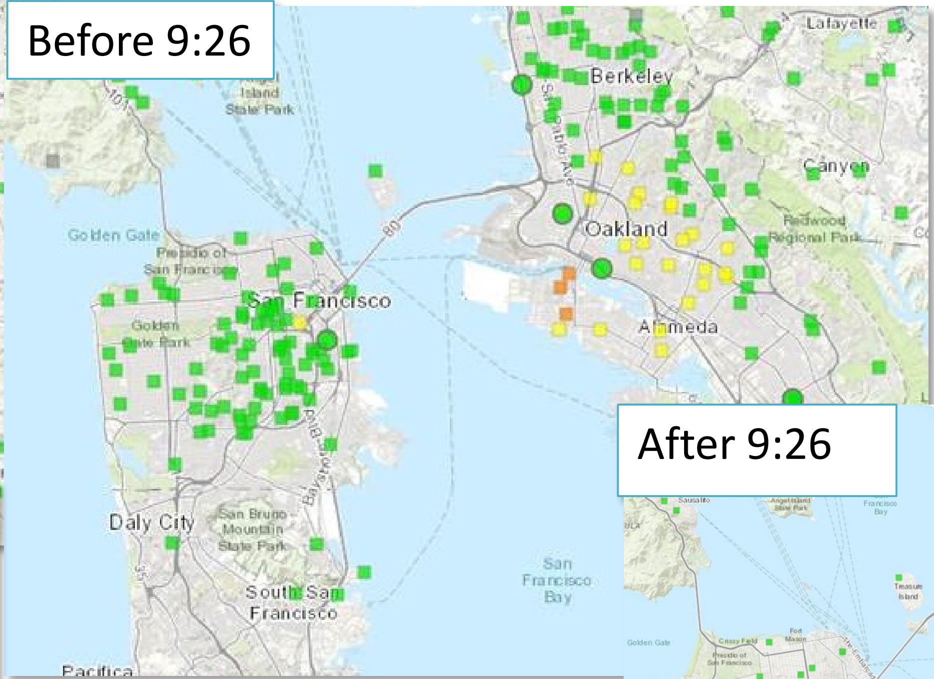
Impact of NowCast: Example of Rapidly Changing $PM_{2.5}$

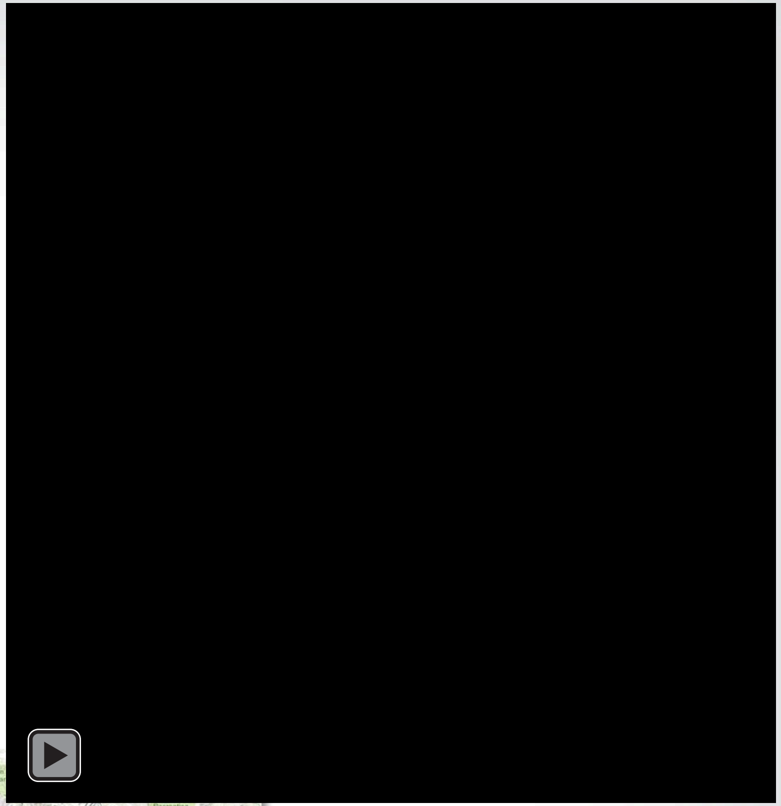
5 alarm fire in SF quickly spreads smoke across the bay area

