U.S. EPA STAR Grant

Engage, Educate and Empower California Communities on the Use and Applications of Low-cost Air Monitoring Sensors

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University Village Apartments
February 7, 2019

South Coast AQMD

UCLA

STi Sonoma Technology

Main Objective

Provide communities across California with the knowledge necessary to appropriately select, use, and maintain “low-cost” sensors and to correctly interpret the collected data

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Specific Aim #1

Develop new methods to engage, educate, and empower local communities on the use and applications of “low-cost” sensors

Best practices for…
- Sensor deployments
- Data collection
- Data analysis and interpretation
- Next steps: communicating results, planning outreach, developing mitigation strategies

Recruit local communities to help inform toolkit materials through in-person meetings as well as survey on their knowledge and perception of sensors

↓

Draft guidebook, training videos, and data collection checklist

↓

Share draft toolkit with community members and survey them regarding sensor use to assess if their interaction and perception of sensors has changed

↓

Revise toolkit materials based on community feedback

South Coast AQMD

Specific Aim #2

<u>Conduct field and laboratory testing to characterize the performance of commercially-available "low-cost" sensors and to identify candidates for field deployment</u>

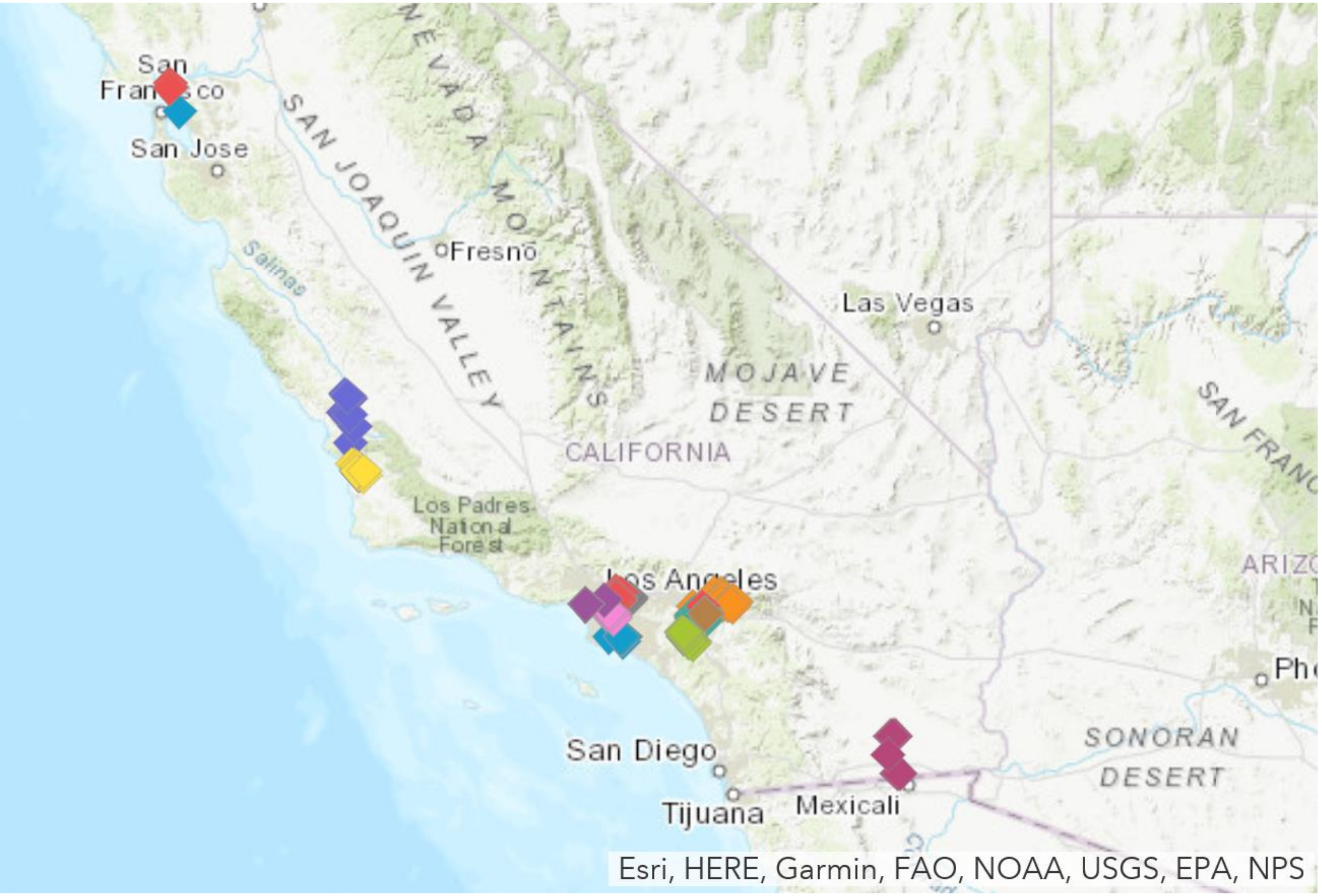
- Field Testing:
  - Sensor tested in triplicates
  - Two months deployment
  - Comparison with FRM/FEM instruments
  - Testing performed at a fixed monitoring station

- Laboratory Testing:
  - State-of-the-art characterization chamber
  - Particle and gas testing
  - T and RH controlled conditions

South Coast AQMD
AQ-SPEC
Air Quality Sensor Performance Evaluation Center

Specific Aim #3

Deploy the selected sensors in multiple California communities and perform a thorough validation and interpretation of the collected data



- San Gabrial Valley
- Seal Beach
- Temescal Valley
- West Los Angeles
- Redlands
- San Luis Obispo - South
- South Gate
- Sycamore Canyon
- Riverside USD
- San Luis Obispo - North
- Imperial Valley
- El Monte USD
- SF Bay Area - Richmond
- SF Bay Area - Oakland

Specific Aim #4

Communicate the lessons learned to the public and organize outreach activities

Disseminate study results and help answer these key questions:

- ✓ Which tools will be most successful in educating communities to effectively use air monitoring sensors and to engage them in using sensor data?
- ✓ Will a community more likely take action to reduce air pollution exposure when sensors and sensor data are made readily available?
- ✓ Which sensors are the most suitable for community use?
- ✓ How does sensor data quality change with time after sustained use by communities under “real-world” conditions?
- ✓ How do sensor data compare (spatially and temporally) to that of existing monitoring networks?
- ✓ What value is added by these sensors that we are not getting with current network data?

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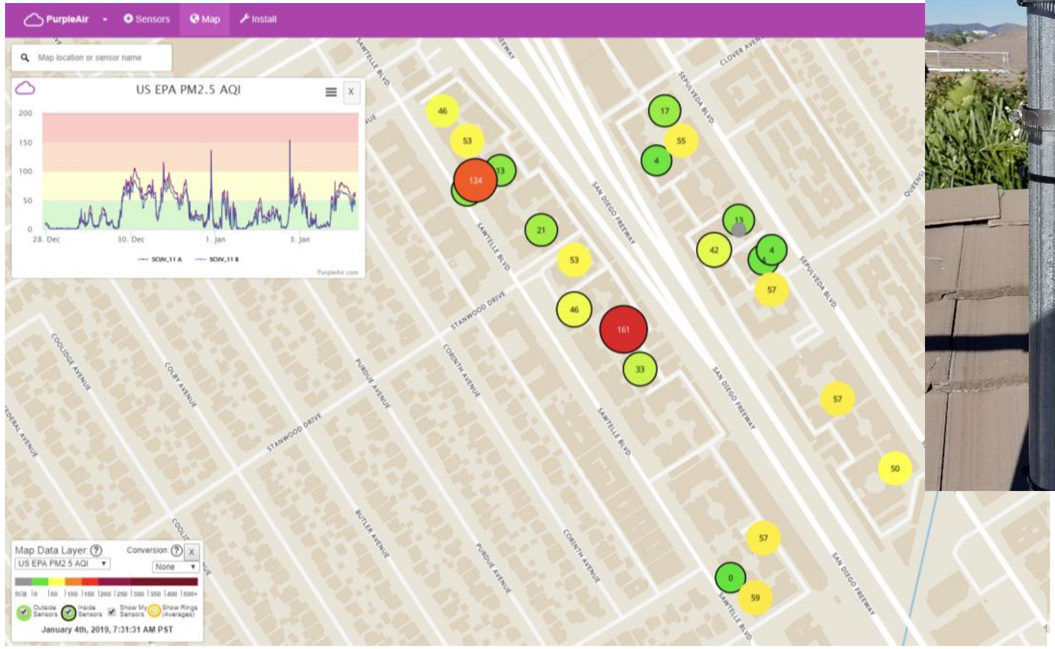
PurpleAir Sensors & Feedback

PM Sensor Network
- 12 outdoor sensors
- 18 indoor sensors



Feedback

- Issues installing or running the sensors?
- Issues accessing or understanding the data?
- Is there any information or training that you feel would help you to make better use of the sensors?
- Are there any questions they would like to know how to answer using the sensors? Or would like to try to answer using sensor data?
- Any ideas about how the sensor info can be helpful for the community?

Sensor Installation/Non-Installation e-Survey

Available at: www.arcg.is/1jeSKz (installation)
https://arcg.is/1WqD9e (non-installation)

9 installation surveys submitted for the indoor set *(9 remaining)

The Science To Achieve Results (STAR) Grant team at the South Coast AQMD would like to thank you for your participation in the project entitled, " Engage, Educate and Empower California Communities on the Use and Applications of "Low-cost" Air Monitoring Sensors" and to invite you to participate in this very brief online survey about your sensor installation location. Completing this survey with a smart device with a camera will allow you to easily submit a picture.

Installation Survey

Moving forward, please keep an eye out for upcoming community group meetings, an email containing the electronic log note entry form, and changes for end user data visualization and accessibility!

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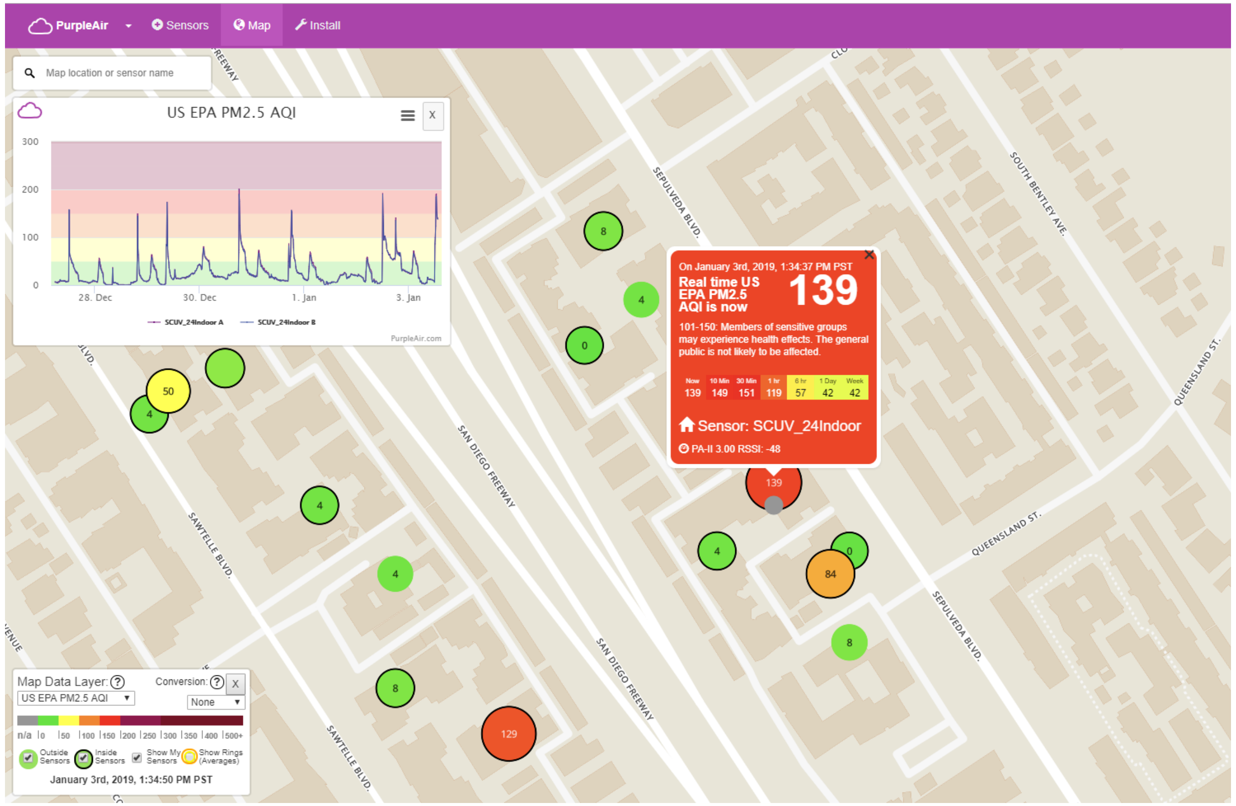
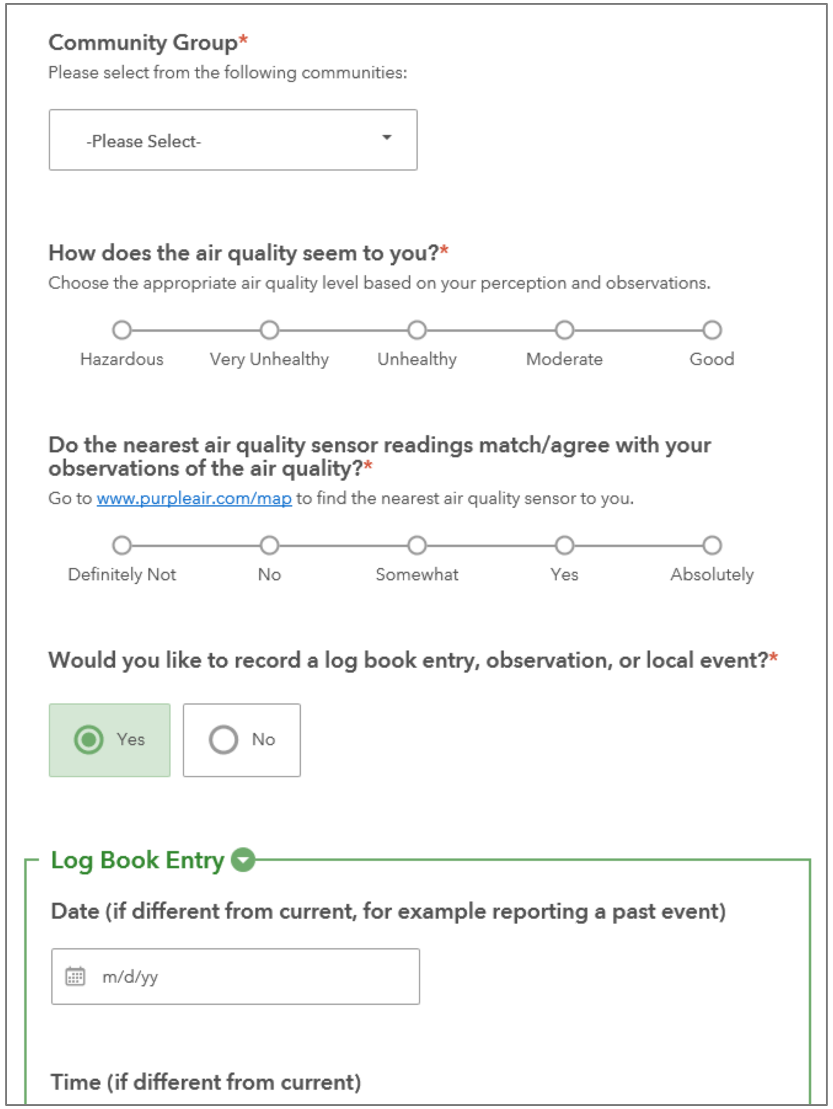
Unsubscribe Forward to a friend
South Coast Air Quality Management District • 21865 Copley Drive, Diamond Bar, CA 91765
909-396-2000 • www.aqmd.gov

