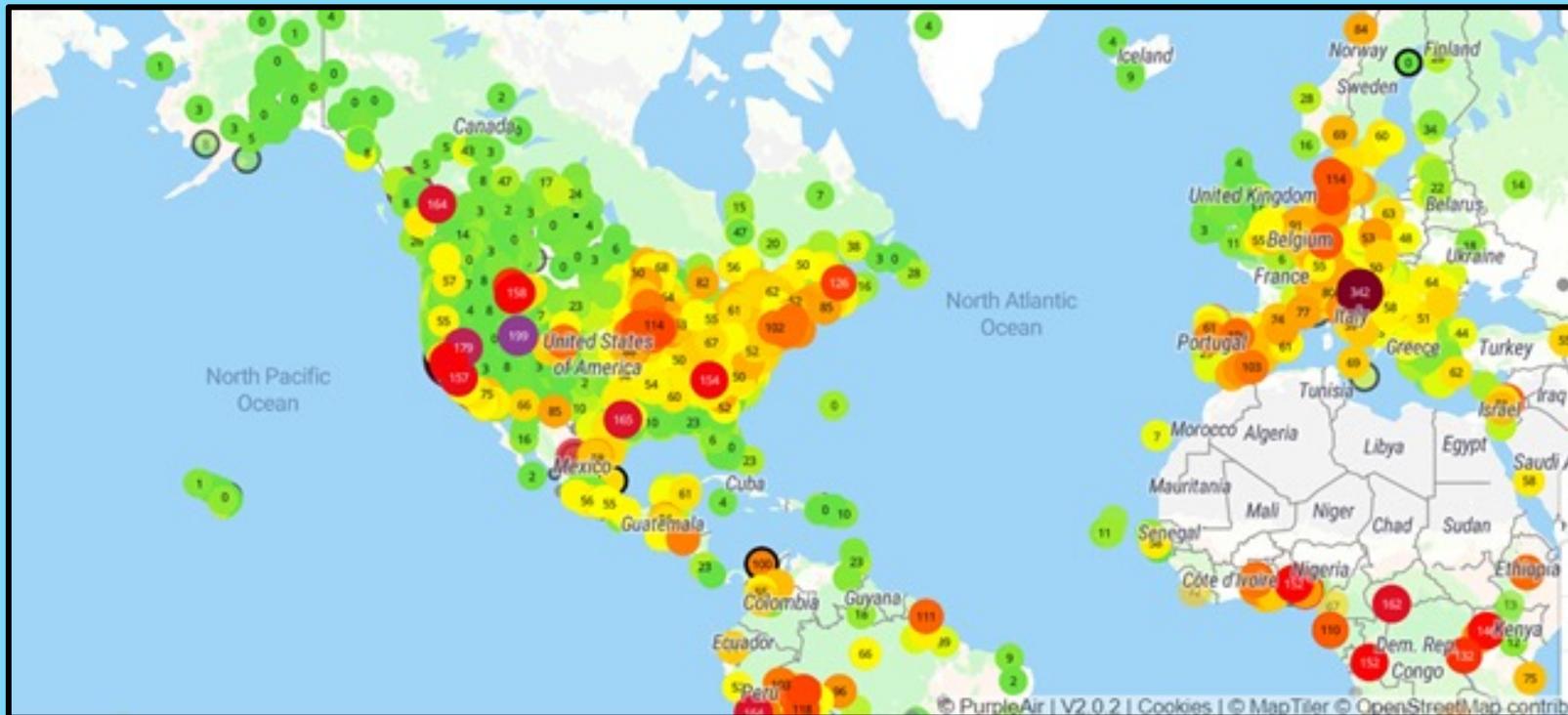# An evaluation of the U.S. EPA's correction equation for Purple Air Sensor data in smoke, dust and urban pollution events

Daniel A. Jaffe[1], Colleen Miller[1,2], Katie Thompson[1], Brandon Finley[1], Manna Nelson[3], James Ouimette[4], Elisabeth Andrews[5]

> **Purple Air sensors are the largest network of PM measurements in the world. I estimate more than 1600 sensors in WA state. More than 700 in the Puget Sound.**

> **How do we use and interpret the data?**

[1]**University of Washington**

[2]**Now at UCI**

[3]**Seattle U.**

[4]**Retired**

[5]**NOAA Global Monitoring Laboratory and CIRES**

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Purple Air Sensors (PAS)

Indoor PAS

Outdoor PAS

- ➢ Based on Plantower PMS5003, laser scattering.
- ➢ Conversion of scattering to PM mass makes assumptions about aerosol size distribution and composition.
- ➢ Off the shelf units appears to be precise, but not accurate.
- ➢ Empirical corrections for $PM_{2.5}$ have been developed LRPA, U.Utah and EPA. The LRAPA and EPA calibration equations give similar results. Utah eqn gives higher values.
- ➢ EPA now integrates PAS data into Airnow fire and smoke map.

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Purple Air Sensors data

Raw PAS data include: PM_1, $PM_{2.5}$, PM_{10} mass concentrations, temperature, humidity and particle counts (>0.3um, >0.5um >1.0um, 2.5um, >5.0um, >10.0um)
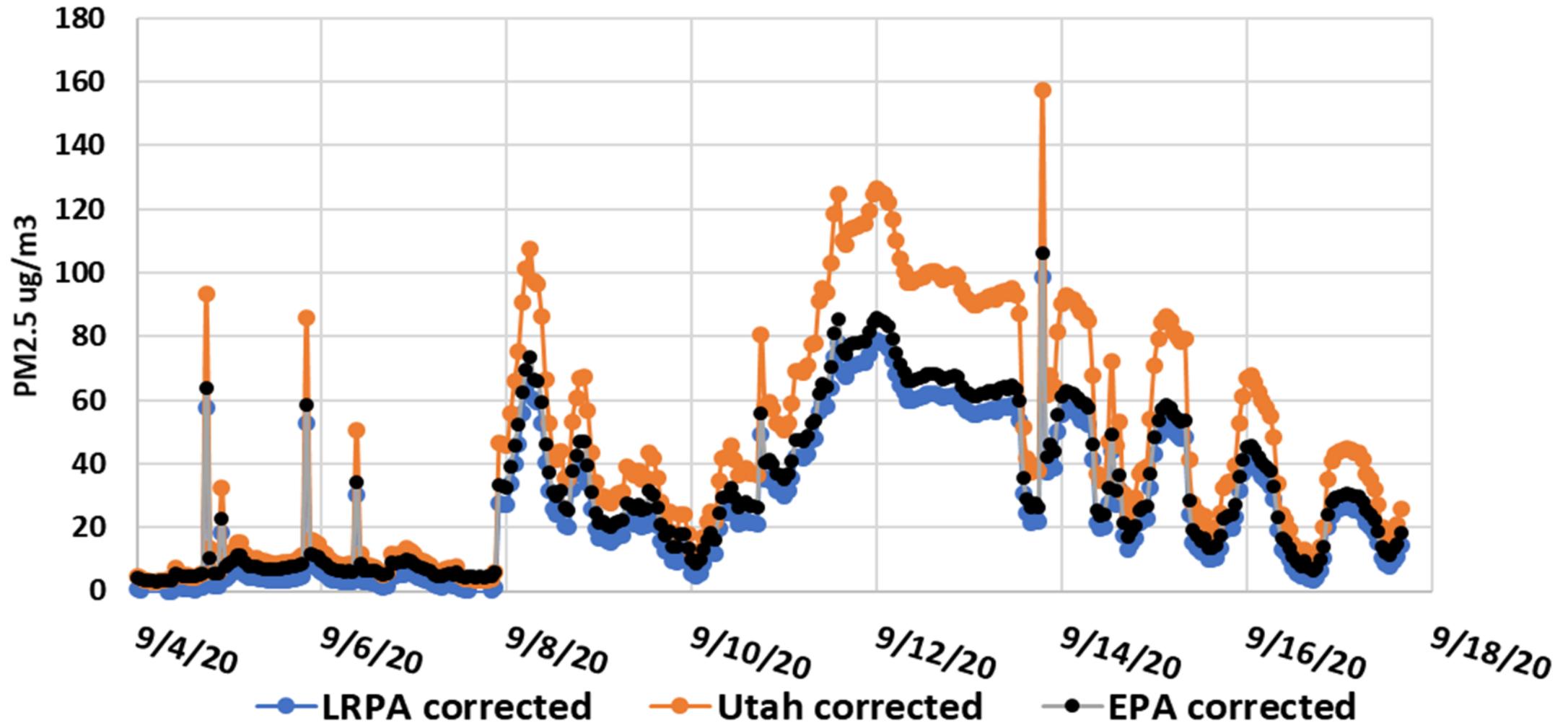
But a number of studies have pointed out that the PA data are not an accurate representation of the size distribution.