8:44 AM

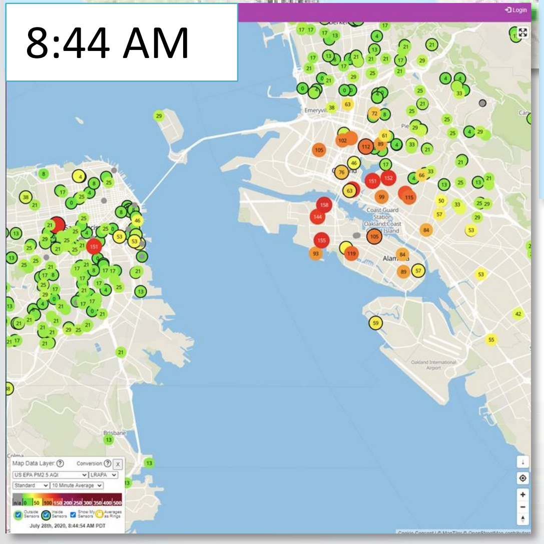


Before 9:26

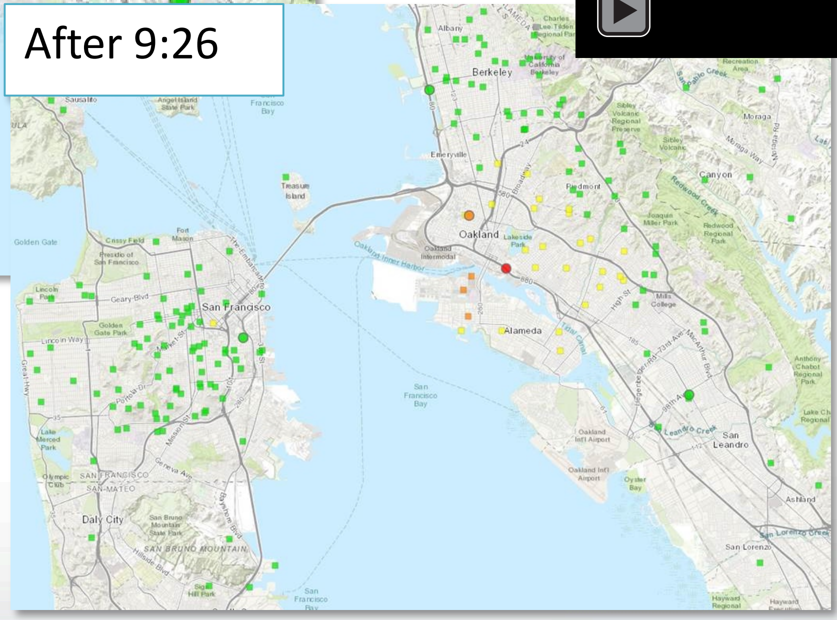




8:44 AM



After 9:26



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

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: $PM_{2.5}$ 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.

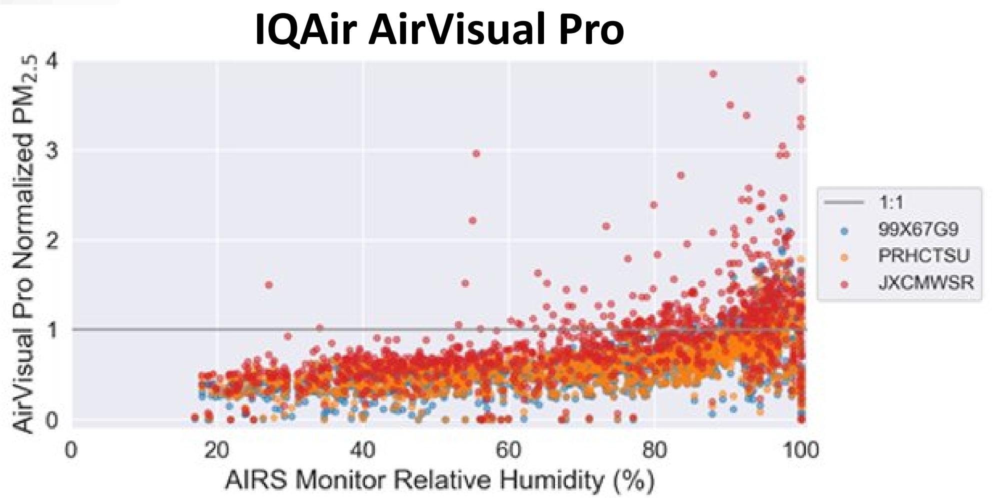
[3]Robinson, D. L.: Accurate, Low Cost $PM_{2.5}$ Measurements Demonstrate the Large Spatial Variation in Wood Smoke Pollution in Regional Australia and Improve Modeling and Estimates of Health Costs, Atmosphere, 2020.