Log-book e-Survey – Adding Context to the Data

Available at: www.arcg.is/1jGKHC



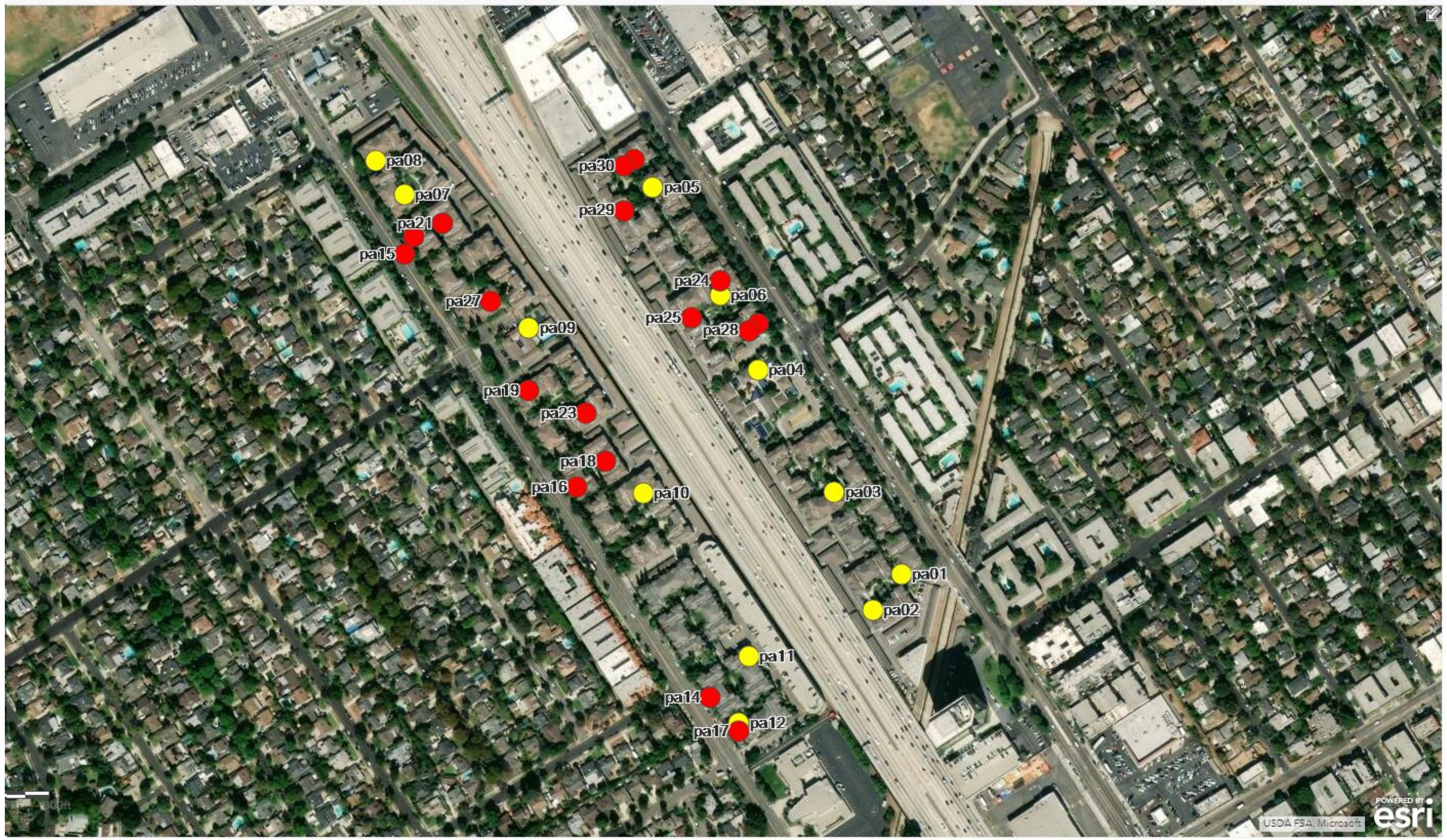
Purple Air Map Link



10-Minute Break

Please Fill in the Questionnaire

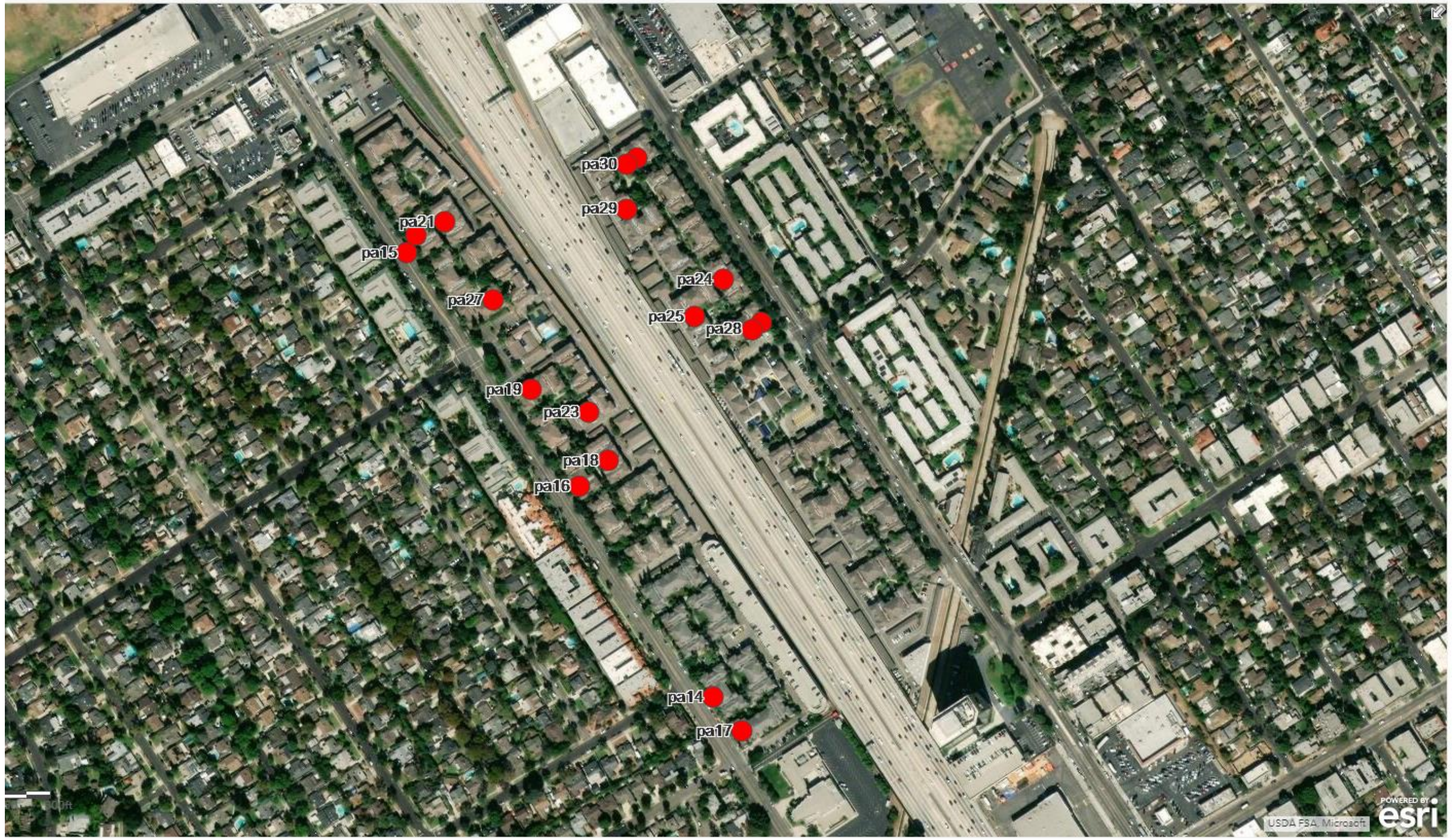
Sensor Locations



Indoor Sensors

Outdoor Sensors

Sensor Locations



Indoor Sensors
Outdoor Sensors

Monitoring Indoor Air Quality Using Low Cost Sensors at a Community Scale

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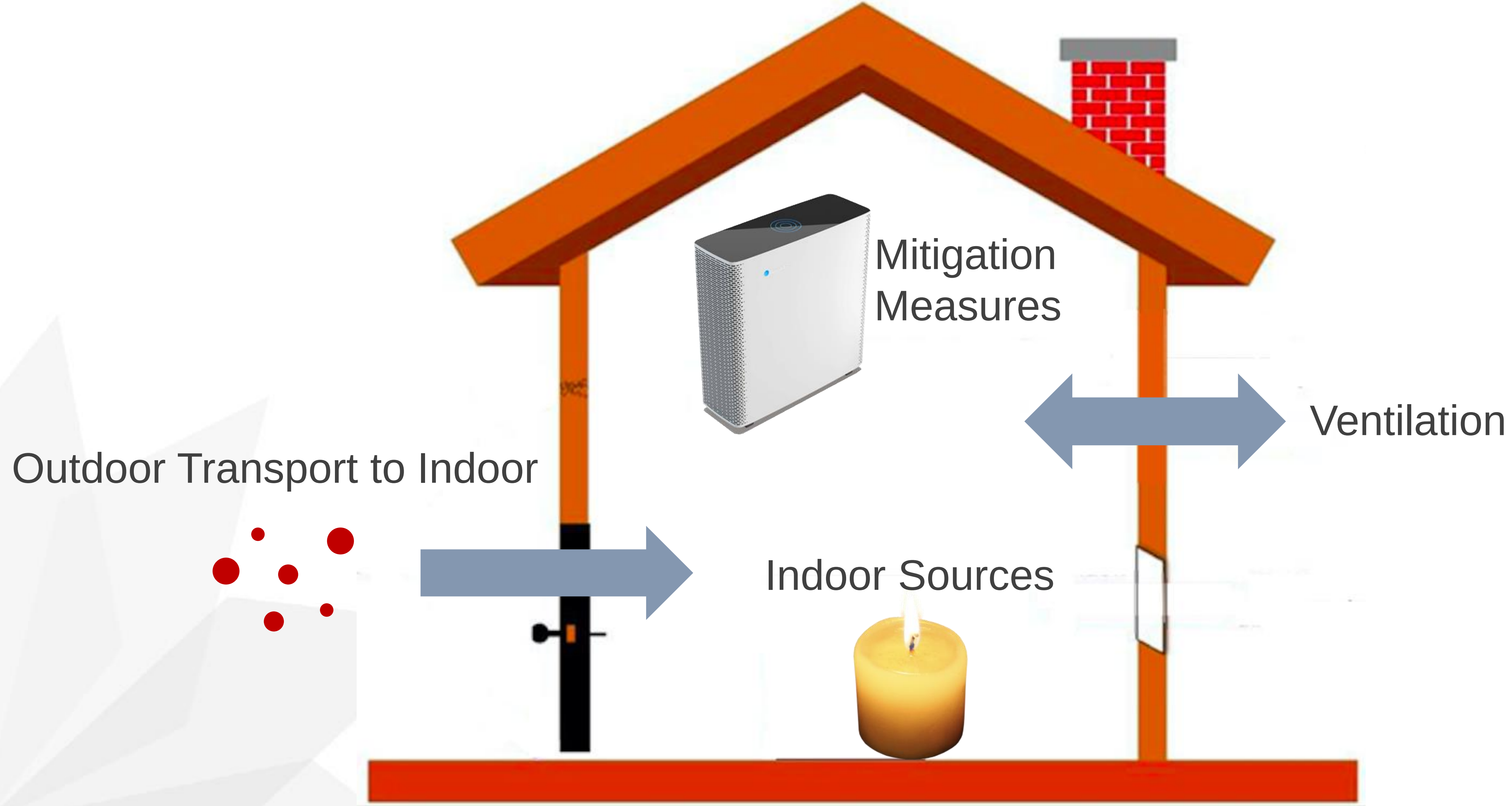
Department of Environmental Health Sciences
University of California, Los Angeles (UCLA)

Vasileios Papapostolou, Brandon Feenstra,
Berj Der Boghossian, Hang Zhang
South Coast Air Quality Management District (AQMD)

Background


Mitigation Measures
Ventilation
Outdoor Transport to Indoor
Indoor Sources

Background

Indoor Sources

- Cooking is a major indoor emission source for PM (Wallace, 2004).
- Burning candles can increase PM levels by multiple times (He et al., 2004).
- Vacuuming was found to increase $PM_{2.5}$ level (He et al., 2004).

Outdoor to Indoor Transport

Significant fraction of outdoor PM can penetrate into indoor environments (Jones et al., 2000).

Ventilation

Ventilated indoor environments have higher I/O ratios for PM (Cyrys et al., 2004).

Mitigation

Air purification could result in more than 50% reduction of $PM_{2.5}$ within hours of operation (Chen et al., 2015).

Objective

To determine to what extent low-cost air sensors can be used to detect and evaluate the impacts of the following on indoor air quality.

- Indoor Sources
- Outdoor to Indoor Transport
- Ventilation
- Mitigation

Study Design

30 Sensors

12 Outdoor Sensors

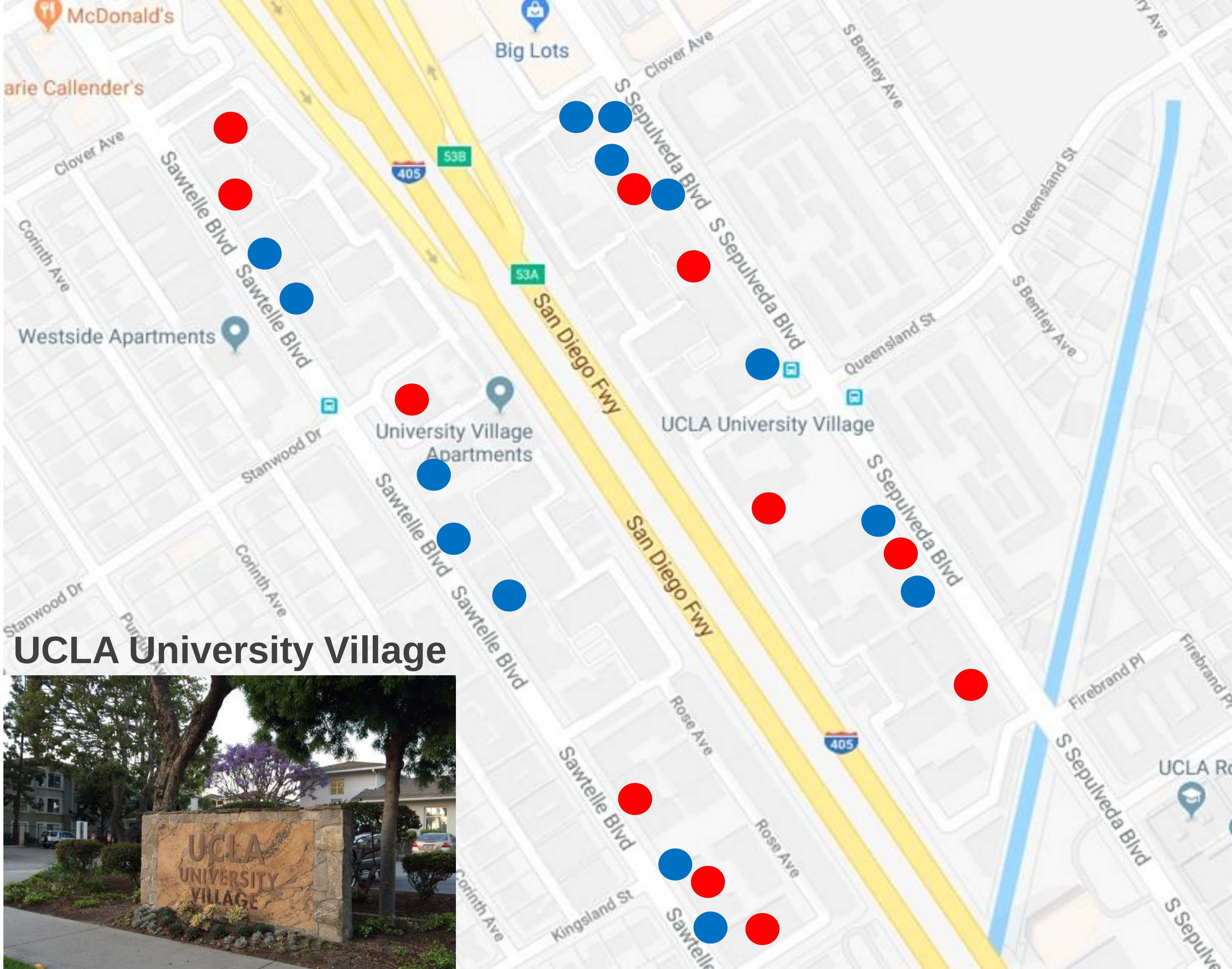
6 in Sawtelle

6 in Sepulveda

18 Indoor Sensors

8 in Sawtelle

10 in Sepulveda



Sensor Selection

TSI (AirAssure)

Air Quality Egg
(Version ||)

Dylos (DC1100)

Foobot

Hanvon (Hanvon N1)

Origins (Laser Egg)

PurpleAir (PA ||)

Shinyei
(PM Evaluation Kit)

Sensor Selection

Manufacturer (Model)	**Pollutant(s)**	**Approx. Cost (USD)**	***Field R^2**	**Lab R^2**
TSI (AirAssure)	$PM_{2.5}$	~$1,500	R^2 ~ 0.82	R^2 ~ 0.99
Air Quality Egg (Version ǁ)	PM	~$240	$PM_{2.5}$: R^2 ~ 0.79 to 0.85 PM_{10}: R^2 ~ 0.31 to 0.40	
DC1100 PRO	$PM_{(0.5-2.5)}$	~$300	R^2 ~ 0.65 to 0.85	R^2 ~ 0.89
Foobot	$PM_{2.5}$	~$200	R^2 ~ 0.55	
Hanvon N1	$PM_{2.5}$	~$200	R^2 ~ 0.52 to 0.79	
Laser Egg	$PM_{2.5}$ & PM_{10}	~$200	$PM_{2.5}$: R^2 ~ 0.58 PM_{10}: R^2 ~ 0.0	
PurpleAir (PA ǁ)	$PM_{1.0}$, $PM_{2.5}$ & PM_{10}	~$200	$PM_{1.0}$: R^2 ~ 0.96 to 0.98 $PM_{2.5}$: R^2 ~ 0.93 to 0.97 PM_{10}: R^2 ~ 0.66 to 0.70	$PM_{1.0}$: R^2 ~ 0.99 $PM_{2.5}$: R^2 ~ 0.99 PM_{10}: R^2 ~ 0.95
Shinyei (PM Evaluation Kit)	$PM_{2.5}$	~$1,000	R^2 ~ 0.80 to 0.90	R^2 ~ 0.93

*The correlation coefficient (R^2) is a statistical parameter indicating how well the performance of each sensor compares to that of a Federal Reference Method (FRM), Federal Equivalent Method (FEM), or Best Available Technology (BAT) instrument.

http://www.aqmd.gov/aq-spec/evaluations/summary

Sensor Selection

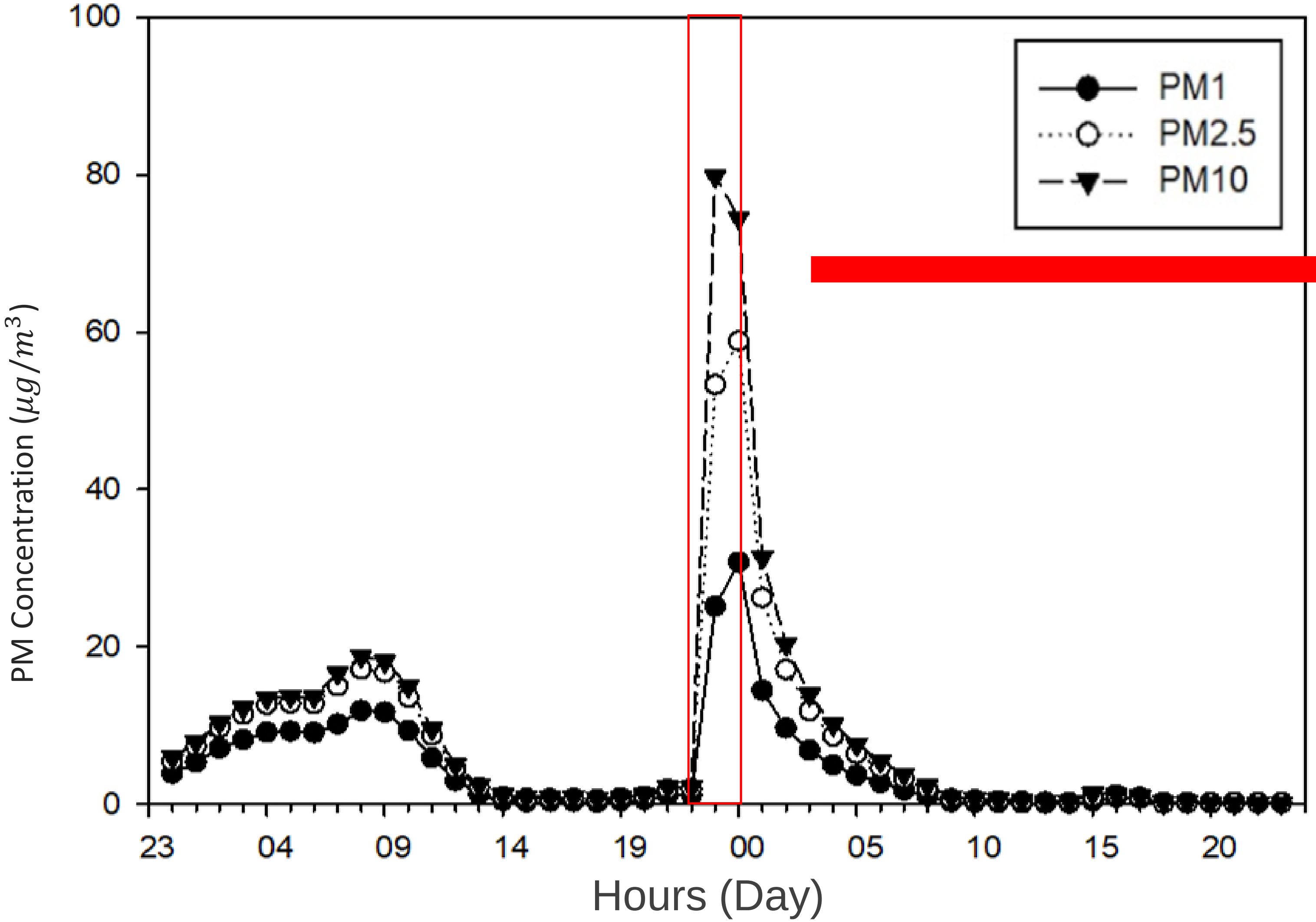
Manufacturer (Model)	**Lab R^2**
TSI (AirAssure)	R^2 ~ 0.99
Air Quality Egg (Version ||)	
DC1100 PRO	R^2 ~ 0.89
Foobot	
Hanvon N1	
Laser Egg	
PurpleAir (PA ||)	$PM_{1.0}$: R^2 ~ 0.99 $PM_{2.5}$: R^2 ~ 0.99 PM_{10}: R^2 ~ 0.95
Shinyei (PM Evalu	R^2 ~ 0.93

*The correlation co ... ormance of each sensor compares to that of a Federal Reference Method (FRM), Federal Equivalent Method (FEM), or Best Available Technology (BAT) instrument.

http://www.aqmd.gov/aq-spec/evaluations/summary

Indoor Sources: Candles

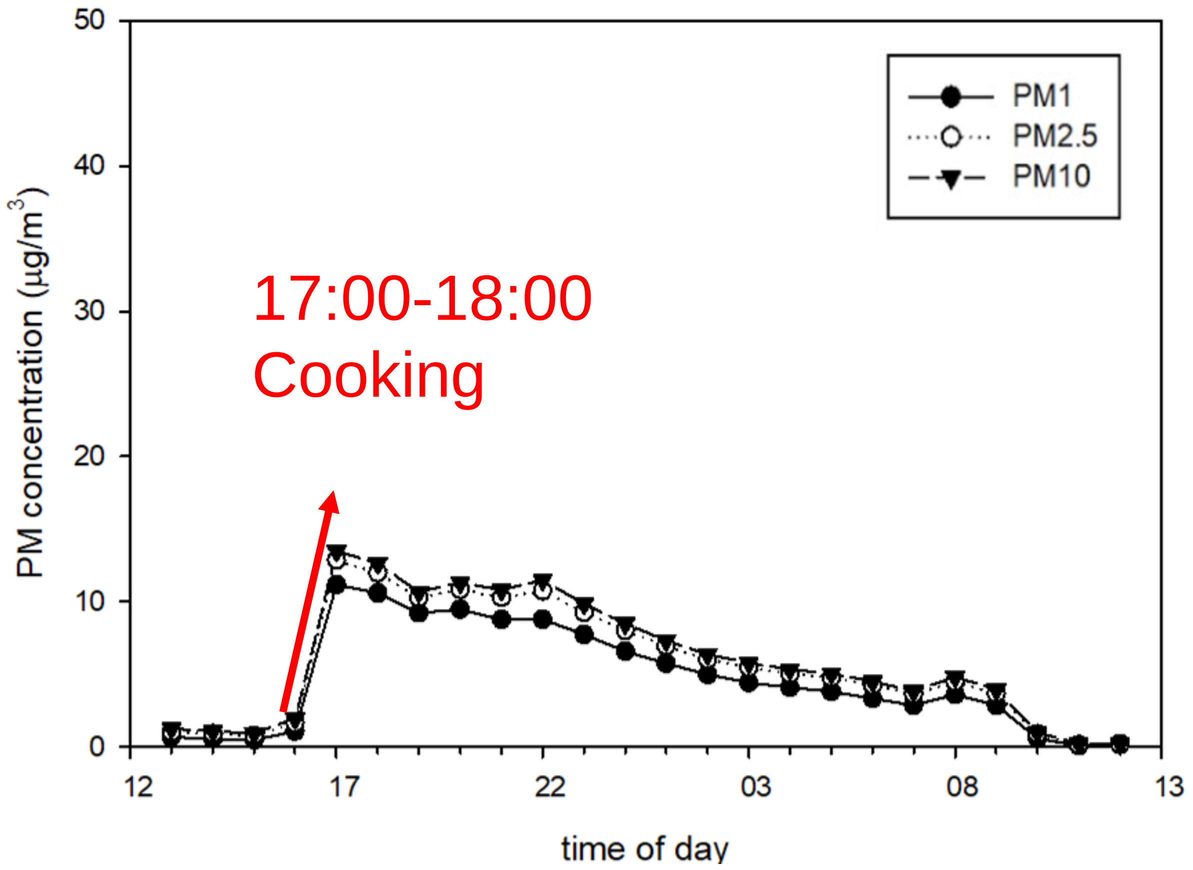
Hourly PM Concentration of an Apartment over 48 Hours

