United States Environmental Protection Agency

EPA Tools and Resources Webinar

AirNow Fire and Smoke Map: Extension of the US-Wide Correction for Purple $PM_{2.5}$ Sensors

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May 19, 2021

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Presentation Outline

- Adding a sensor data layer to the AirNow Fire and Smoke Map
- Planned updates for the AirNow Fire and Smoke Map
- Background on air sensors
- Updating the US-wide correction for PurpleAir sensors
- Sensor user's frequently asked questions (FAQs)
- Take home messages
- Resources

Adding a sensor data layer to the AirNow Fire and Smoke Map

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AirNow Sensor Data Pilot Released by US EPA and USFS[1]

- The Fire and Smoke (F&S) Map on AirNow.gov provides important air quality information during fire and smoke episodes
  - The map showed data from regulatory and temporary (added during fires) monitors along with smoke plumes and fire locations
- In August 2020, a new layer of corrected, publicly available $PM_{2.5}$ data from PurpleAir sensors was added to the map

[1]USFS – US Forest Service

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Goals of the Original Sensor Data Pilot

- Two primary goals:
  - Provide additional air quality information the public can use to protect their health during fire and smoke events
  - Provide more coverage where permanent monitors do not exist

Why did US EPA & USFS conduct the sensor data pilot?

- The pilot gave the public the ability to see air quality information from permanent monitors and sensors in a way that is comparable, consistent, and scientifically credible
- ***Consistency*** and ***comparability*** is important because
  - As sensor use increases, so does the potential for conflicting information and public confusion
  - Sensor websites display data differently at different time scales than AirNow and state websites
  - Private sector air quality indices (AQIs) differ from the US EPA AQI

Timing of Release was Fortuitous

Pilot release coincided with onset of one of the worst fire seasons in US history

Positive Feedback

- Over 7.4 million page views over the first 3 months
- Numerous comments from public and government agencies welcoming the new information
  - "The EPA website change allows lower quality sensors to provide information that helps real people decide how to live their lives in a city threatened by smoke and catastrophic fires. It was a positive and very useful step."
  - "I have asthma and the information on this site has helped me to make critical decisions about how to protect myself during the wildfires in Sonoma County this month August 2020. ….Overall, I give this an A grade for information in real-time to the public."

Next Steps for Fire and Smoke Map

- Work on upgrades and improvements; some will be incorporated before the 2021 fire season
- Map will remain as a pilot to allow us to investigate ways to continue to improve the value of the information and display to the public
- Consult with state, tribal, and local partners and EPA regional staff on map changes
- Publish new version of the map before next fire season, targeting late July 2021

Responding to Map User Comments

- Improving
  - Underlying functionality of the webpage
  - Ability of users to find FAQs
  - Ease of navigation
  - User experience for mobile users
- Clarifying
  - Differences between-the air quality information displayed on the Fire and Smoke map and the AirNow webpage
  - Differences between the values from the PurpleAir Sensors on the Fire and Smoke map and those on the PurpleAir website
  - FAQs
- Exploring
  - Adding information on the map for actions people can take to protect themselves
  - Adding information on the air quality trends in their area

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Planned Updates for the AirNow Fire and Smoke Map

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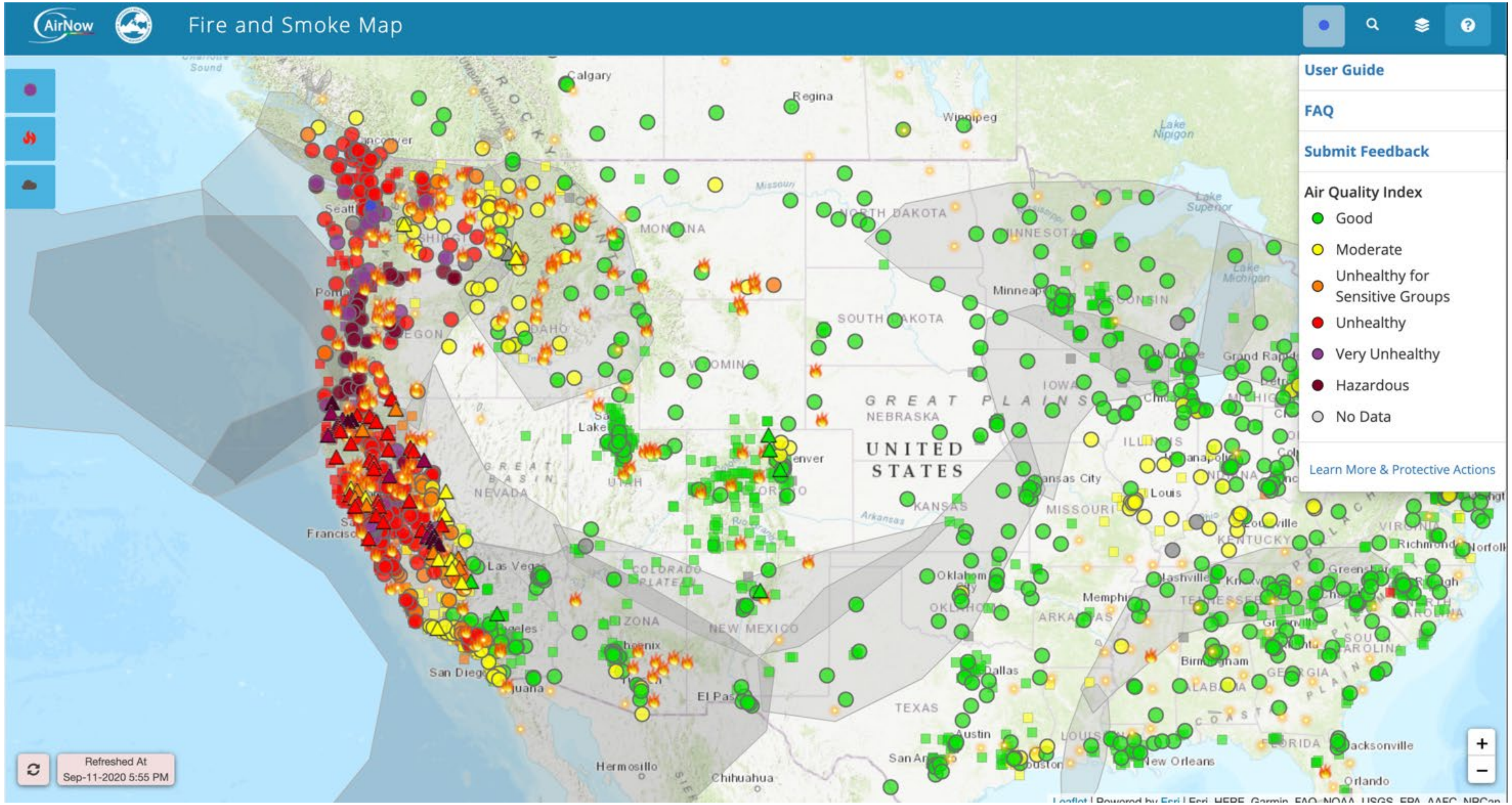
EPA-USFS AirNow Fire and Smoke Map v1 (2020)

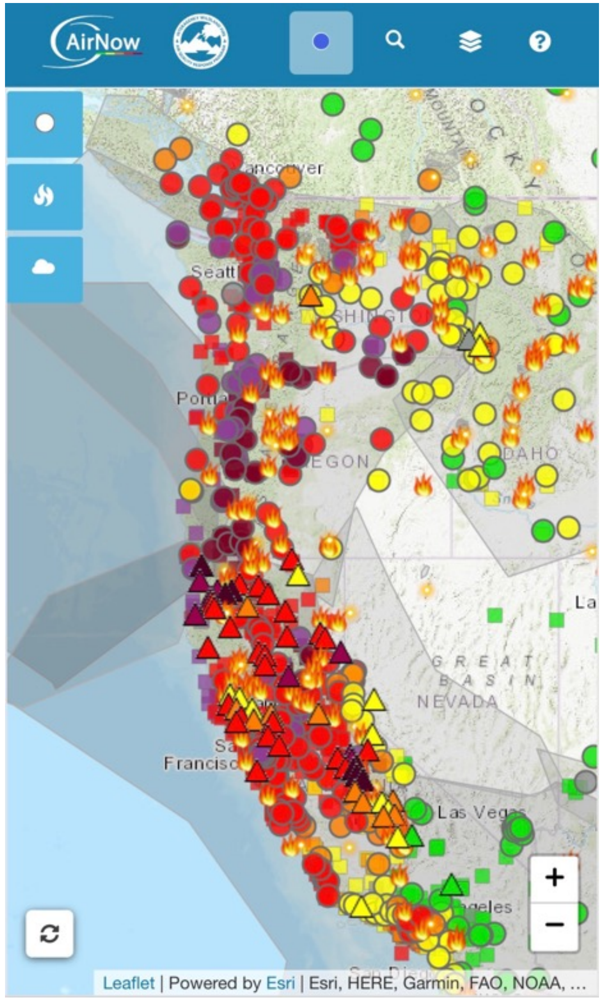
https://fire.airnow.gov

September 11, 2020 shown

Desktop:



Mobile:



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Updates for 2021

Many changes are under development for 2021

Final version subject to change as testing and development continues

Specific changes include

- Updated correction factor
- Faster loading / less data usage
- Enhanced mobile experience
- Additional features

Large updates to backend

Update: More Purple Air Sensors

- Number of Purple Air sensors has significantly increased since 2020

> +50 %

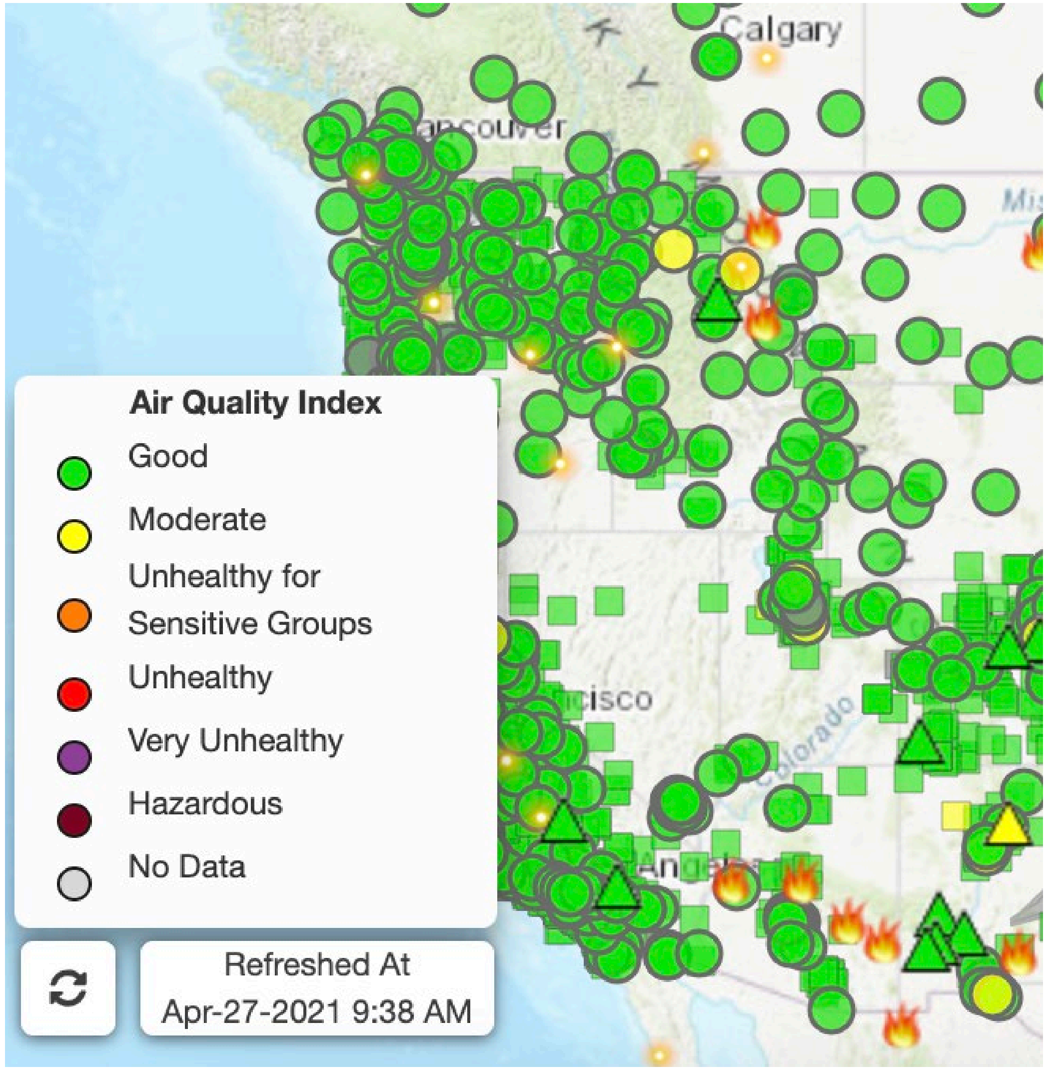
Update: Easier to understand

Map Legend Visibility

- The map legend is being moved to provide easier access and is now visible upon opening to provide easier access and to help users understand the map