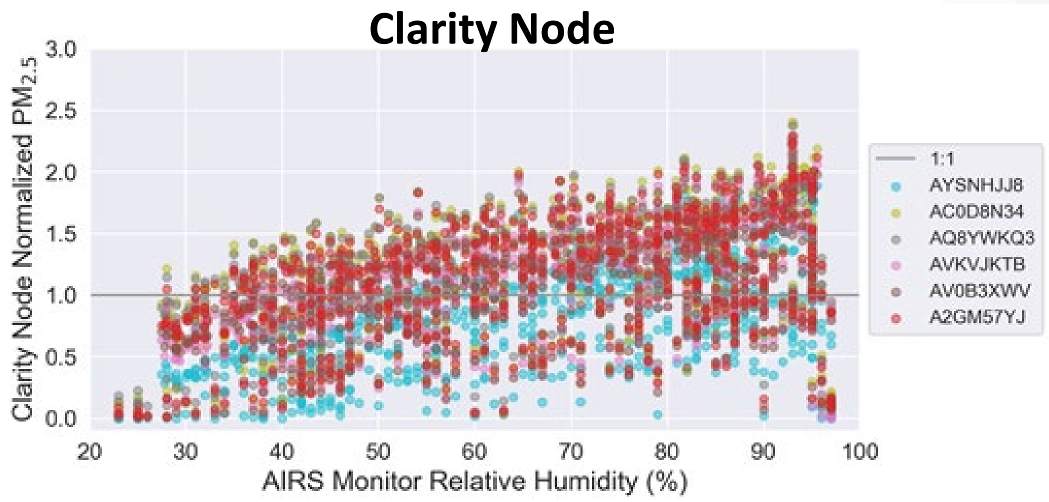
[4]He, et al.: Performance characteristics of the low-cost Plantower PMS optical sensor, Aerosol Science and Technology, 2020.