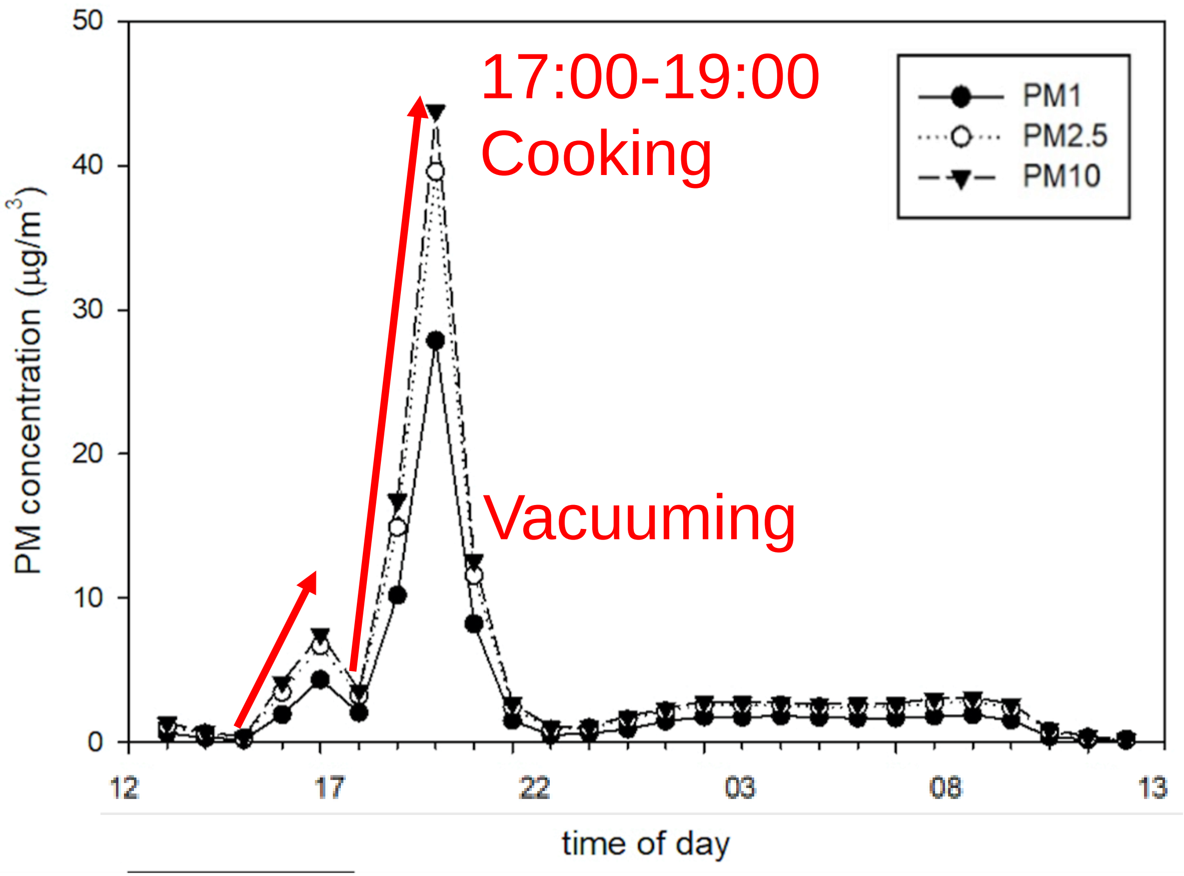


23:00 – 24:00
Candle Burning

Indoor Sources: Vacuuming and Cooking

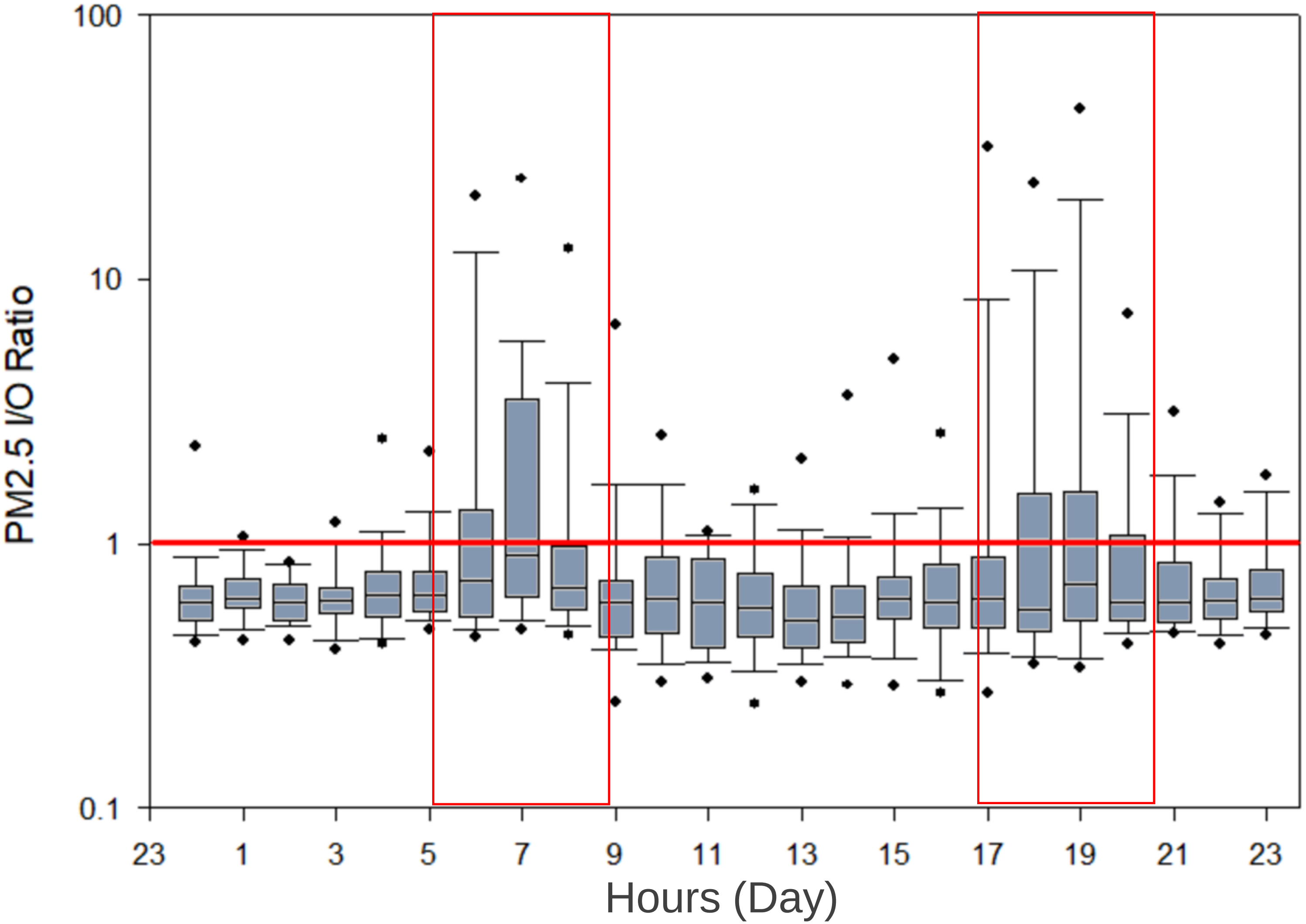
Hourly PM Concentration of one apartment in two separate days



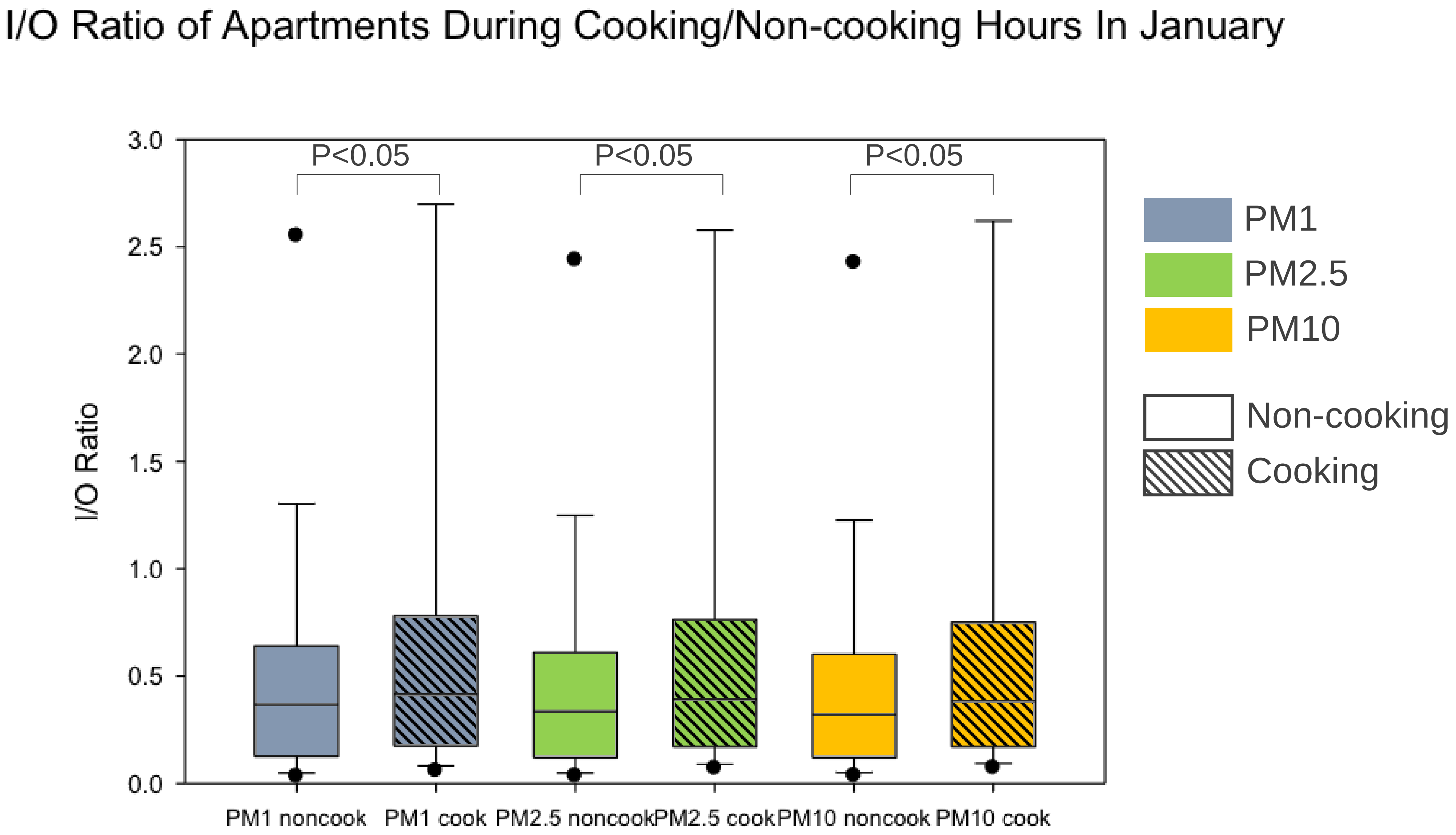


Indoor Sources: Cooking

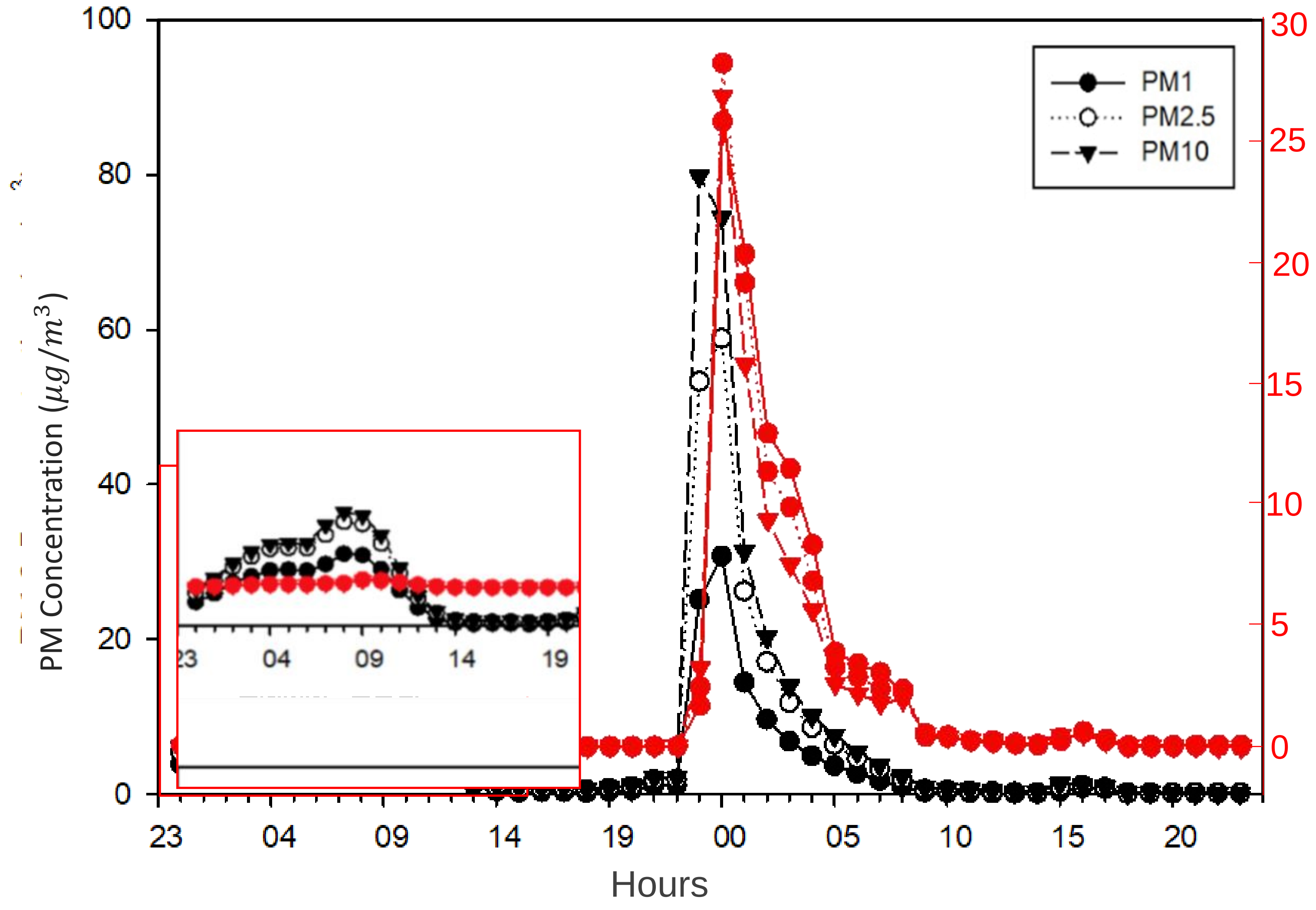
PM 2.5 Hourly Data of one Apartment over January

