The Pittsburgh RAMP network: Development, deployment, results, and lessons learned

Albert Presto

November 20, 2019

CACES

Carnegie Mellon University

Acknowledgments

Postdocs

PhD students

Collaborators

Funding Sources

This research is funded by U.S. EPA - Science To Achieve Results (STAR) Program Grant #

ALLEGHENY COUNTY ACHD HEALTH DEPARTMENT

THE HEINZ ENDOWMENTS
HOWARD HEINZ ENDOWMENT • VIRA I. HEINZ ENDOWMENT

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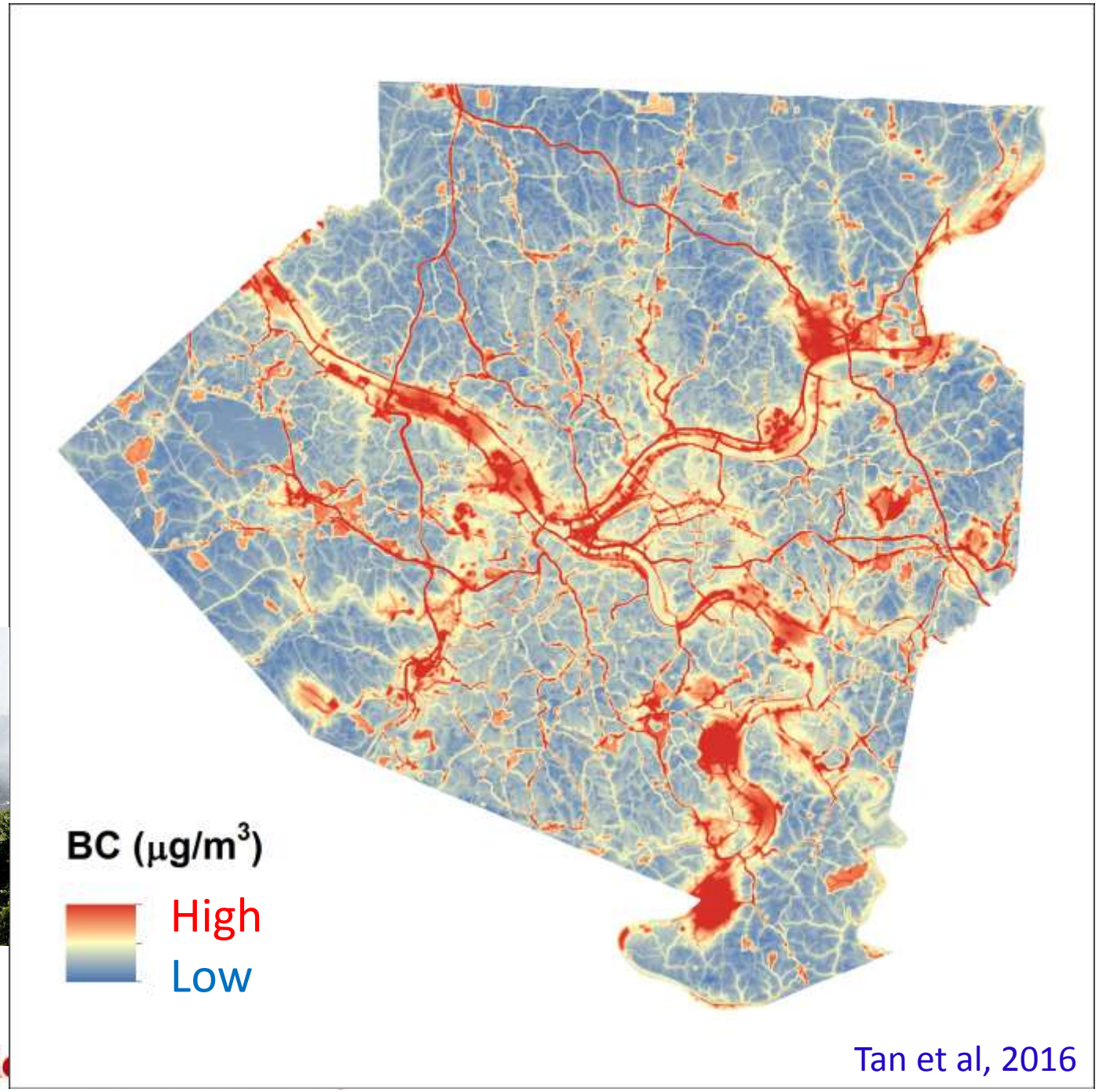
Three main points

- Low-cost sensors can meet EPA metrics for supplemental and exposure monitoring
- Citywide networks can be used to separate local emissions from regional climatology impacts and to evaluate environmental justice, but cannot capture all spatial variations
- Low-cost monitors are good candidates for monitoring in case of extreme or unexpected events

The trend: Hyper-local air quality



Tan et al, 2016

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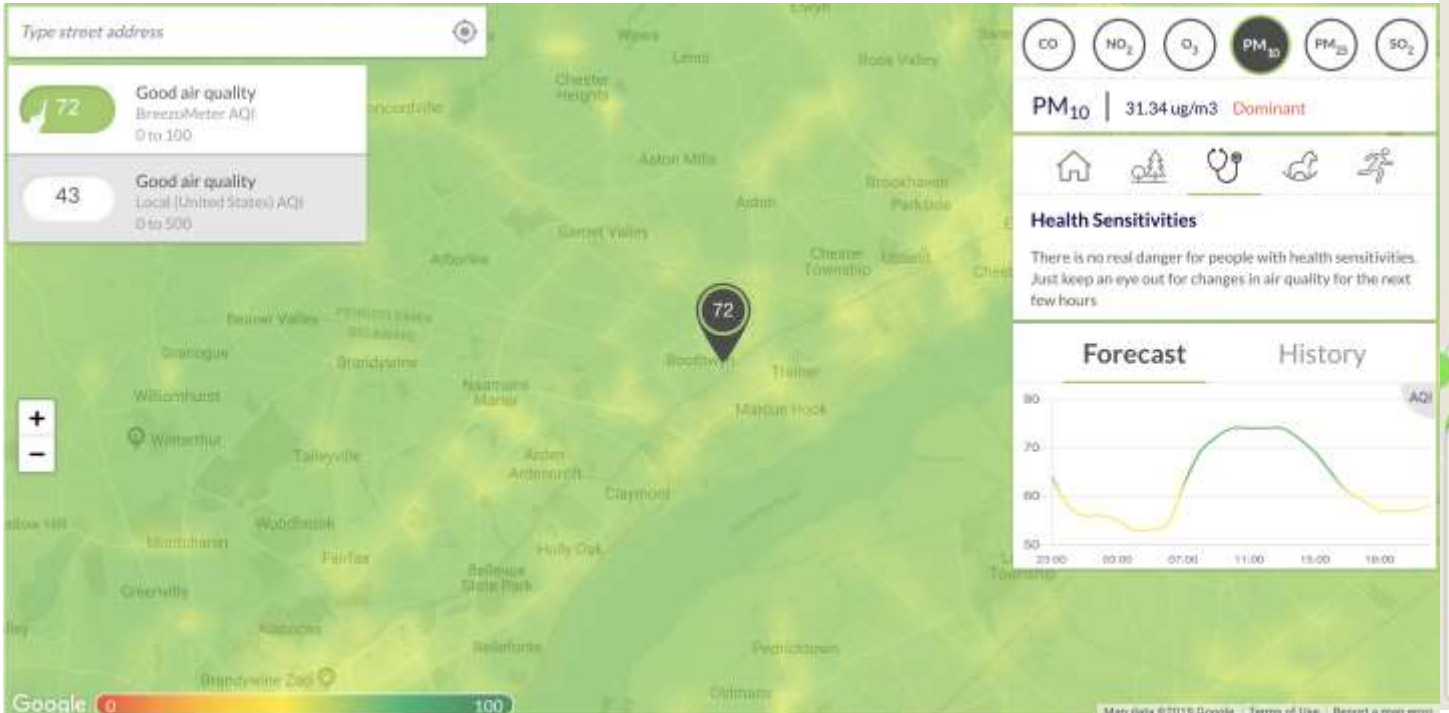
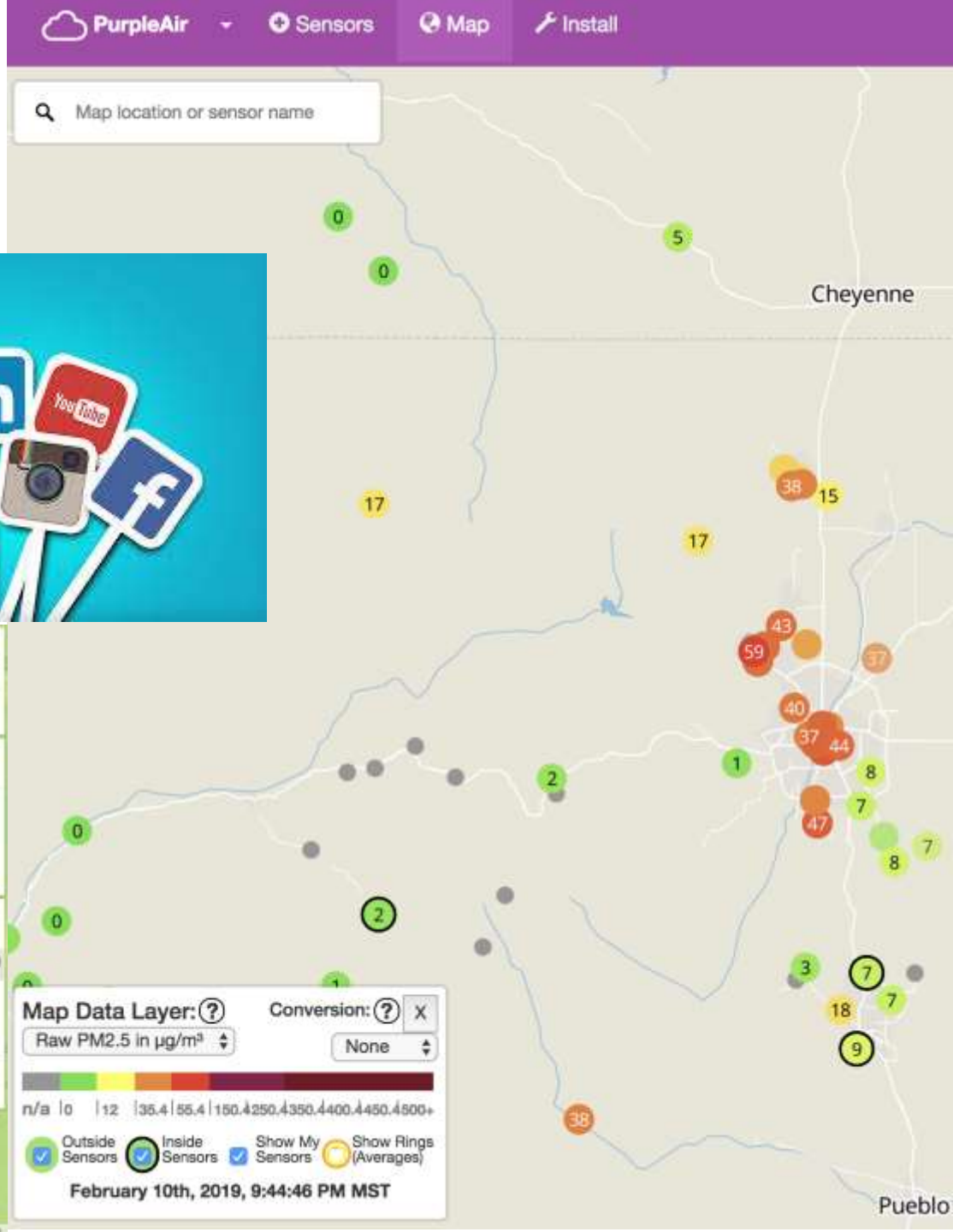
The trend: Hyper-local air quality + social media





Many low-cost sensors are commercially available

PM Sensors

Sensor Image	Make (Model)	Est. Cost (USD)	Pollutant(s)	*Field R^2	*Lab R^2	Summary Report
	Aeroqual (AQY) Ver. 0.5	$3,000	$PM_{2.5}$	0.84 to 0.87	0.99	PDF (1,178 KB)
	AethLabs (microAeth)	$6,500	BC (Black Carbon)	0.79 to 0.94		
	Air Quality Egg (2018 Model)	$249	$PM_{1.0}$	0.86 to 0.88	0.99	PDF (771 KB)
			$PM_{2.5}$	0.84 to 0.85	0.99	
			PM_{10}	0.12 to 0.13		
	Air Quality Egg (Version 1)	$200	PM	~ 0.0		
	Air Quality Egg (Version 2)		PM	$PM_{2.5}$: 0.79 to 0.85 PM_{10}: 0.31 to 0.40		
	AirThinx (IAQ)	$1000	$PM_{1.0}$	0.68 to 0.70		
			$PM_{2.5}$	0.54 to 0.57		
			PM_{10}	0.03 to 0.05		
	Airviz Inc. (Speck)	$150	$PM_{2.5}$	0.32		
	Alphasense (OPC-N2)	$310	$PM_{1.0}$	0.63 to 0.82	0.99	PDF (1,291 KB)
			$PM_{2.5}$	0.65 to 0.80	0.99	
			PM_{10}	0.45 to 0.57	0.99	

Gaseous Sensors

Sensor Image	Make (Model)	Est. Cost(USD)	Type	Meas.	*Field R^2	*Lab R^2	Summary Report
	2B Technologies (POM)	$4,500	UV absorption (FEM Method)	O_3	1.00	0.99	PDF (1,295 KB)
	Aeroqual (AQY) Ver. 0.5	$3,000	Electrochem	NO_2	0.77	0.98	PDF (1,158 KB)
			Metal Oxide	O_3	0.95	0.98	PDF (1,163 KB)
	Aeroqual (S-500)	$500	Metal Oxide	O_3	0.85	0.99	PDF (1,197 KB)
	Air Quality Egg Ver. 1	$200	Metal Oxide	CO	0.0		
				NO_2	0.40		
				O_3	0.85		
	Air Quality Egg Ver. 2	$240	Electrochem	CO	0.0		
				NO_2	0.0		
	Air Quality Egg	$240	Electrochem	O_3	0.0 to 0.20		
				SO_2	n/a		