Kuula, J., Mäkelä, T., Aurela, M., Teinilä, K., Varjonen, S., González, Ó., and Timonen, H.: Laboratory evaluation of particle-size selectivity of optical low-cost particulate matter sensors, Atmos. Meas. Tech., 13, 2413–2423, https://doi.org/10.5194/amt-13-2413-2020, 2020.

Ouimette, J. R., Malm, W. C., Schichtel, B. A., Sheridan, P. J., Andrews, E., Ogren, J. A., and Arnott, W. P.: Evaluating the PurpleAir monitor as an aerosol light scattering instrument, Atmos. Meas. Tech., 15, 655–676, https://doi.org/10.5194/amt-15-655-2022, 2022.

Hagan, D. H. and Kroll, J. H.: Assessing the accuracy of low-cost optical particle sensors using a physics-based approach, Atmos. Meas. Tech., 13, 6343–6355, https://doi.org/10.5194/amt-13-6343-2020, 2020.

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PA data from Dan's home with 3 different corrections

Legend: LRPA corrected, Utah corrected, EPA corrected

EPA correction based on work by Barkjohn et al 2020.

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Goals of this analysis

1. Evaluate the accuracy of the standard (EPA) correction (Barkjohn et al 2020) equation for three different ambient aerosol types: "typical urban", smoke and dust.

2. Examine whether the correction changes at very high $PM_{2.5}$ levels (e.g. > 250 µg m^{-3});

3. If necessary, identify a new equation that improves accuracy for all aerosol types.

To do this, we examined the relationship between nearby PAS and regulatory $PM_{2.5}$ for 50 pollution events with a min hourly $PM_{2.5}$ of 47 ug m$^{-3.}$

➢Urban PM cases: Mostly winter stagnation events.

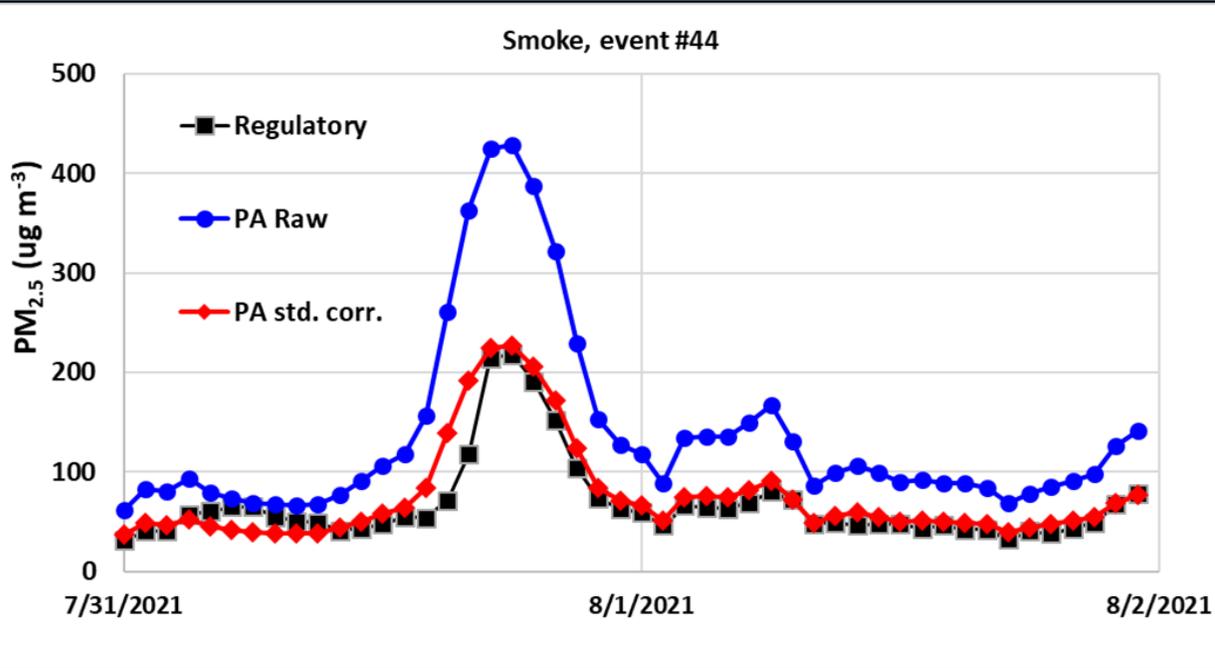➢Smoke events: too many to chose from!

➢Dust cases come from:

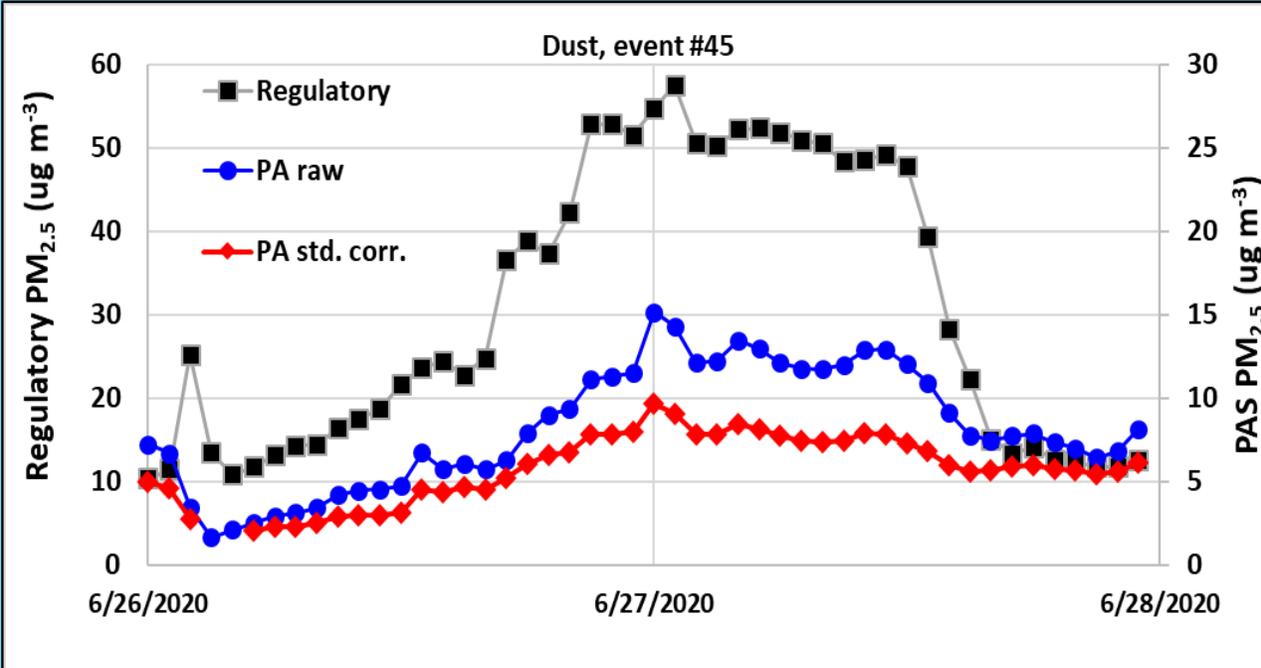- Large Saharan dust event that impacted SE U.S. in June 2020.

  Separately we analyzed three years of data from a site in Keeler CA (Owens Lake), which is probably the largest dust source in the U.S.