Better Frequently Asked Questions (FAQs)

- The FAQs will be updated, expanded to offer more information, and will be easier to revise/clarify as needed



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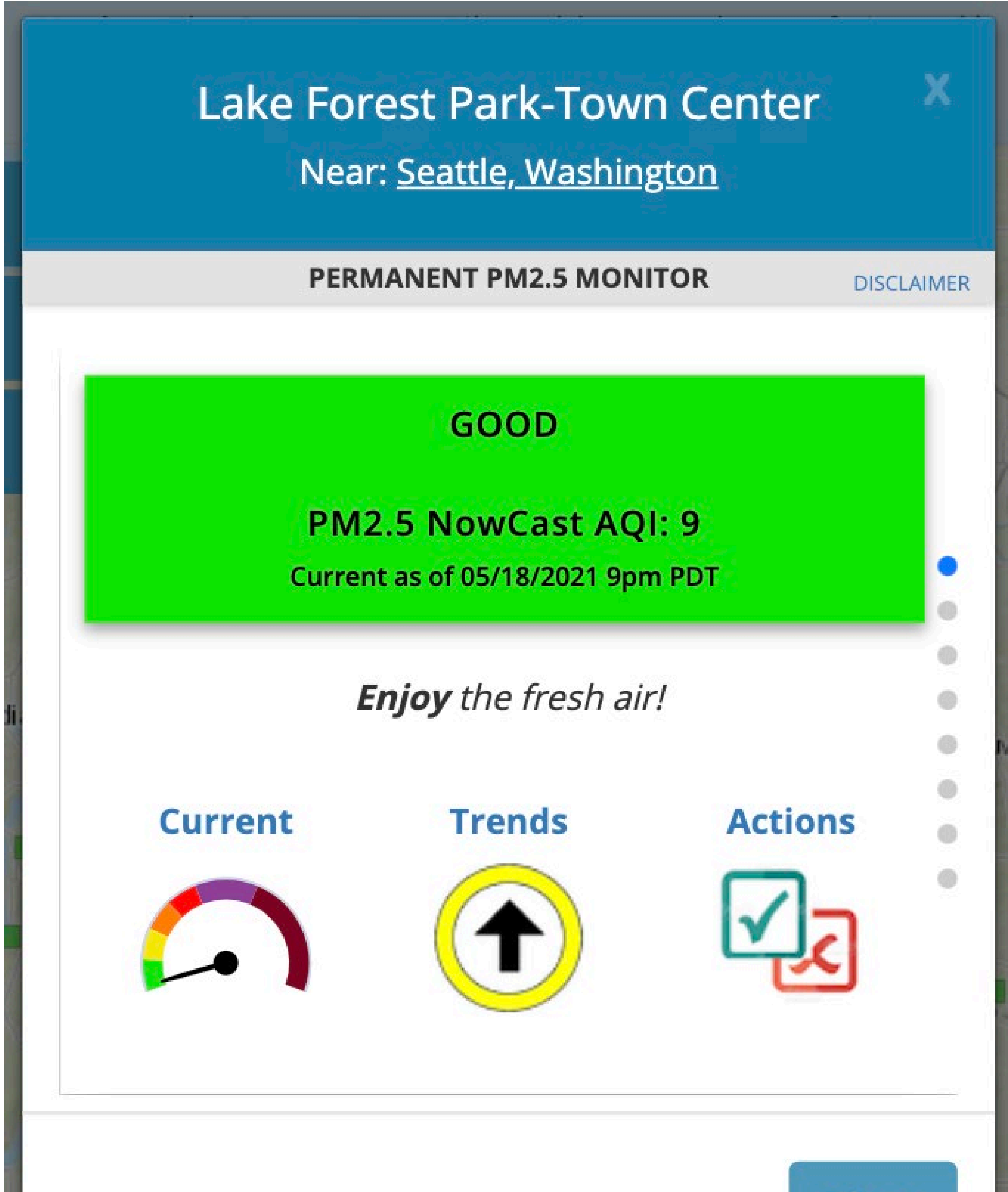
Update: Easier to find the info you are looking for

- When clicking on a monitor or sensor, a new display highlights the most pertinent information

- The first page provides a quick overview; click through to see details

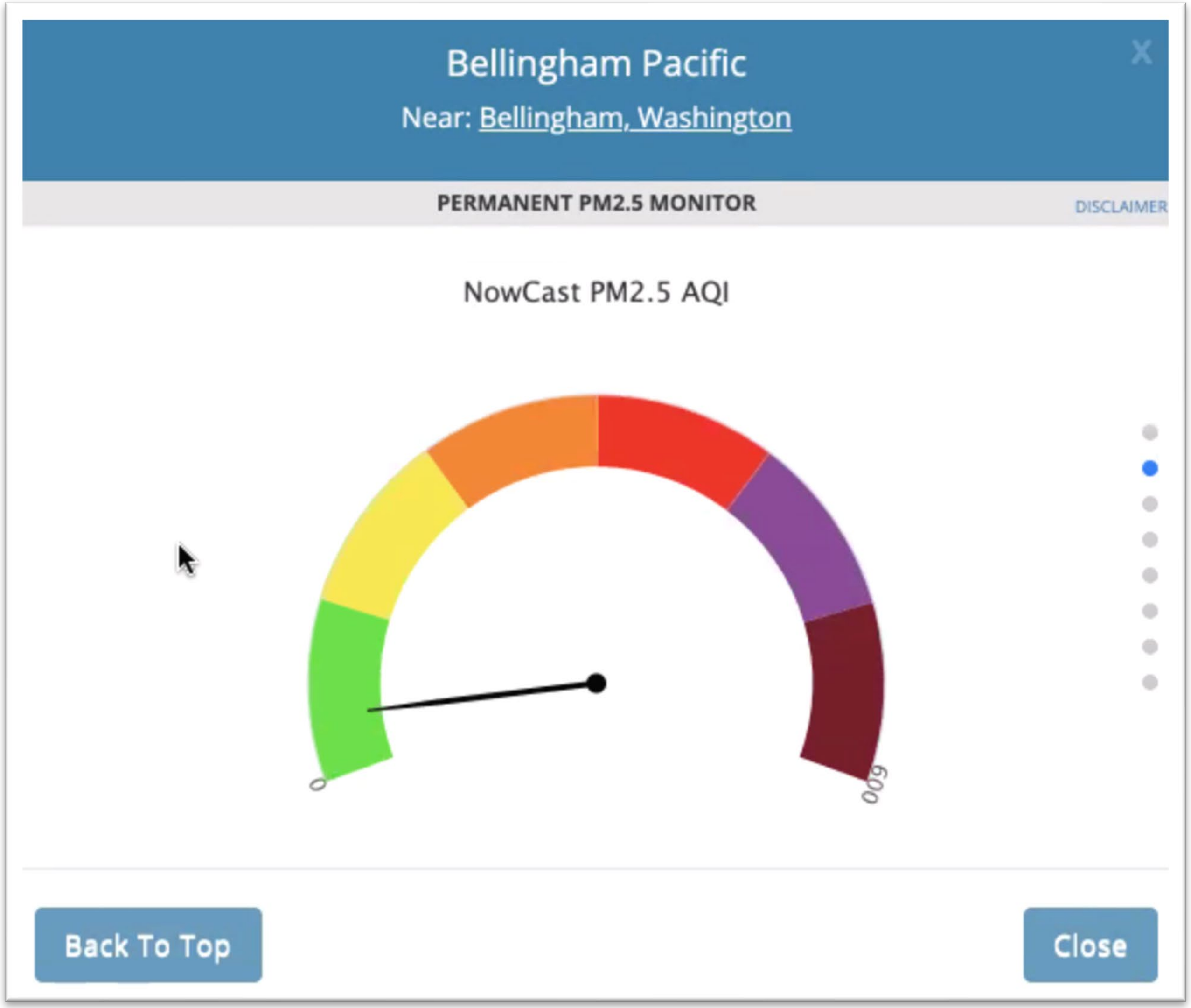


Example only

Update: A variety of ways to see the data

- Since everyone responds to information in a different way, offering many ways to view the data is important

- Working to make this graphical gauge similar to the AirNow main site



Update: Take advantage of the rapidly updating low-cost sensor data

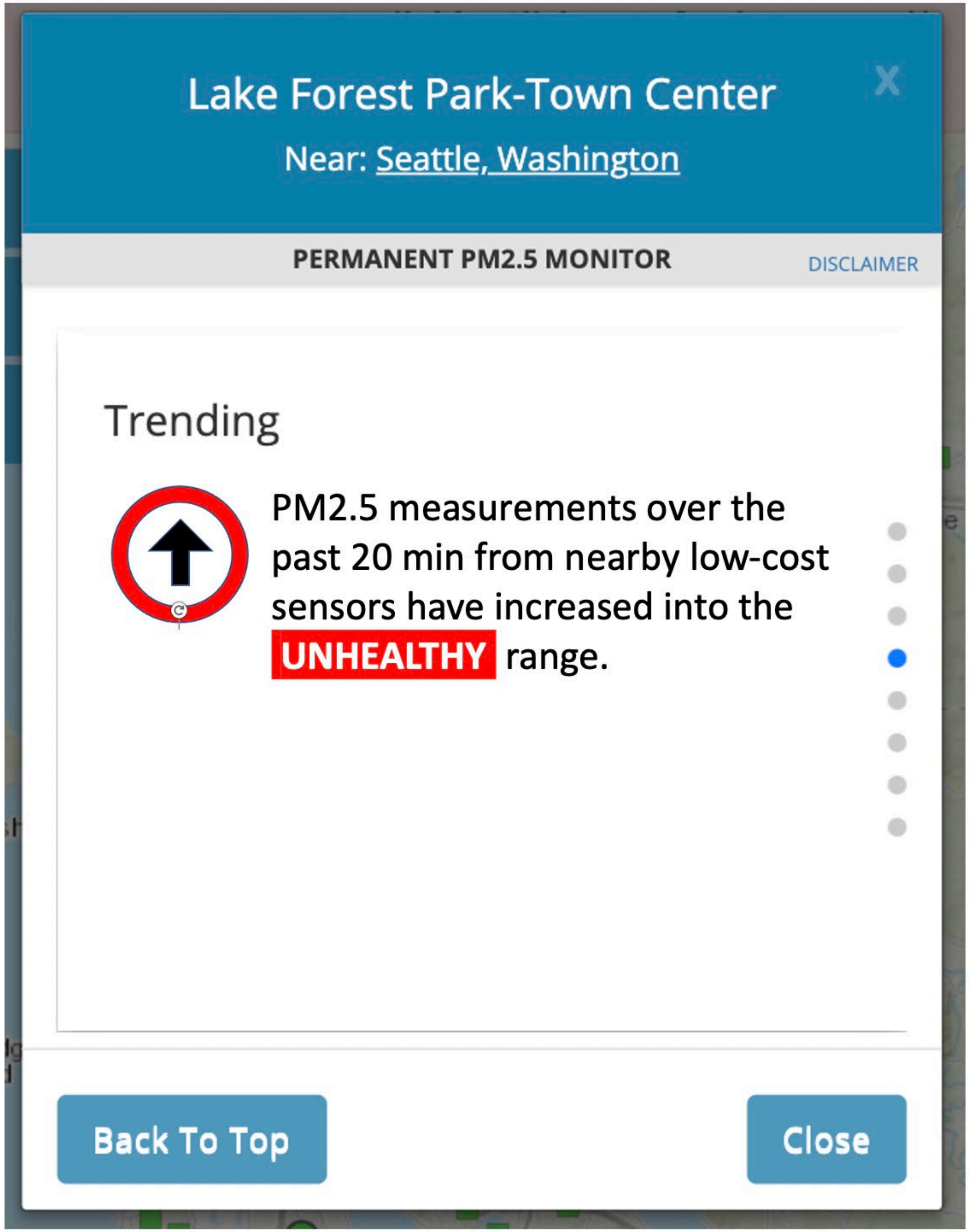
Primary Display = NowCast AQI; Updates Hourly