AQ-SPEC

Air Quality Sensor Performance Evaluation Center

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				NO_2	0.0		
	Air Quality Egg	$240	Electrochem	O_3	0.0 to 0.20		
				SO_2	n/a		

Real-time Affordable Multi-Pollutant (RAMP) monitor

- **Pollutants measured:**
- CO, O_3, NO_2, SO_2, $PM_{2.5}$
- GSM communication
- Deployed for 1+ year

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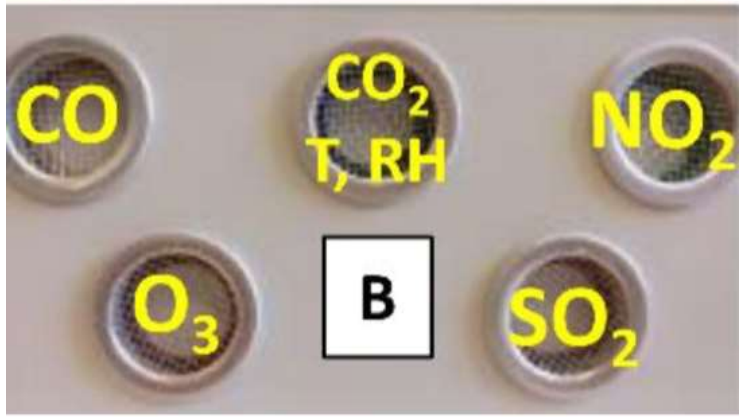
RAMPs use electrochemical gas sensors and optical $PM_{2.5}$ measurement



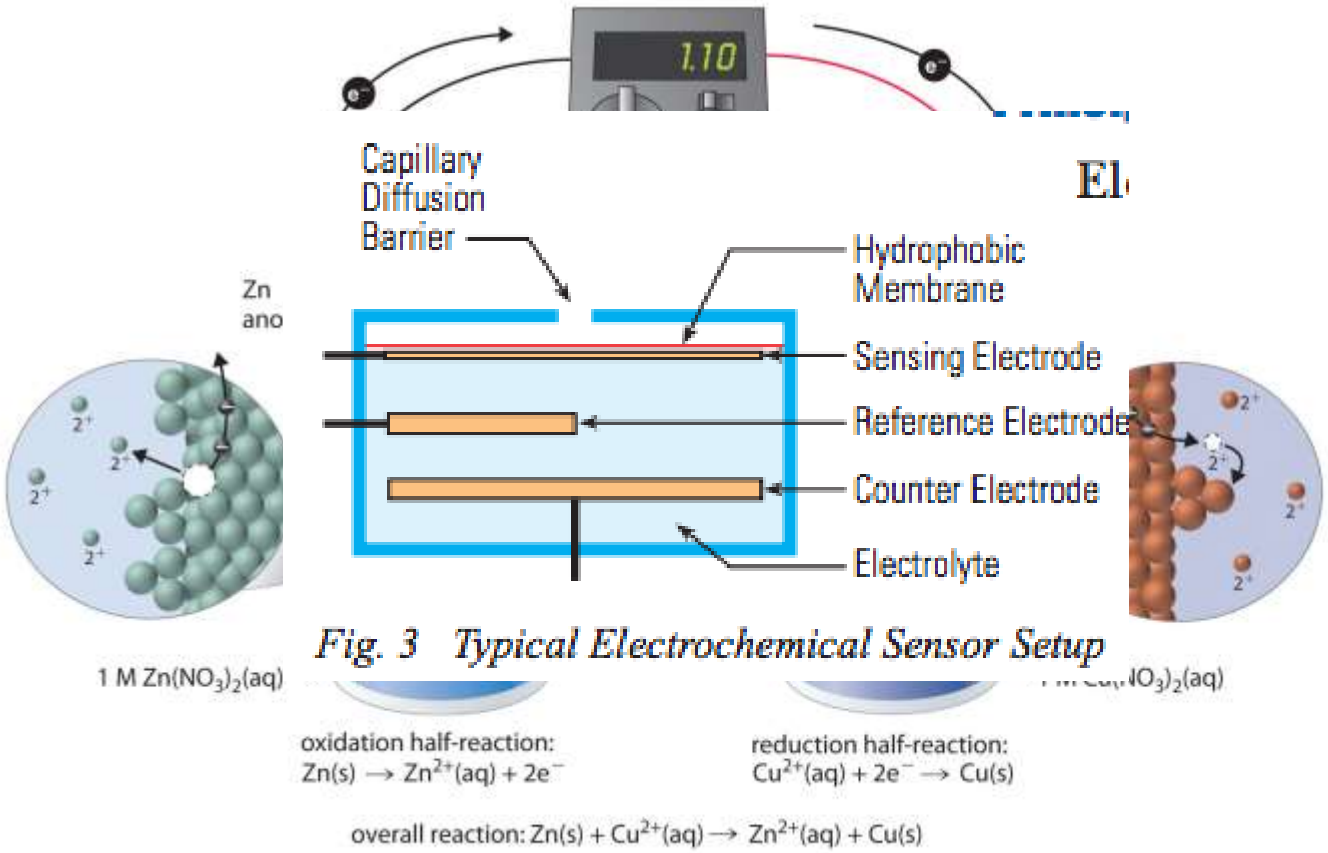


Fig. 3 Typical Electrochemical Sensor Setup

(b)

http://www.intlsensor.com/pdf/electrochemical.pdf

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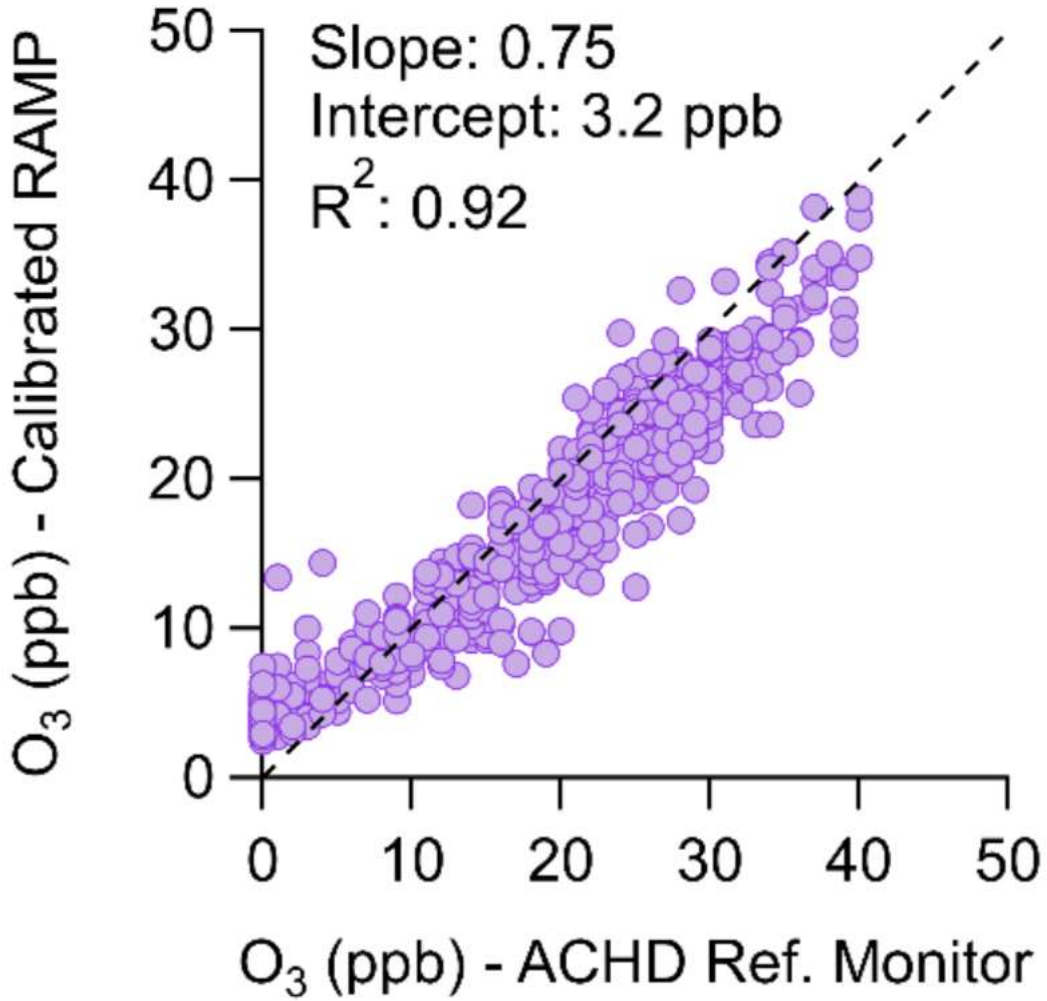
Zimmerman et al, *AMT*, 2018

We developed machine learning calibration algorithms for electrochemical gas sensors



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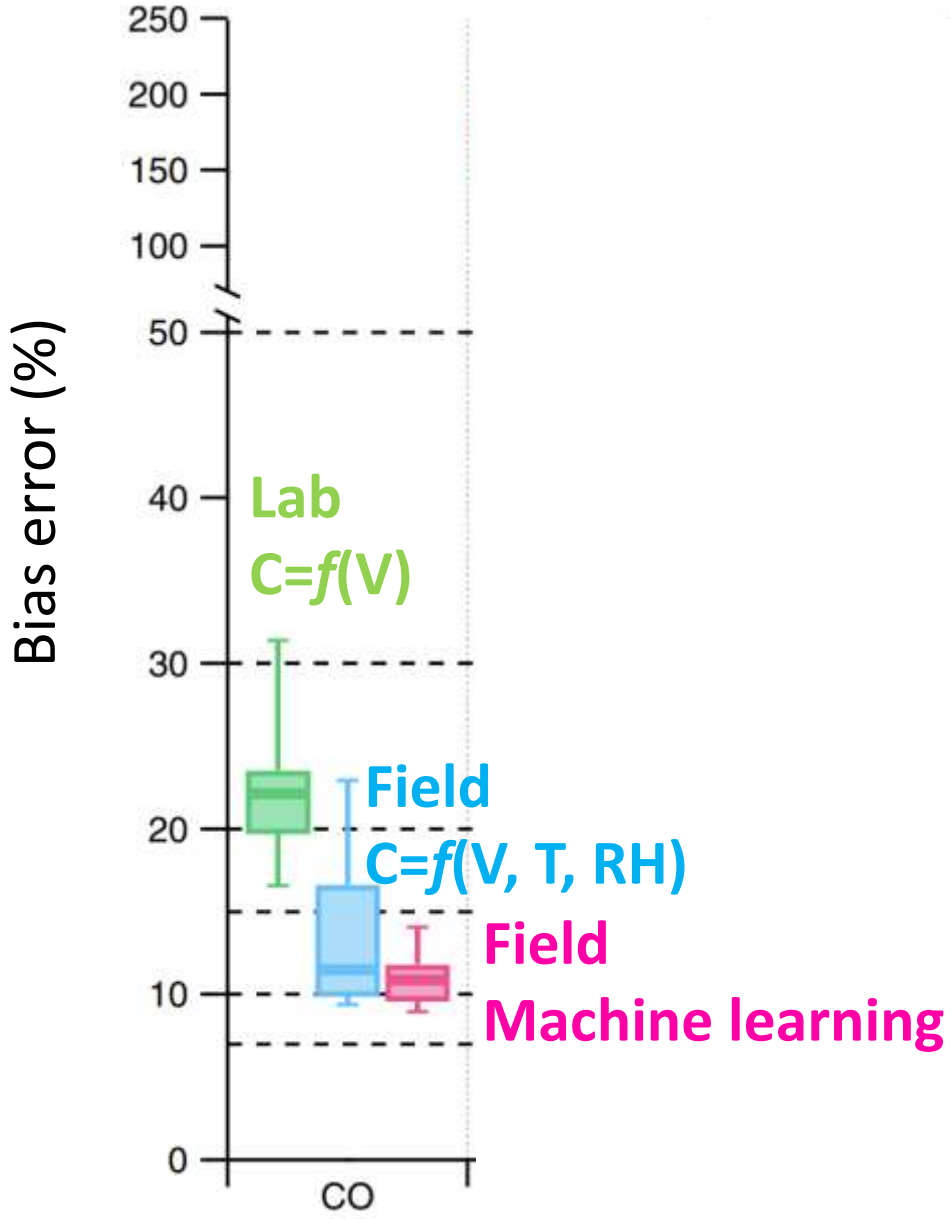
Zimmerman et al, *AMT*, 2018
Malings et al, *AMT*, 2019

Machine learning cals give performance close to EPA standards for reference monitoring



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Zimmerman et al, *AMT*, 2018