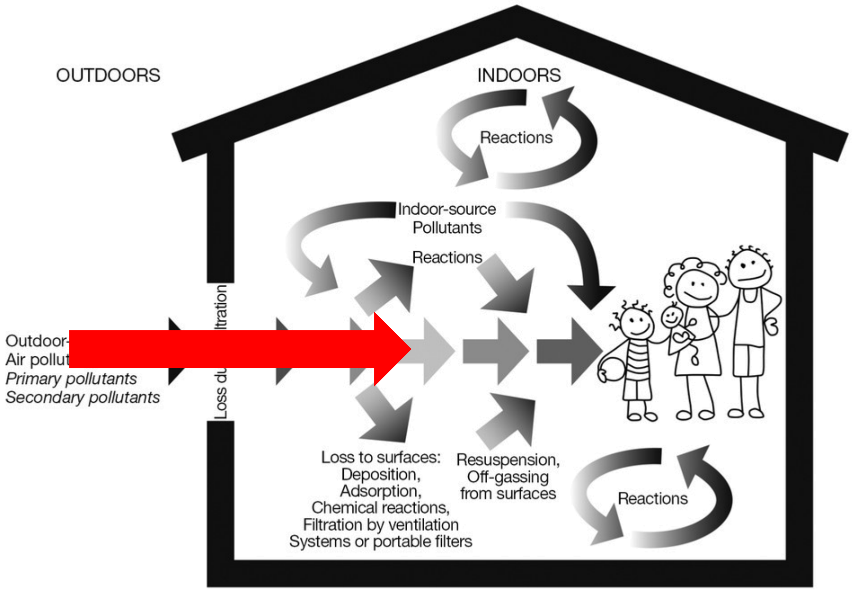


Indoor Sources: Cooking

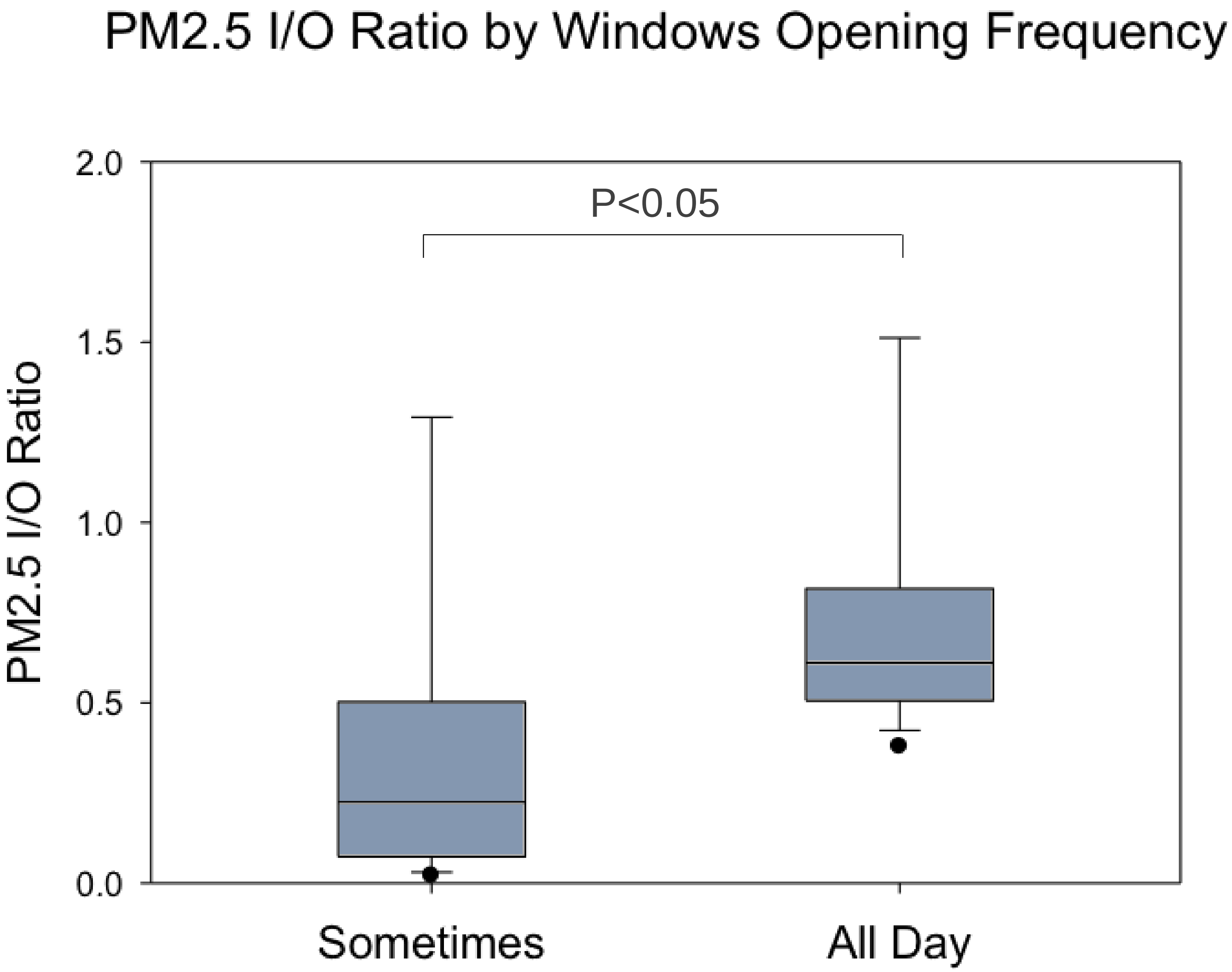


Outdoor to Indoor Transport

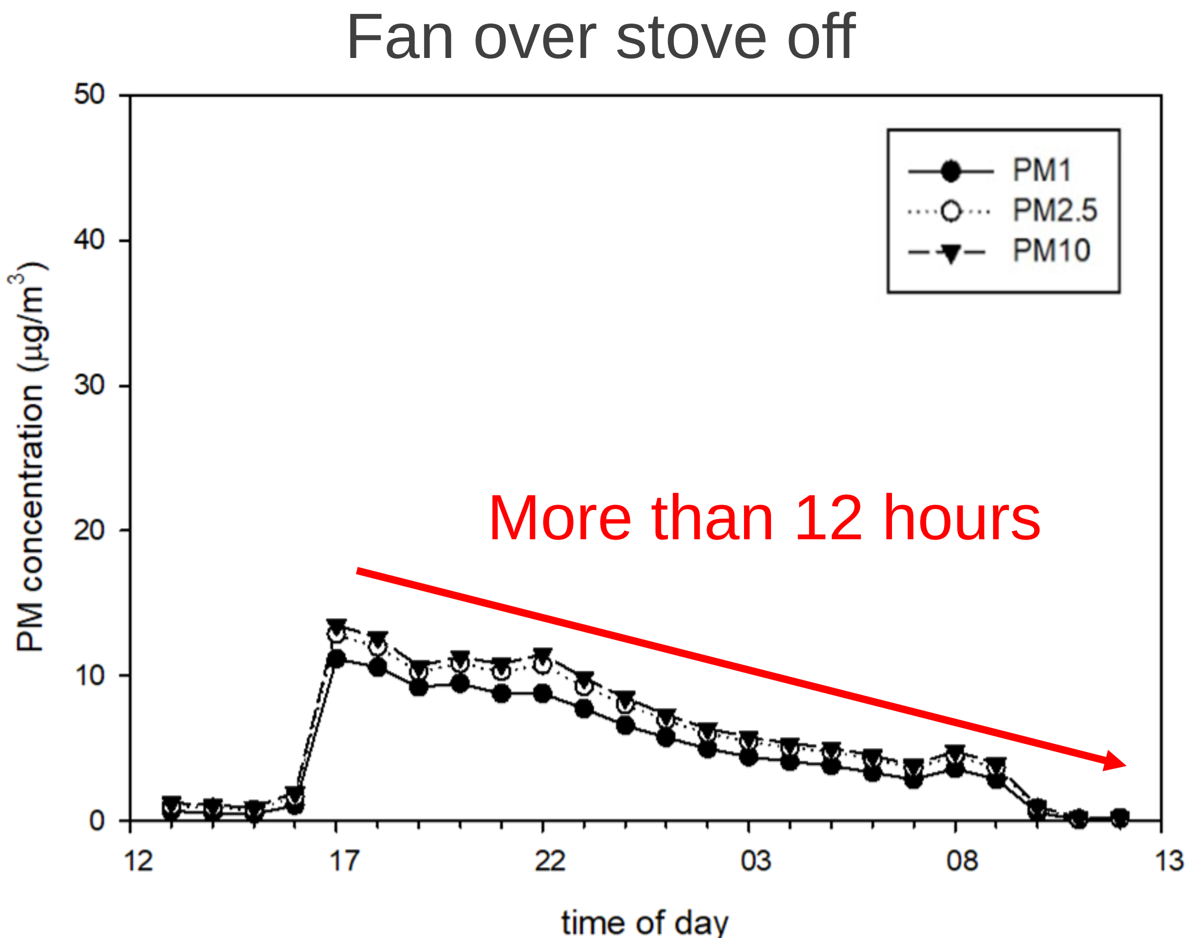


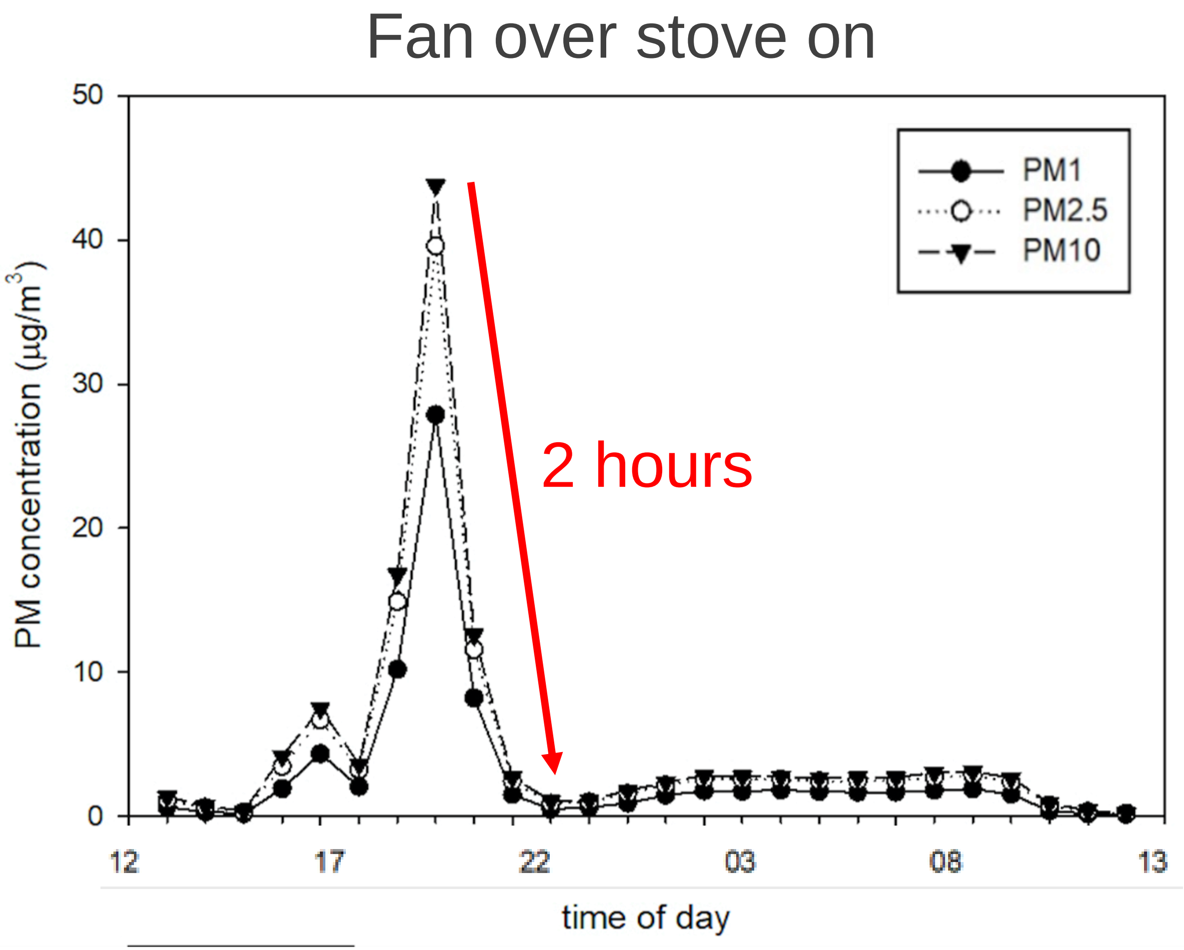


Ventilation

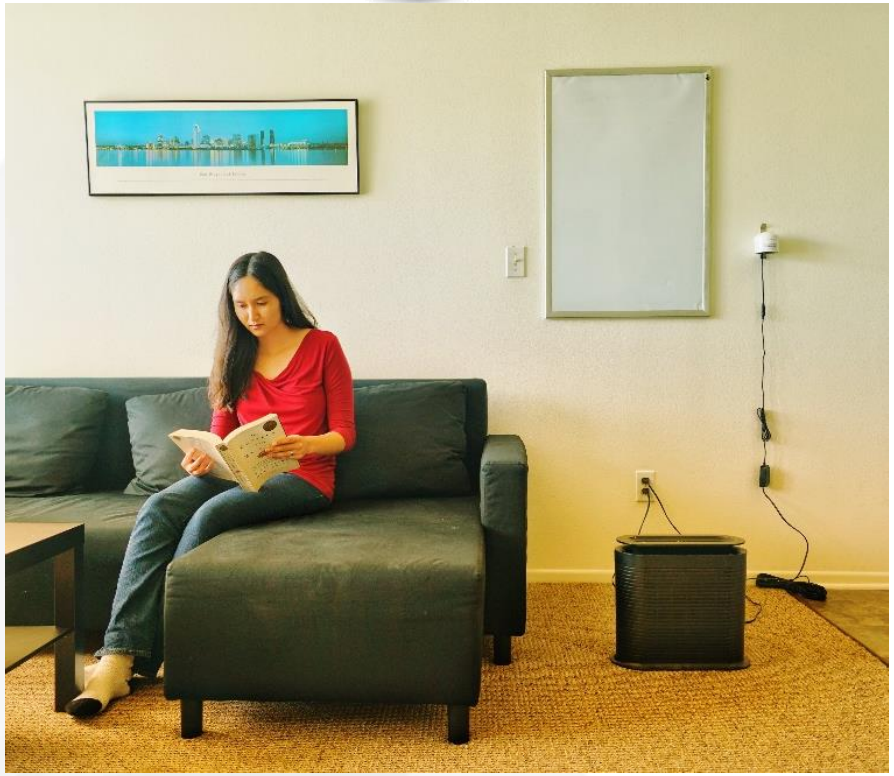


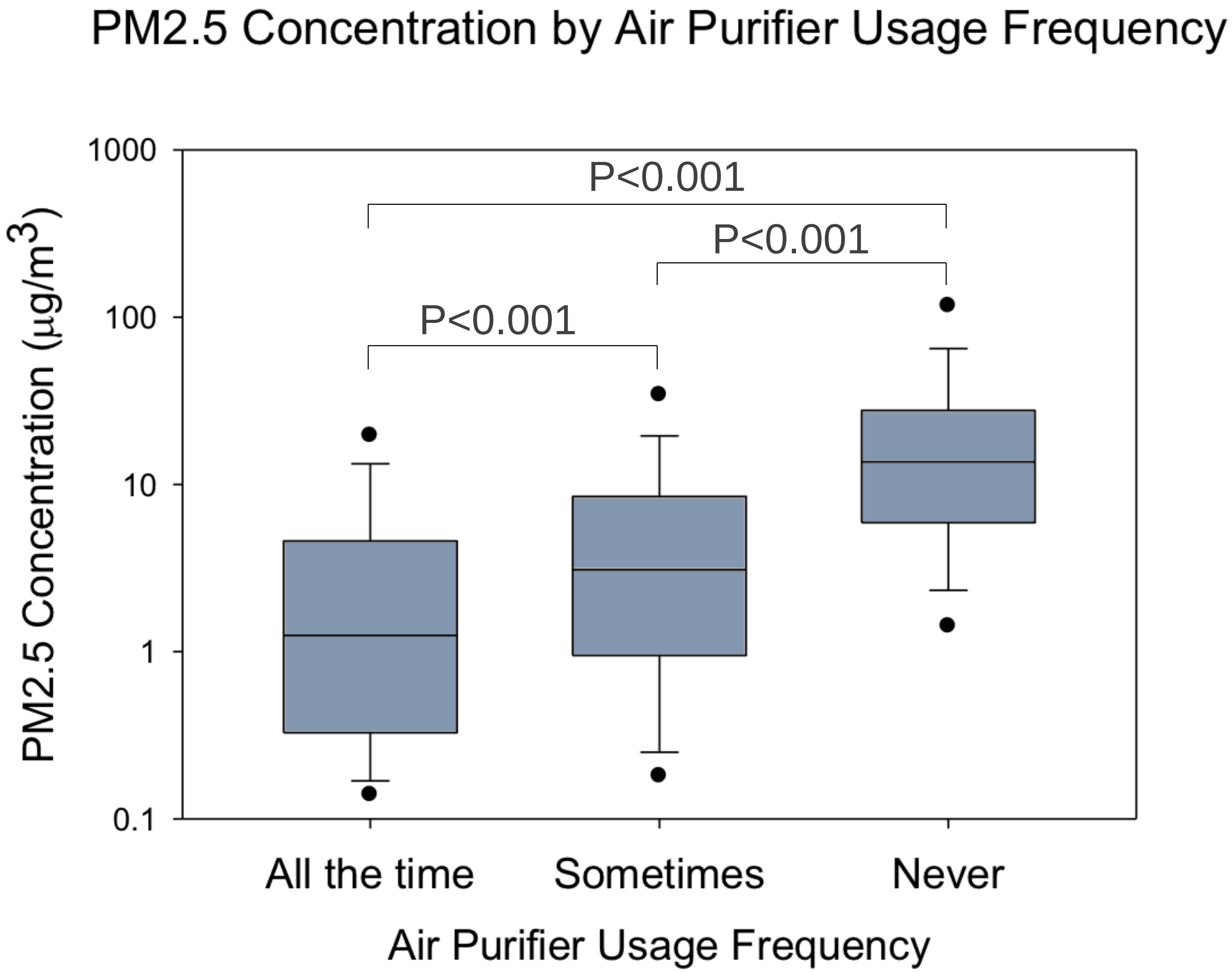
Mitigation: Fan over Stove





Mitigation: Air Purifier





Conclusions

- ✓ Low-cost sensors are effective to monitor indoor air quality.
- ✓ Low-cost sensors can capture indoor PM sources and outdoor to indoor transport.
- ✓ Low-cost sensors can be used to evaluate indoor PM mitigation measures.
- ✓ Low-cost sensors are effective and reliable to be used in the indoor environments.

Acknowledgement

EPA STAR Grant Number: R836184

Engage, Educate, and Empower California Communities on the Use and Applications of “Low-cost” Air Monitoring Sensors

Emily Marino is supported by the Benenson Award from the UCLA Fielding School of Public Health, Environmental Health Sciences Department

All students and their family living in the UCLA Village who participated in the study

University Village Outdoor Sensor Data

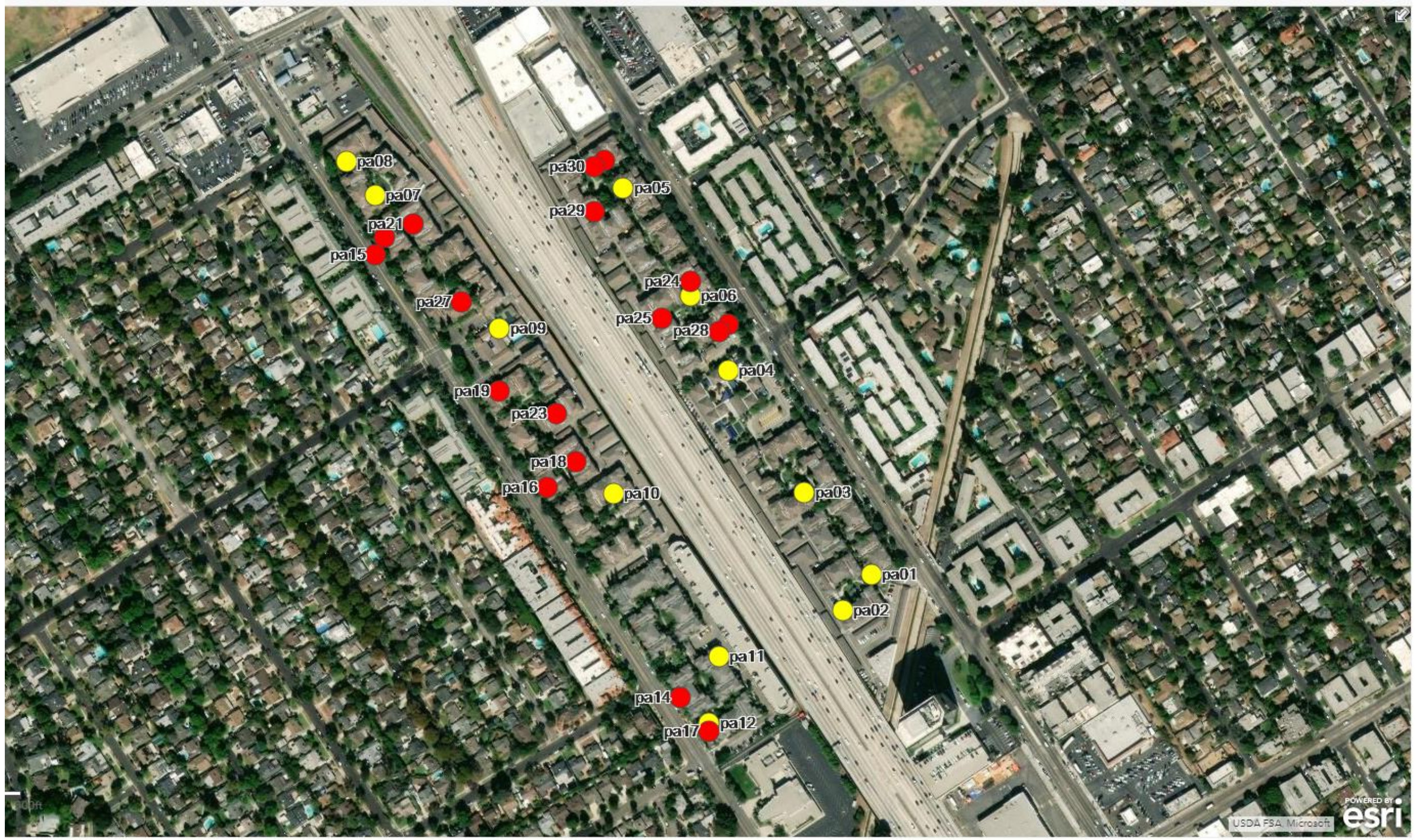
What can we do with this data?

- Assess spatial and temporal variability
- Compare regional and local trends across network
- Evaluate impact of wind speed & wind direction
- Determine when particle or gas pollution is high/low
- Identify potential nearby pollution sources

AQMD Data Analysis

- Data Downloads: 12/1/17 to 12/1/18 - (1 year)
- PurpleAir – $PM_{2.5}$
- Nearest Reference Station – North Main (Downtown LA, ~ 10 miles)
- Wind Data – Los Angeles VA Hospital