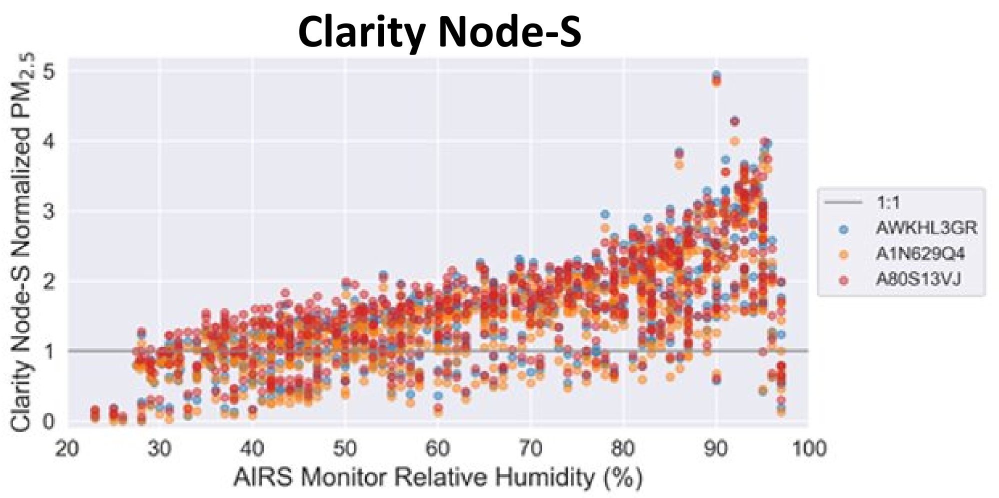
Impacts of Relative Humidity

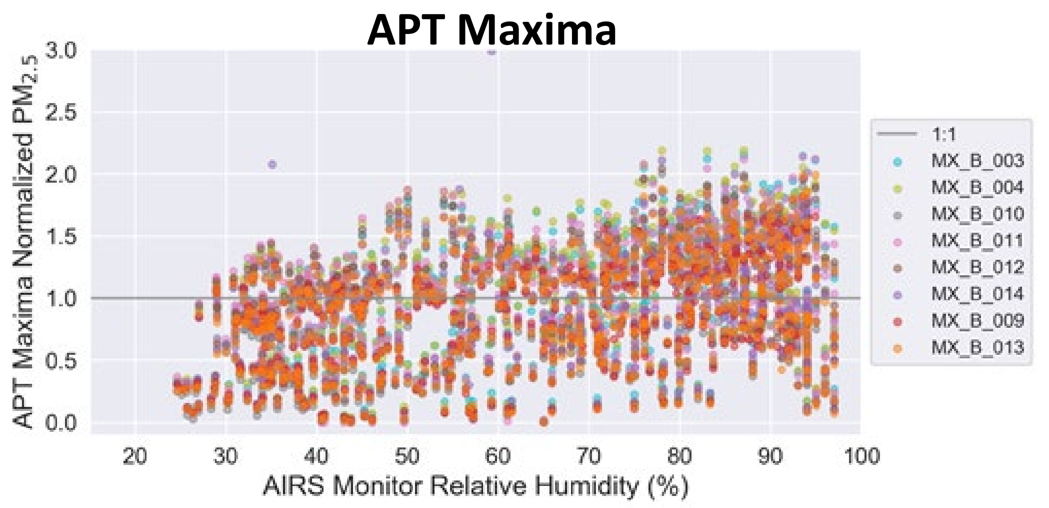
Significant overestimation at high RH (> ~50 %)

Slight overestimation at high RH (> ~50 %)