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Example for two events

Smoke event (Colville WA)
Slope (reg vs PAS corr) = 0.81

Dust event (Birmingham AL)
Slope (reg vs PAS corr) = 6.76

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Results for urban, smoke and dust (n=50 events)

|	Average Peak Reg $PM_{2.5}$ ($\mu g \, m^{-3}$)	Average Peak PAS $PM_{2.5}$ w/std corr ($\mu g \, m^{-3}$)	Average slope for Reg versus PAS w/std corr (R^2)
Urban poll (N=16)	75.6	59.2	1.00
Smoke (N=28)	280.3	217.8	0.99
Dust (N=6)	59.8	11.9	5.54

Slope (reg vs PAS corrected) vs Max 1 hour reg PM$_{2.5}$
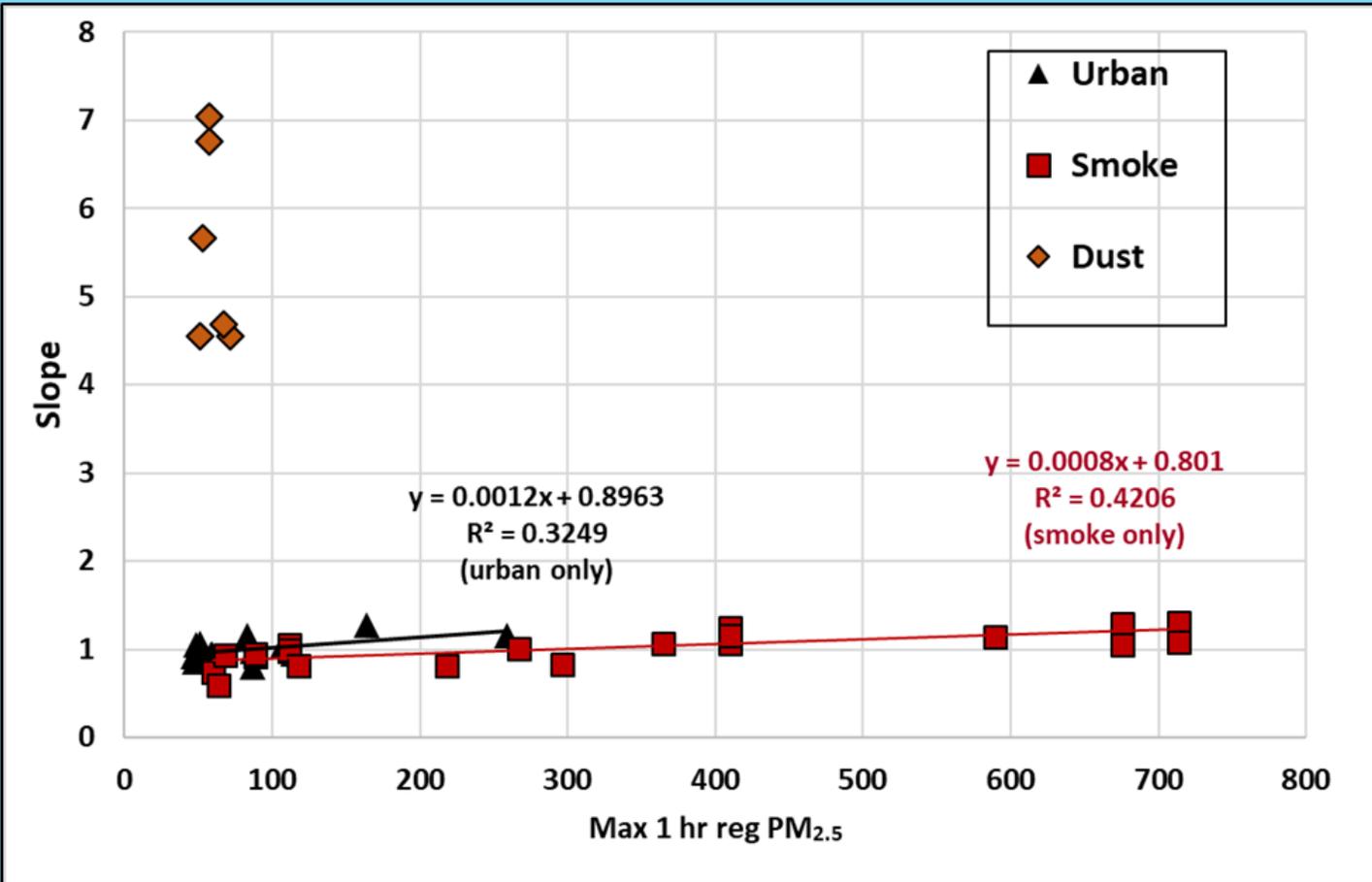
1. PAS corrected data give very good results for smoke and wintertime urban pollution events.

2. Dramatic underestimate in dust PM$_{2.5}$ reported by PAS.

3. Small shift in slope at very high PM$_{2.5}$. This suggests that PAS is under-reporting PM$_{2.5}$ by ~20% at concentrations above 500 ug m^{-3}.

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Coarse Aerosol Fraction from regulatory and PAS data
## $CAF = (PM_{10} - PM_{2.5}) / PM_{10}$
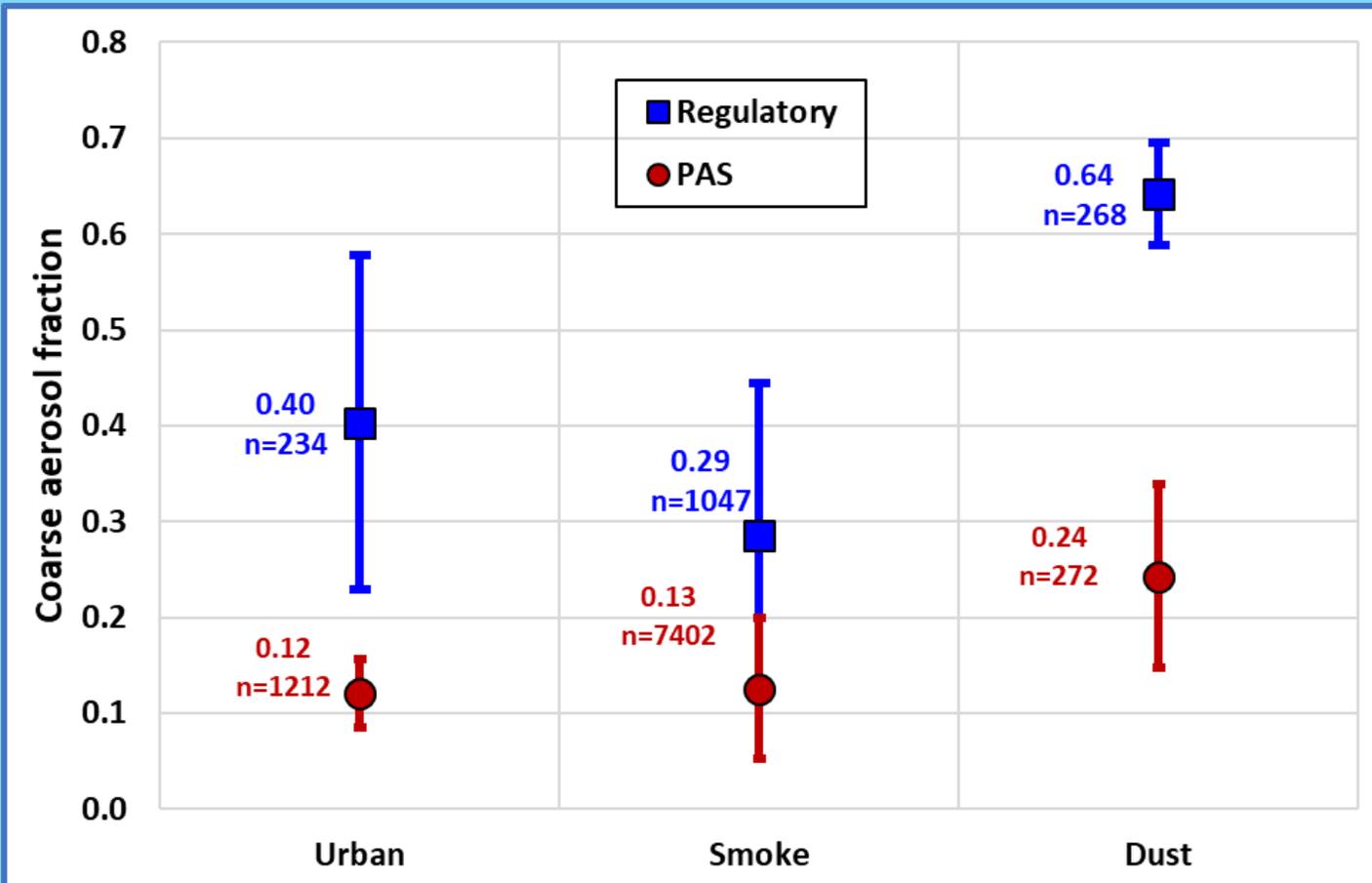
- From reg $PM_{2.5}$ and PM_{10}:
  - Urban and smoke events have CAF <0.5.
  - Dust events have CAF>0.5
- While PAS data does not match these values, it does show higher CAF for dust, indicating some information in the PAS size data.

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Keeler CA

- Adjacent to Owens Lake, which is now a dry lakebed due to water diversions. This is thought to be the largest dust source in the U.S.