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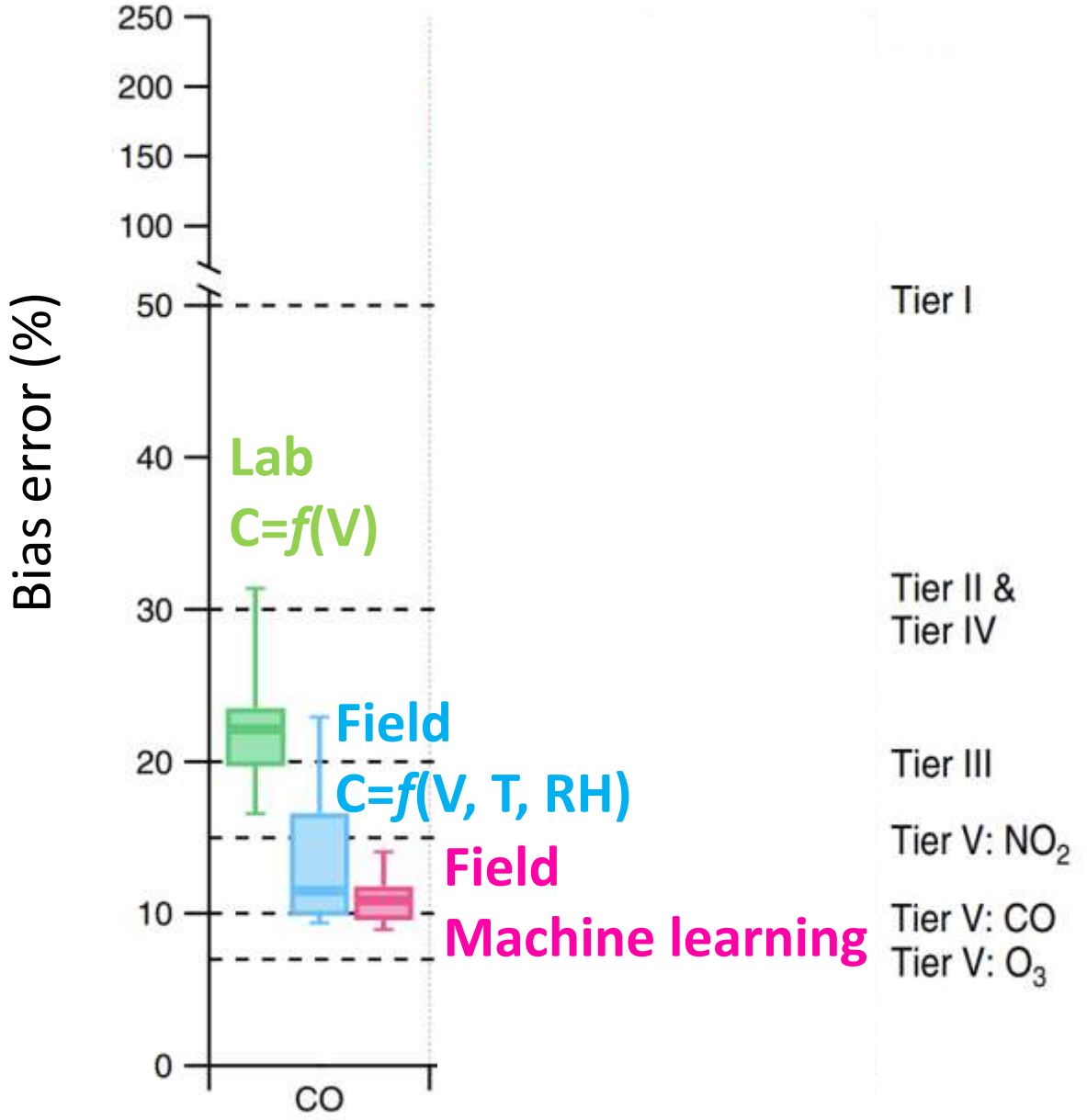

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Zimmerman et al, *AMT*, 2018

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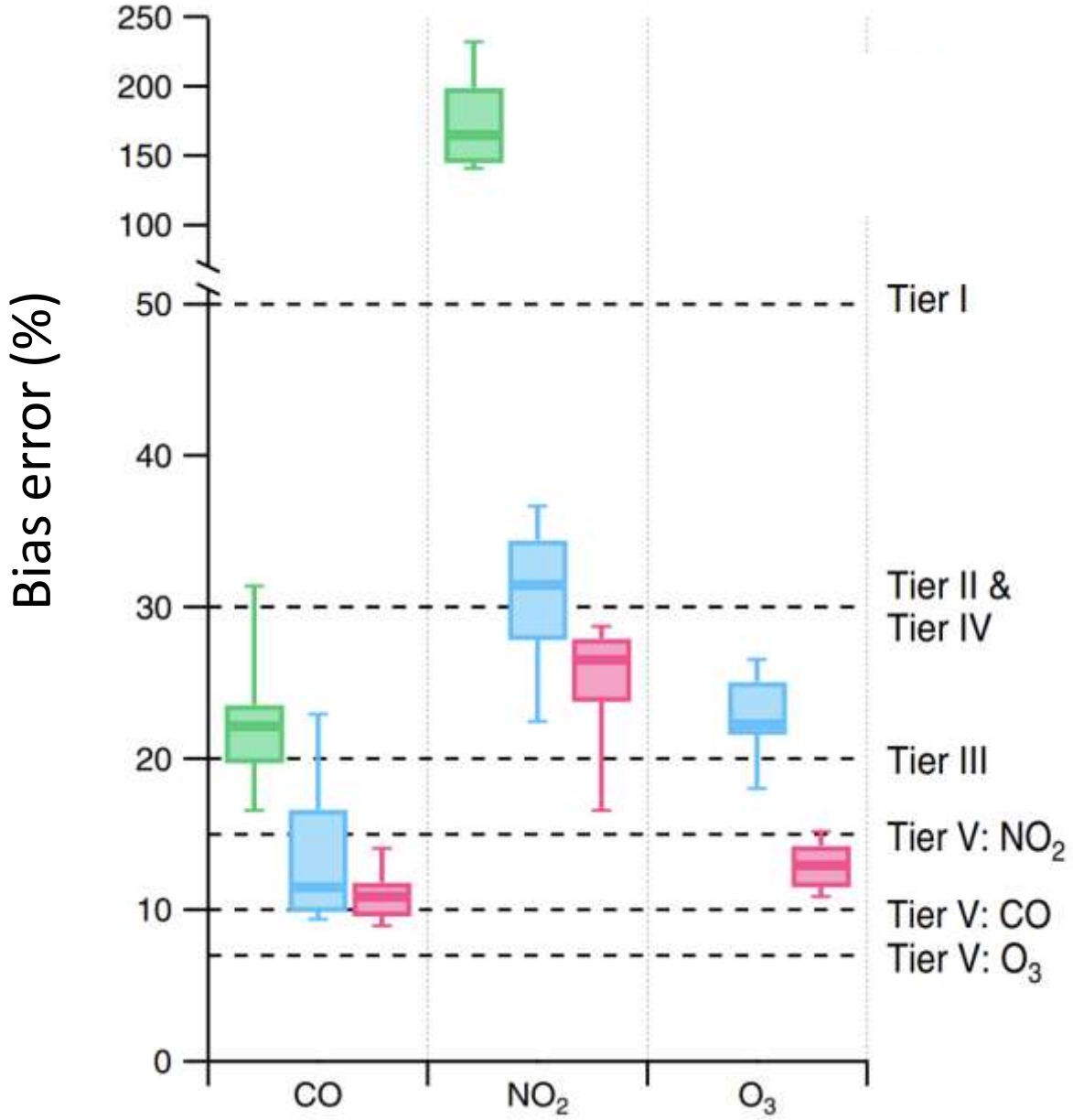
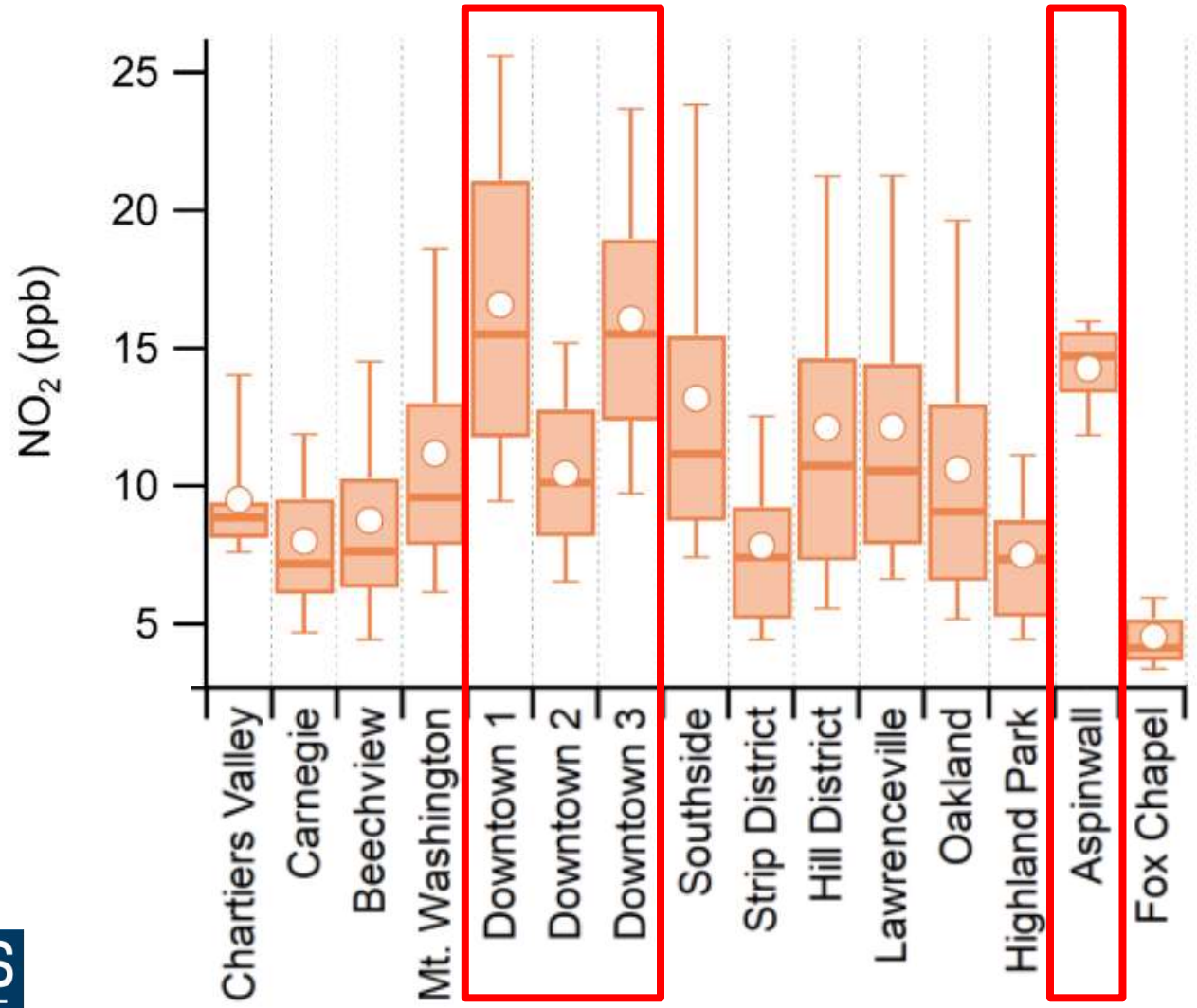


Zimmerman et al, *AMT*, 2018

Calibrations allow us to resolve differences between sites



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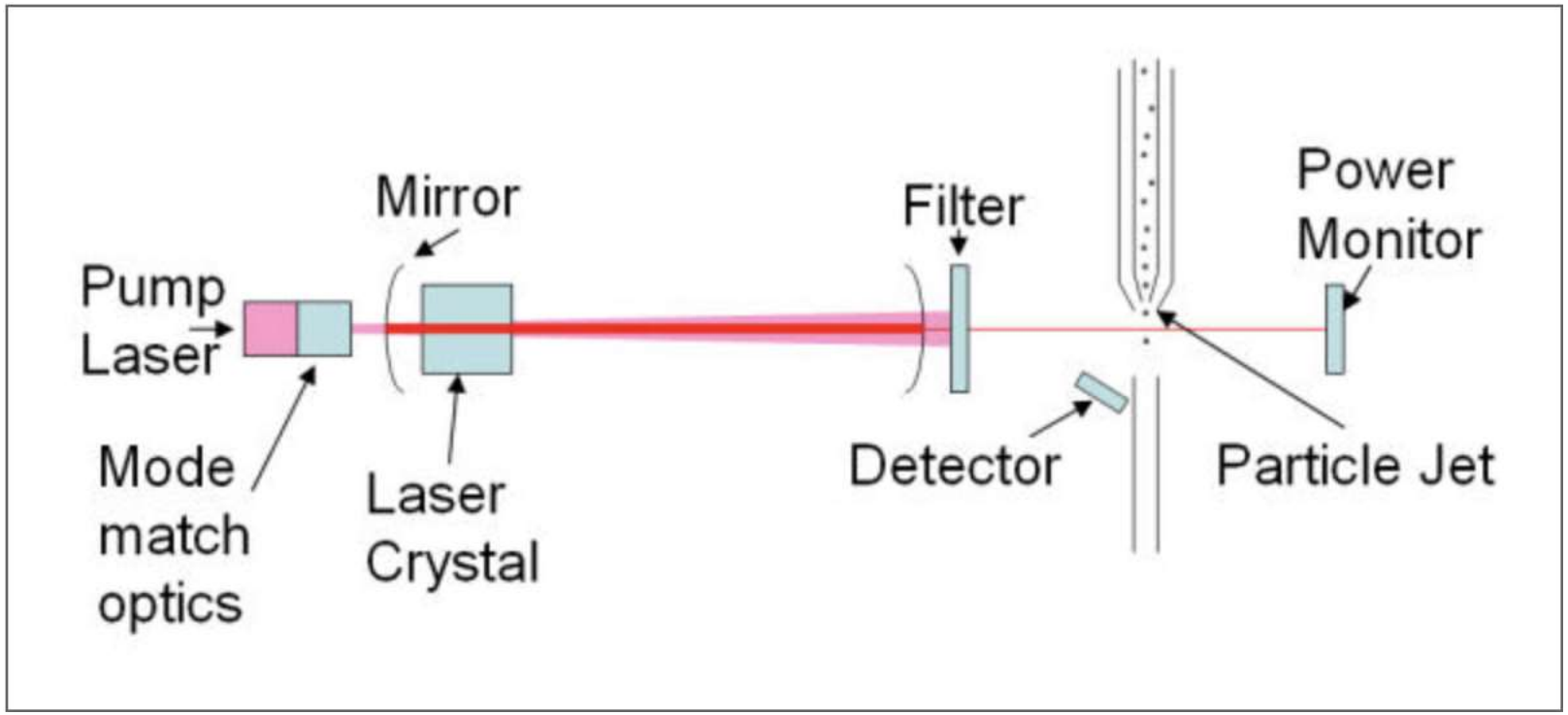
Zimmerman et al, *AAQR*, 2019