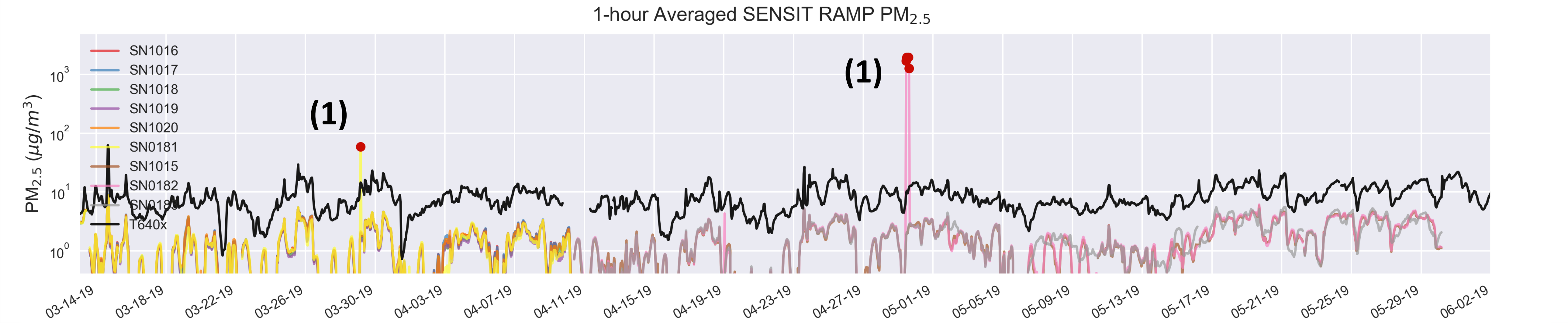


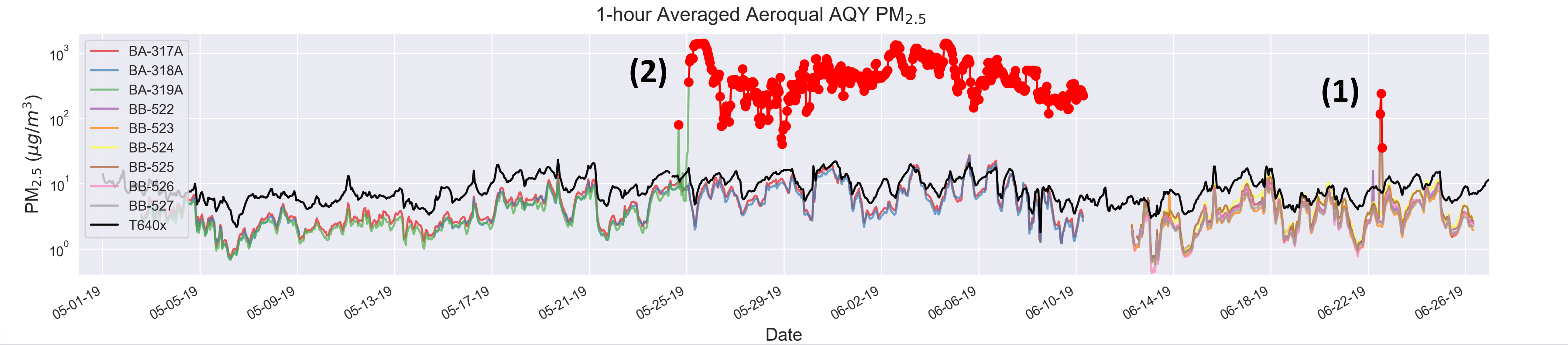




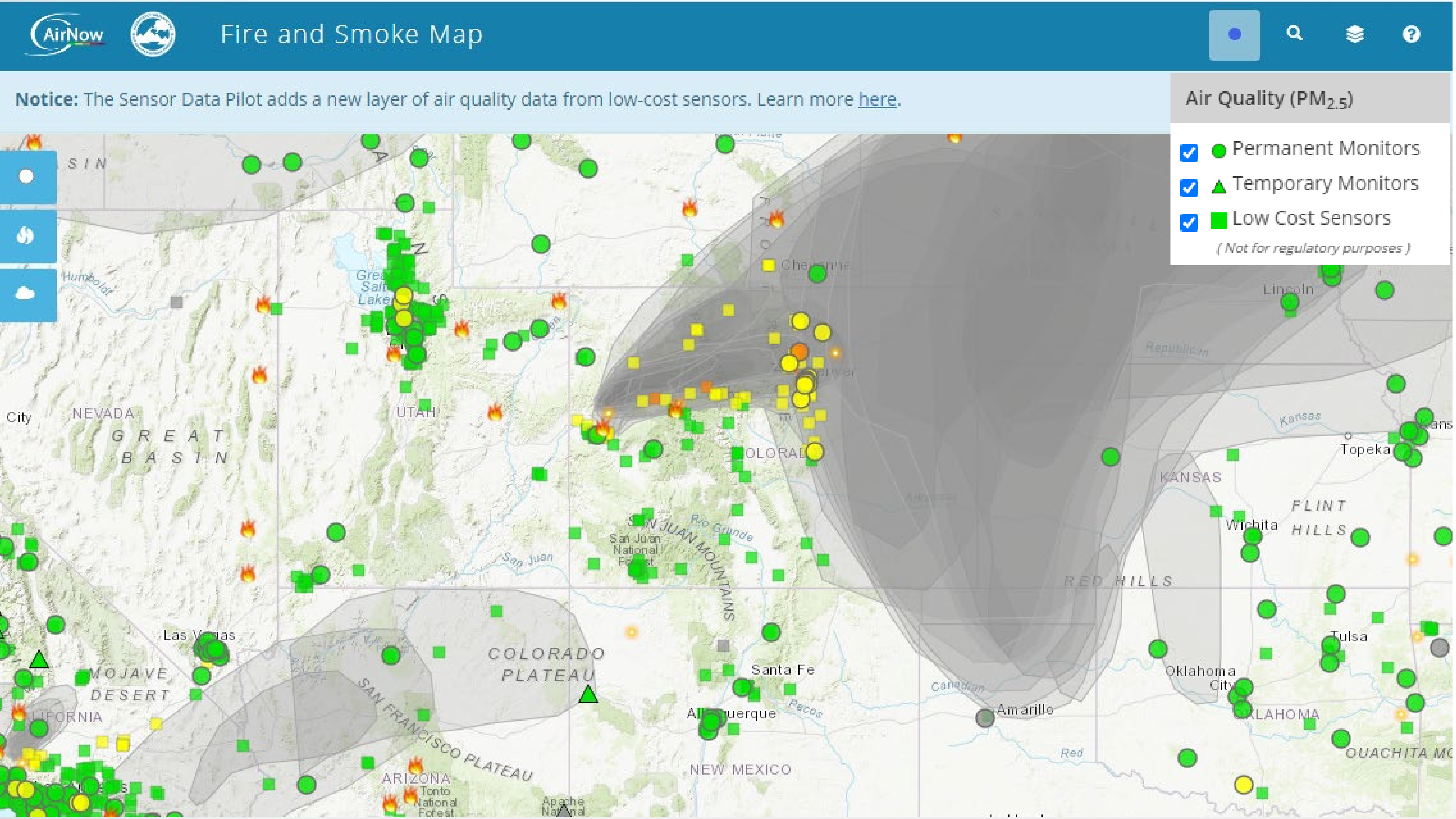
Air Sensor Data Quality Concerns

1. **Brief outlier spiking events**
   - Sensor concentrations briefly increase for a period of a few hours, settle back down to typical ambient concentration range
2. **Large magnitude baseline offset**
   - Disrupted air flow through detection chamber due to buildup of dust, dirt, insects, etc.
   - Likelihood may depend on design of sensor inlet





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