- Primary display will remain the $PM_{2.5}$ NowCast Air Quality Index (AQI) due to relationship with health messaging
- For permanent/temporary monitors, we only have hourly $PM_{2.5}$ data

More Recent Conditions = Trending

- Use shorter time average / rapidly refreshed low-cost sensor data to display more recent conditions *(For permanent and temporary monitors, use an average of nearby low-cost sensor data)*

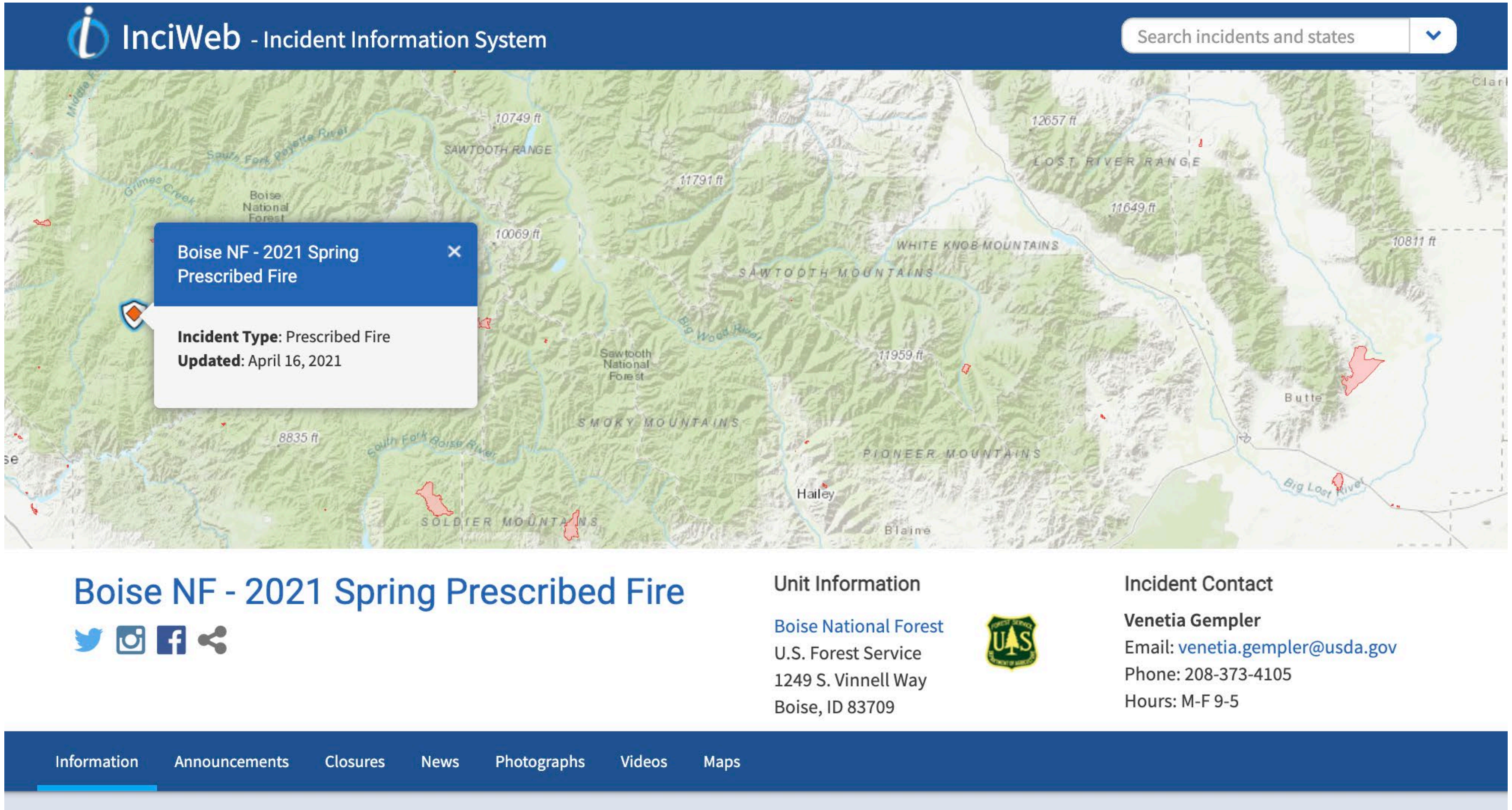
Trend Example



Example only; not real data

Update: Fire Information Linked to Inciweb

- Inciweb contains the latest incident information



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Future: Addition of Other Air Sensors

- Accuracy and data availability criteria are being defined under which we can consider bringing in other air sensor networks
- Any decision to add other sensor networks to the map will be done in consultation with State, Local, and Tribal air monitoring agencies
- This will likely not happen in time for the start of the 2021 western wildfire season

Background on Air Sensors

Background: Collocation

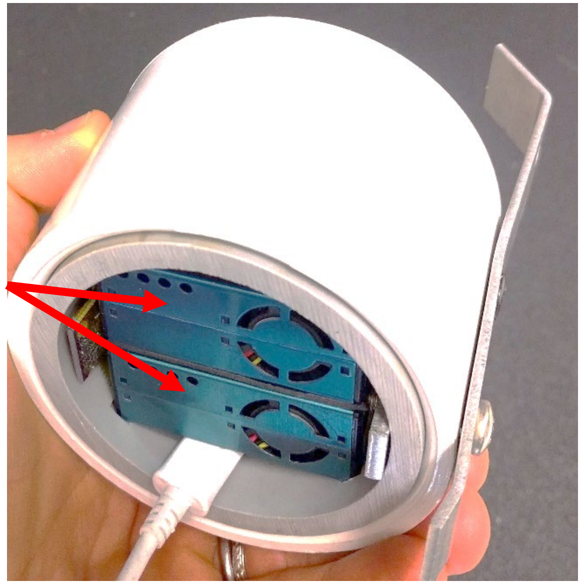
- How do we determine the performance of air sensors?
  - Collocation: Running side by side with trusted methods
- Why do we need to collocate sensors?
  - Sensors often have systematic offsets and may be influenced by relative humidity or other external conditions
- How do we improve performance?
  - Build corrections based on collocated data to account for offsets

Air sensors (red circle) collocated with a temporary smoke monitor during the **Natchez Fire (Happy Camp, CA)**
Photo Credit: Lauren Maghran

How does this apply to PurpleAir?

- How we determined the performance of PurpleAir sensors?
  - Collocations across the US under typical ambient and smoke impacted times
- How do we improve performance?
  - We built a US-wide correction in 2019
  - We developed data cleaning steps based on the duplicate (A & B) channels

A & B channels



PurpleAir underside view

Updating the US-wide correction

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2019

US-wide correction built

US-wide Correction Timeline

- Built and tested on 24-hr averaged data from Federal Reference and Equivalent methods (FRMs and FEMs)
- 16 States

Review status: a revised version of this preprint was accepted for the journal AMT.

Development and Application of a United States wide correction for $PM_{2.5}$ data collected with the PurpleAir sensor

Karoline K. Barkjohn[1], Brett Gantt[2], and Andrea L. Clements[3]

https://doi.org/10.5194/amt-2020-413

Original US-wide correction

$$PM_{2.5} = 0.52*PA_{cf\_1} - 0.086*RH + 5.75$$

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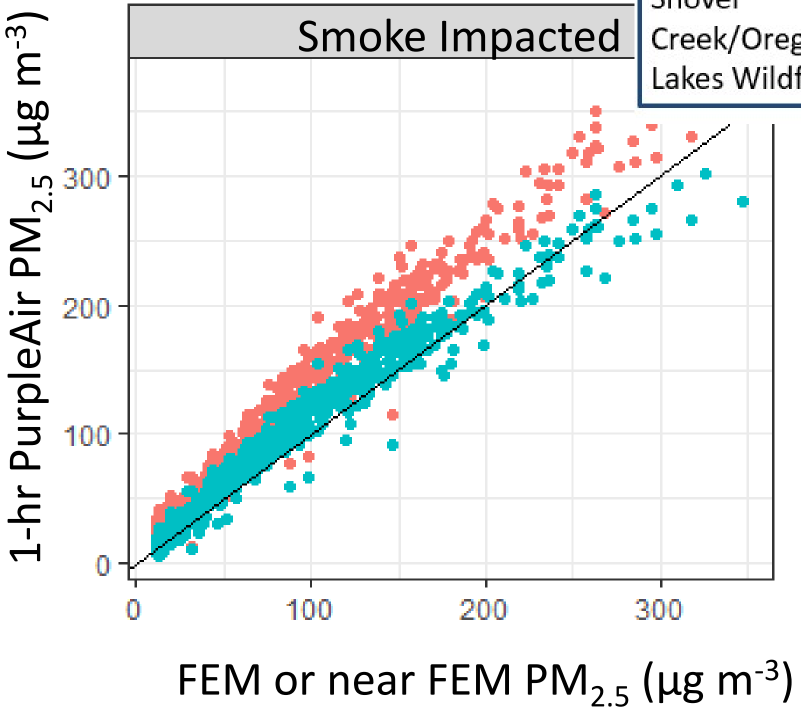
US-wide Correction Timeline

2019
US-wide correction built

2020
Evaluated on smoke impacted datasets from 2018 & 2019

- Tested on 1-hr smoke and ambient datasets

Smoke site
Ambient site



Correction
- Cf_1
- US-wide correction

Article

Field Evaluation of Low-Cost Particulate Matter Sensors for Measuring Wildfire Smoke