RAMPs use electrochemical gas sensors and optical $PM_{2.5}$ measurement



http://www.cas.manchester.ac.uk/restools/instruments/aerosol/opc/cavity/index.html

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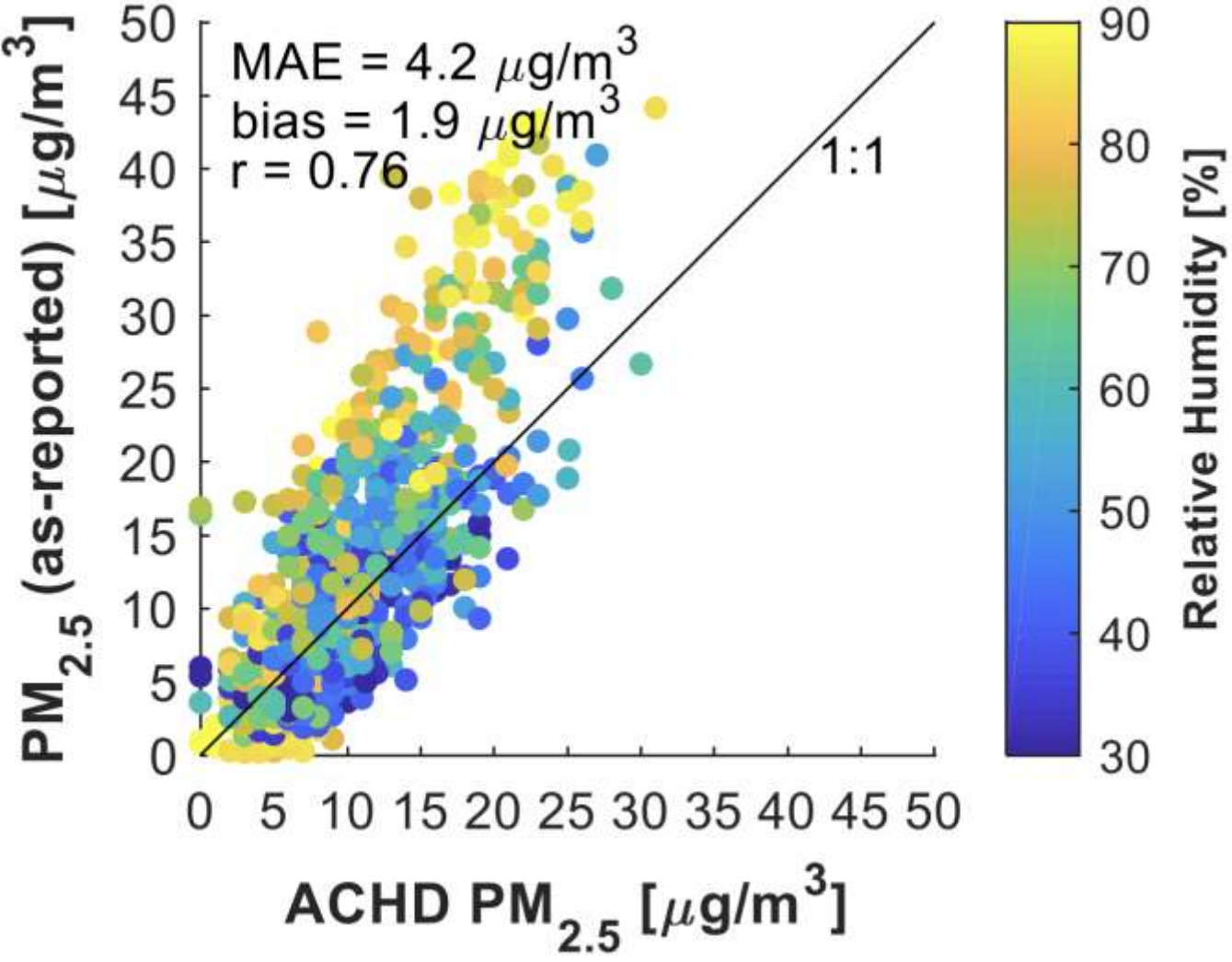
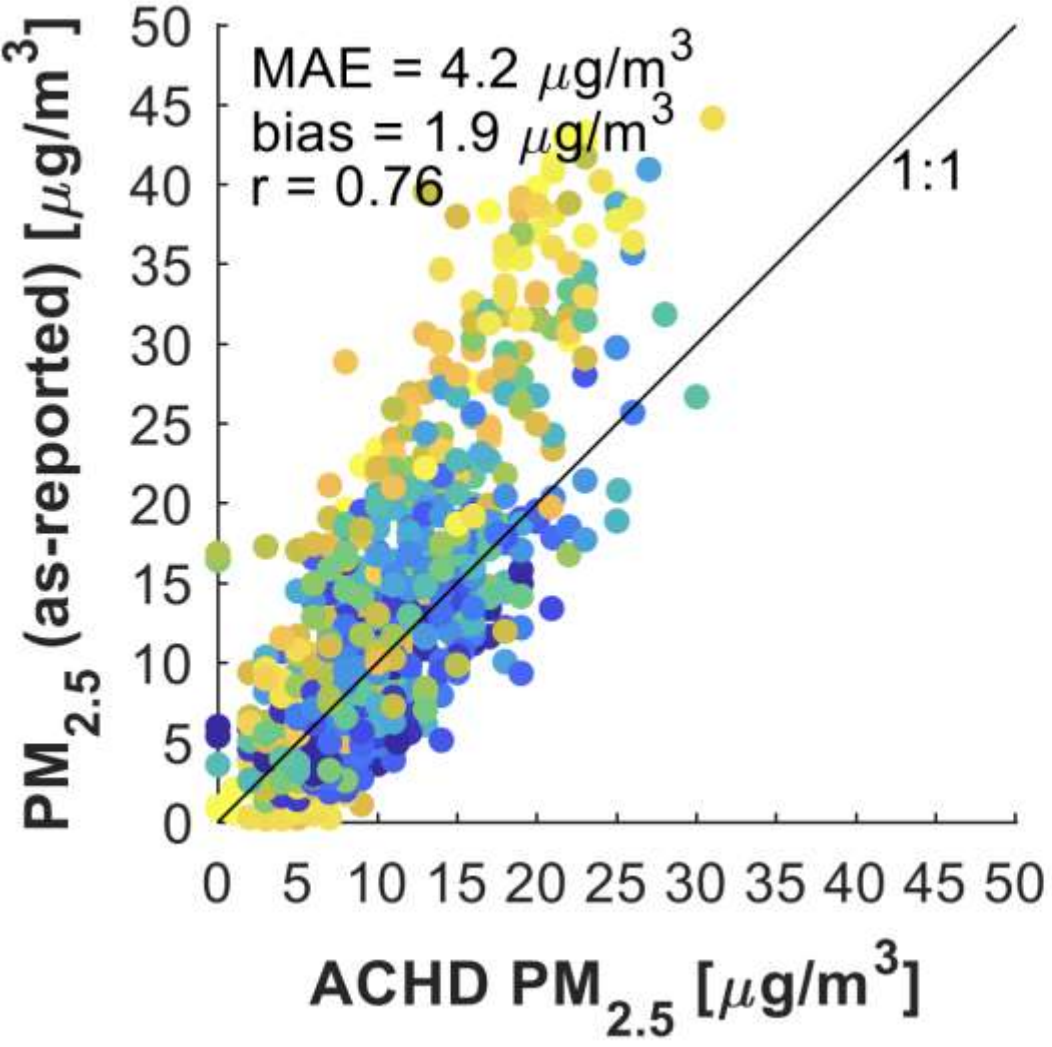
Raw Purple Air output shows humidity bias

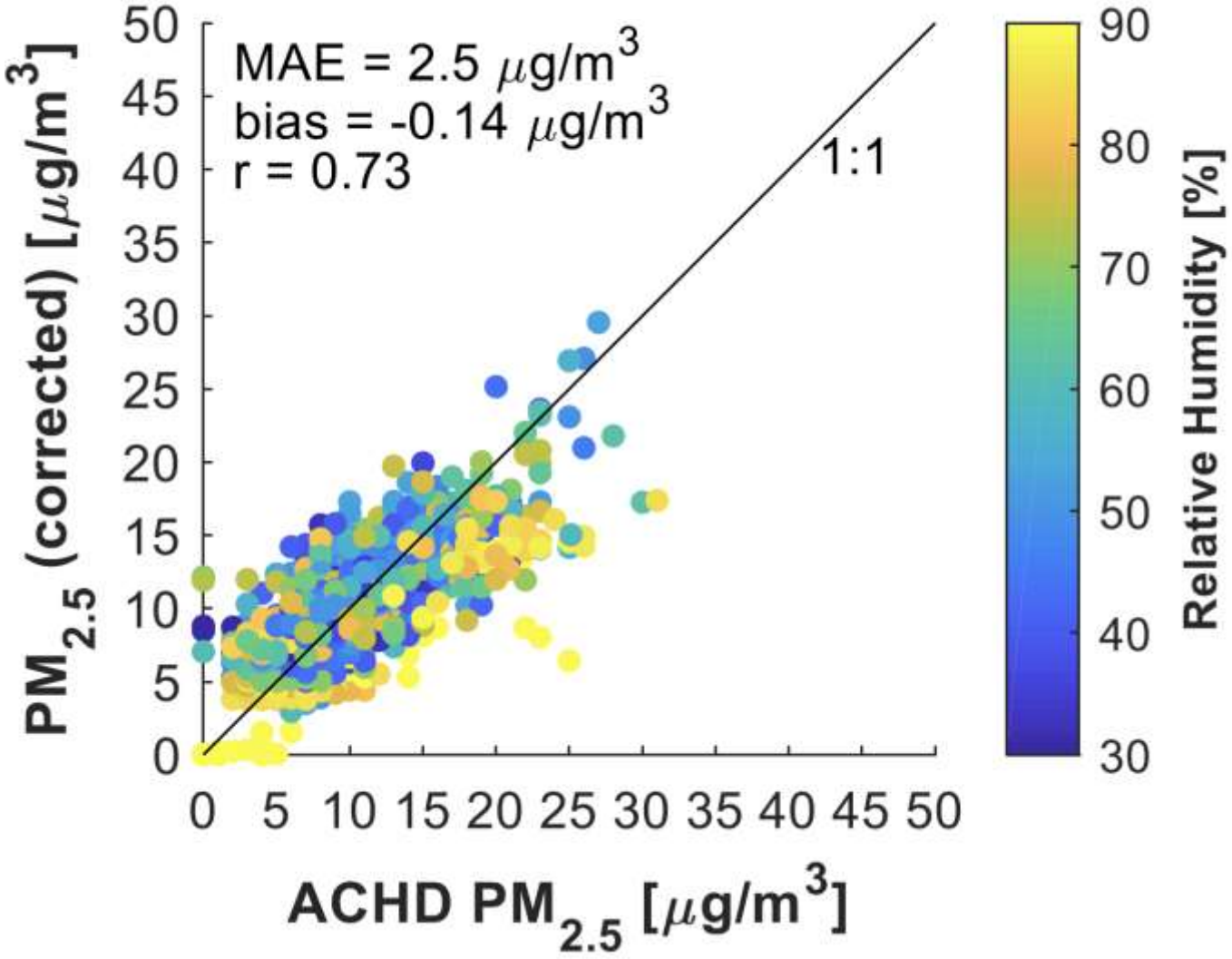


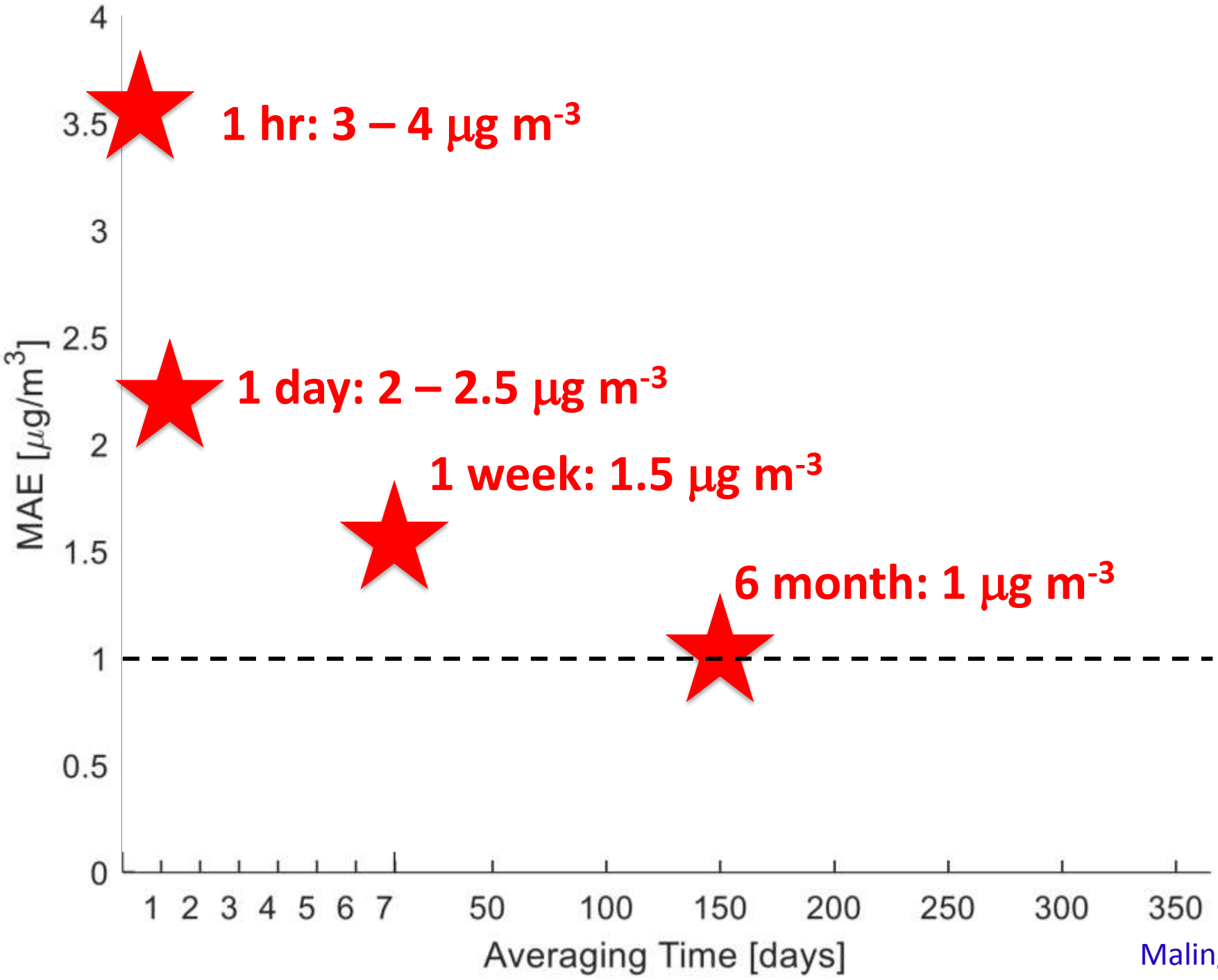
University

Malings et al, *AS&T*, 2019

Humidity correction removes the bias; hourly data are still scattered







Malings et al, *AS&T*, 2019

Pittsburgh RAMP network (2017)