- Reg monitors include $PM_{2.5}$ and PM_{10} and also a PAS.

- In addition to dust, frequent incursions of smoke.

- For this analysis we used 3 years of data from Keeler.

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Regulatory PM$_{2.5}$ vs PAS corrected PM$_{2.5}$ split by Coarse Aerosol Fraction from reg data
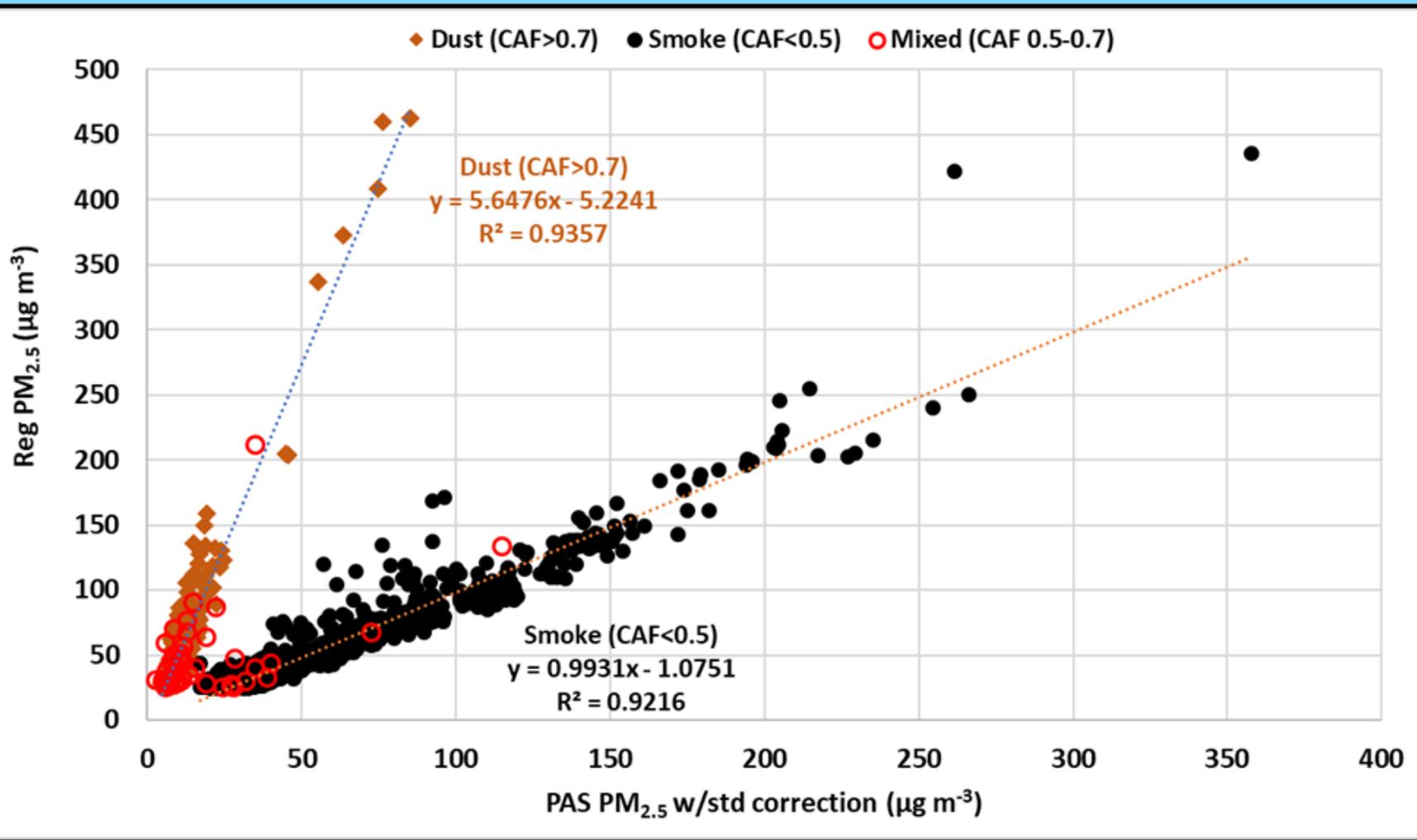

- At low CAF, smoke dominates. Std PAS correction if very effective.

- At high CAF, dust dominates. Std PAS correction is factor of 5-6 low. Consistent with event analysis presented earlier.
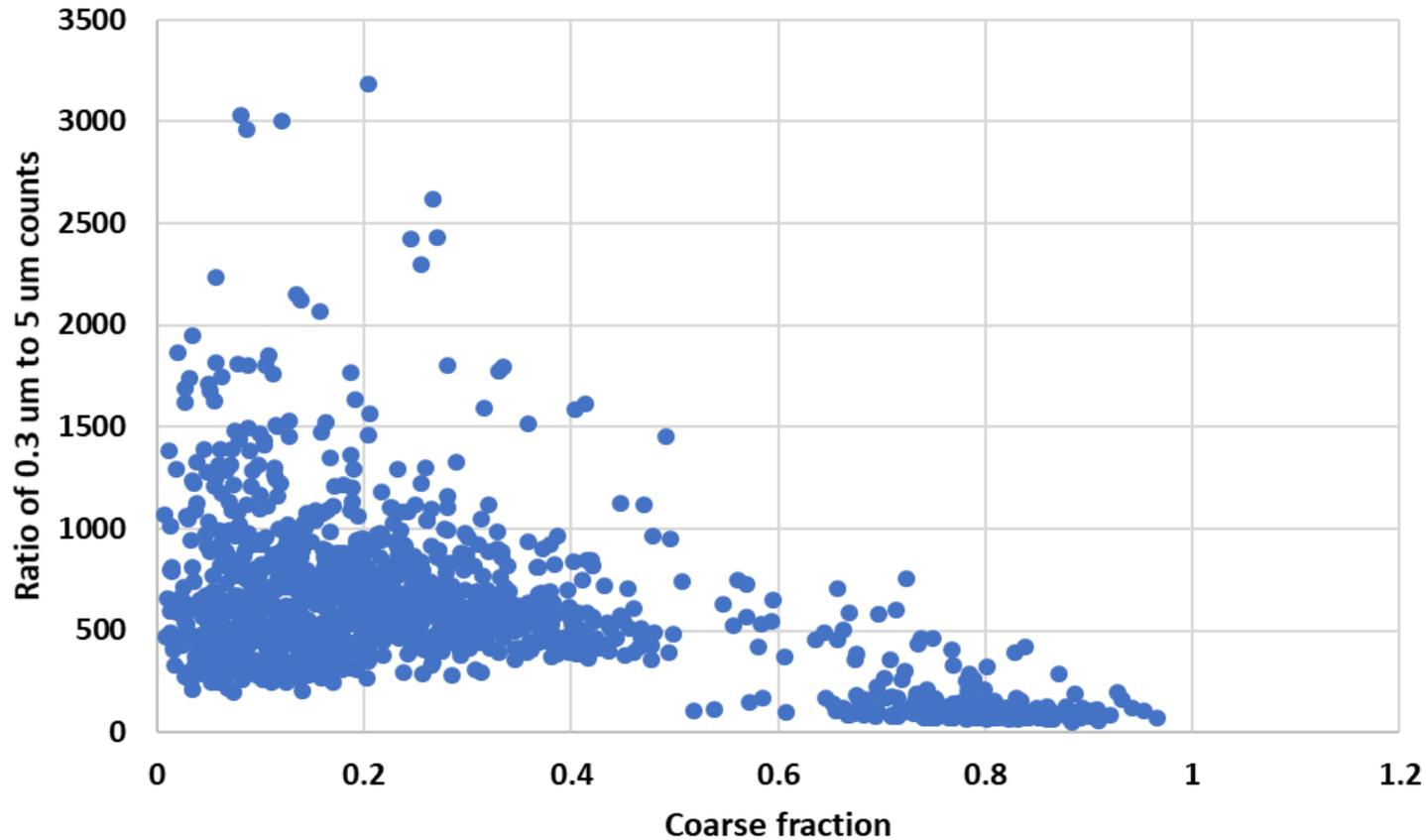
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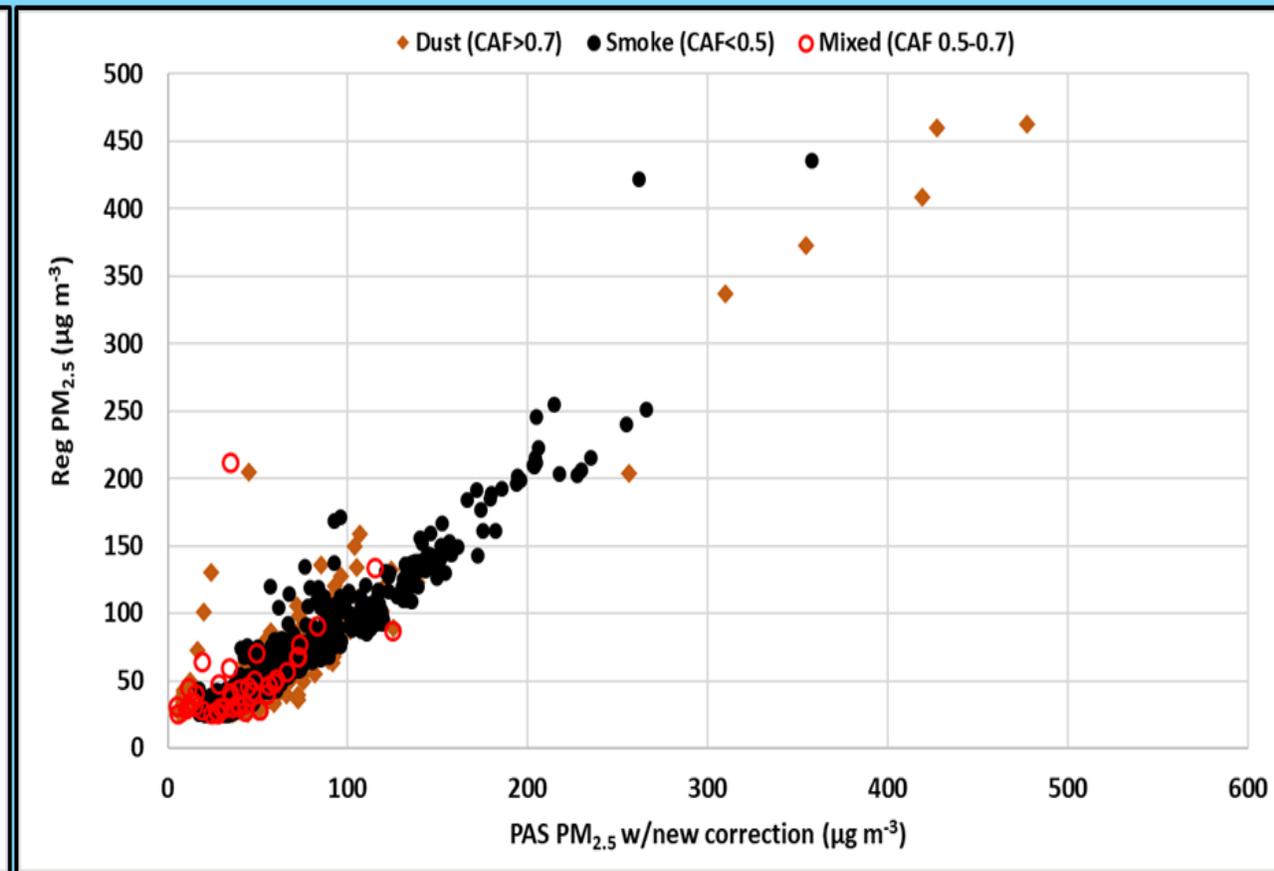# Ratio of 0.3 um counts to 5 um counts (PAS data) vs CAF (reg data)