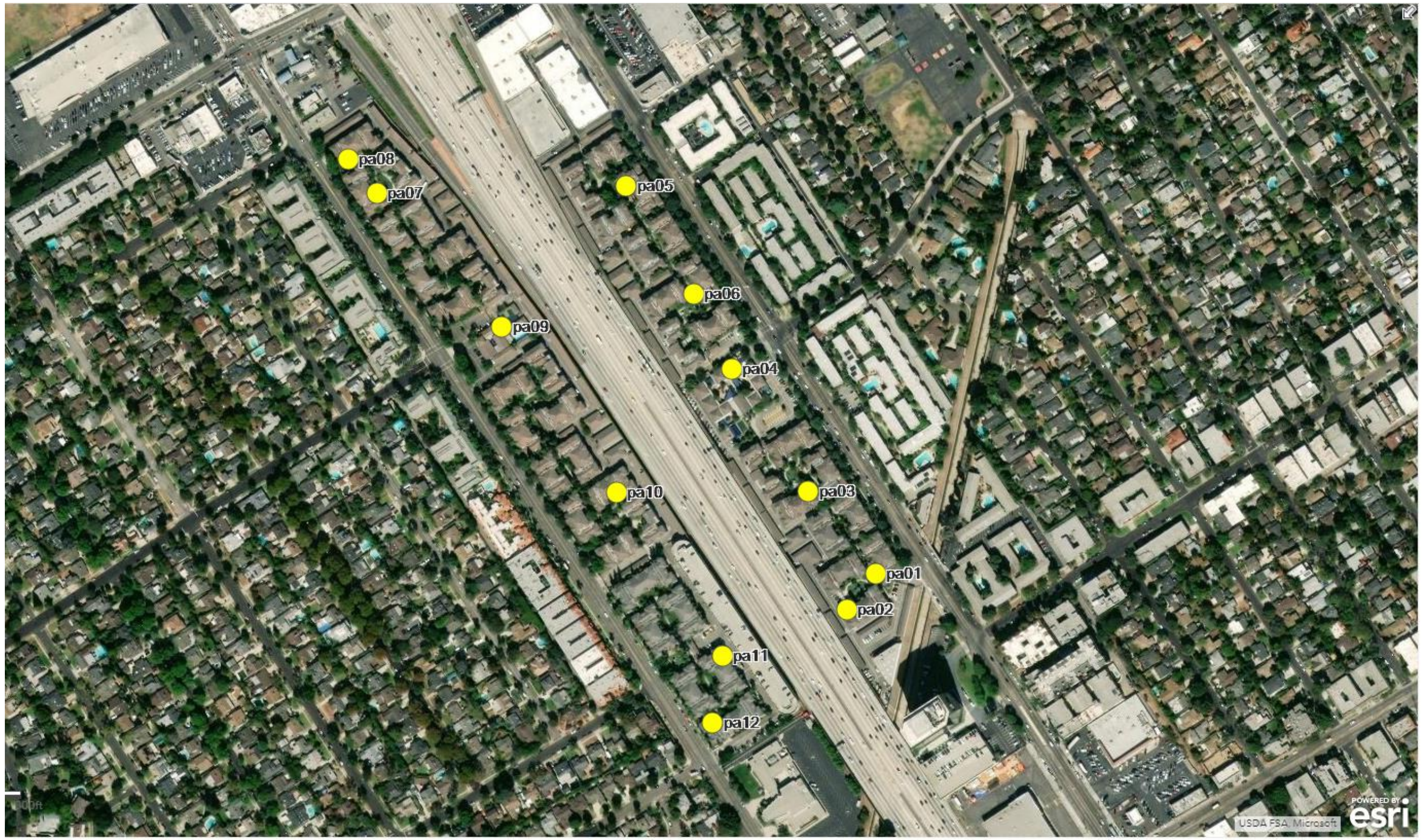
Sensor Locations



Indoor Sensors

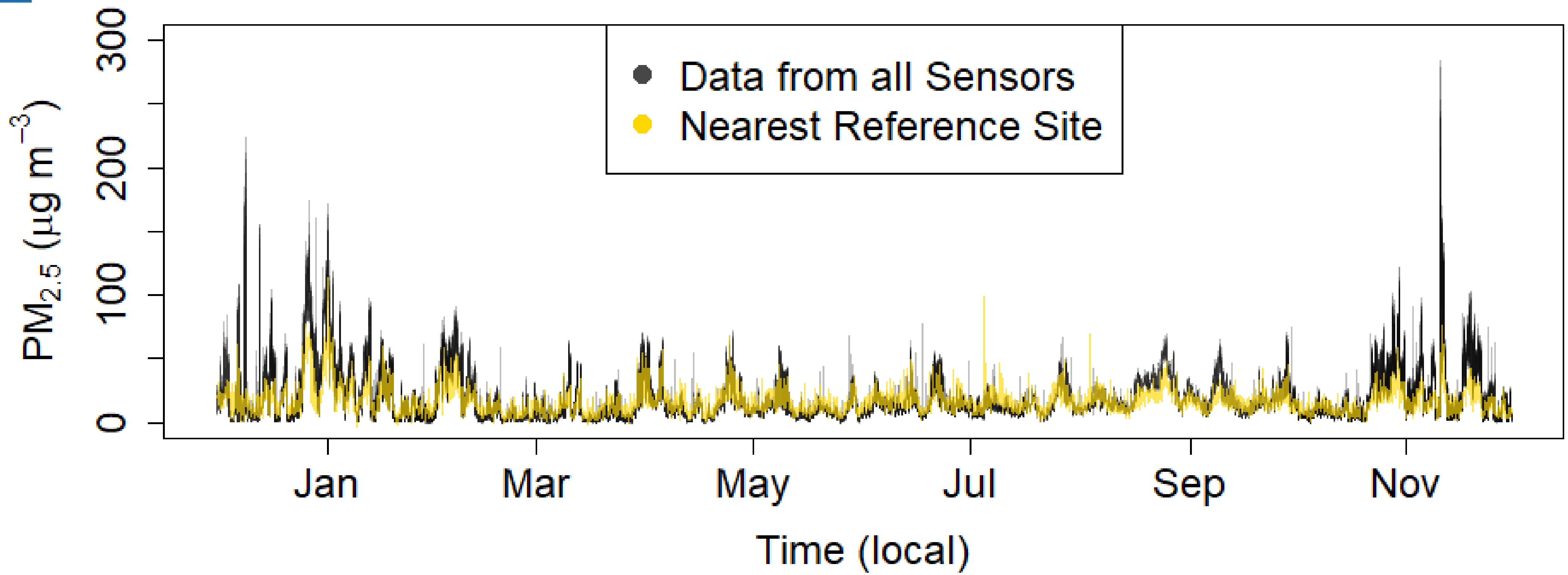
Outdoor Sensors

Sensor Locations



Indoor Sensors
Outdoor Sensors

Complete Sensor Data



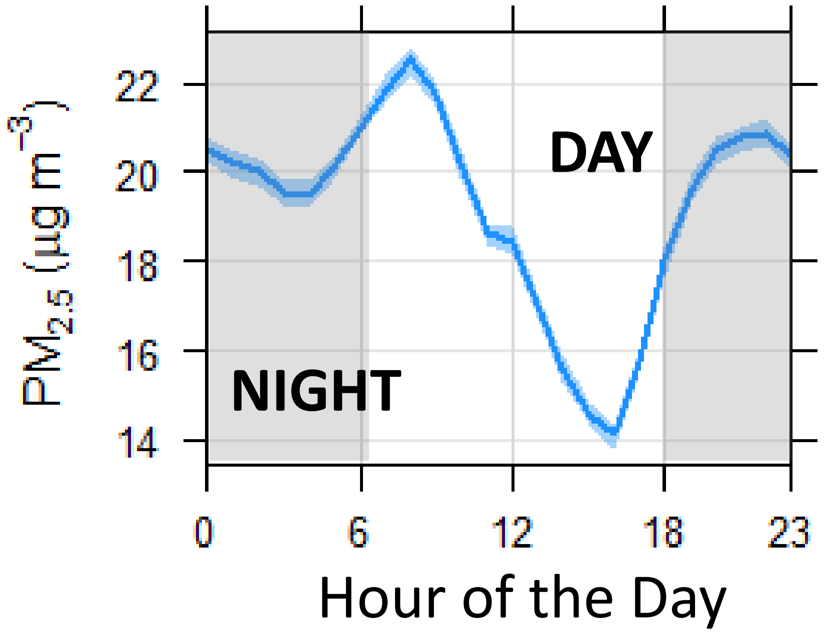
- All sensors plotted together
- Darker indicates overlapping, lighter indicates a single sensor signal

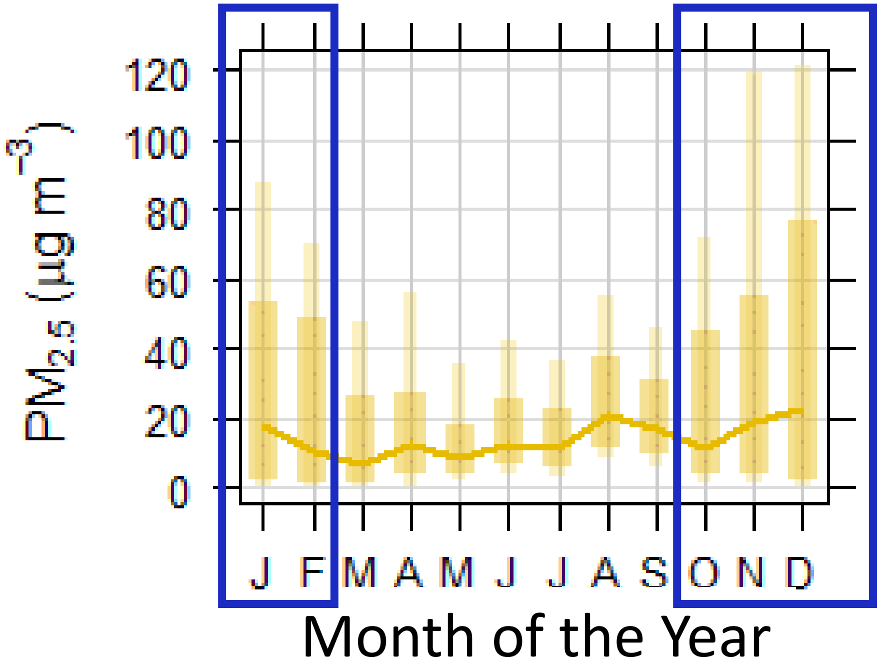
Observations

- *What sort of temporal and spatial patterns do we see?*
- *Does there appear to be an influence from the highway?*
- *What about other events like the wildfire?*

Temporal Trends

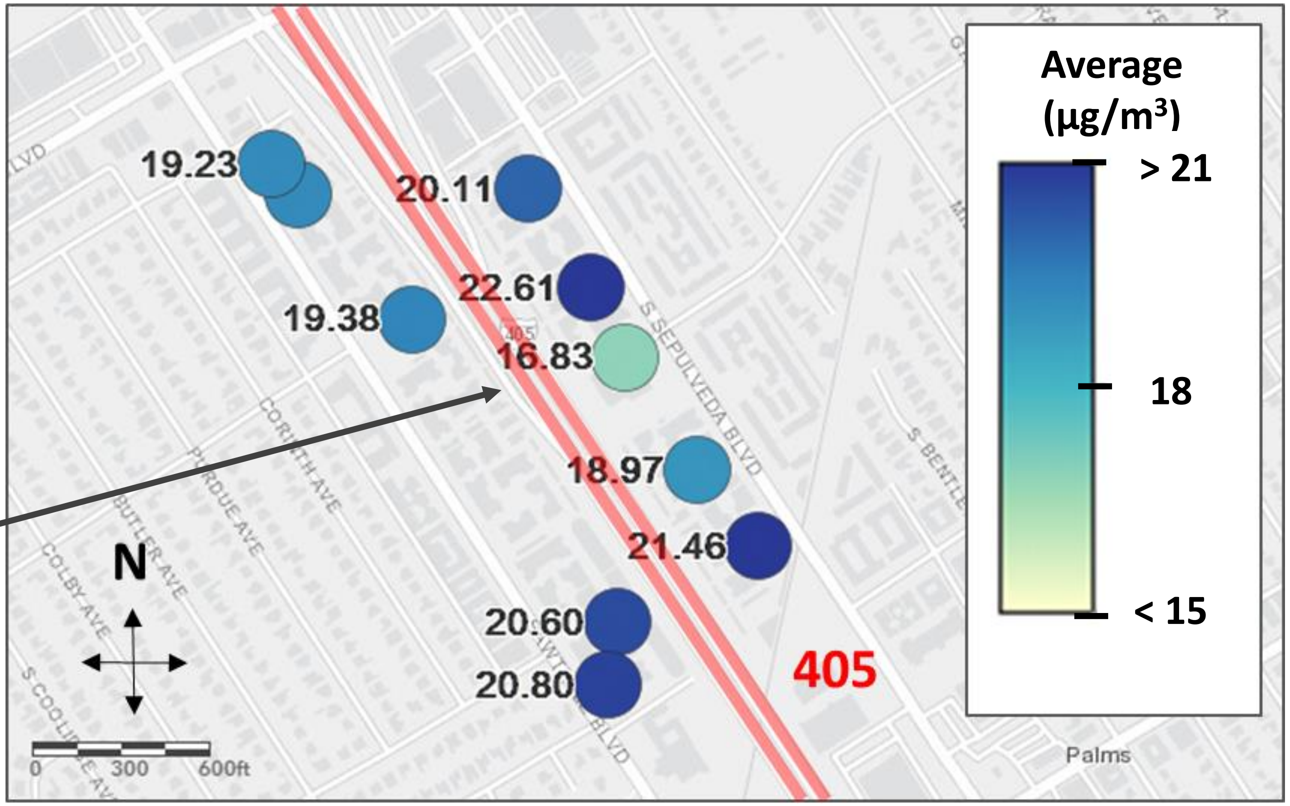
- Daily: Generally seeing elevated $PM_{2.5}$ at night and in the early morning
- Seasonally: Larger range of $PM_{2.5}$ in the fall and winter
- ***Here our sensor network is reflecting expected trends - what about differences?***





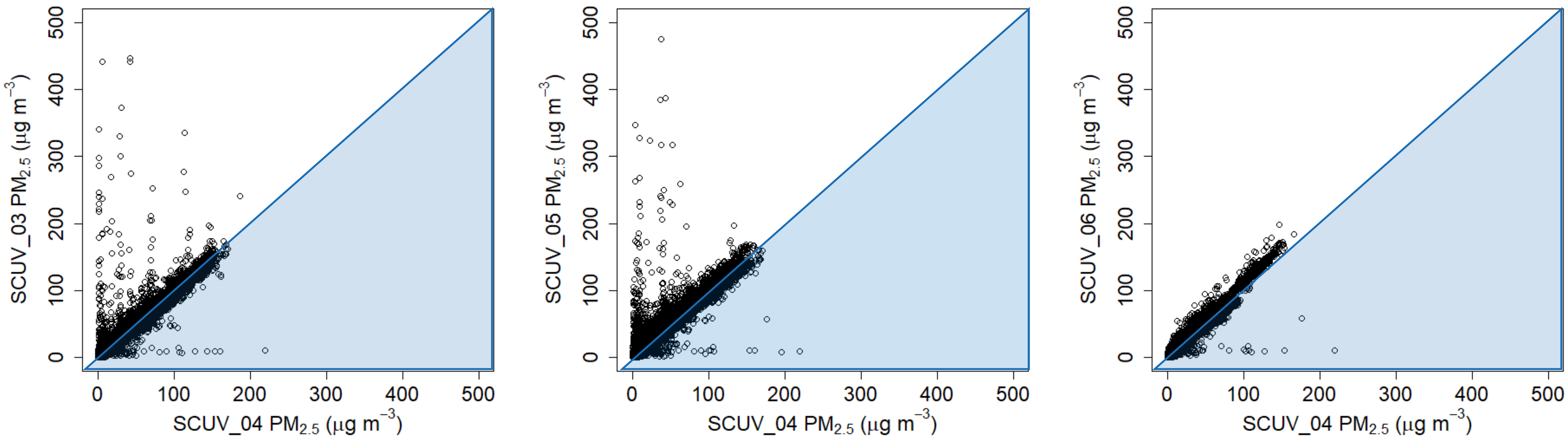
Spatial Trends

- No obvious patterns (e.g., differences between the east and west side of the freeway)
- Does appear that rooftop sites have higher averages while more "sheltered" sites have lower averages (e.g., the childcare center)



Spatial Trends

- Comparing the daycare site to the others on the east side of the freeway
- More occurrences of high PM2.5 on rooftop sites for SCUV_03 and SCUV_05
- Researchers have observed that sound barriers and trees along roadways can reduce concretions on the opposite side



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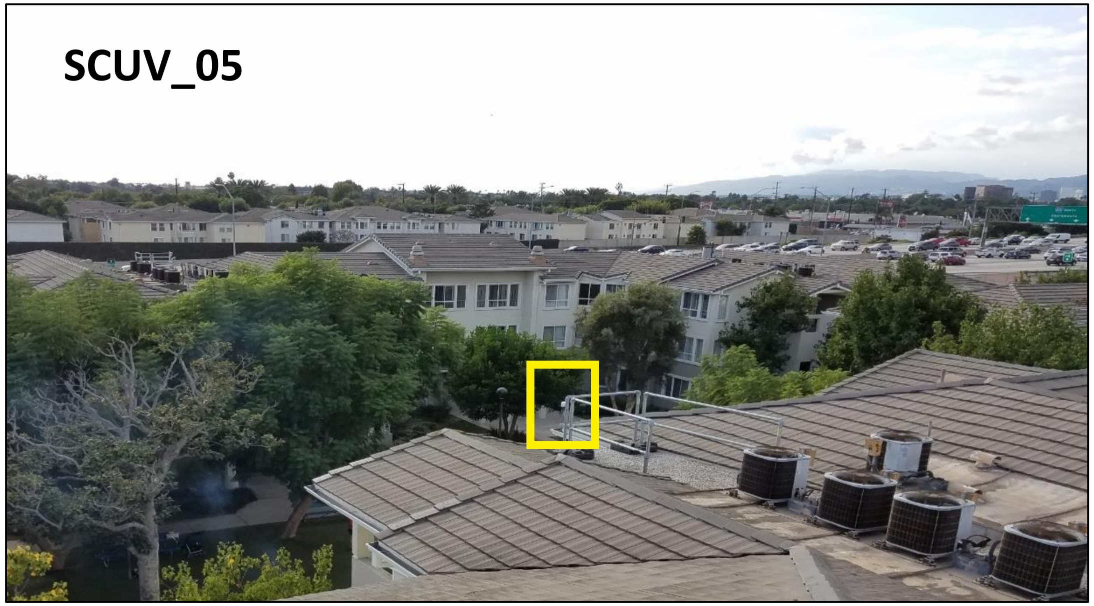
SCUV_04

SCUV_06



SCUV_05

SCUV_03

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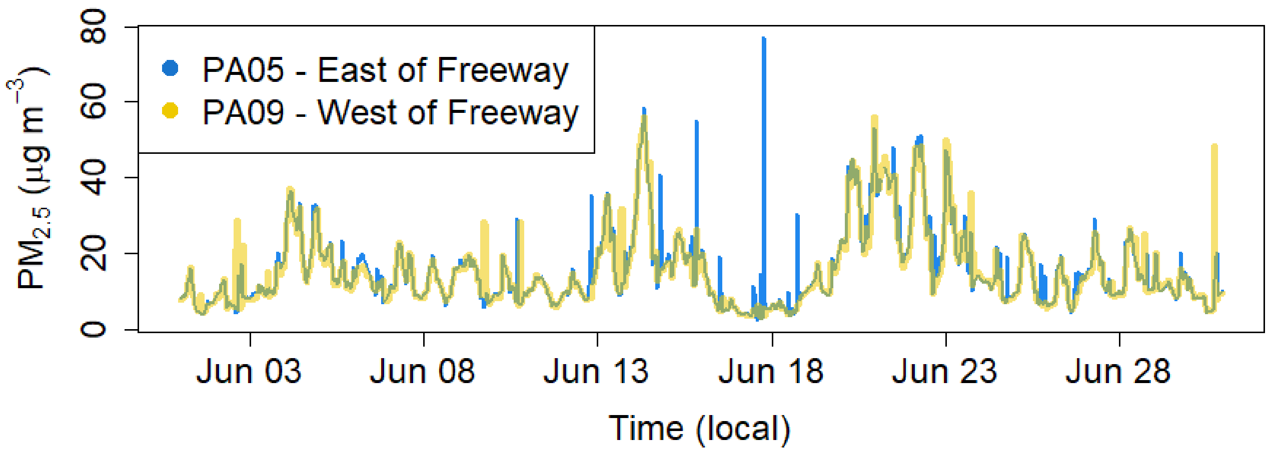
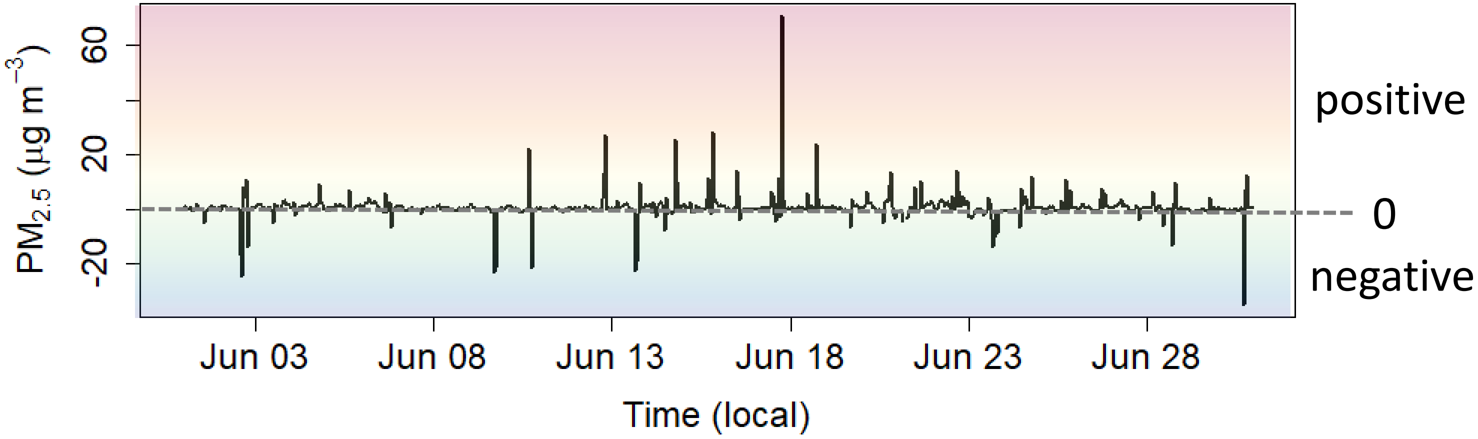
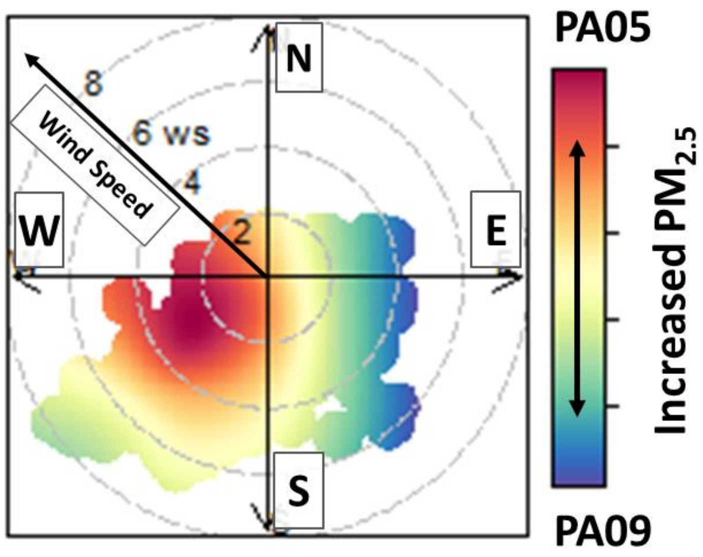
Emission Events

Sensors allow us to look at individual ‘events’



$$Difference = PA05 - PA09$$

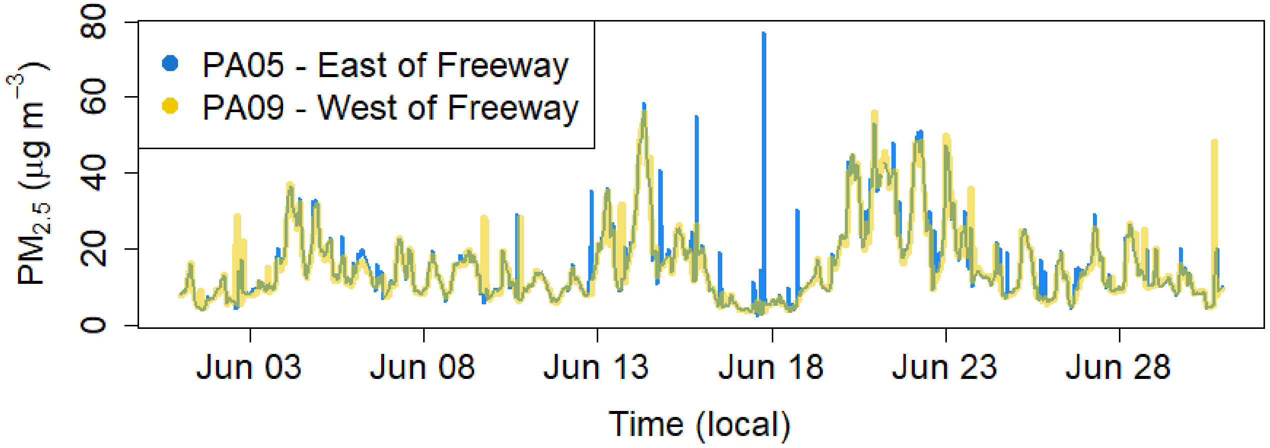




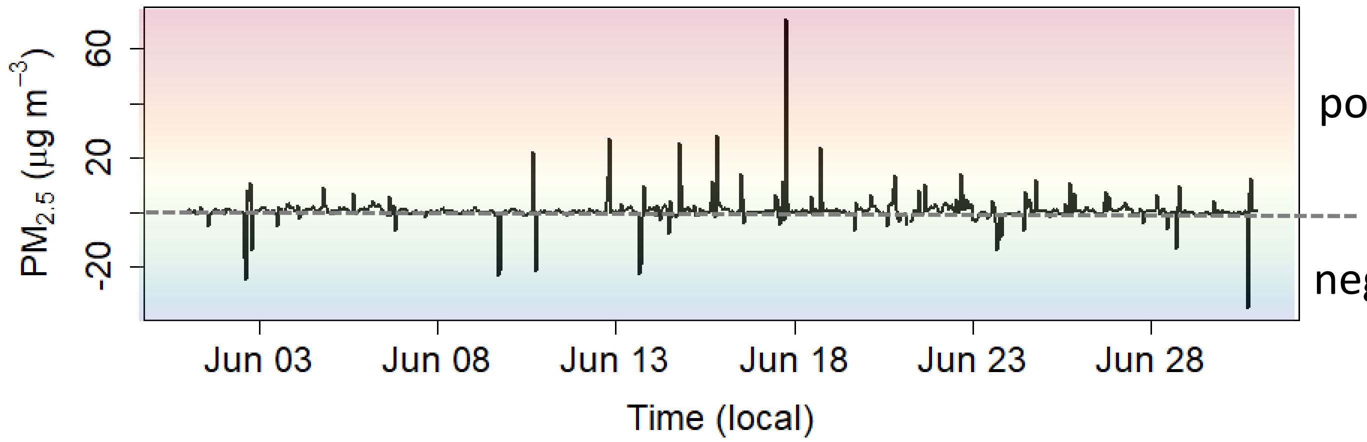
- Enhancements on the east side come from sources to the west, and vice versa
- Possible Sources: heavy duty vehicles on the highway, cooking/grilling, landscaping