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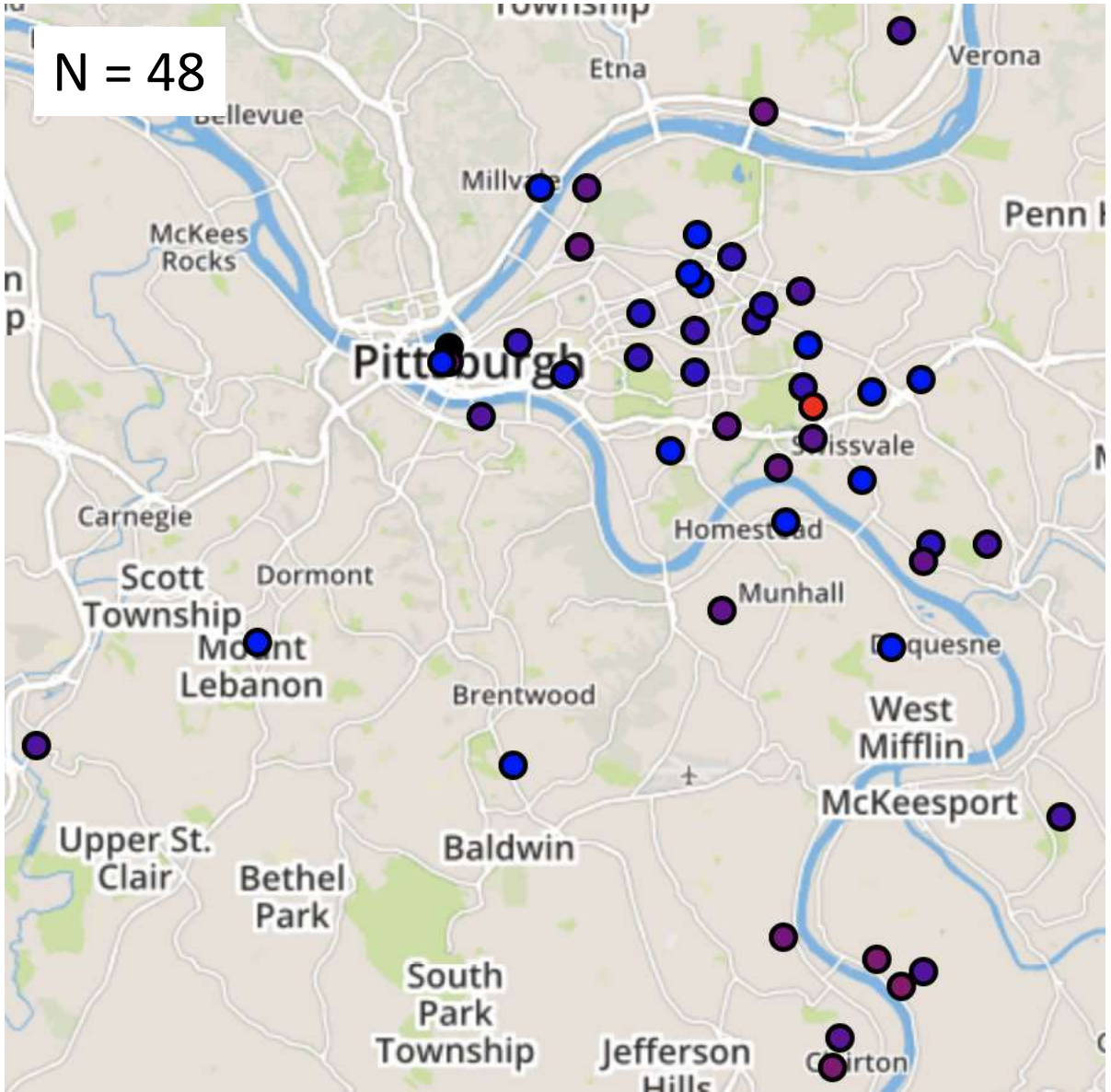

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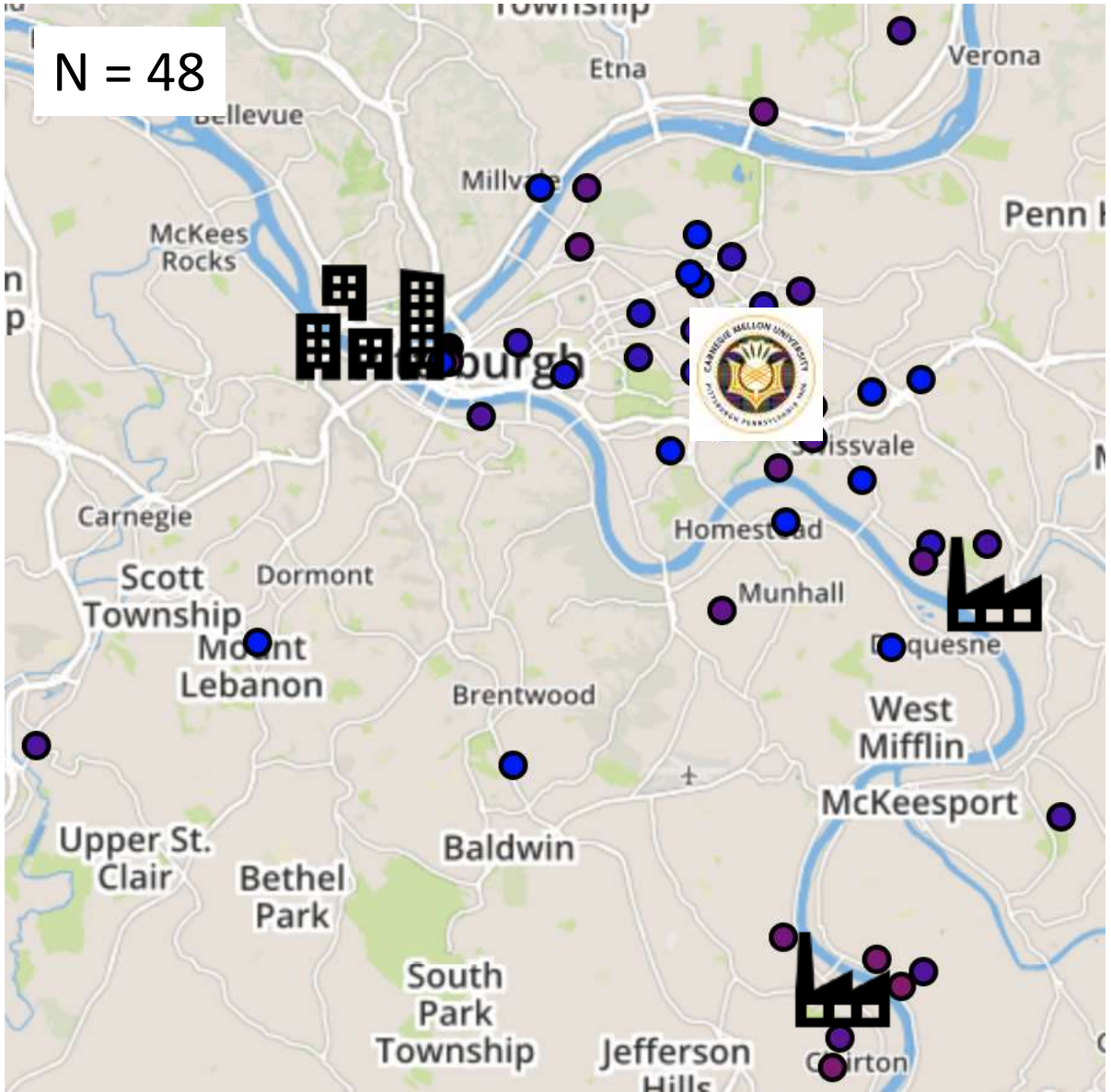
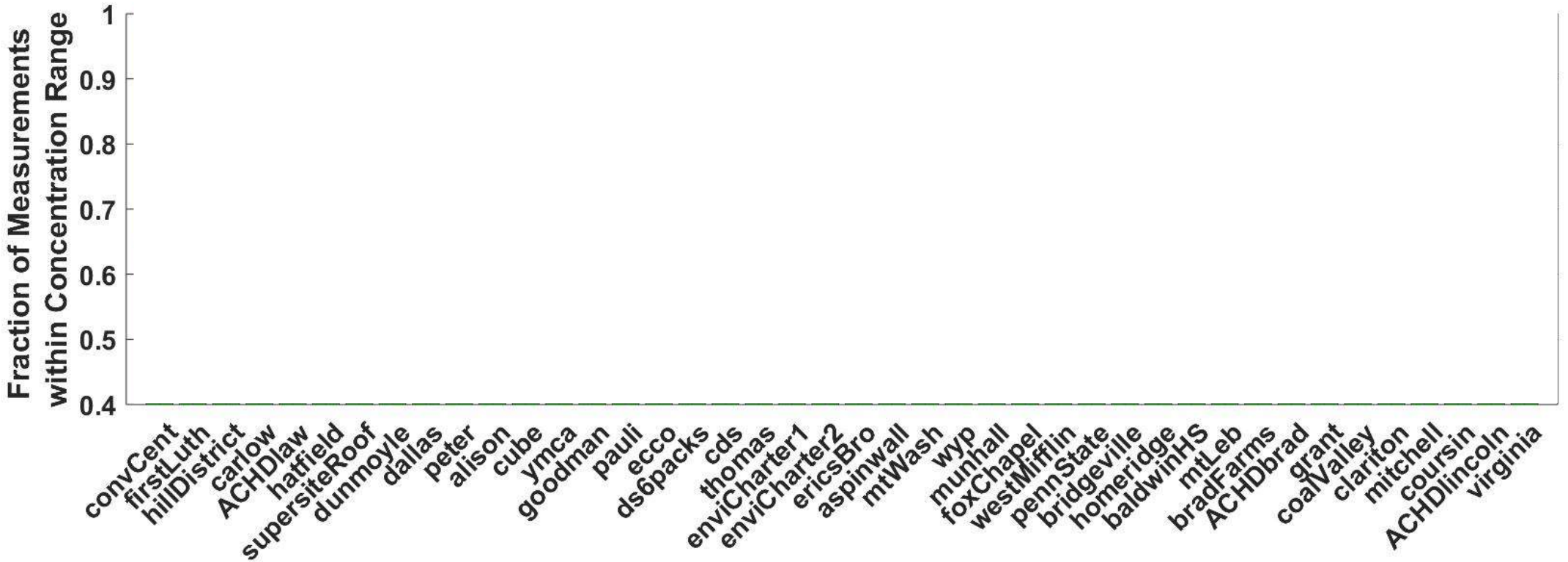


$PM_{2.5}$ spatial variability is largely driven by emissions spikes



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Tanzer et al, *IJERPH*, 2019