- **Difference between low and high CAF data is statistically significant.**
- **This tells us that PAS does show a response to larger particles in dust events.**
- **Potentially could use this ratio to identify dust from PAS data and improve the PAS algorithm.**

Ratio of 0.3 um counts to 5 um counts (PAS data) vs CAF (reg data)
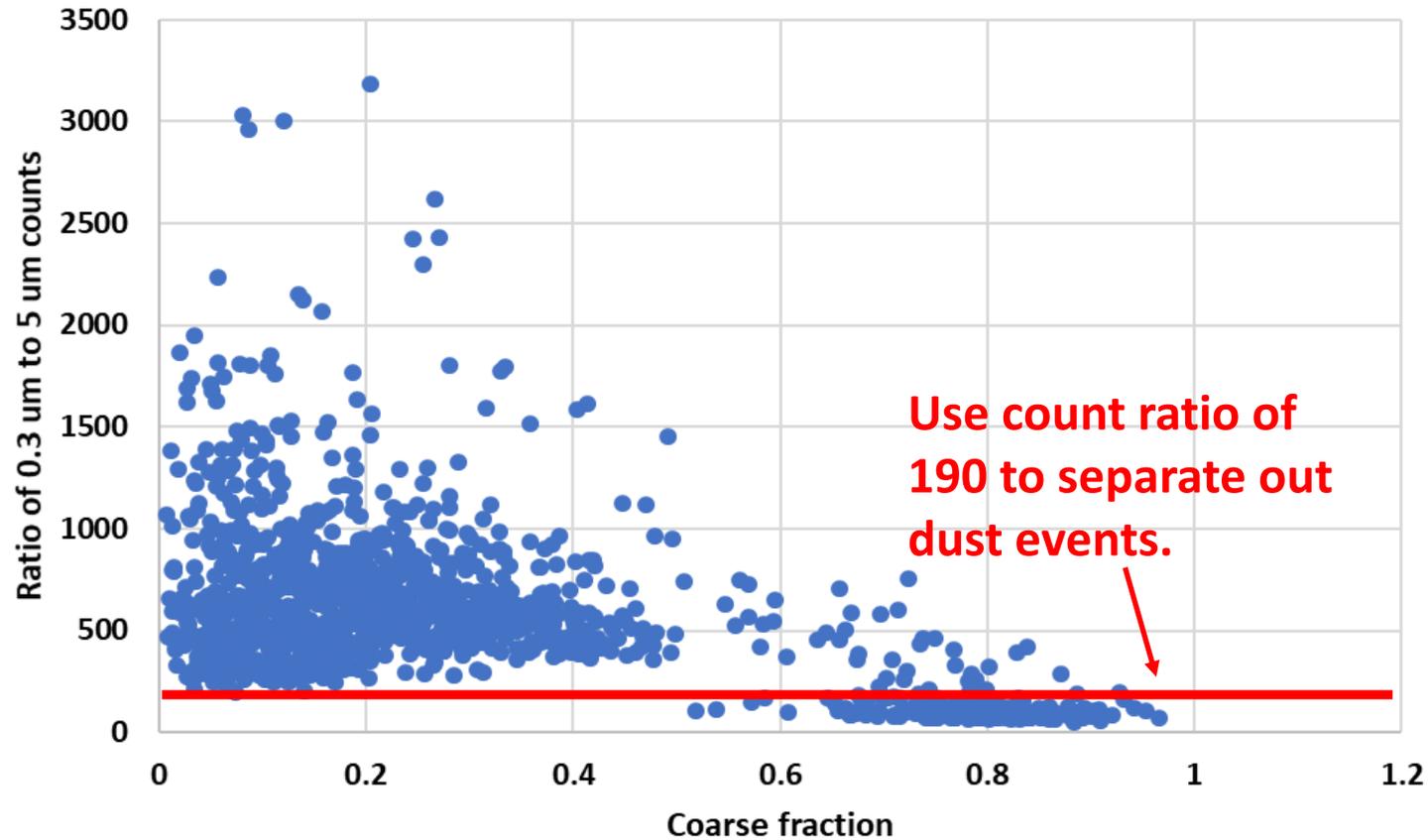
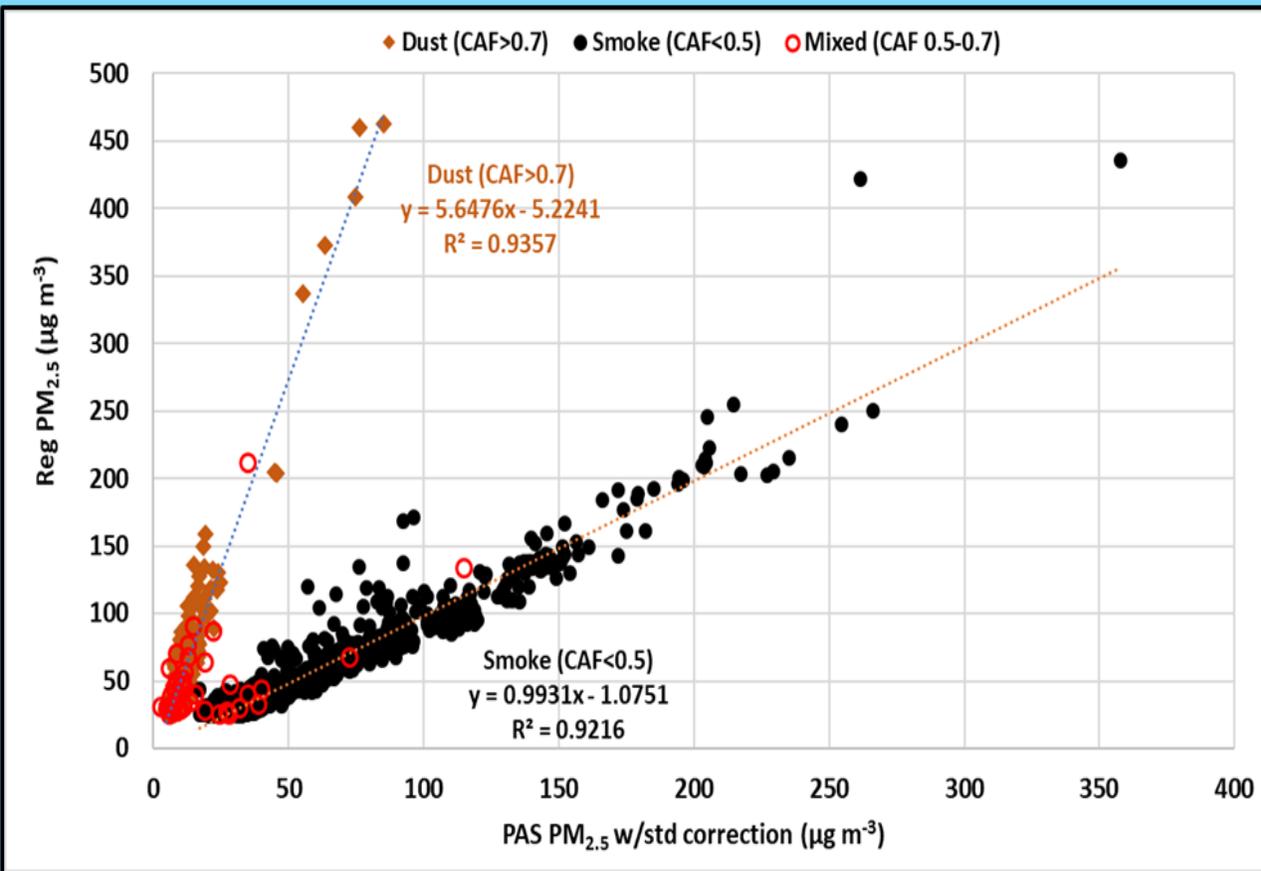Use count ratio of 190 to separate out dust events.