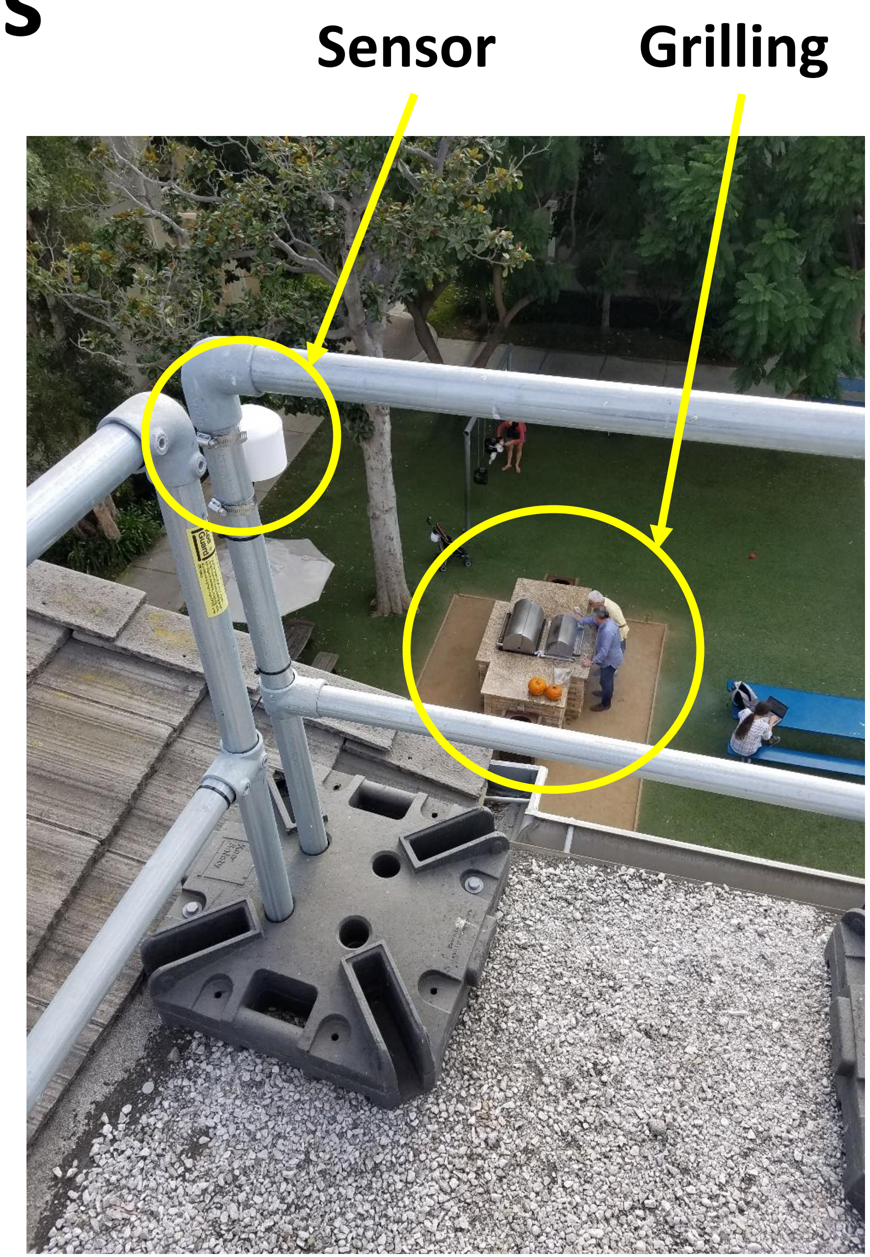
Emission Events

Sensors allow us to look at individual 'events'



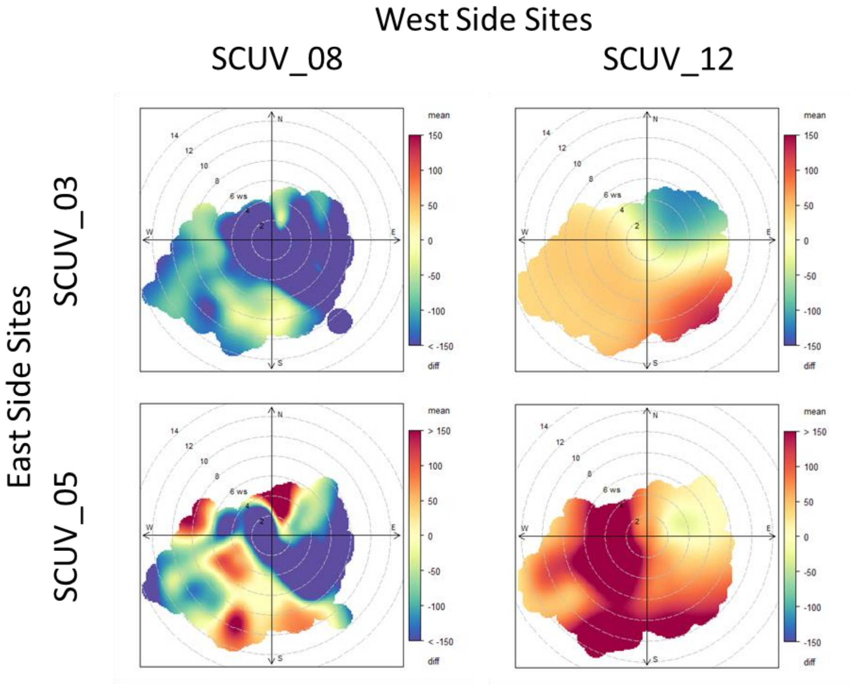
$$Difference = PA05 - PA09$$



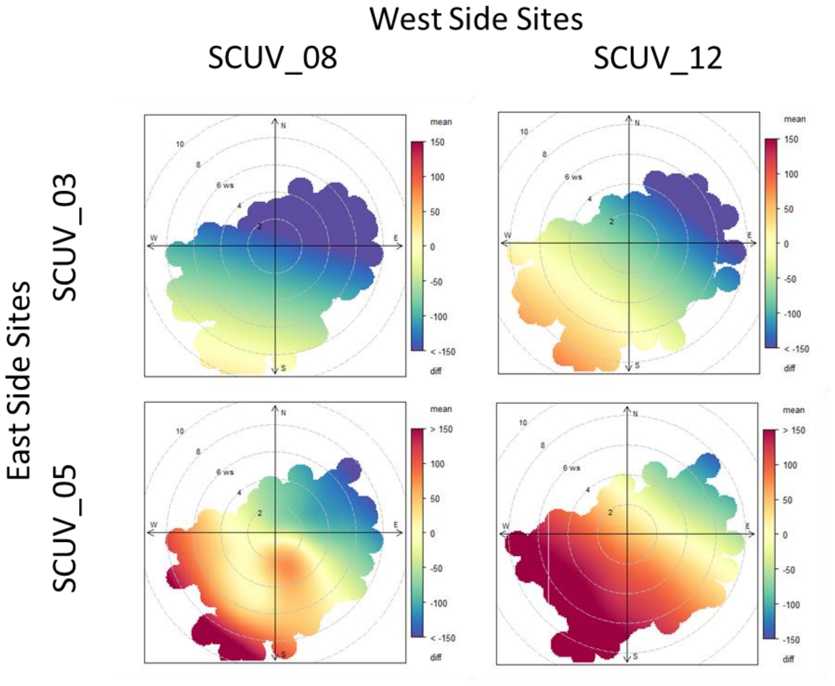


A Deeper Dive into the PurpleAir Data

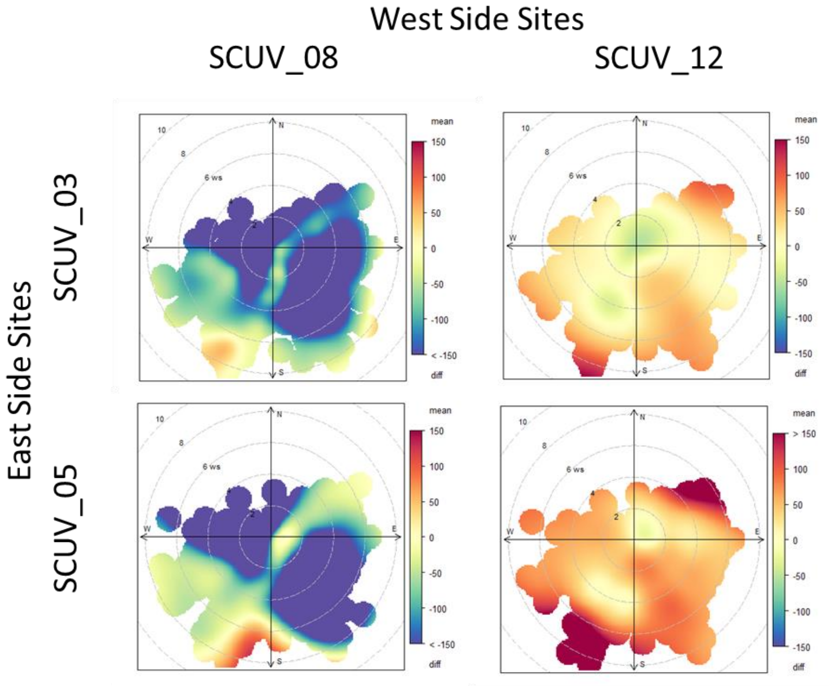
- Polar plots of the difference between sites (i.e., east – west)
- **Warmer colors ~ higher PM to the *east*; Cooler colors ~ higher PM to the *west***
- Additionally, looking at raw particle counts (instead of mass concentration), in an effort to better target vehicle emissions (# of particles <= 0.3 µm)



Complete June Data



Morning Rush Hour – Weekday

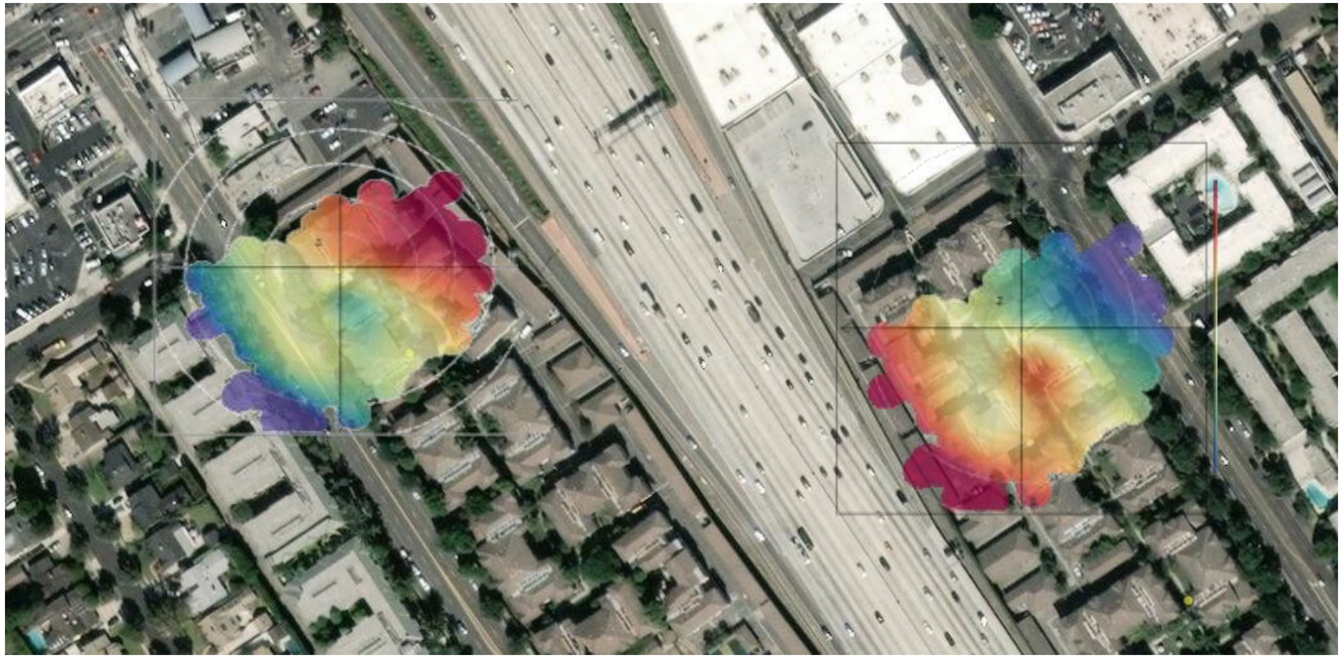


Morning Rush Hour – Weekend

A Deeper Dive into the PurpleAir Data

- Polar plots of the difference between sites SCUV_05 and SCUV_08, for weekday rush hour (6-9am), in the month of June
- It seems PurpleAir sensors may be able to pick up some fresh vehicle emissions, but as we know based on the sensor specifications not with high efficiency
- Thus these sensors may be able to provide useful qualitative information regarding the impacts of the freeway

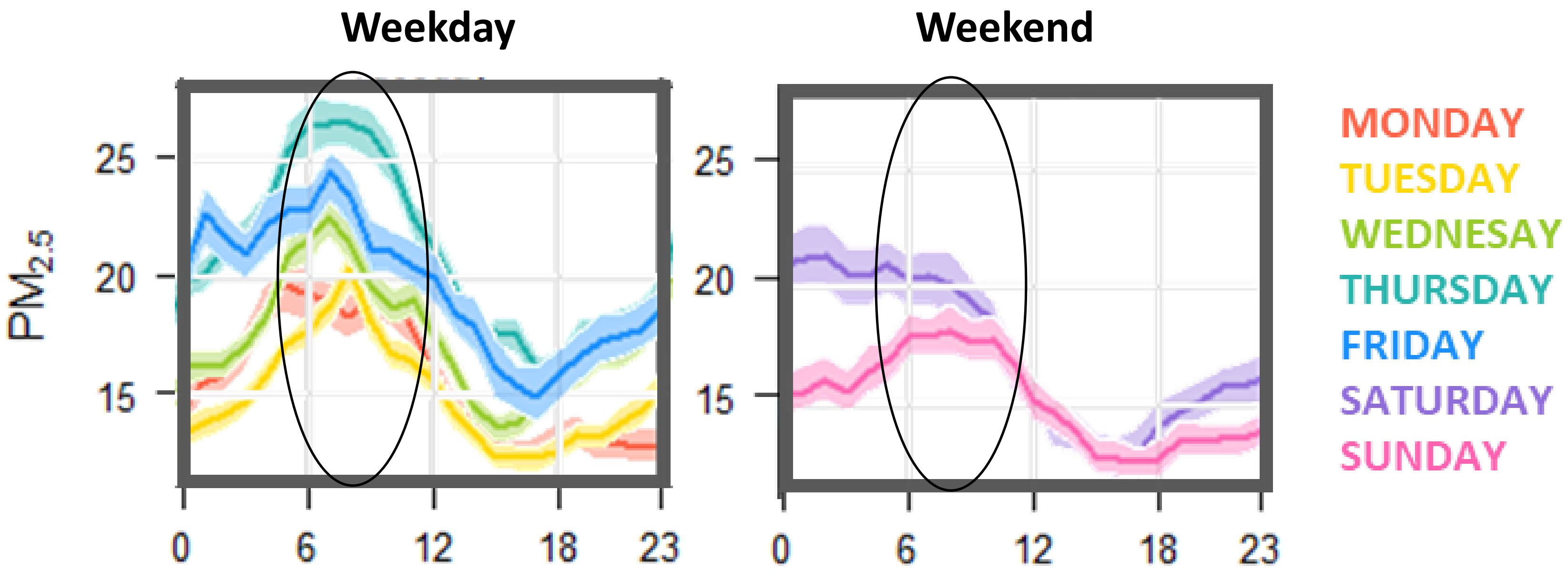
***Reminder that is it good to understand the strengths limitations of your tools**



Here: warmer colors indicate direction of origin of higher emissions

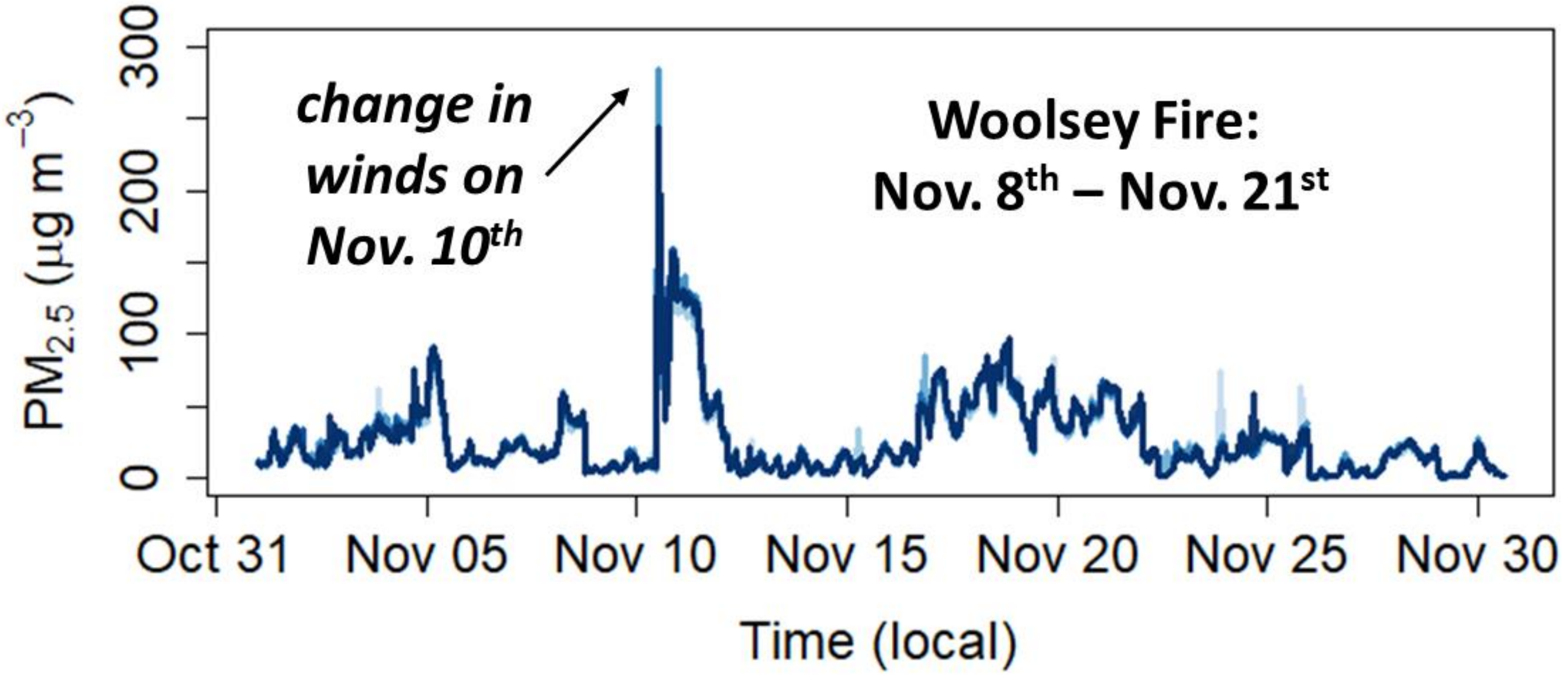
Temporal Trends

- Here: summer data – averaged by hour of the day and separated by day of the week
- The morning rush hour peak is also missing from the averaged $PM_{2.5}$ weekend data, indicating that we seem to be picking up some of these emissions



Unique Emission Events

- Enhancements occurred across all the outdoor sensors when the Woolsey fire was active, in particular the first weekend after the fire began
- Sensors – well-suited to detecting wild-fire smoke (larger particles)



Community Member Findings & Observations

Would anyone like to share things they learned from their sensors?