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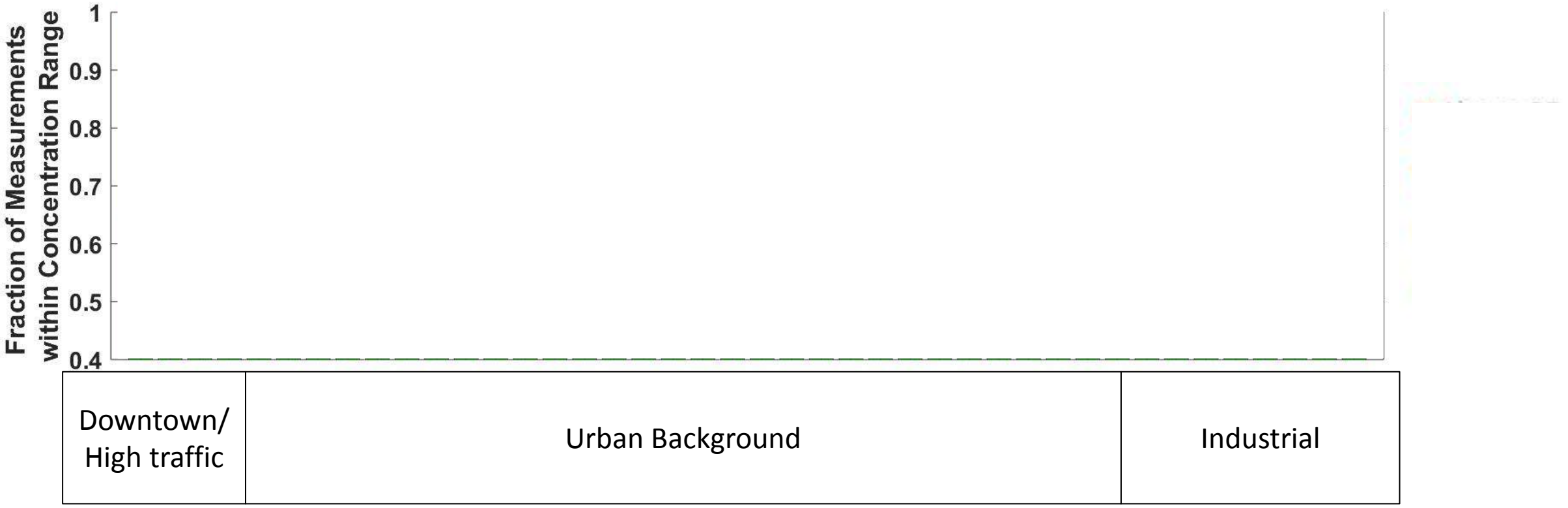

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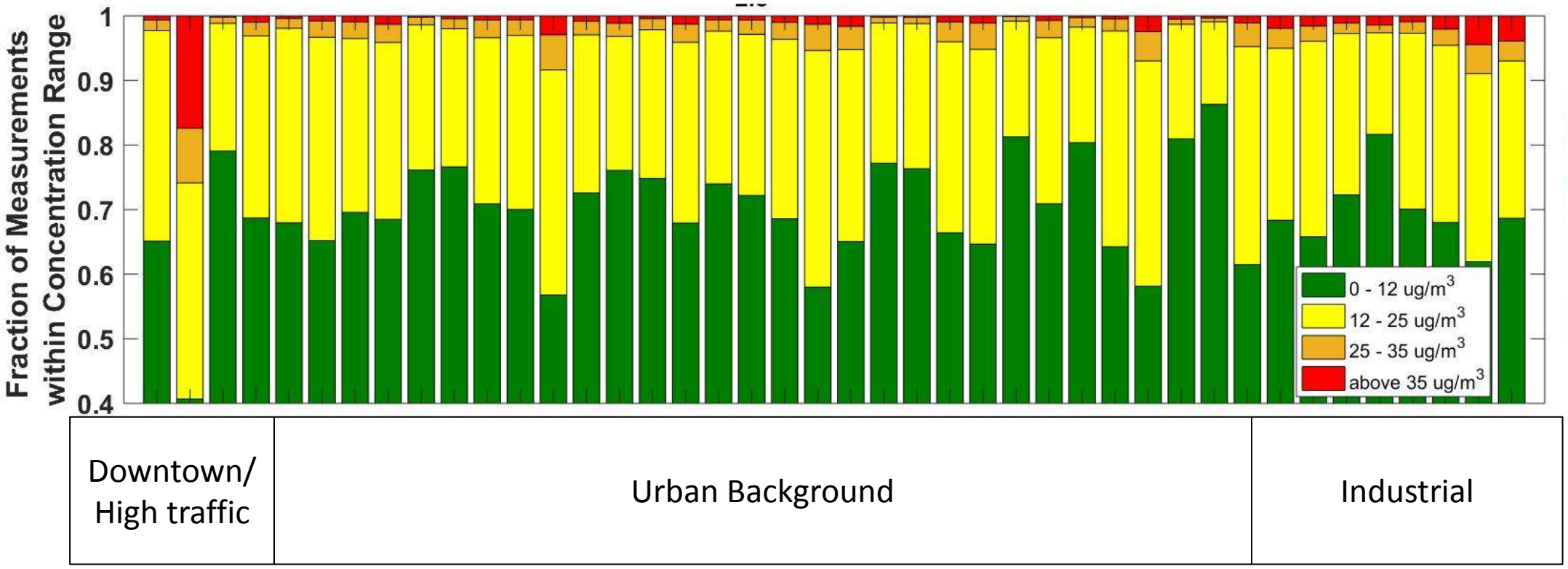

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Tanzer et al, *IJERPH*, 2019

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Tanzer et al, *IJERPH*, 2019

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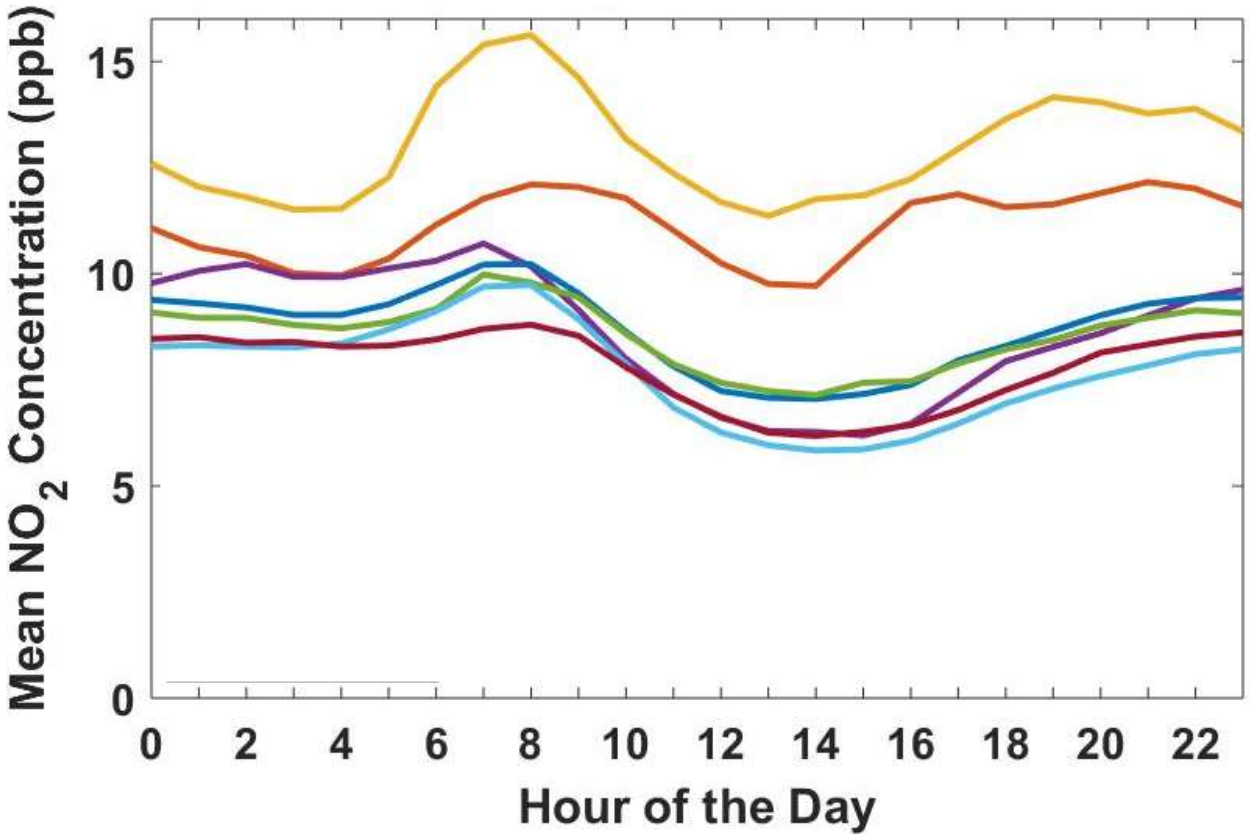
Tanzer et al, *IJERPH*, 2019

Some source-impacted sites are never "background"



Highway

Downtown

Downwind Industrial

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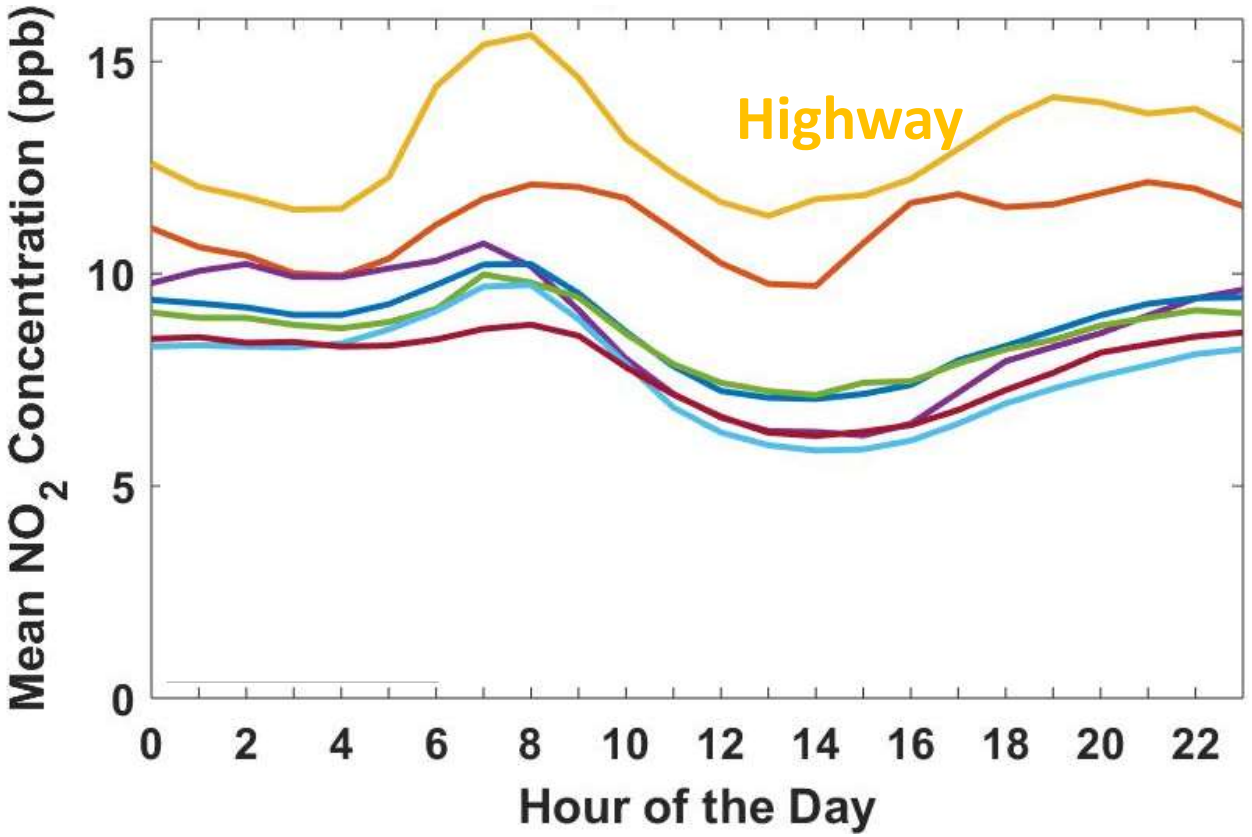
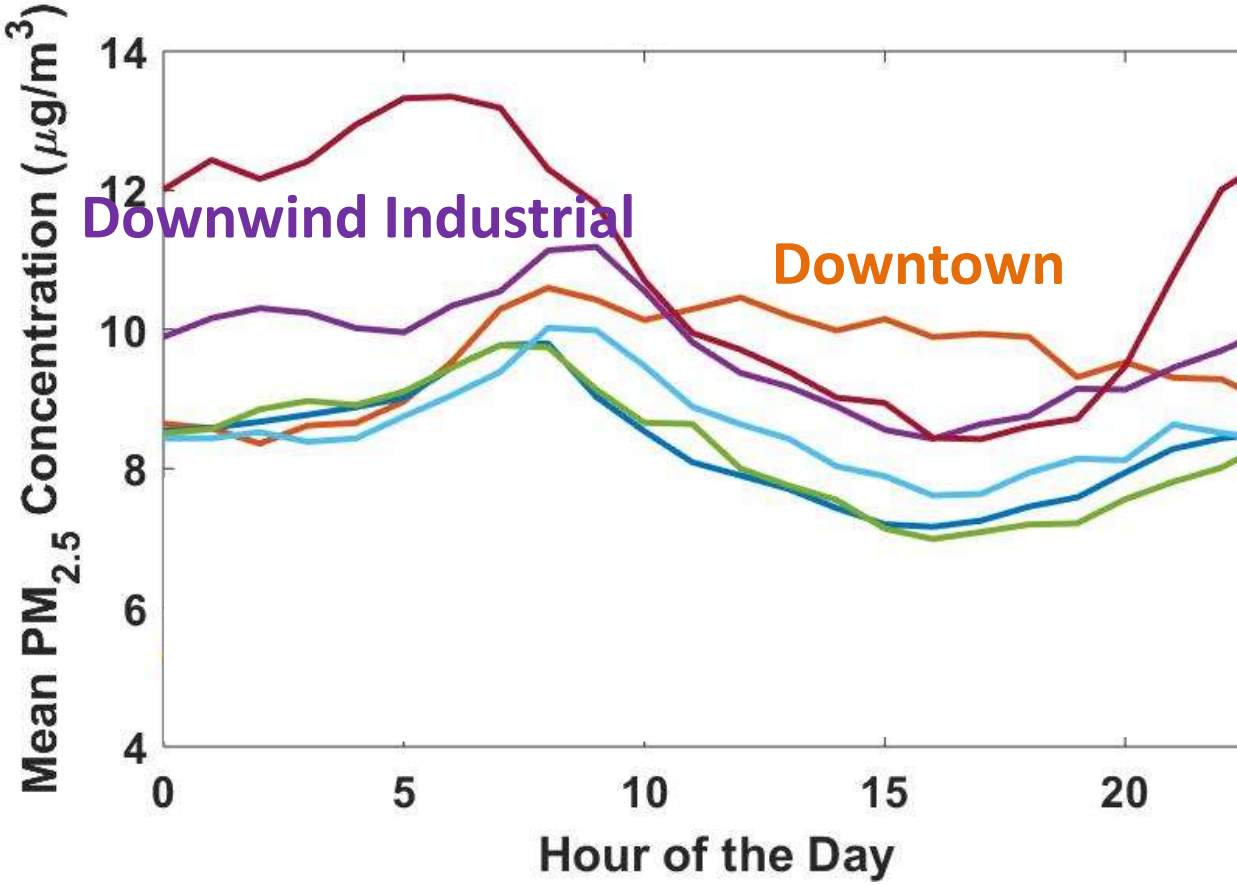
Tanzer et al, *IJERPH*, 2019