Amara L. Holder [1,*], Anna K. Mebust [2], Lauren A. Maghran [2], Michael R. McGown [3], Kathleen E. Stewart [2], Dena M. Vallano [2], Robert A. Elleman [3] and Kirk R. Baker [4]

https://doi.org/10.3390/s20174796

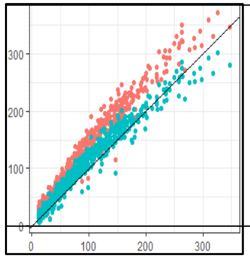
US-wide Correction Timeline

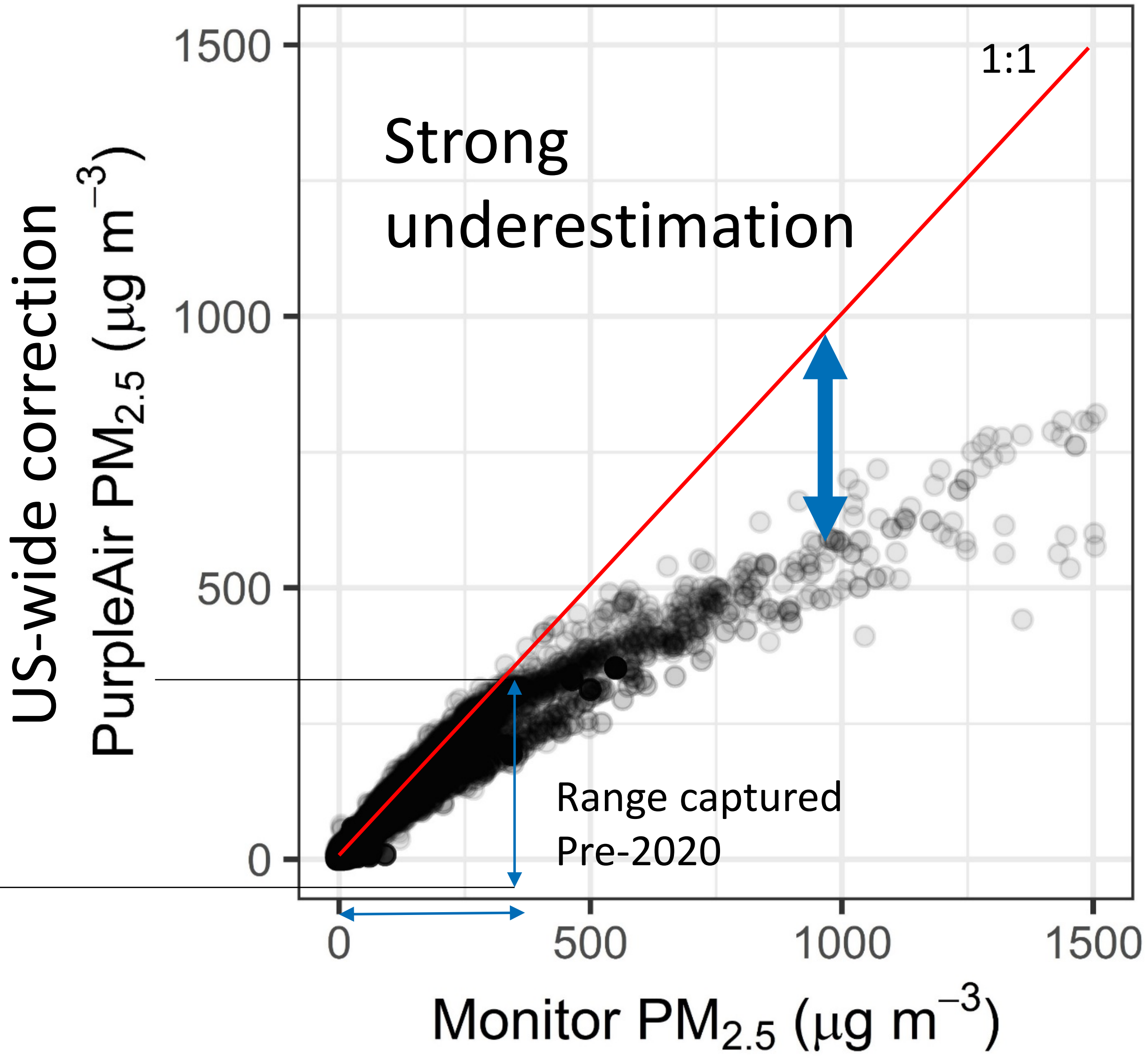
2019
US-wide correction built

2020
Evaluated on smoke impacted datasets from 2018 & 2019

Summer 2020
Underpredicts at <u>extreme</u> smoke concentrations

- Collocation data captured in 2020 spanned a much larger range of concentrations





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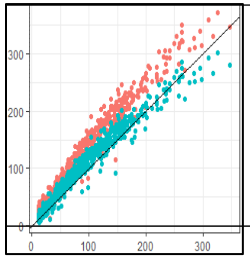

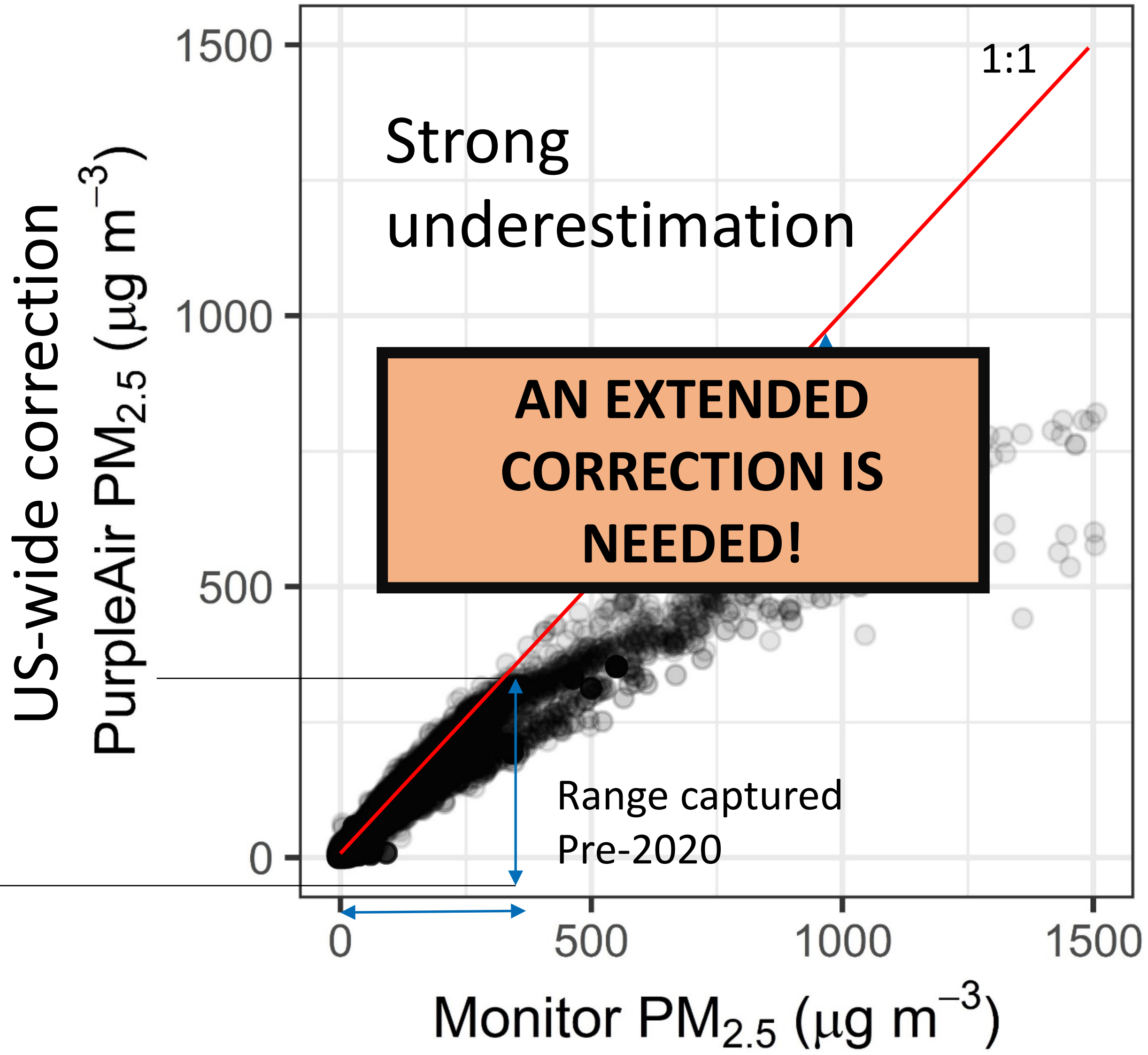

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Past Work

- 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)

ELSEVIER

Environmental Pollution

Volume 245, February 2019, Pages 932-940

Long-term field evaluation of the Plantower PMS low-cost particulate matter sensors ☆

T. Sayahi, A. Butterfield, K.E. Kelly

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INDOOR AIR

International Journal of Indoor Environment and Health

ORIGINAL ARTICLE | Full Access

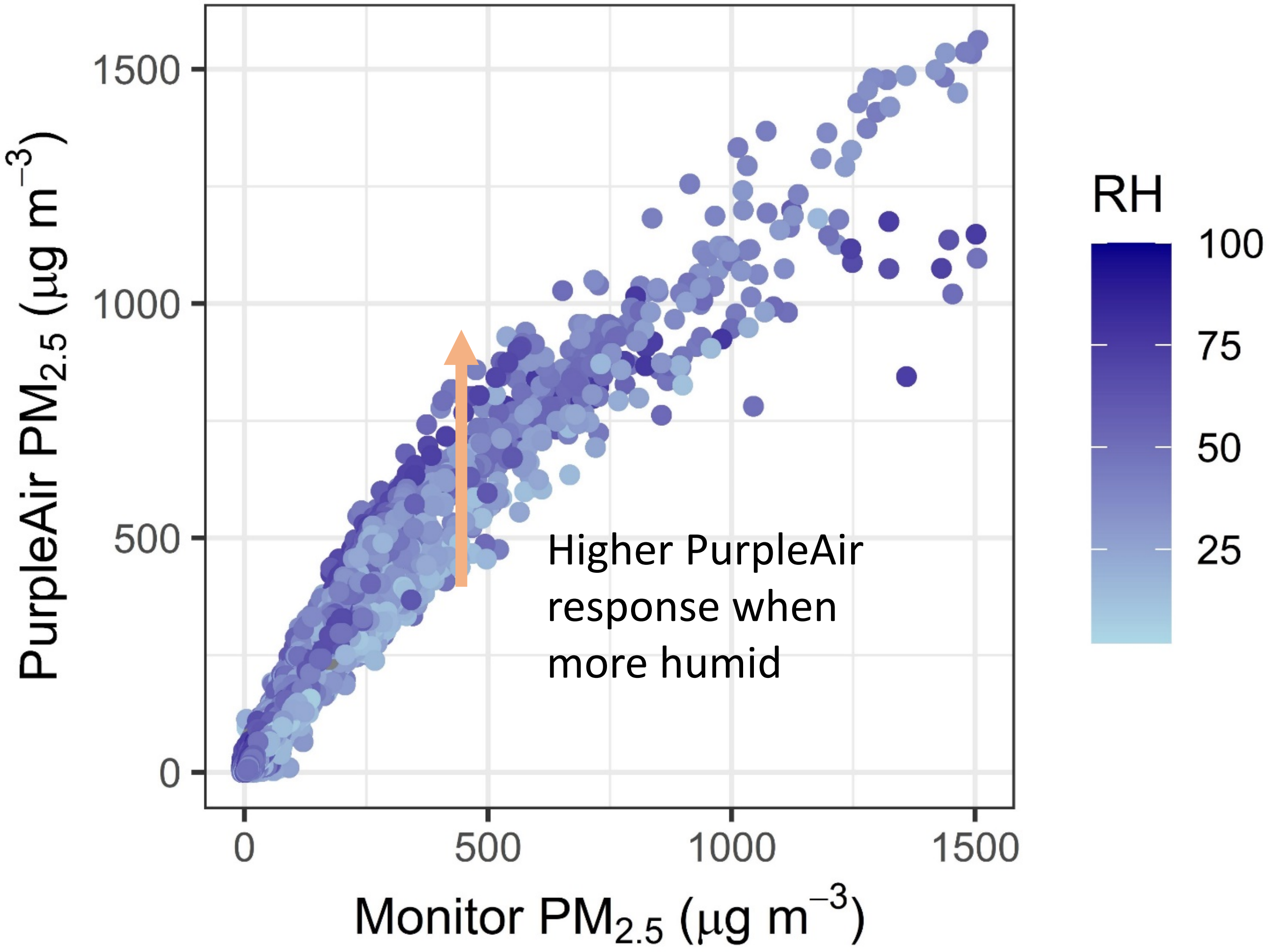
Examining the functional range of commercially available low-cost airborne particle sensors and consequences for monitoring of indoor air quality in residences

Yangyang Zou, Matthew Young, Jiawei Chen, Jiaqi Liu, Andrew May, Jordan D. Clark

First published: 11 November 2019 | https://doi.org/10.1111/ina.12621 | Citations: 7