- **Difference between low and high CAF data is statistically significant.**
- **This tells us that PAS does show a response to larger particles in dust events.**
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Regulatory PM$_{2.5}$ vs PAS corrected PM$_{2.5}$ split by Coarse Aerosol Fraction

Standard correction

If PAS 0.3 μm/5μm>190, use standard correction;

If PAS 0.3 μm/5μm<190, use standard correction * 5.6

Atmospheric
Measurement
Techniques
Discussions

Open Access

EGU

An evaluation of the U.S. EPA's correction equation for Purple Air Sensor data in smoke, dust and wintertime urban pollution events

- In review: Atmospheric Measurement Techniques Discussions
- https://doi.org/10.5194/amt-13-2413-2020

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Distinguishing the Signatures of Aerosol Events in the Confederated Tribes of the Colville Reservation Using PurpleAir Data

Manna Nelson – Seattle University

Dr. Jaffe – University Washington Bothell
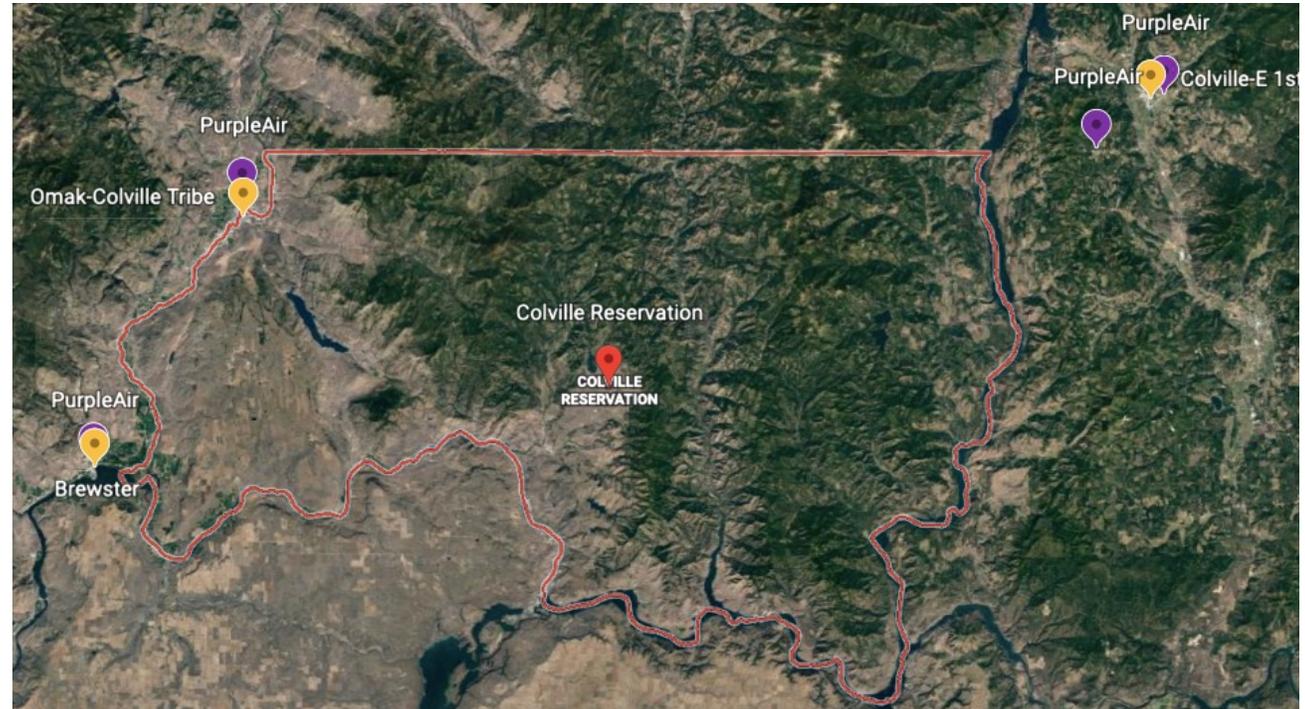
Coville Reservation

- **The Confederated Tribes of the Colville Reservation received an Environmental Justice Grant from the EPA to install and monitor aerosol events from PurpleAir Sensors**
  - **Worked alongside with Dr. Jaffe and Dr. Finley (UWB)**