Some source-impacted sites are never "background" – but it depends on the pollutant





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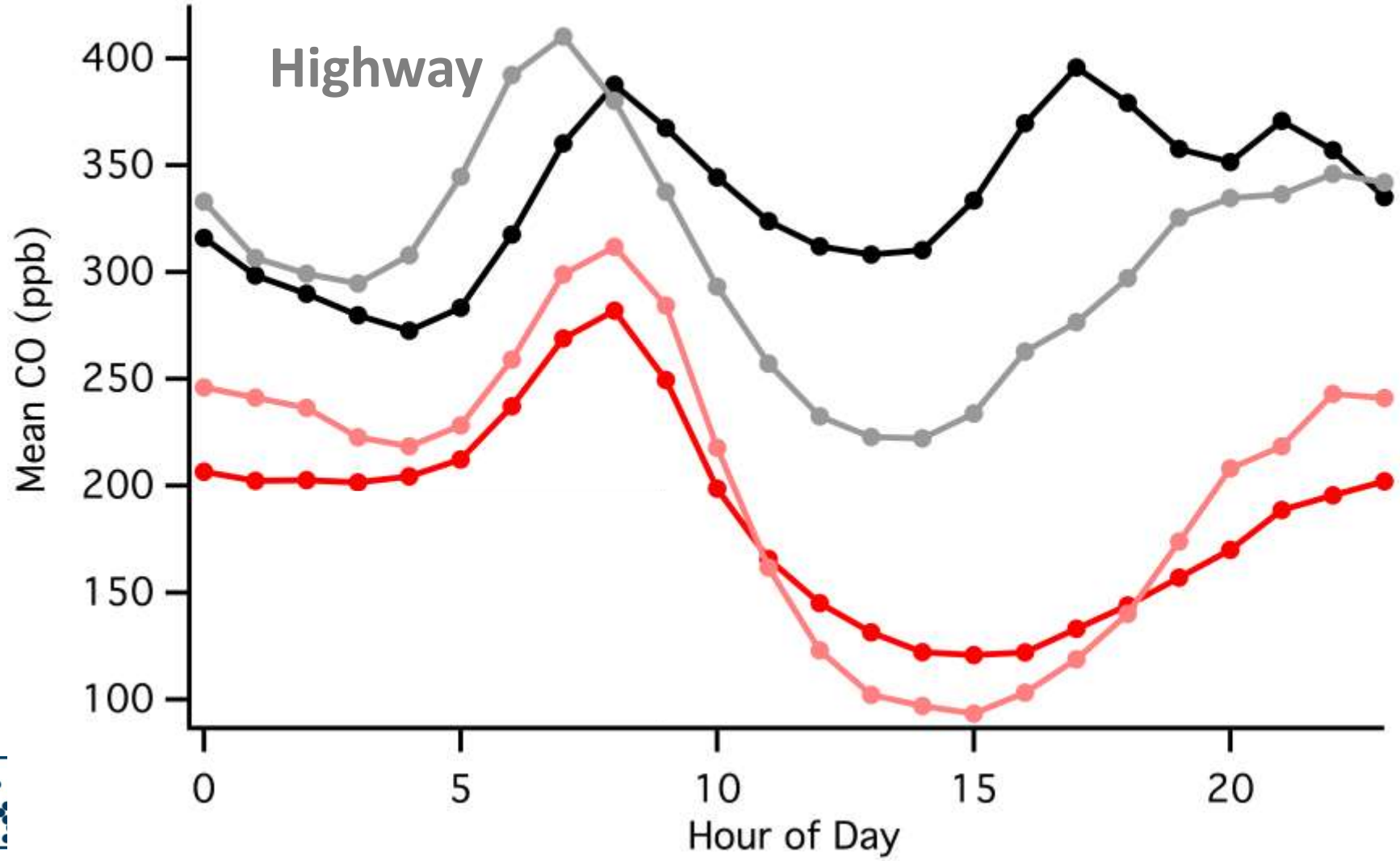
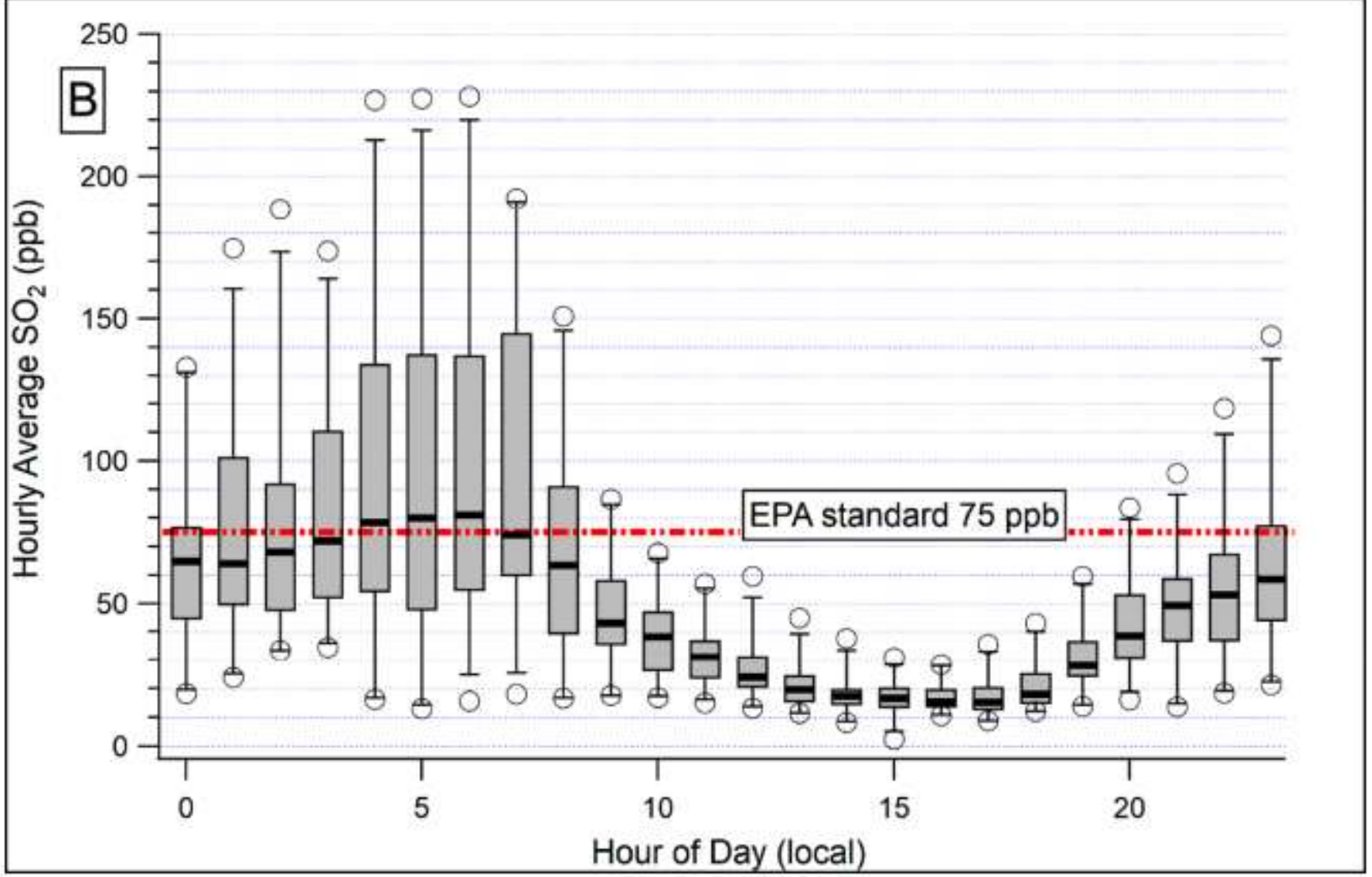
Tanzer et al, *IJERPH*, 2019

The network provides information on how exposure patterns change throughout the day



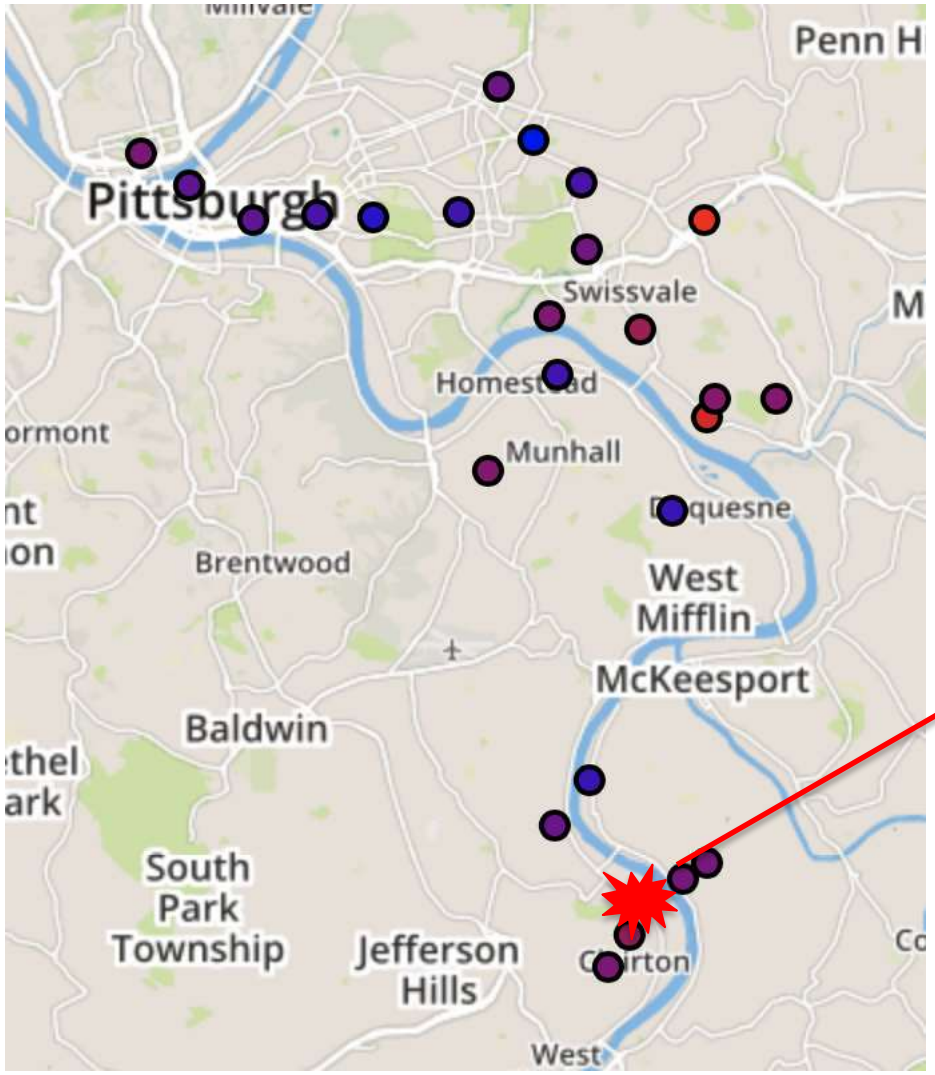
Application to extreme events



ACS EARTH AND SPACE CHEMISTRY

Air Quality in Puerto Rico in the Aftermath of Hurricane Maria: A Case Study on the Use of Lower Cost Air Quality Monitors

R. Subramanian,*[,†] Aja Ellis,[†,∞] Elvis Torres-Delgado,[‡] Rebecca Tanzer,[†] Carl Malings,[†] Felipe Rivera,[§] Maité Morales,[‡] Darrel Baumgardner,[∥] Albert Presto,[†] and Olga L. Mayol-Bracero[‡]