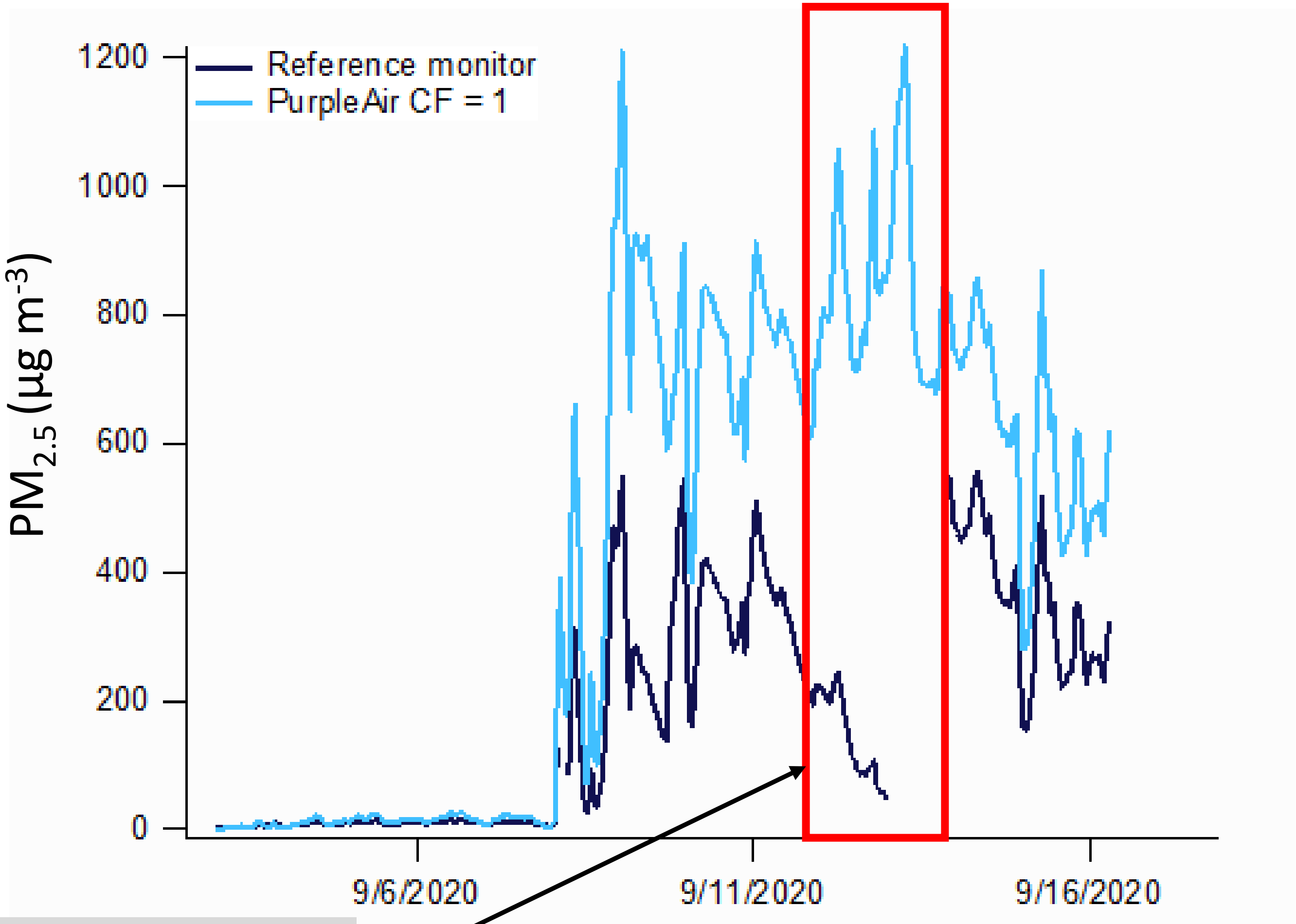
Correction Requirements

- **Fits full range**
  - Important so that the map can be used during times of the year with and without smoke impacts
- **Considers relative humidity (RH) influence**
  - Important since monitors measure dry $PM_{2.5}$ and RH can increase light scattering per mass
- **Simple is better**
  - Want model to be broadly applicable and easy to interpret



Correction Development: Site identification

- **Identify nearby sensor/monitor pairs** on the AirNow Fire and Smoke map in smoke impacted areas (Aug-Oct 2020)
- **Exclude some sites** with poor agreement and some distinct outlier points
  - ***Suspected issues with the sensor*** (e.g., poor performance leading to data exclusion, mid-season replacement, location uncertainty)
  - ***Suspected issues with FEM and near-FEM*** performance at extreme conditions > 500 µg m^{-3}



Example of site excluded due to likely FEM error at elevated concentration

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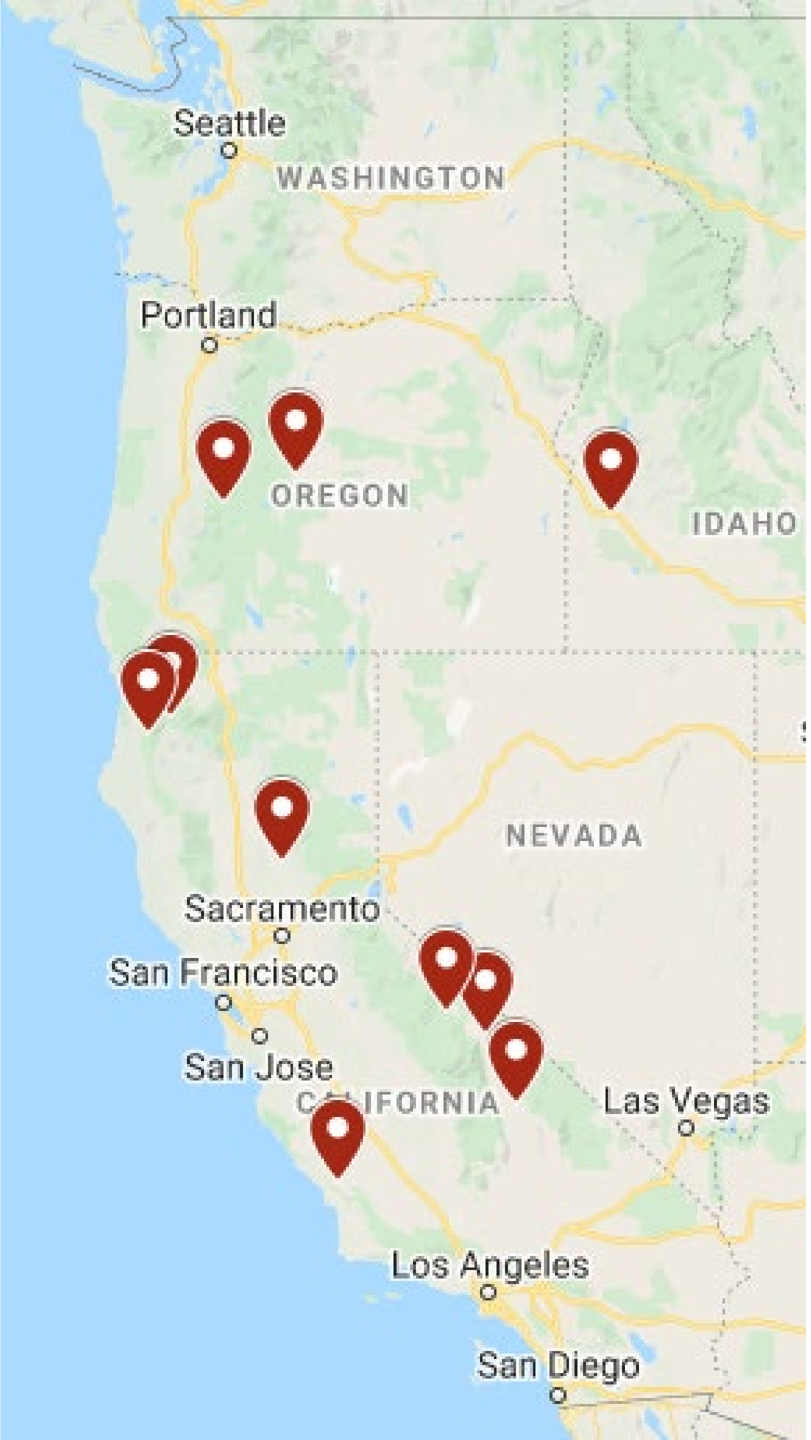
2020 Sites

Site Characteristics:

- Experiencing smoke concentrations greater than 250 µg m^{-3}
- Moderate range of temperature and relative humidity
- Range of ecosystems and fire conditions

Site	Fire	Date Range 2020	Concentration Range 1-hour averaged (µg/m^3)
Atascadero, CA	River – Dolan	08/01 - 10/19	-2-448
Bend, OR	Beachie Creek	08/01 - 10/19	2-485
Bishop, CA	Creek	08/01 - 10/20	2-496
Boise, ID	Aged OR smoke	08/01 - 10/20	-4-158
Forks of Salmon, CA	Red Salmon Complex	08/14 - 10/20	-5-1504
Hoopa, CA	Red Salmon Complex	07/31 - 10/20	-5-1502
Keeler, CA	Creek	08/01 - 10/20	0-260
Mammoth Lakes, CA	Creek	08/01 - 10/19	1-1464
Oroville, CA	North Complex	08/25 - 10/15	-5-1506



Map of Smoke and Ambient Sites

- Included previous smoke collocations
- Included typical ambient sites for ~1+ year

Ambient collocations

Site	Date Range
Atascadero, CA	01/2018 - 10/2019
Davenport, IA	01/2019 - 10/2020
Decatur, GA	08/2019 - 08/2020
Denver, CO	08/2019 - 09/2020
Research Triangle Park, NC	08/2019 - 10/2020
Edmond, OK	08/2019 - 09/2020
Missoula, MT	11/2019 - 07/2020
Phoenix, AZ	10/2019 - 07/2020
Sarasota, FL	05/2019 - 06/2020
Topeka, KS	03/2019 - 06/2020
Wilmington, DE	07/2019 - 06/2020

Ambient

2018-2019 smoke

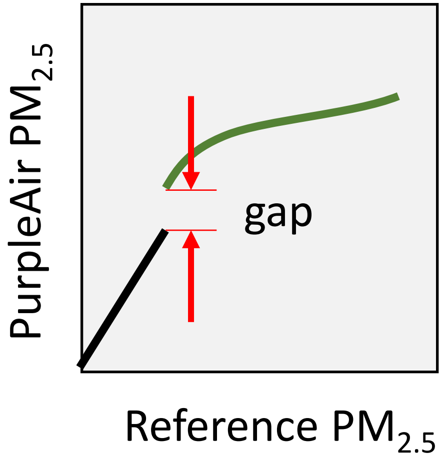
2020 smoke

Corrections Considered

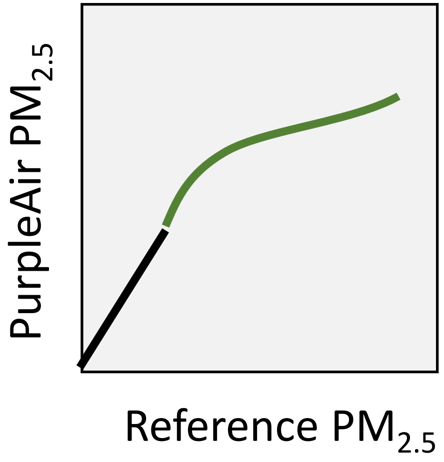
- **Considered a variety of terms**
  - Linear, quadratic, and cubic fits
    - PA, PA^2, PA^3
  - Relative humidity
    - RH
  - Interaction between RH and $PM_{2.5}$
    - RH*PA, $RH*PA^2$
- **Piecewise fits**
  - Switch equations at a specific concentration
  - Targets:
    - Reduce any gaps that may occur
    - Limit to ≤ 2-piece equation if possible

From Simple:
US-wide correction: Ref = $0.52*PA_{cf\_1} - 0.086*RH + 5.75$

To complex:
Ref = $a \times PA^2 + b \times PA^2 \times RH + c \times PA + d \times PA \times RH + e \times RH + f$