Or interesting ways in which they are using them?

Next Steps

Develop a cloud-based computing platform to ingest, store, analyze, and display sensor data

Data analysis workloads larger than typical tools can handle

Fence-line monitoring: ~15 million rows of data

Regional monitoring network: ~40 million rows of data

STAR Grant: ~50 million rows of data

South Coast AQMD R1180: XX million rows of data

CA AB617: X billion rows of data

Specific Aim #4

Communicate the lessons learned to the public and organize outreach activities

Disseminate study results and help answer these key questions:

- ✓ Which tools will be most successful in educating communities to effectively use air monitoring sensors and to engage them in using sensor data?
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- ✓ Which sensors are the most suitable for community use?
- ✓ How does sensor data quality change with time after sustained use by communities under "real-world" conditions?
- ✓ How do sensor data compare (spatially and temporally) to that of existing monitoring networks?
- ✓ What value is added by these sensors that we are not getting with current network data?

Final Activity

Please discuss the following 3 questions in small groups:

(1) What result that was presented did you find most interesting or unexpected? Why?

(2) What result was the most actionable, or the most relevant to your concerns? Would you change your behavior based on this results or did it give you any ideas of how we may be able to improve air quality using sensors?

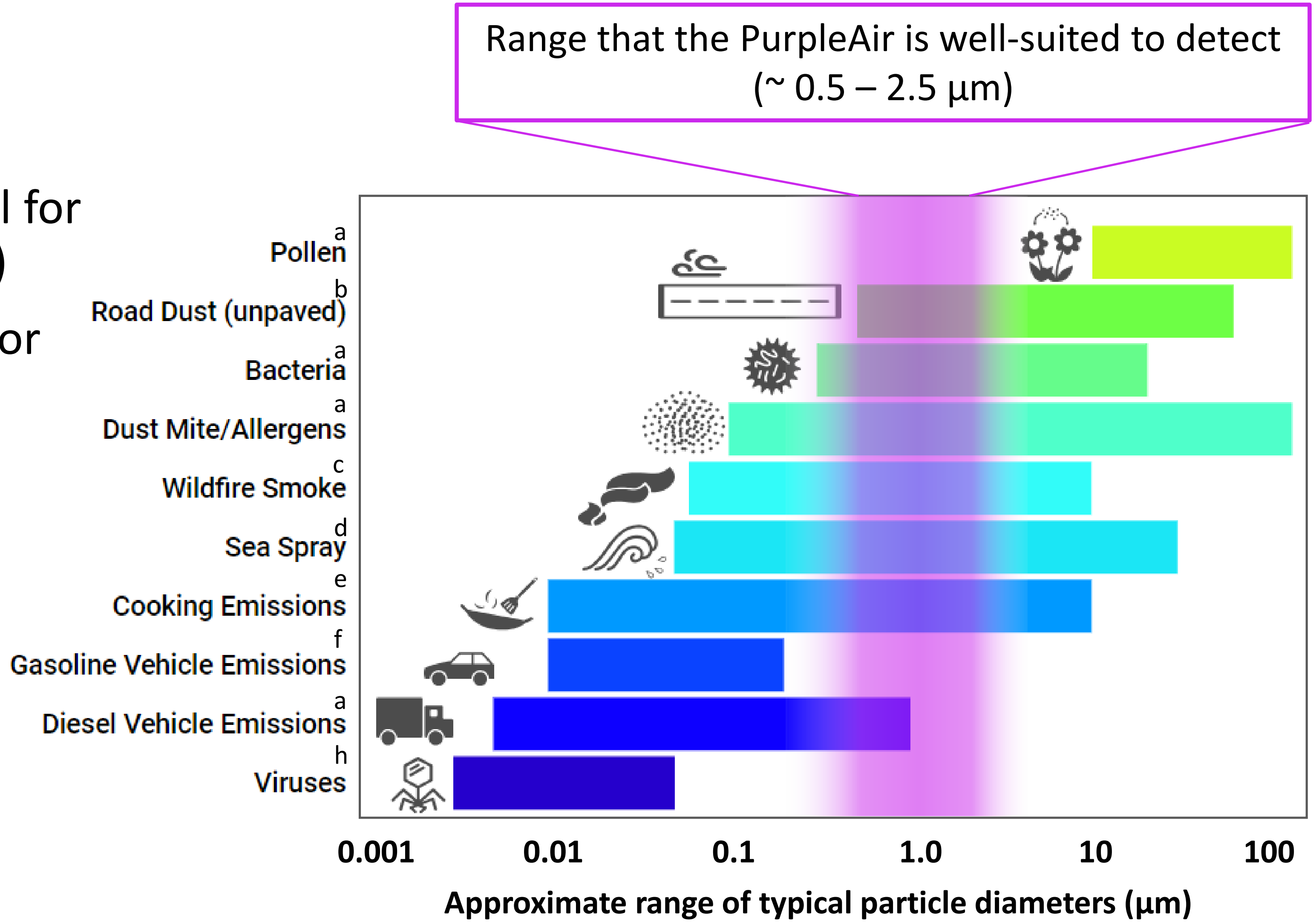
(3) Was there a particular plot, or visual, or story regarding the data that you found most easy to connect with? In other words, what way of presenting data do find most effective?

Thank you!

Extra Slides

PurpleAir Sensor Limitations

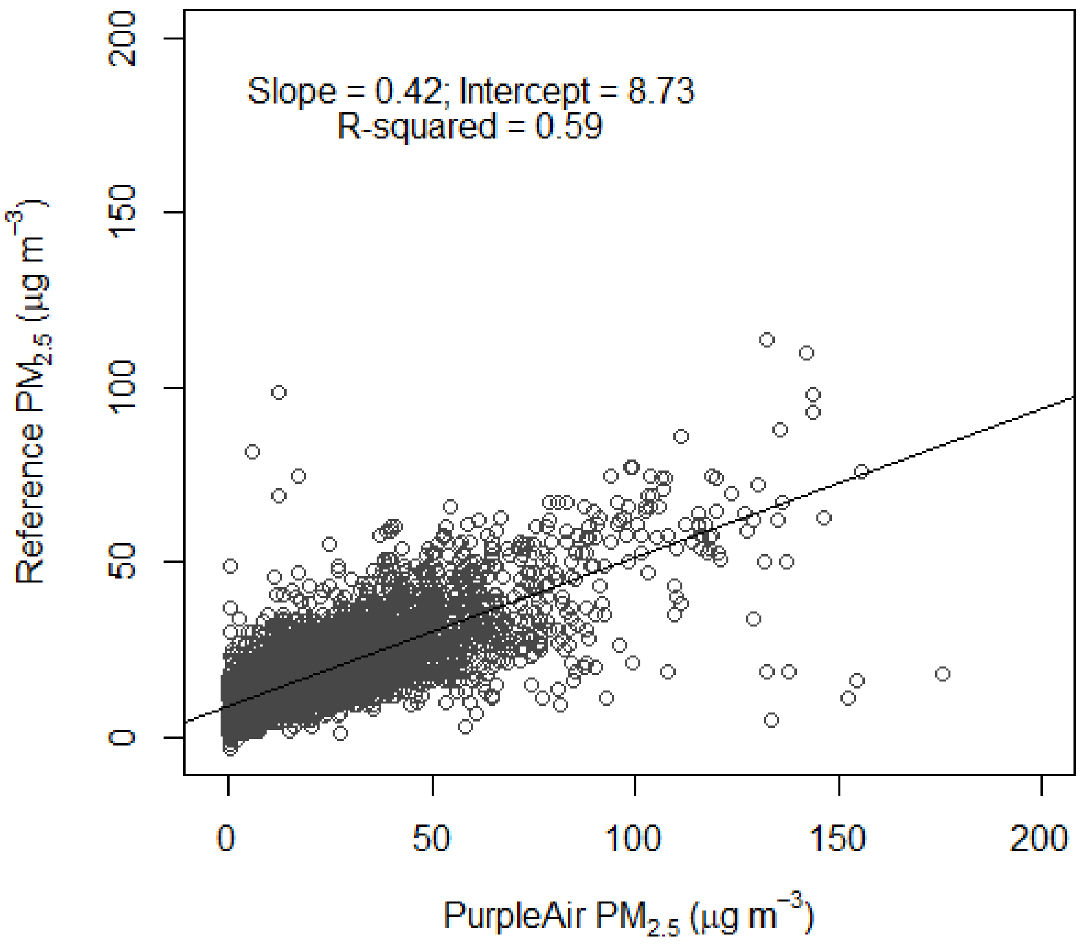
- PurpleAir Sensors perform well for $PM_{2.5}$ (PM diameters < 2.5 µm)
- However, detection drops off for smaller particles
  - From the PurpleAir data sheet:
  - 98% counting efficiency @ 0.5 µm
  - Only 50% counting efficiency @ 0.3 µm
- *Which means PM from gasoline vehicles is likely not detected*



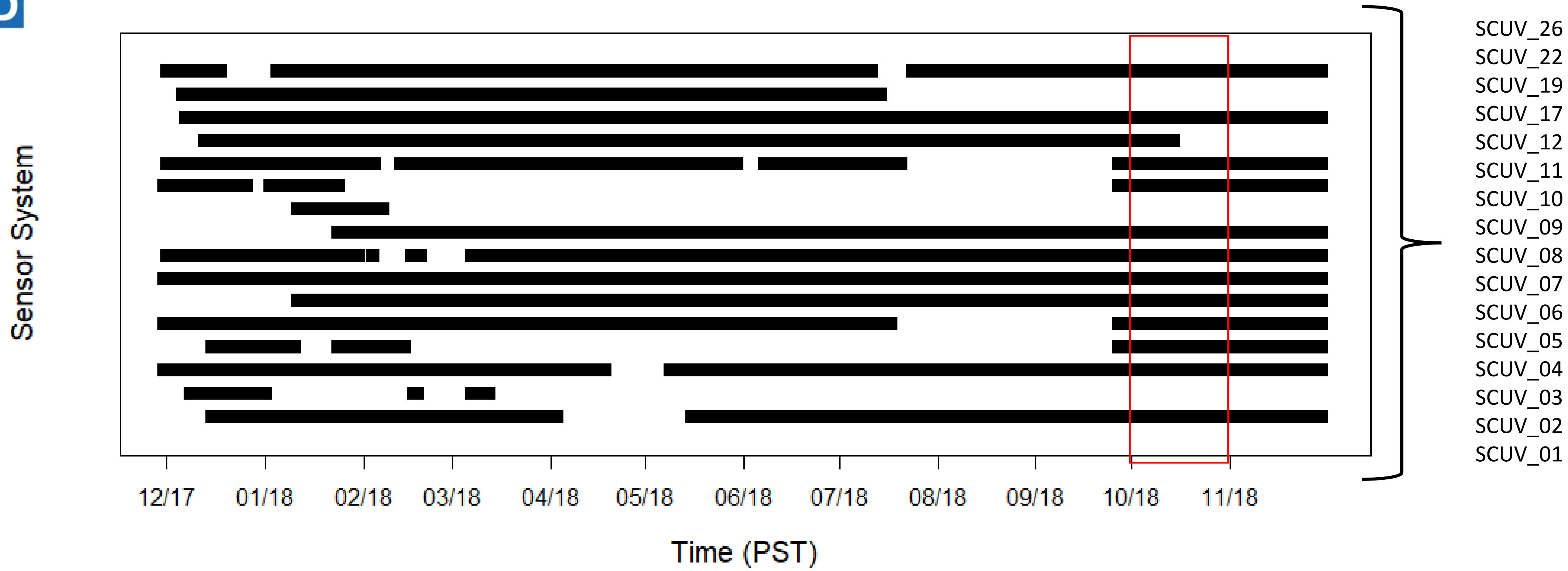
Particle Size Sources: [a](Owen & Ensor, 1992), [b](Zhao et. al., 2017), [c](Saarnio et. al., 2010), [d](O'Dowd et. al., 1997), [e](Buonanno et. al., 2009), [f](Karjalainen et al., 2014), [g](Biswas et. al., 2008), [h](Hinds, 1982)

Sensor Measurements

- A complete year of data; hourly reference $PM_{2.5}$ vs. SCUV_07
- Reasonably high correlation, especially given the distance



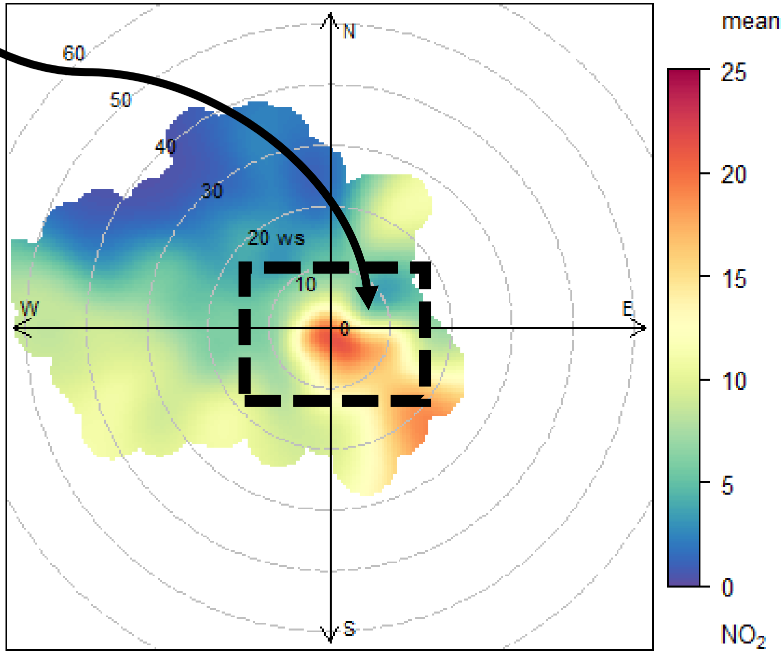
Sensor Reliability

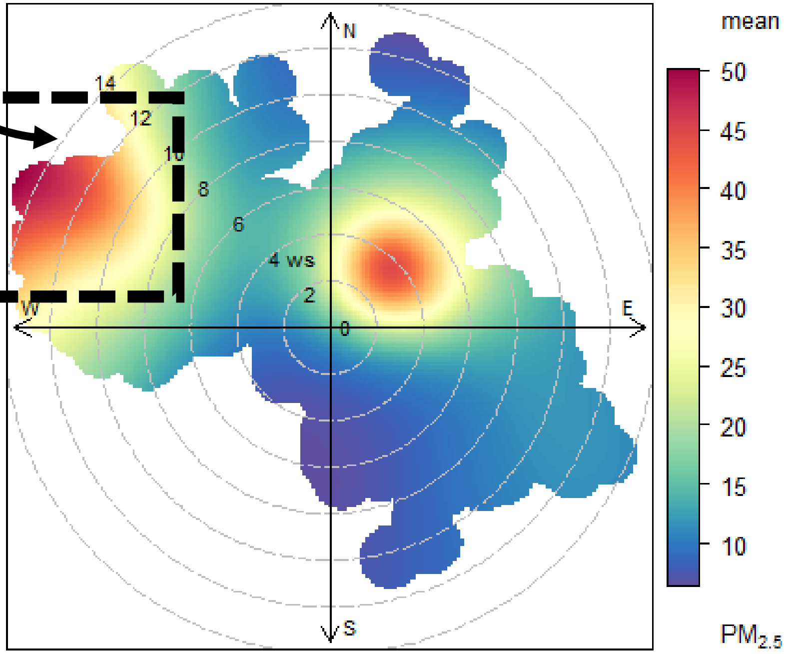


- Black indicates sensor was collecting data, white indicates missing data
- Broad range in reliability demonstrated

How to Read a Polar Plot

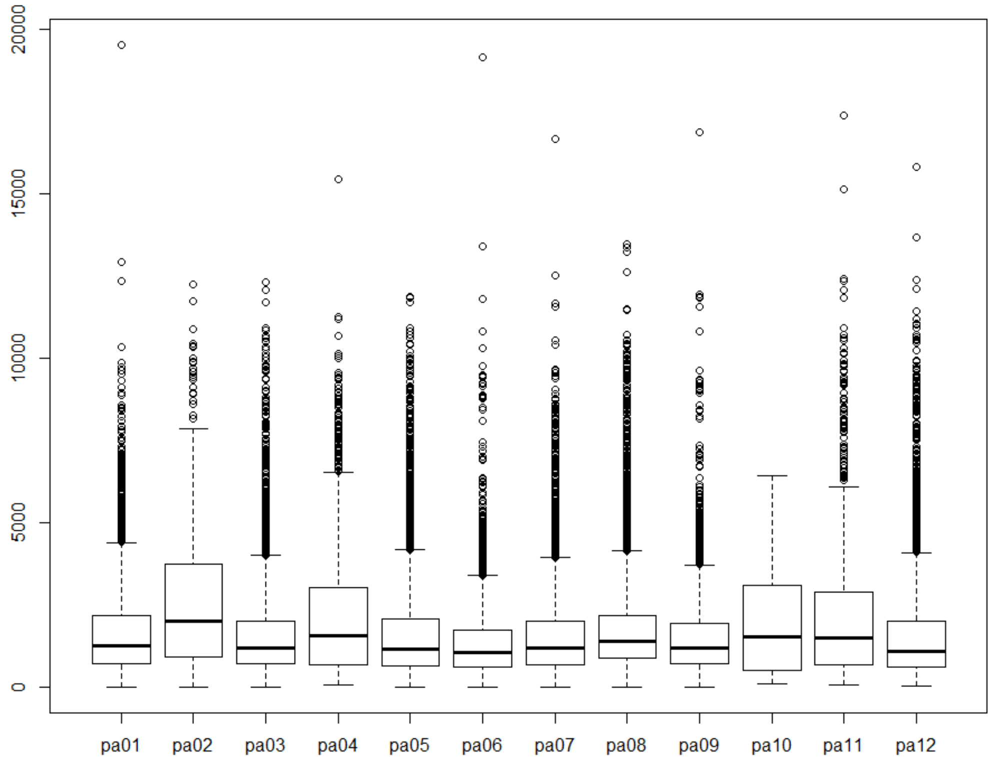
- *Polar plots tell you where the elevated levels of pollutants are coming from and at what wind speeds they are seen*
- Example 1: elevations occurring at the origin (when wind speeds are close to zero) will be closer/more local sources
- Example 2: elevations occurring at higher wind speeds mean these pollutants are being transported to the monitoring site

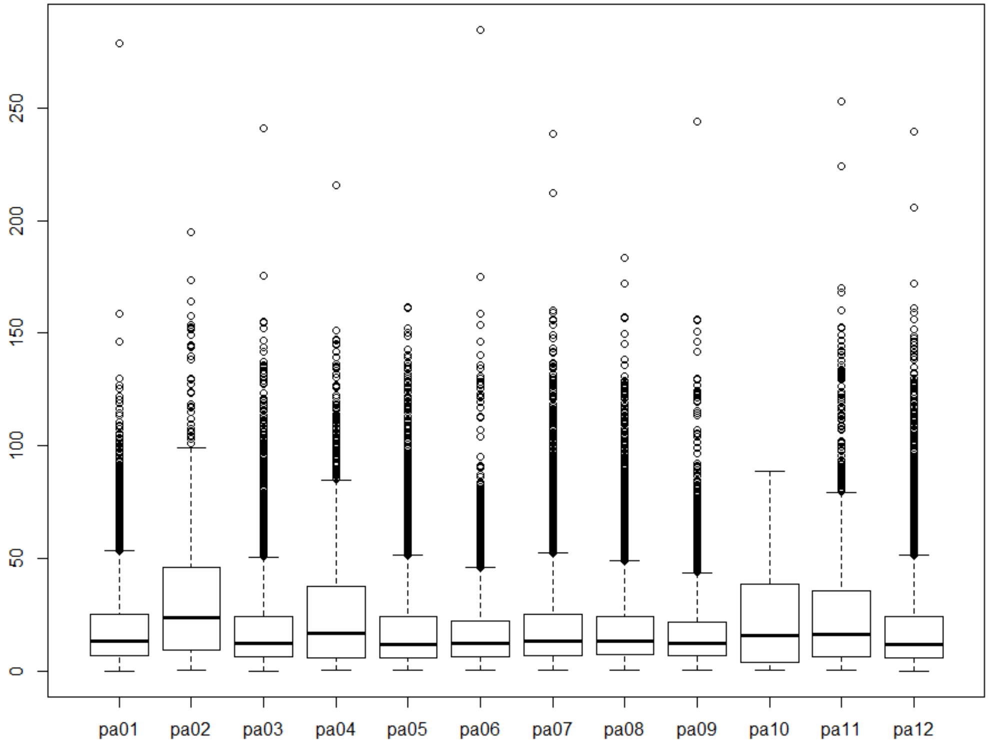




Comparing PM Counts vs. Mass

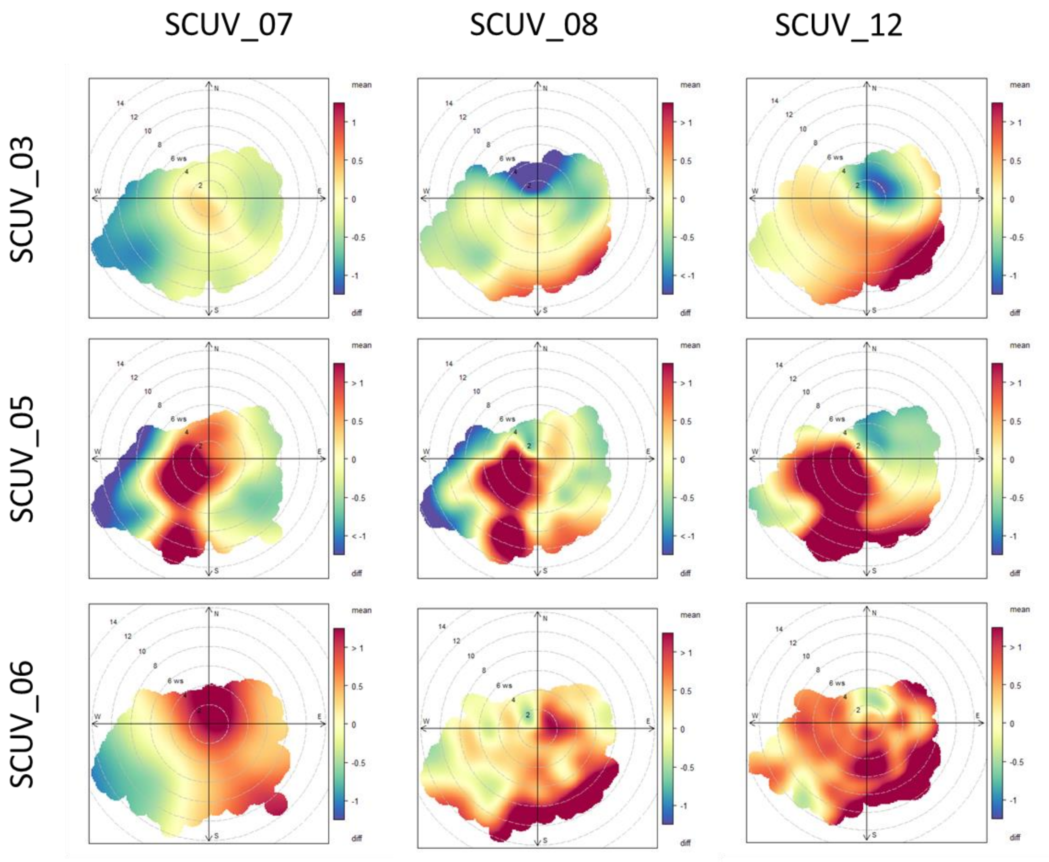
- Left – PM0.3-PM0.5 counts; right PM2.5 mass
- No difference in relative trends across all sensors