- Goals:
  - **Use data from the PAS to characterize types of aerosol events within the past year**
  - **Compare the regulatory and PA monitors**
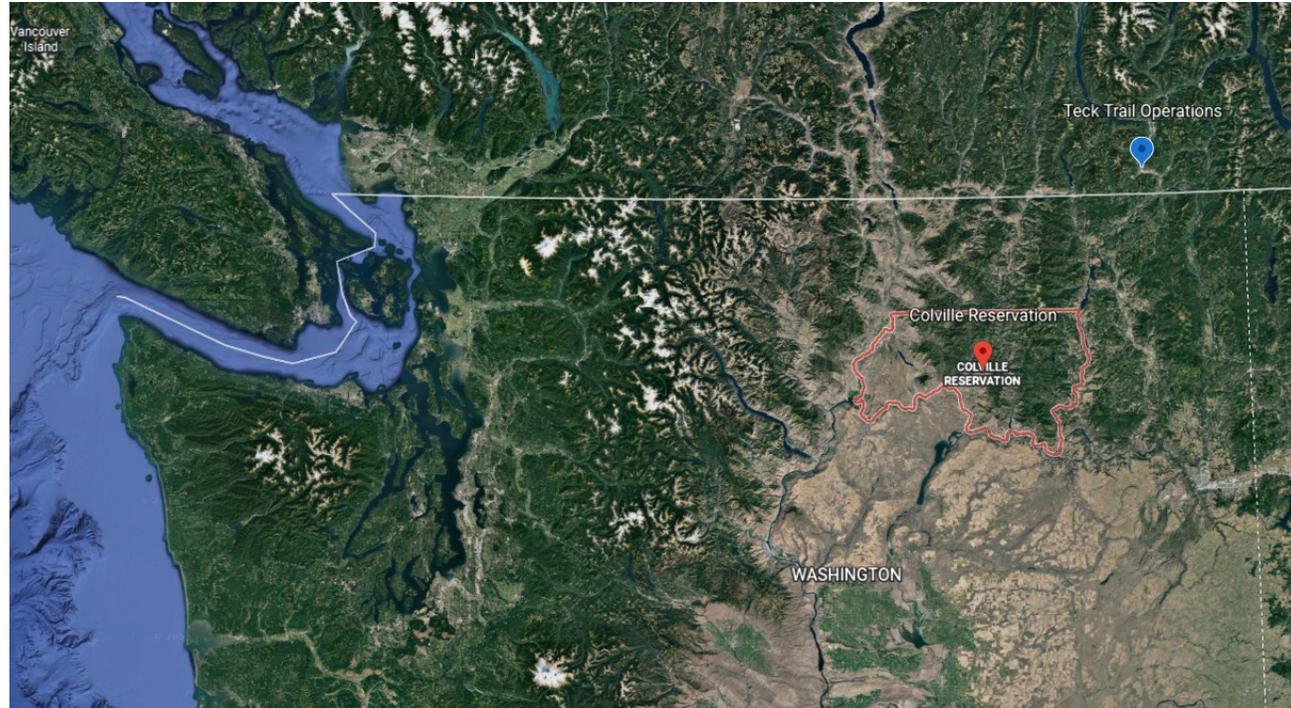
Satellite image of Teck Trails Operation (blue pin) and the outline of the Colville Reservation (red).

Background

- Several areas in the upper Columbia Plateau region are vulnerable to wind erosion
  - Dust storms

- Wildfires during the summer

- One of the concerns among the Colville community was toxins or emissions from the Teck's Trails smelter located in BC, Canada.

- "Teck's Trail Operations is one of the world's largest fully integrated zinc and lead smelting and refining complexes."
  - Zinc and Lead chemical isotopes 144km downwind of the smelter (Child et al. 2018).

- Limited number of PA and reg monitors

Satellite image of the Colville Reservation along with the selected regulatory (yellow pin) and PurpleAir sites (purple pin).

Dust

- **One concern is that dust from the Columbia river valley will hold past pollution from the Teck's Trails smelter (BC, Canada) and be hazardous during windblown dust events.**

- **"Teck's Trail Operations is one of the world's largest fully integrated zinc and lead smelting and refining complexes."**
 - **Zinc and Lead chemical isotopes 144km downwind of the smelter (Child et al. 2018).**

Dust event that occurred on May 18th (around 14:00-15:00). Taken from the French Rocks Boat Launch, facing south towards Barnaby Island.

Image credit: Whitney Fraser

Methods

- **Identified and paired PAS with a regulatory sensor (max distance between the paired sensors was 6.07 mi / 9.78 km)**

- **Using regulatory data from (Aug 2021 – Aug 2022) we identified events which reported high PM2.5 and PM10 concentrations.**
  - **Used AirNowTech's navigator (map) to identify the presence of fires/smoke**
    - **Smoke Cases – high PM2.5 concentrations with the presence of smoke**
      - **Average PM2.5 – 66.0 µm/m^3 (Average max PM2.5 - 147.4 µm/m^3)**
    - **Likely dust Cases –high PM2.5 concentrations**
      - **Average PM2.5 – 43.6 µm/m^3 (Average max PM2.5 – 67.0 µm/m^3)**
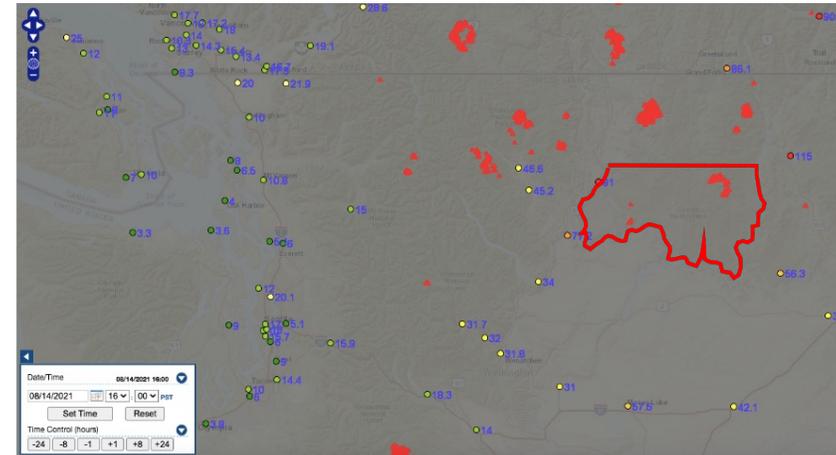

Screenshot of AirNowTech's website during a smoke event in Washington. The outline of the Colville Reservation is in red. This was from August 14, 2021. There are high PM concentrations in the areas near the fires.
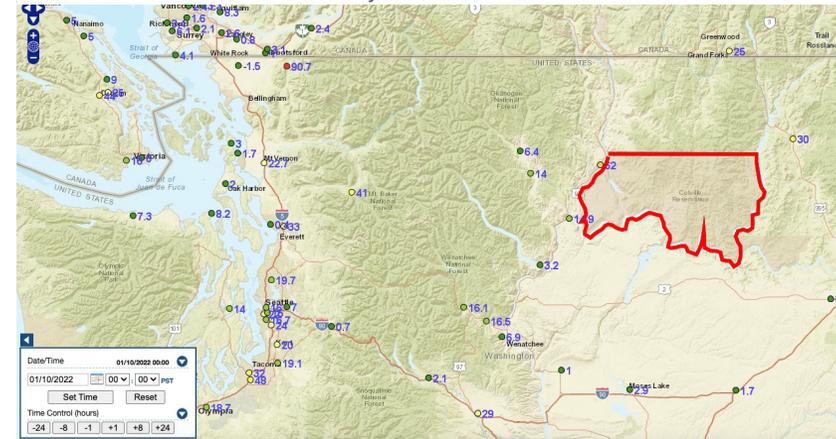

Screenshot from AirNowTech's website during a dust event that took place on January 10, 2022. There is no presence of smoke or any fires in the area, yet the PM2.5 concentrations were high on this specific date.