Gap between piecewise corrections



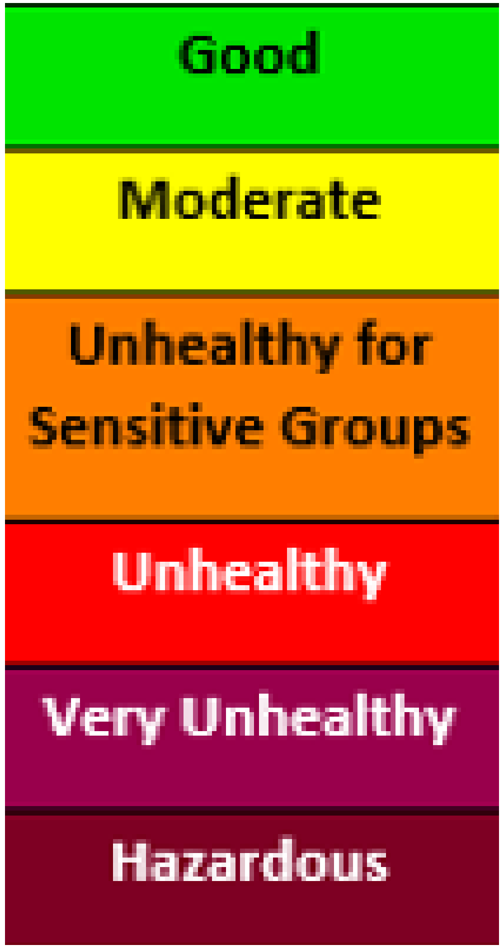
Well fitting piecewise corrections

PA = Reported PurpleAir cf_1 $PM_{2.5}$ Concentration

Methods: Model Evaluation

- **Evaluate performance at each AQI** breakpoint
  - Important since AQI is the primary way risk is communicated on the map
- **Build and test using withholding**
  - Gives us a better idea of how the correction may work on sites not included in our dataset
  - It helps us avoid selecting too complicated of a model
- **Targets:**
  - Bias* ≤ ± 5% in each bin
  - Reduce error† in each bin

AQI Categories



Bins to evaluate Performance

break points ±20%

10-14 µg m^{-3}

28-42 µg m^{-3}

44-66 µg m^{-3}

120-180 µg m^{-3}

200-300 µg m^{-3}

400-600 µg m^{-3} (calOSHA respirator)

*Normalized mean bias error (NMBE)

†Normalized mean absolute error (NMAE)

Final Correction

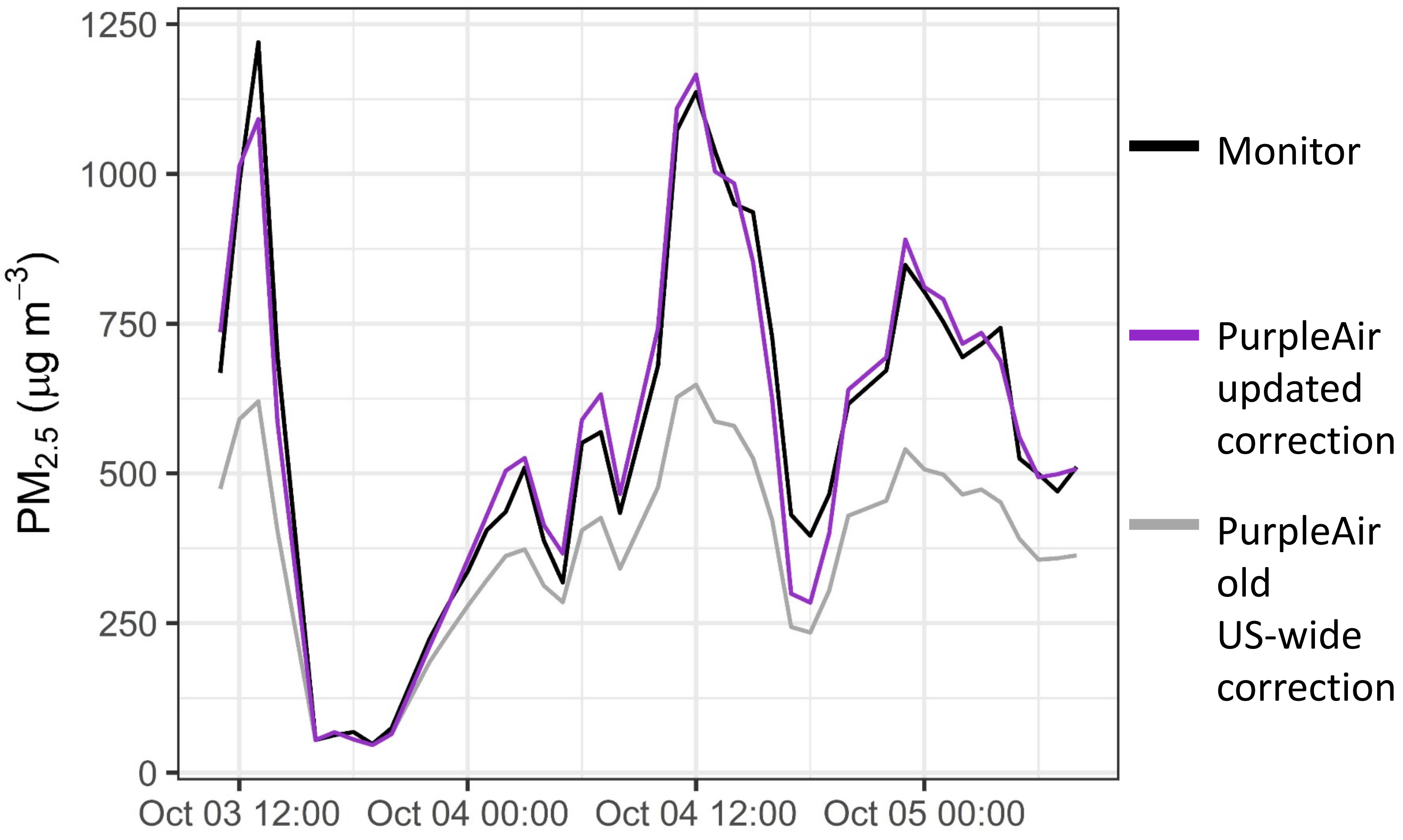
Use the US-wide correction until PA_{cf_1} exceeds 343 µg m^{-3} then use a quadratic fit

Low Concentration $PA_{cf\_1} \leq 343$ µg m^{-3}	$PM_{2.5} = 0.52 \times PA_{cf\_1} - 0.086 \times RH + 5.75$
High Concentration $PA_{cf\_1} > 343$ µg m^{-3}	$PM_{2.5} = 0.46 \times PA_{cf\_1} + 3.93 \times 10^{-4} \times PA_{cf\_1}^{2} + 2.97$

How does this change the $PM_{2.5}$ estimates?

Better agreement over the full range of concentrations

Example: Forks of Salmon



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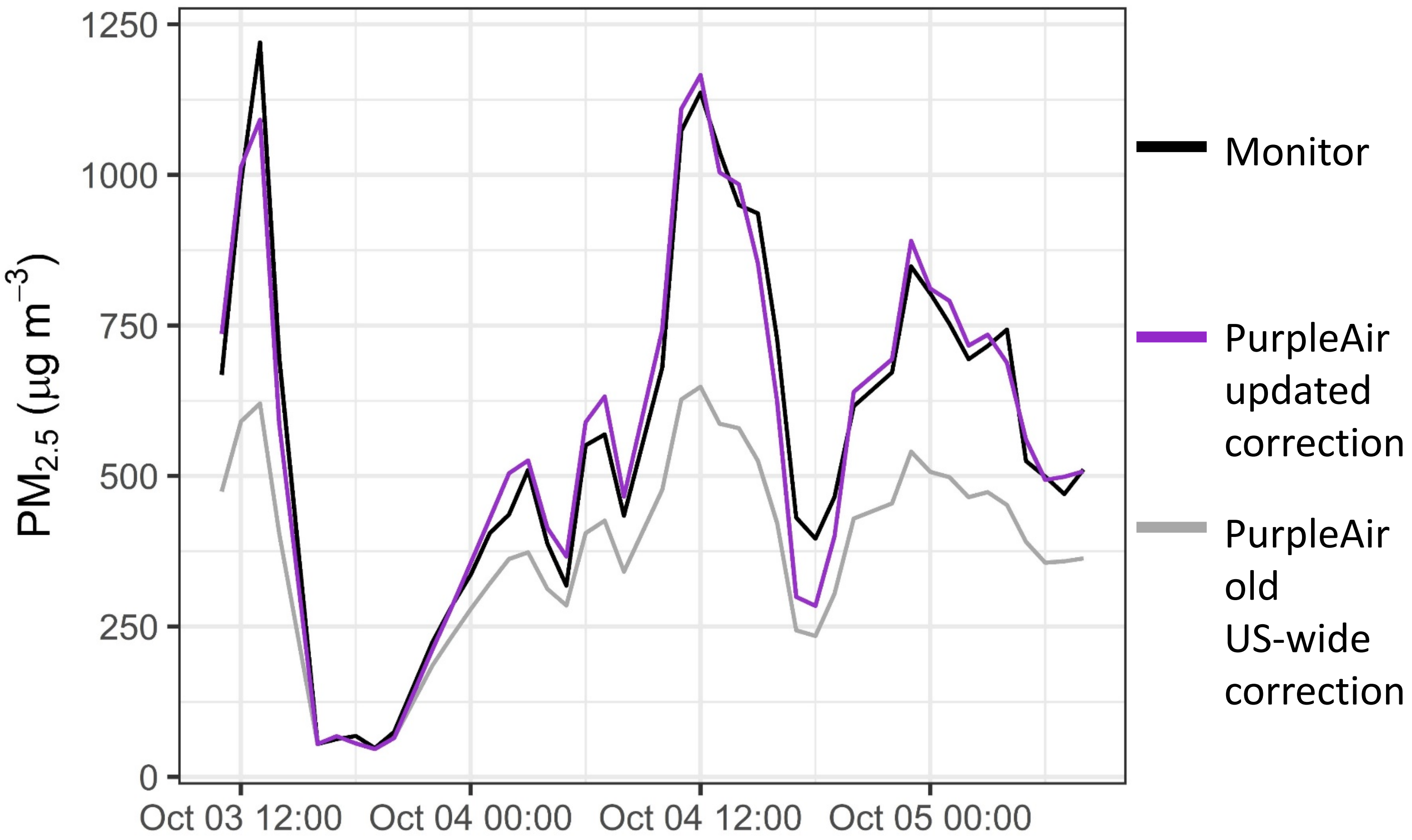
How does this change the $PM_{2.5}$ estimates?

Better agreement over the full range of concentrations

Note: Other corrections available on PurpleAir.com look very similar to the old US-wide correction except the LRAPA[1] correction which underestimates above 60 µg m^{-3}

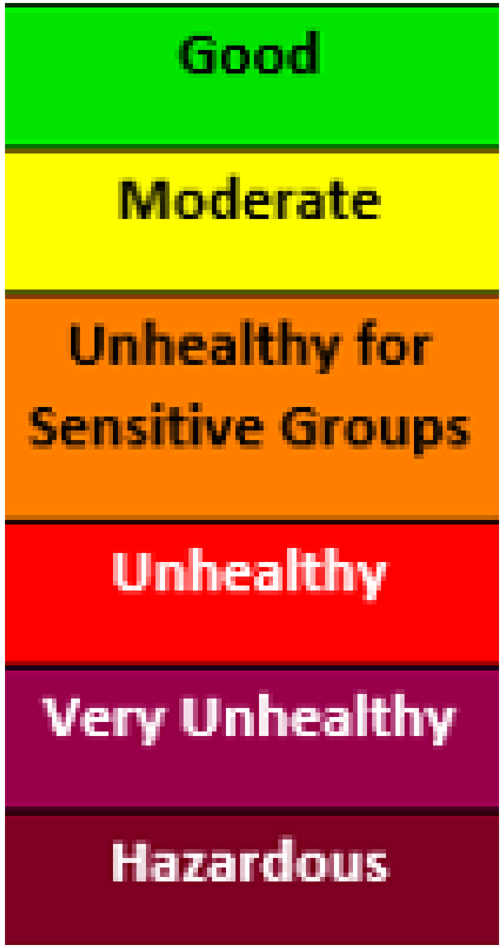
Example: Forks of Salmon



[1]LRAPA – Lane Regional Air Protection Agency

How does this change the $PM_{2.5}$ estimates?