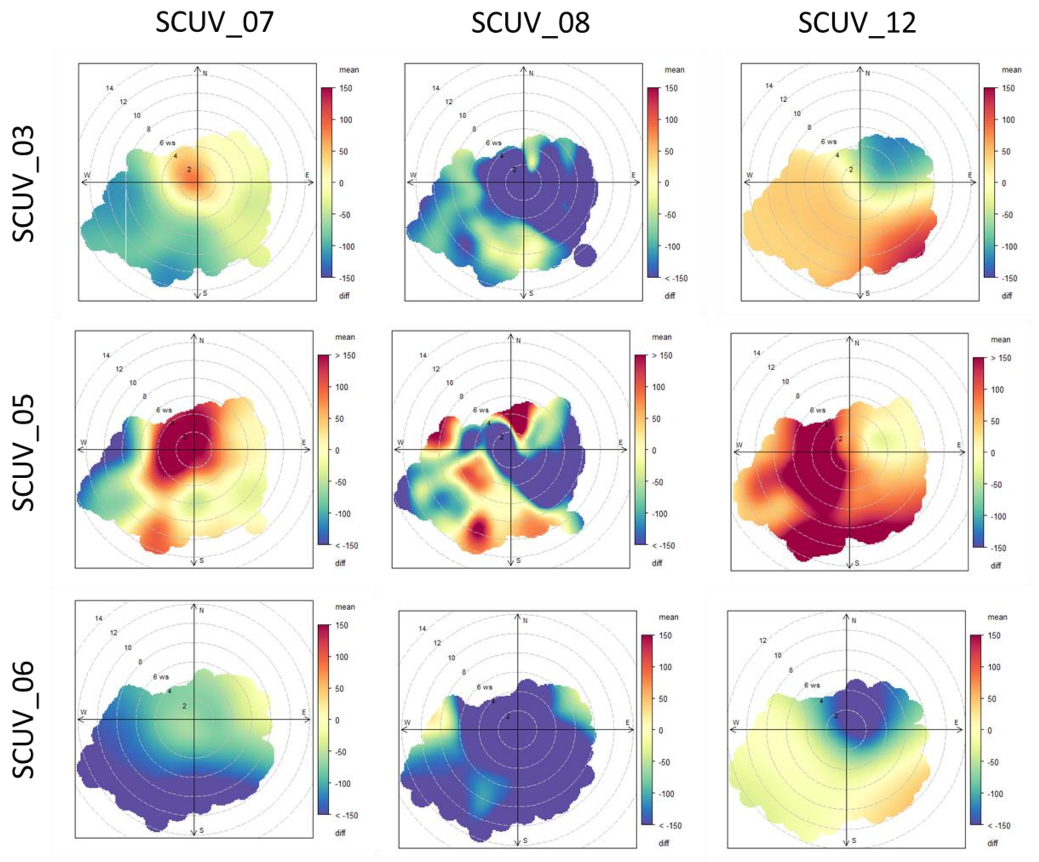




Comparing PM Counts vs. Mass

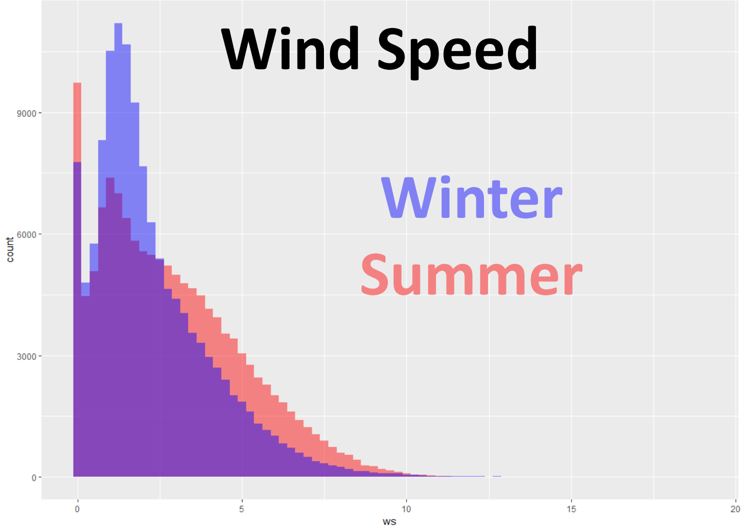
- These are polar plots for the difference between two sites (east minus west)
- Both are the complete data from June for the 6 sensors (left – PM2.5, right – PM.3-PM.5)
- No differences in averages, but different patterns here -> ***differences in the details?***

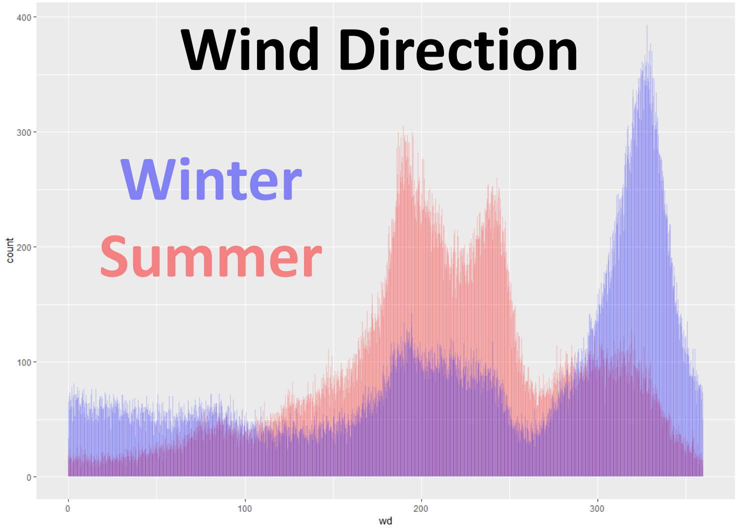


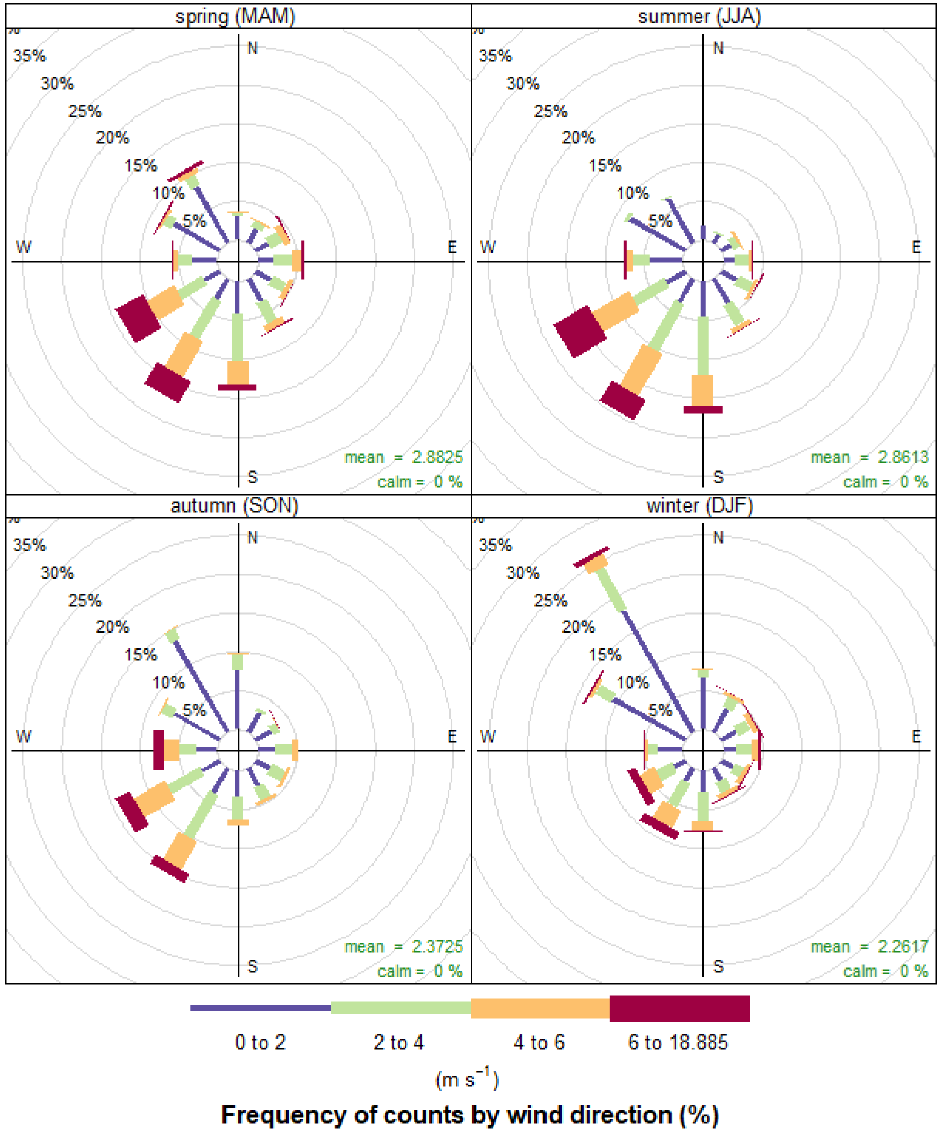


South Coast AQMD

Slower Wind Speeds in the Winter

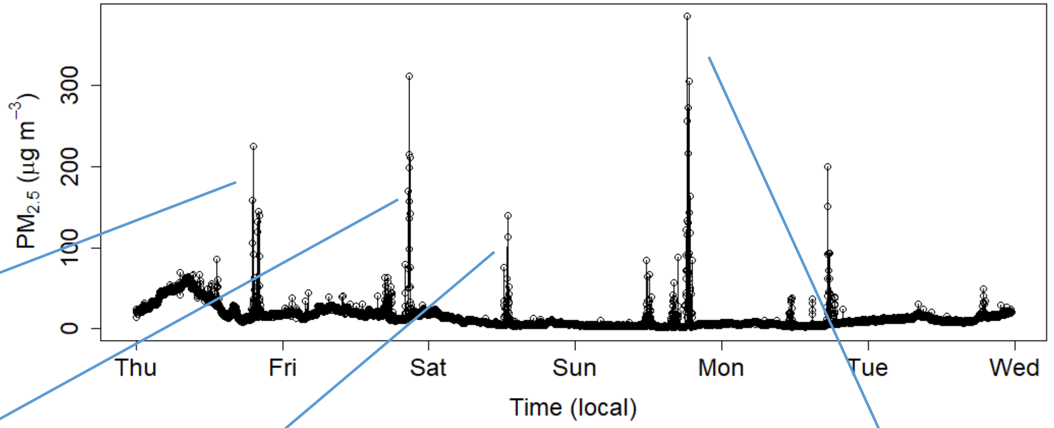


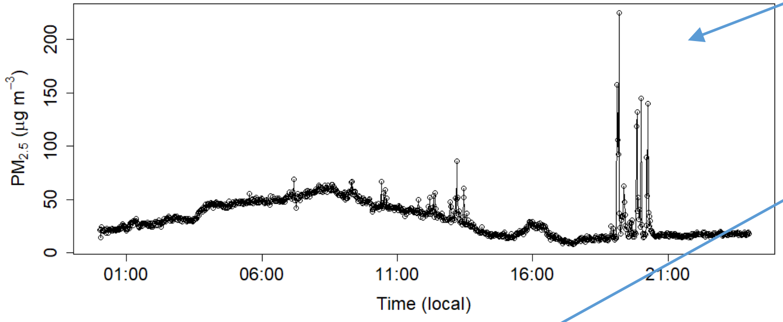


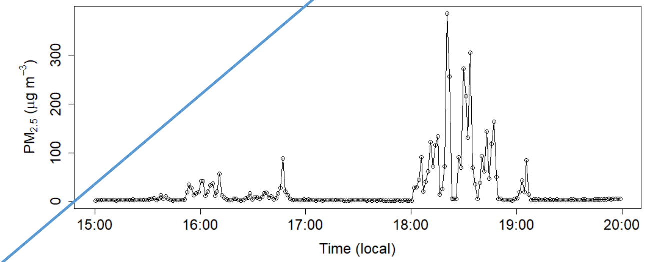


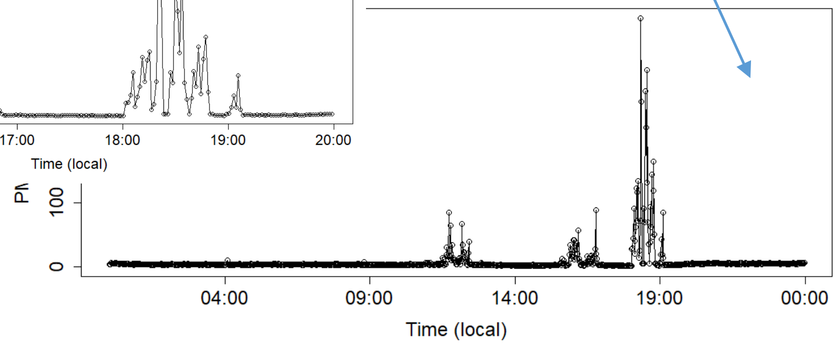
Sensor Measurements

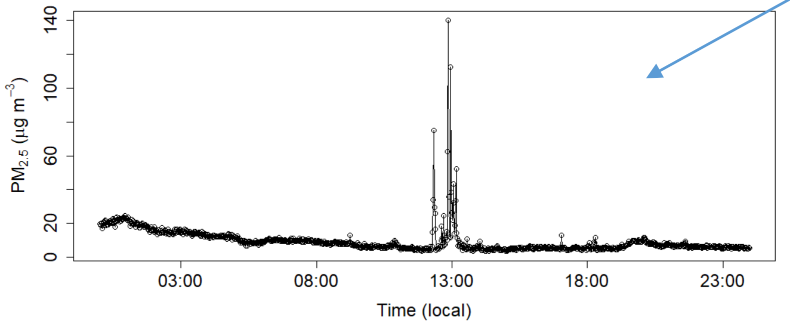
- Short term events, at PA05 – more detail

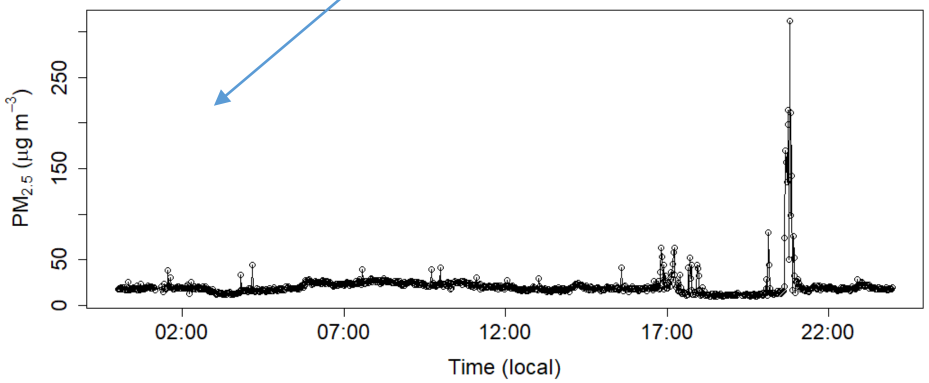






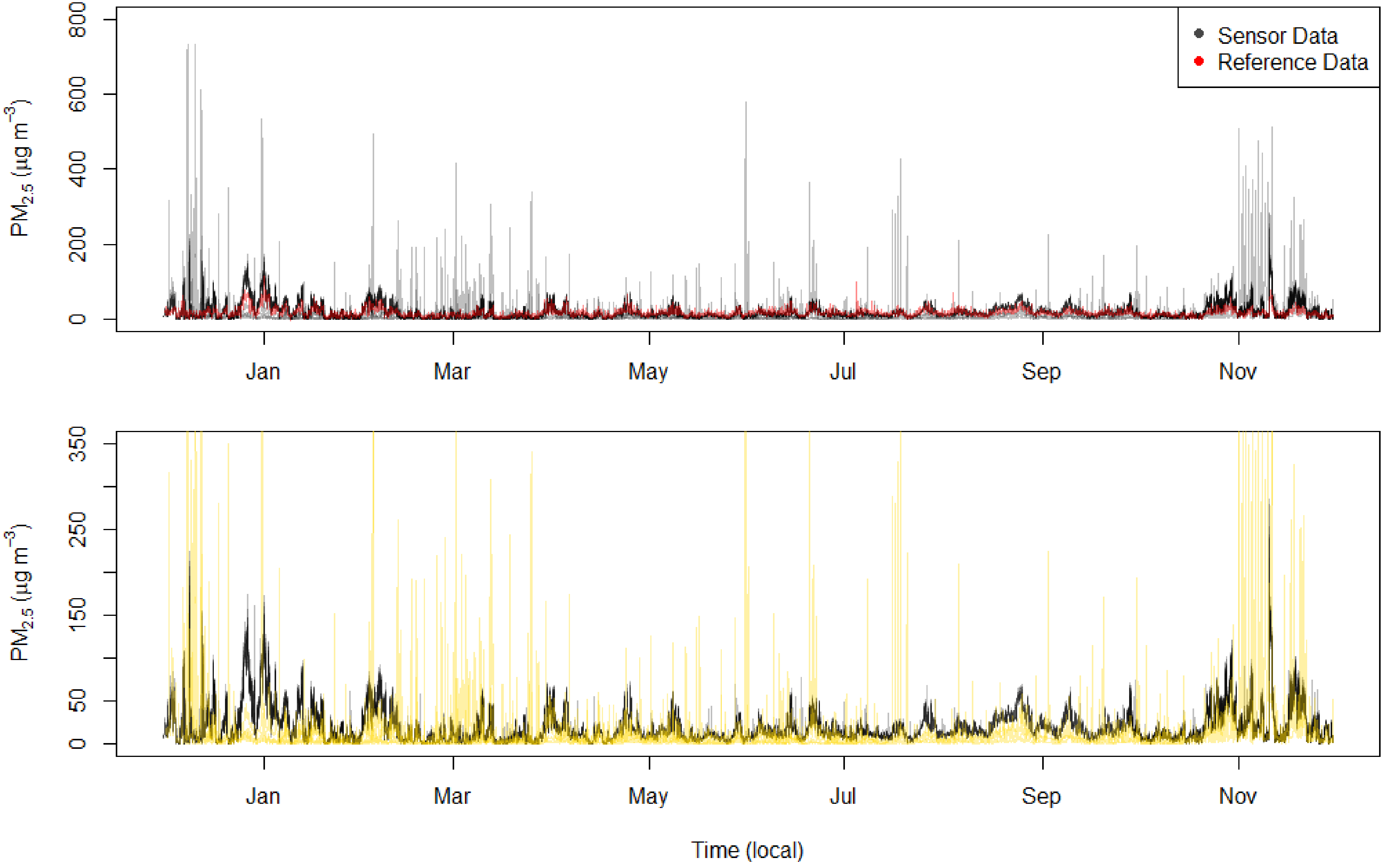






Sensors Excluded from Analysis

- Sensors: 13, 17, 22, 26
- Baseline does not match other outdoor sensors (yellow)
- **Mislabeled indoor sensor**



A Deeper Dive into the PurpleAir Data

- Polar plots of the difference between sites (i.e., east – west)
- **Meaning**
  - **Warmer colors indicate higher PM at sites east of the freeway**
  - **Cooler colors indicate higher PM at sites west of the freeway**
- Additionally, looking at raw particle counts (instead of mass concentration), in an effort to better target vehicle emissions
  - 0.03 µm < # of particles < 0.2 µm