PA Raw PM2.5 overestimates Regulatory PM2.5 for smoke events

PA Raw PM2.5 underestimates Regulatory PM2.5 for dust events
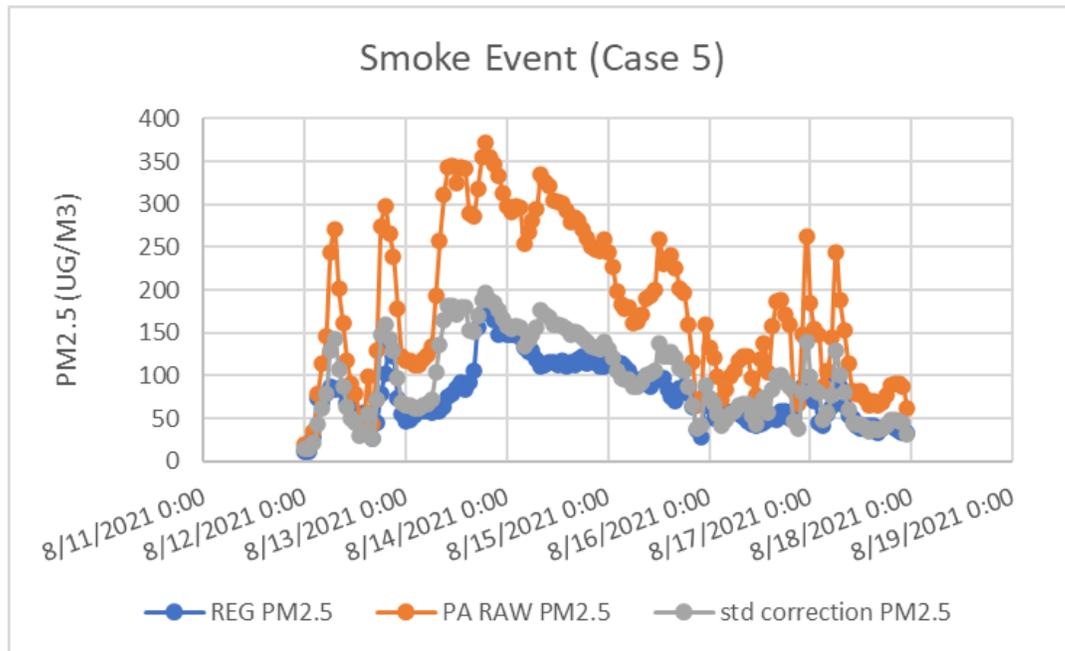
Graph of the PM2.5 concentrations measured from the regulatory site (blue) and the PA site (orange). The correction equation applied to the raw PA PM2.5 is labeled as std correction PM2.5 (grey). This was from a smoke event that took place from August 12, 2021 – August 17, 2021.
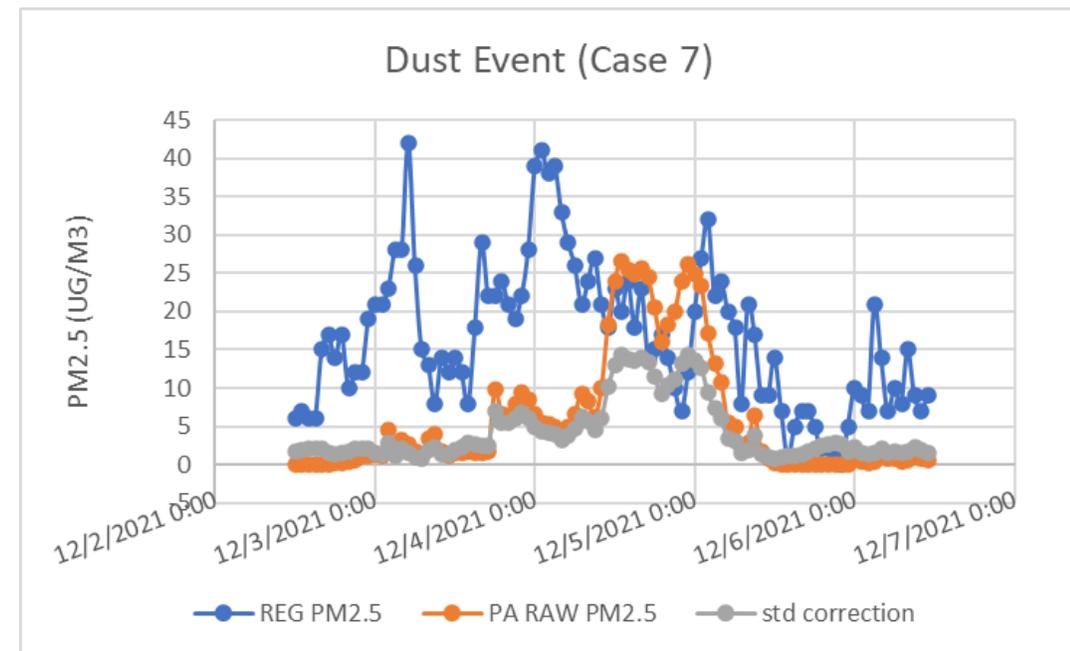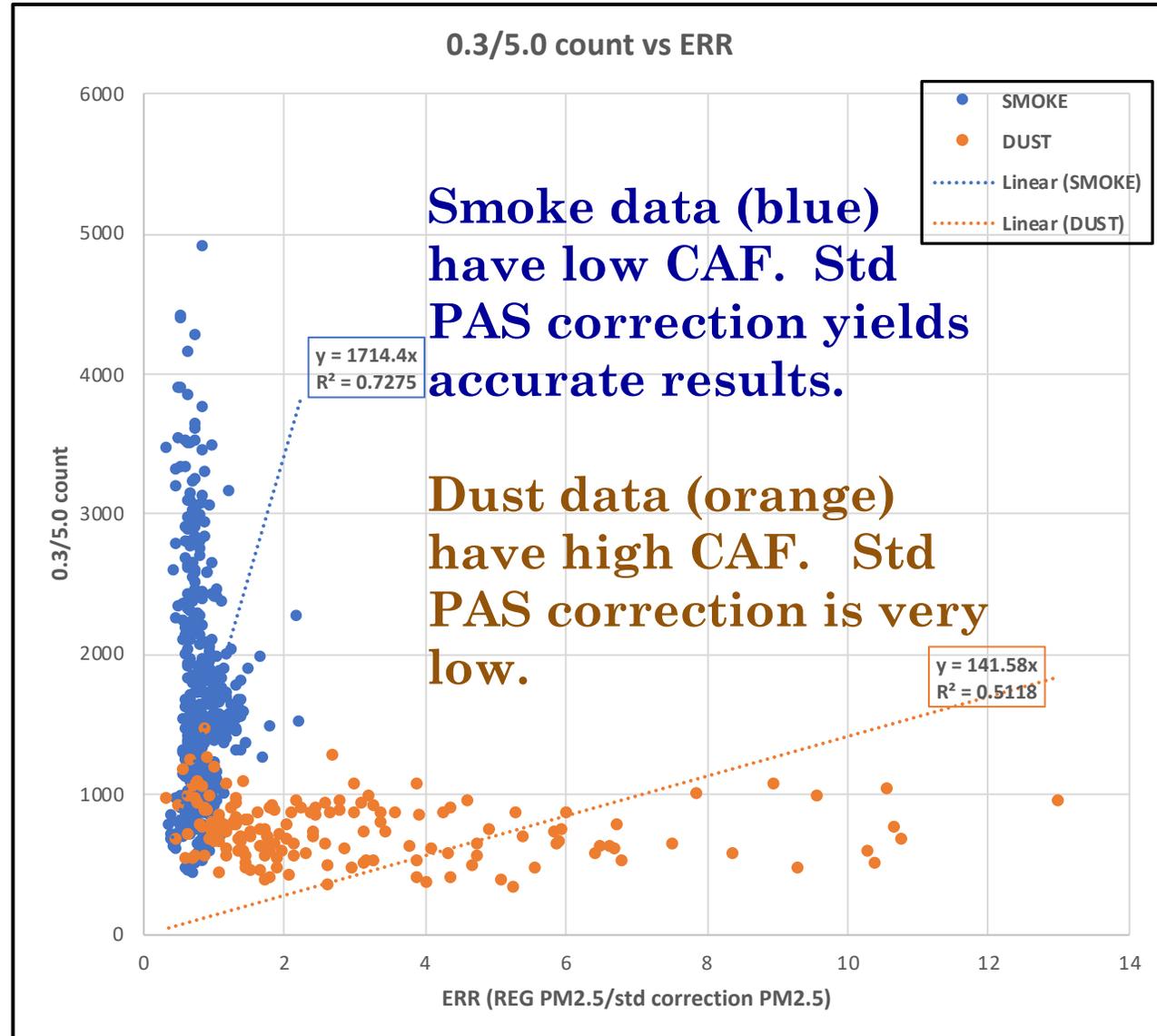
Similar to the graph shown on the left, this graph is from a dust event that took place from December 2, 2021- December 6, 2021.

0.3/5.0 count ratio vs ERR

ERR is defined as the regulatory PM2.5 to PAS PM2.5 ratio (correction equation has been applied to the PAS PM2.5)

This graph shows that the PAS is detecting the different chemical and physical composition of the smoke and dust cases

0.3/5.0 count vs ERR

Smoke data (blue) have low CAF. Std PAS correction yields accurate results.

Dust data (orange) have high CAF. Std PAS correction is very low.

y = 1714.4x
R² = 0.7275

y = 141.58x
R² = 0.5118

This graph shows the 0.3 to 5.0 count ratio vs the ERR, which is the regulatory PM2.5 / PA PM2.5 with the correction equation applied to it. This shows the 11 smoke cases and 5 dust cases that were identified. T-test for the average 0.3 to 0.5 count ratio for the smoke and dust is 2.90×10^{-4}. T-test for the regulatory to the std correction is 3.07×10^{-5}.

Summary

- Purple Air Sensors are now the largest network of PM observations in the world.

- Data are reasonably precise but need corrections to yield accurate data.

- Our analysis suggests that the standard (Barkjohn et al 2020) correction is very good in smoke and wintertime urban pollution events.

- At very high concentrations (>500 ug m^{-3}), corrected PAS data underestimate regulatory values by ~20%.

- For dust events, corrected PAS data underestimate regulatory concentrations by a factor of 5-6.

- While PAS size distributions are not accurate, they still give some information on the size distributions which can be used to improve the correction algorithm for dust events.

- **Additional PurpleAir Sensors on the Coville Reservation (soon) will improve our understanding of air quality in the region.**

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