- Better agreement over the full range of concentrations
- Evaluation by breakpoint:
  - Bias*: ±5%
  - Error‡: ± 22%

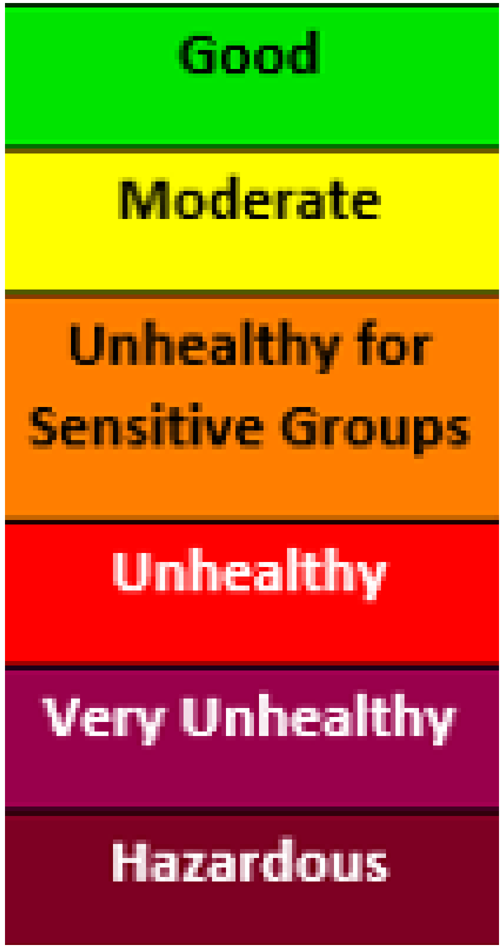


*Normalized mean bias error (NMBE)
‡Normalized mean absolute error (NMAE)

How does this change the $PM_{2.5}$ estimates?

- Better agreement over the full range of concentrations
- Evaluation by breakpoint:
  - Bias*: ±5%
  - Error‡: ± 22%

Note: It is challenging to truly estimate error on the PurpleAirs because:
- Uncertainty in the monitors
- Potential distance between PurpleAirs and monitors
- Variations between individual sensors



*Normalized mean bias error (NMBE)
‡Normalized mean absolute error (NMAE)

Sensor Users FAQs

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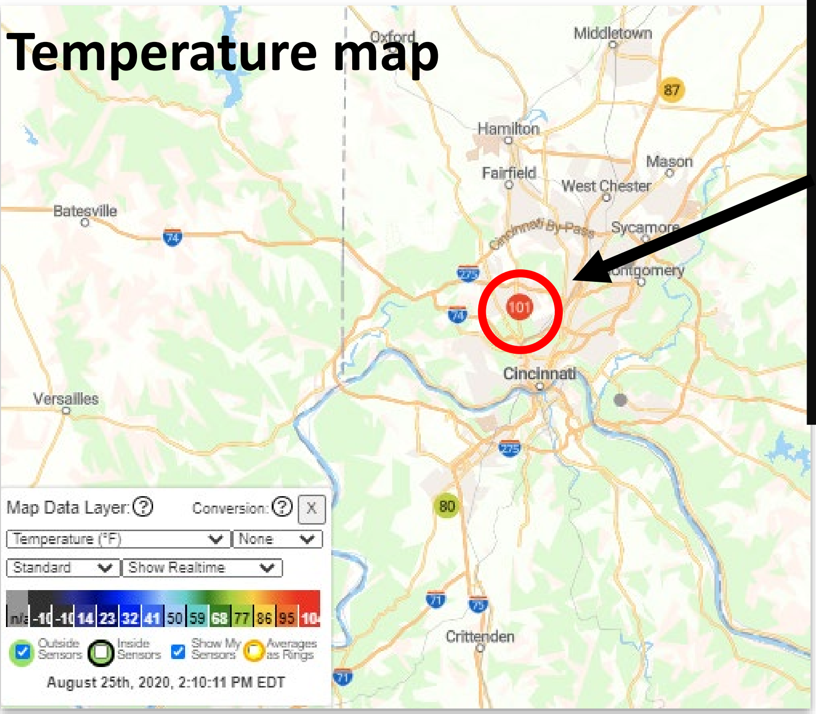
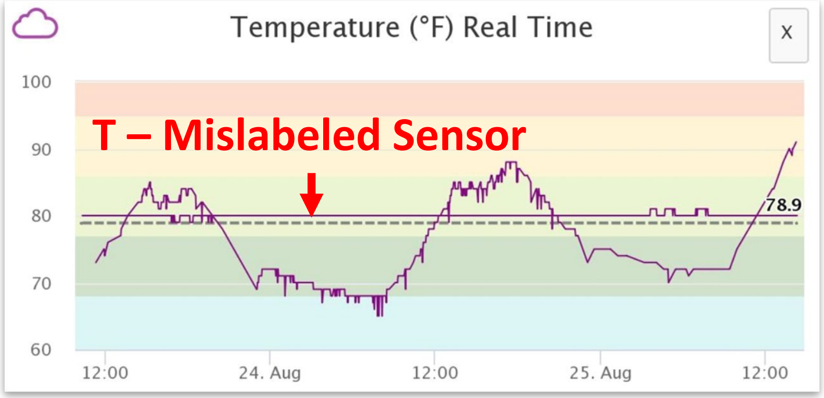
Why doesn't my PurpleAir show up on the Fire and Smoke Map?

- Indoor user label
- Installed <48 hours ago
- Too much recent missing data
- Poor agreement between channels
- Appeared problematic removed by USFS/EPA
    - Showed trends that suggested it was indoors or incorrectly located on the map

Example



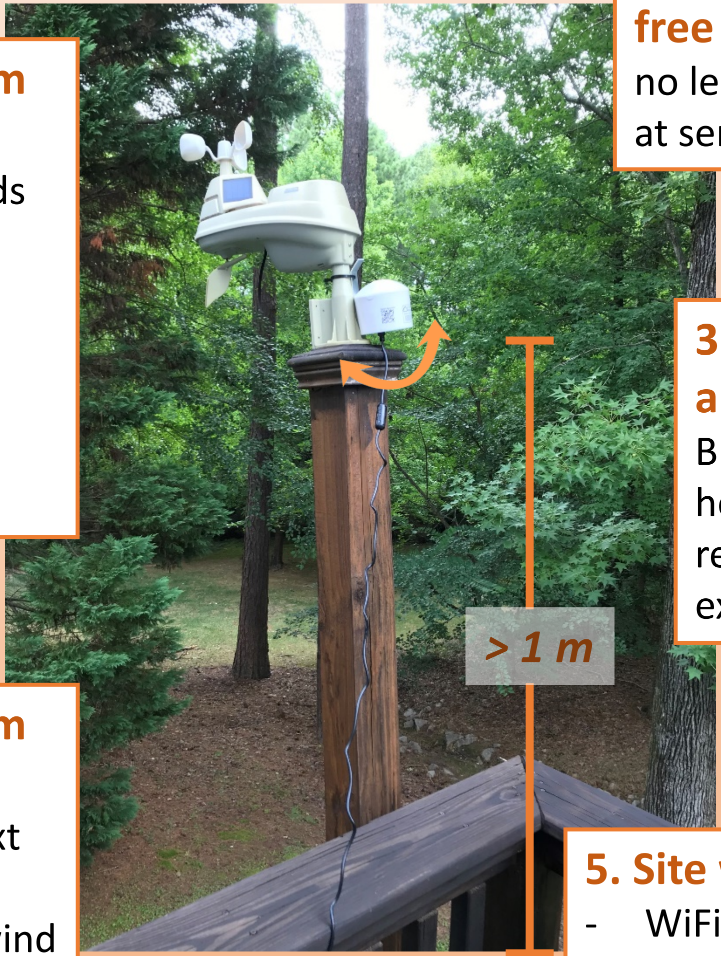


Example of outdoor sensor with T and PM that disagree with neighbors

How should I site my Air Sensor?

Top 5 siting considerations

1. Away from PM sources
- Dusty roads
- Building exhausts
- Barbecue grills
- Fire pits
- Smokers



2. Ideally >270° free air flow
no less than 180° at sensor

3. At least 1 m above ground
Breathing zone height better represents exposure

4. Away from structures
If must be next to building, place on up wind side

5. Site with support
- WiFi/Cellular signal
- Power available
- Tamper resistant
- Safe to install

Siting Quality Control Assessment
- Review the data to determine if the site may be impacted by a local source or environmental conditions
- Does high time resolution data show spikes (e.g., indicative of a local source – smoking, cooking)? Do spikes have a routine nature (e.g., indicative of cyclic operation of an HVAC fan)?
- Compare to a nearby reference, do long term trends agree?

Are you planning a collocation to develop a correction?

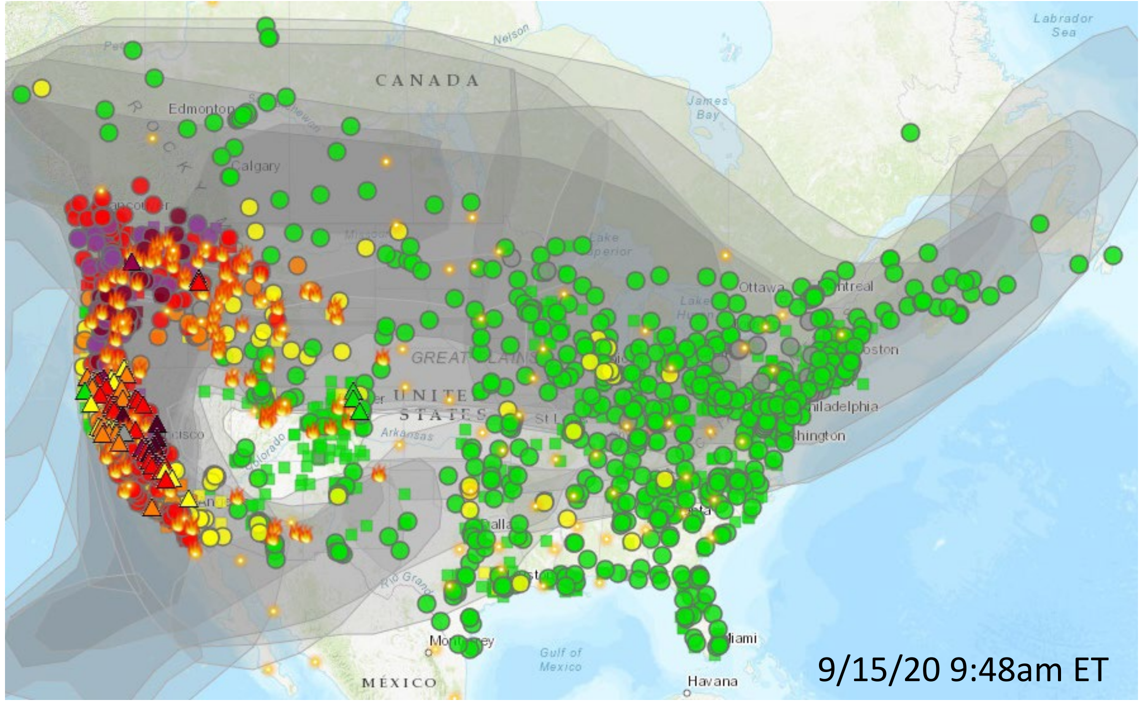
See EPA's sensor collocation guide for more siting criteria and analysis tools
https://www.epa.gov/air-sensor-toolbox/air-sensor-collocation-instruction-guide

What would be needed to have similar confidence in a different sensor for this application?

- Need evaluations over the full range of conditions
  - Typical ambient
    - <25 µg m^{-3}
  - Smoke
    - Ideally 0-600 µg m^{-3} (0-300 µg m^{-3} minimum)
    - Fresh and aged
    - Variety of fuel types
  - Relative humidity & temperature
- Locations across the country
- Deployments lasting a year or more
- Quality assurance procedures
  - Procedures developed for PurpleAir sensors depend on duplicate sensors
  - May be more challenging if no duplicate sensor

Take Home Messages

- The AirNow Fire and Smoke Map is a useful tool to understand local $PM_{2.5}$ conditions
  - Shows sensors and monitors side by side allowing users to better compare
- The quality assurance and correction allow data from sensors to be comparably displayed
  - Gives users a consistent picture of air quality
- The extended correction will allow sensors to provide measurements comparable to monitors over ~0-1500 µg m^{-3}



Resources & Publications

Additional resources and details about EPA's work with air sensors

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

AirNow Fire and Smoke Map

https://fire.airnow.gov/

Project Publications:

Holder, A., A. Mebust, L. Maghran, M. McGown, K. Steward, D. Vallano, R. Elleman, and K. Baker, 2020. 'Field Evaluation of Low-Cost Particulate Matter Sensors for Measuring Wildfire Smoke', Sensors. https://doi.org/10.3390/s20174796

Barkjohn (Johnson), K, B. Gantt, A. Clements, 2020 'Development of a United States Wide Correction for $PM_{2.5}$ Data Collected with the PurpleAir Sensor', Atmospheric Measurement Techniques Discussion. https://doi.org/10.5194/amt-2020-413

Barkjohn (Johnson), K, A. Holder, S. Frederick, A. Clements, (in preparation) 'PurpleAir $PM_{2.5}$ US Correction and Performance During Smoke Events'.

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Q&A

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Additional detailed slides

Full list of considered equations

- US-wide correction
  - Ref=5.72+PA*0.524-0.0852*RH

- Linear with RH (PA*RH PA~<200)
  - ref=a+b*PA+c*RH+d*PA*RH
- Quadradic
  - ref=a+b*PA+cPA^2

- Quadradic (PA*RH)
  - ref=a+b*PA+c*RH+d*RH*PA+ePA^2

- Quadradic (PA^2*RH)
  - ref=a+b*PA+c*RH+d*RH*PA+ePA^2+fPA^2*RH

- Quadradic (PA^2+RH)
  - ref=a+b*PA+c*RH+dPA^2

- Cubic (PA^3)-initially considered but didn't improve the relative standard error over quadradic
- Piecewise fits: using the intersection of above equations @ 50% RH

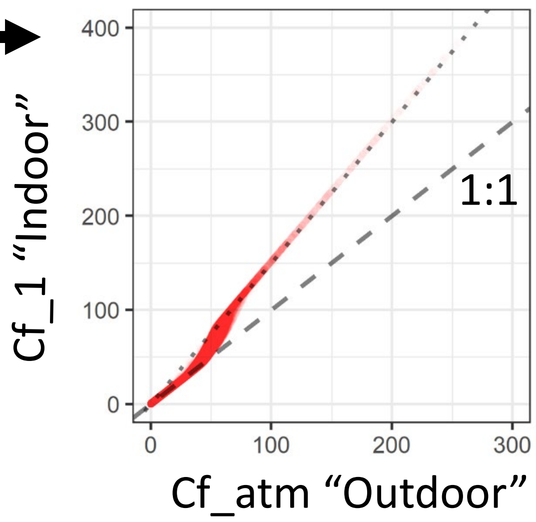
What are PurpleAir sensors?

PurpleAir Data

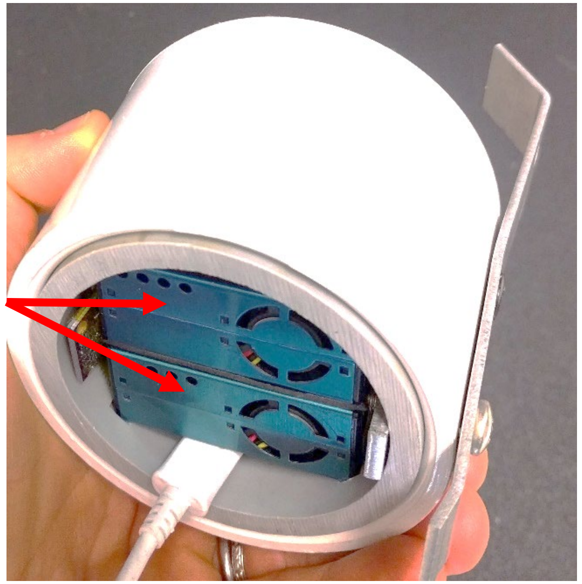
- 2 Plantower PMS5003 PM sensor (channels A & B)
- Channels alternate 10 s sampling intervals
- Reports 2 min averages (previously 80 s)

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)



A & B channels



PurpleAir underside view

2020 Fire Season Site Details

Targeted sites:

- PurpleAir collocated or nearby monitor
- Limited spatial variation of $PM_{2.5}$
- Experiencing smoke concentrations greater than 250 $\mu g/m^3$

Site	State/Agency	Instrument	Fire	Date Range 2020	Concentration Range 1-hour averaged ($\mu g/m^3$)
Atascadero	CA/SLOCAPCD	BAM1020	River – Dolan	08/01-10/19	-2-448
Bend	OR/DEQ	Nephelometer	Beachie Creek	08/01-10/19	2-485
Bishop	CA/GBUAPCD	T640x	Creek	08/01-10/20	2-496
Boise	ID/DEQ	BAM1020	Aged OR smoke	08/01-10/20	-4-158
Forks of Salmon	CA/SCAQMD	E-BAM	Red Salmon Complex	08/14-10/20	-5-1504
Hoopa	CA/NCUAQMD	E-BAM	Red Salmon Complex	07/31-10/20	-5-1502
Keeler	CA/GBUAPCD	R&P TEOM 1400a	Creek	08/01-10/20	0-260
Mammoth Lakes	CA/GBUAPCD	T640x	Creek	08/01-10/19	1-1464
Oroville	CA/BCAQMD	E-BAM	North Complex	08/25-10/15	-5-1506

SLOCAPCD =San Luis Obispo County Air Pollution Control District; DEQ = Department of Environmental Quality; GBUAPC= Great Basin Unified Air Pollution Control District; SAQMD = Siskiyou County Air Quality Management District, NCUAQMD = North Coast Unified Air Quality Management District ; BCAQMD = Butte County Air Quality Management District

Ambient Site Details

- Captures various parts of the country
- Some sites do experience smoke impacts though not smoke specific sites
  - Grass fires in KS
  - Residential burning in AZ
- Most sites 1 year+

Site	State/Agency	Instrument	Date Range	Concentration Range 1-hour averaged (µg/m^3)
Atascadero	CA/SLOCAPCD	BAM1020	01/01/2018-10/24/2019	-5-108
Davenport	IA/SHL	T640	01/03/2019-10/31/2020	0-243
Decatur	GA/DEP	T640	08/01/2019-08/31/2020	0-64
Denver	CO/DPHE	T640	08/14/2019-09/30/2020	0-206
Durham	NC/EPA	T640x	08/01/2019-10/14/2020	1-45
Edmond	OK/DEQ	T640	08/01/2019-09/30/2020	1-91
Missoula	MT/DEQ	BAM1020	11/22/2019-07/28/2020	-6-27
Phoenix	AZ/Maricopa	TEOM	10/28/2019-07/31/2020	-2-550
Sarasota	FL/SCG	T640	05/30/2019-06/30/2020	1-98
Topeka	KS/DHE	T640	03/12/2019-06/30/2020	0-202
Wilmington	DE/DAQ	T640	07/27/2019-06/30/2020	1-44

SLOCAPCD =San Luis Obispo County Air Pollution Control District; SHL = State Hygienic Laboratory; DEP = Department of Environmental Protection; DPHE = Department of Public Health and Environment; EPA = Environmental Protection Agency; DEQ = Department of Environmental Quality; Maricopa = Maricopa County Air Quality Department; SCG = Sarasota County Government; DHE = Department of Health and Environment; DAQ = Division of Air Quality

Methods: Building corrections using withholding

- For each correction considered:
  - Build an equation based on all but one site
  - Fit to the withheld site
  - Build a corrected dataset where each site has been built using withholding
  - Repeat the process using withholding by week of the year

Note: Withholding is important!

It gives us a better idea of how the correction may work on sites not included in our dataset

It helps us avoid selecting too complicated of a model

Examples

Withholding by site

Build a quadratic equation based on all sites but Oroville

Ref=a x PA^2 + b x PA + c

Apply the correction to the Oroville dataset

(x28)
Repeat for the other 27 sites

Withholding by week of year

Build a quadratic equation based on all but the first week of January

Ref=a x PA^2 + b x PA + c

Apply the correction to the first week of January dataset

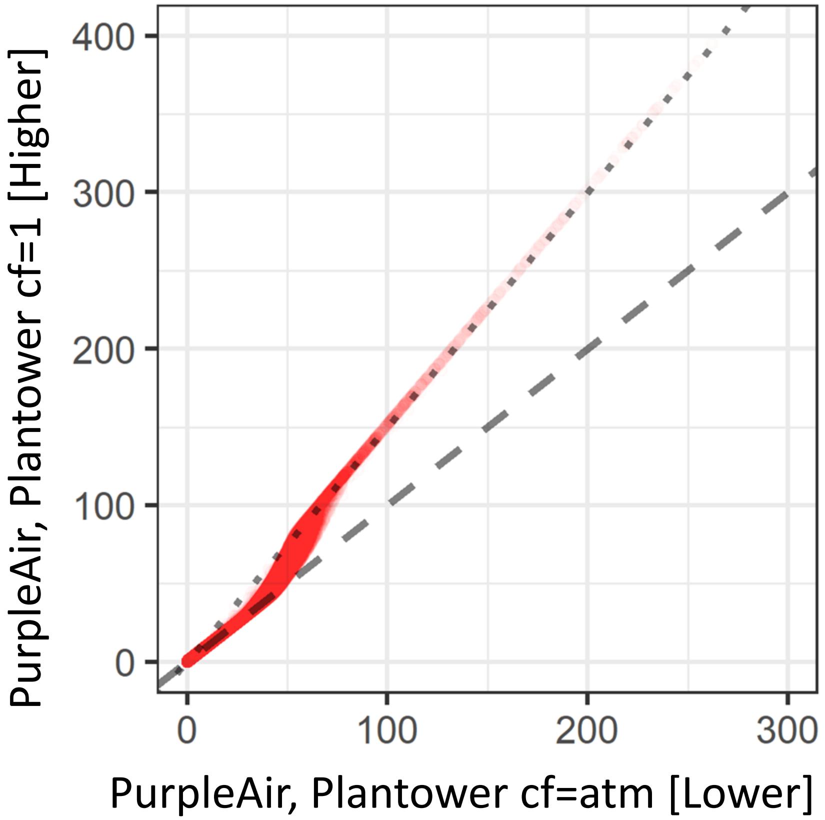
(x52)
Repeat for the other 51 weeks of the year

Repeat for each model form

Final Correction (cf_atm)

- The PurpleAir US-wide & extended corrections were developed using **cf=1 [higher]**
  - Cf=1 is more strongly correlated with FRM/FEM/near FEM over the full concentration range
- If cf_atm must be used due to API limitations this piecewise equation may be used
- There may be slightly more uncertainty at the breakpoint (~30 µg m^{-3} as measured by the reference) depending on what averaging interval this is applied to

2-min comparison of cf_1 and cf_atm data



Low Concentration PA_{cf_atm} < 50 µg m^{-3}	$PM_{2.5} = 0.52 \times PA_{cf\_atm} - 0.086 \times RH + 5.75$
Mid Concentration 50 µg $m^{-3} \leq PA_{cf\_atm} < 229$	$PM_{2.5} = 0.786 \times PA_{cf\_atm} - 0.086 \times RH + 5.75$
High Concentration PA_{cf_atm} > 229 µg m^{-3}	$PM_{2.5} = 0.69 \times PA_{cf\_atm} + 8.84 \times 10^{-4} \times PA_{cf\_atm}^{2} + 2.97$