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Crews res lant

Thankfully, no o

798
Shares

12 PM EST Dec 24, 2018

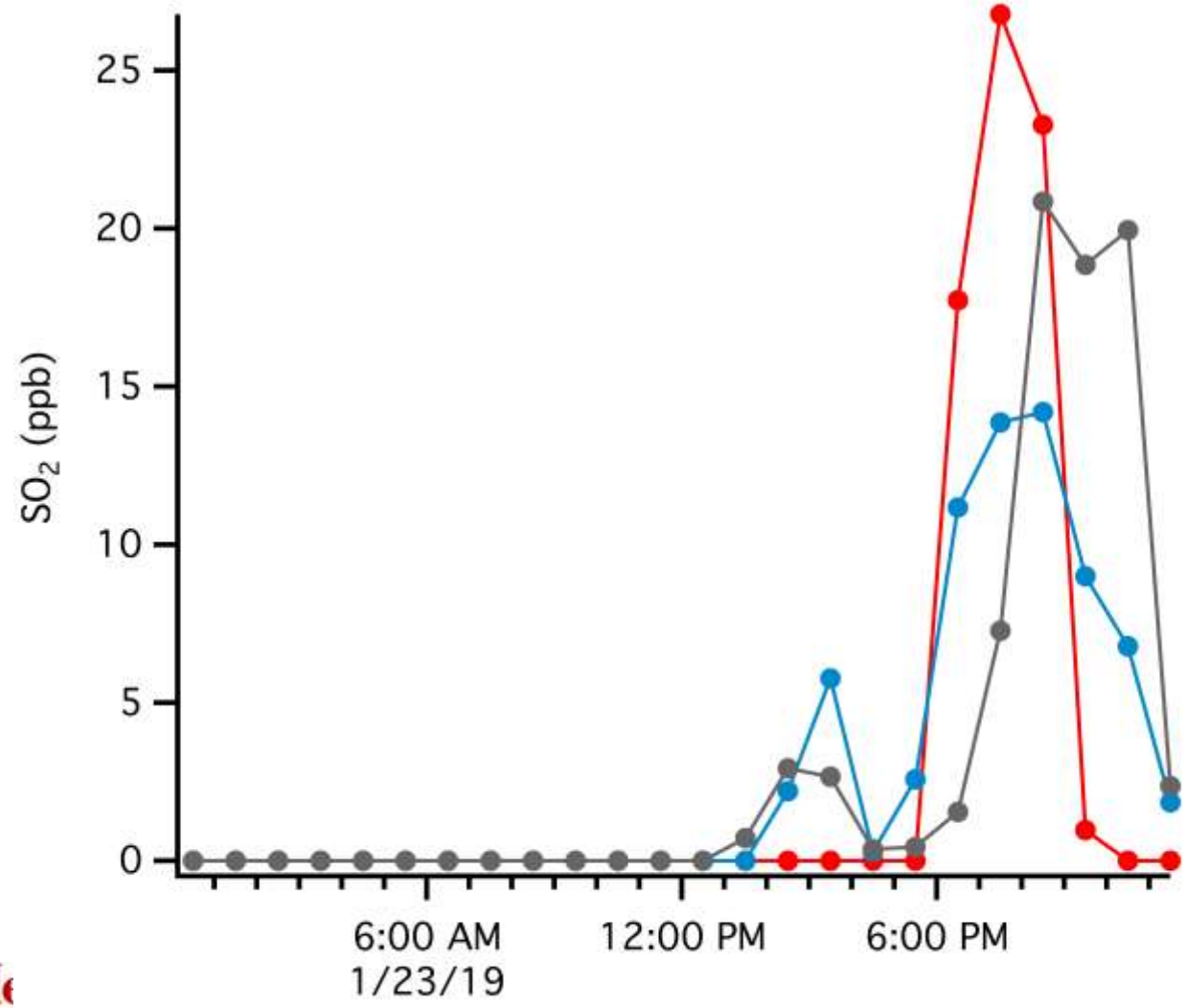
M Cl t

demand action after Coke works fire caused dangerous emissions

DON HOPEY
Pittsburgh Post-Gazette
dhopey@post-gazette.com

JAN 22, 2019 | 7:24 PM

The RAMP network captures upset events at Clairton



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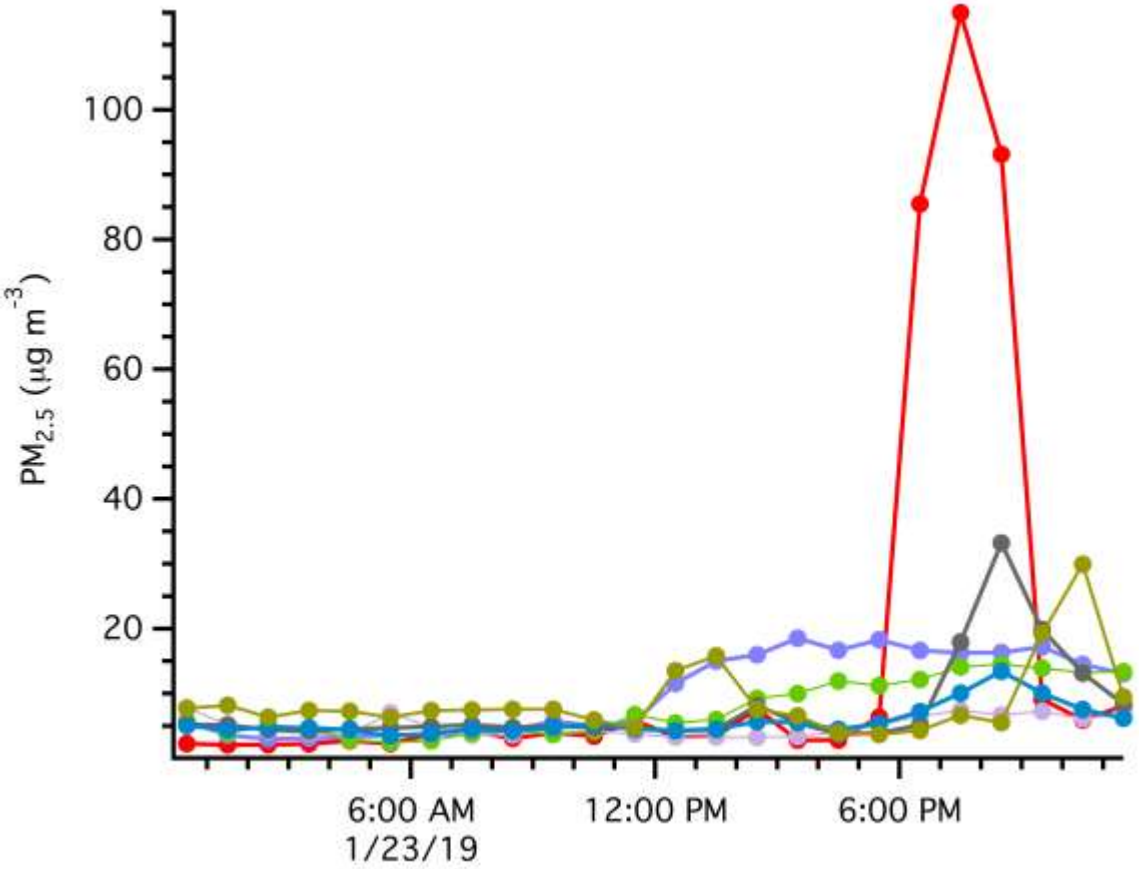

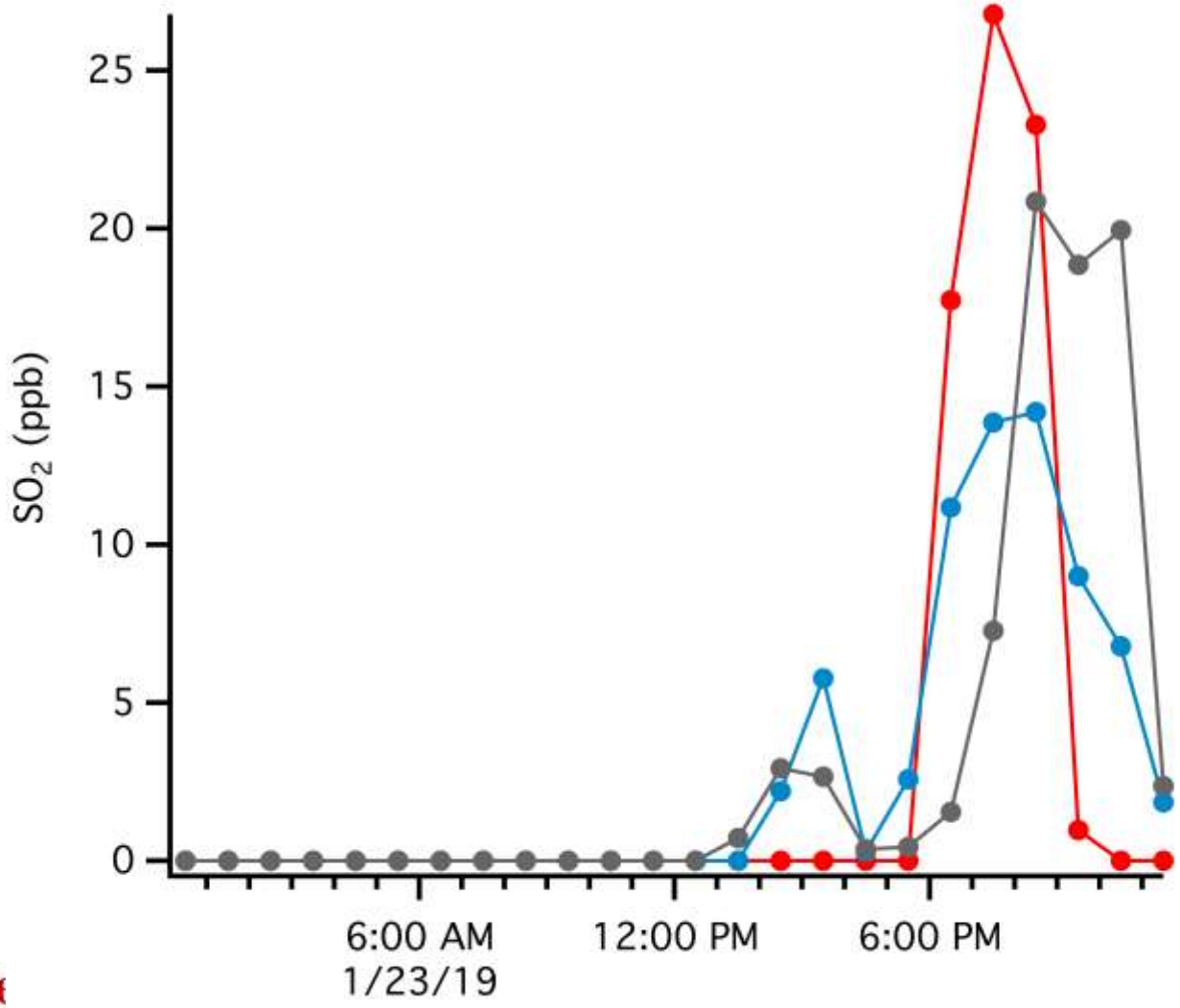

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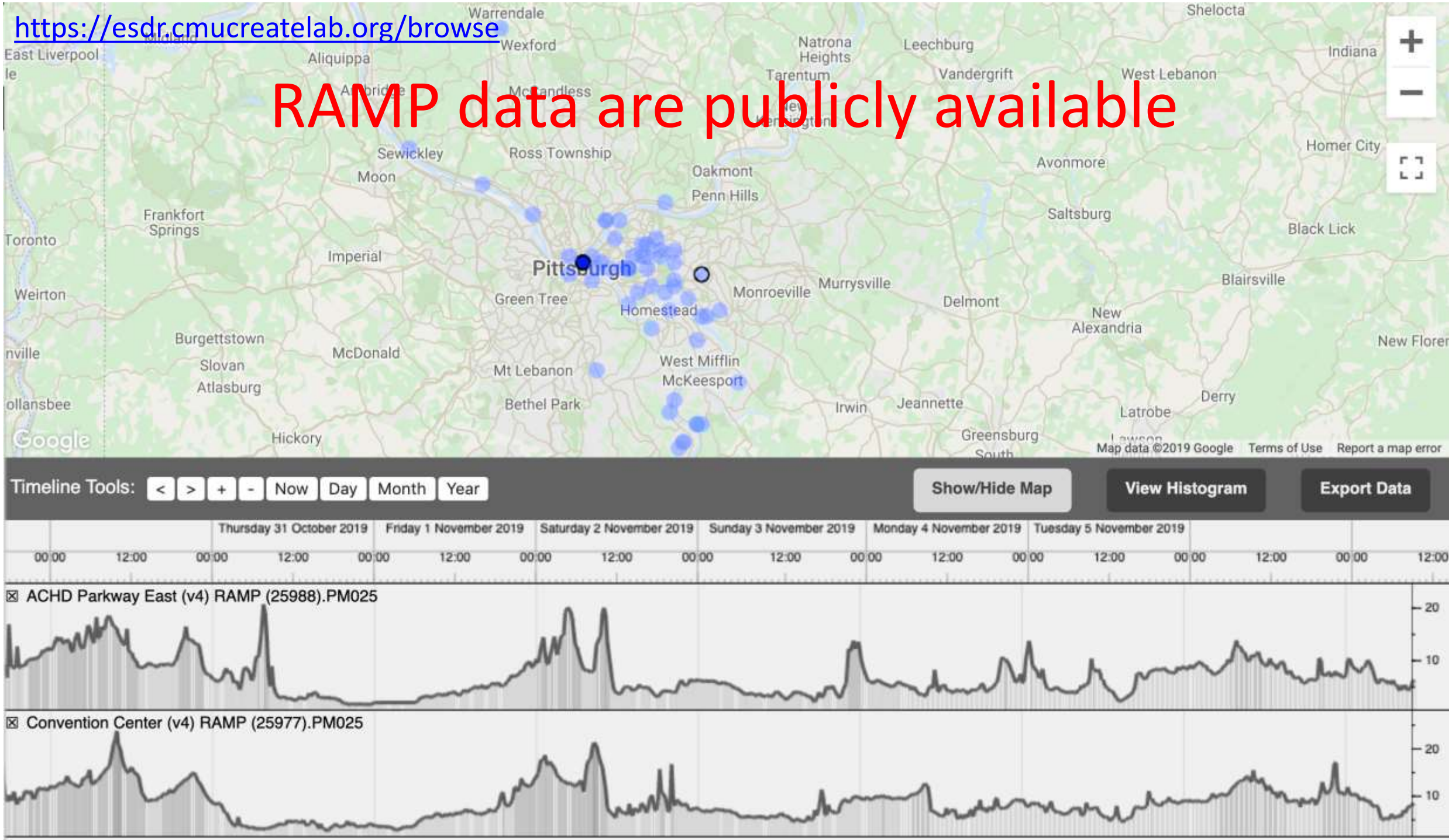
https://esdr.cmucreatelab.org/browse

RAMP data are publicly available



We provide RAMP reports to hosts

Greater Pittsburgh Northwest RAMP Report July 17th – 21st ,2019

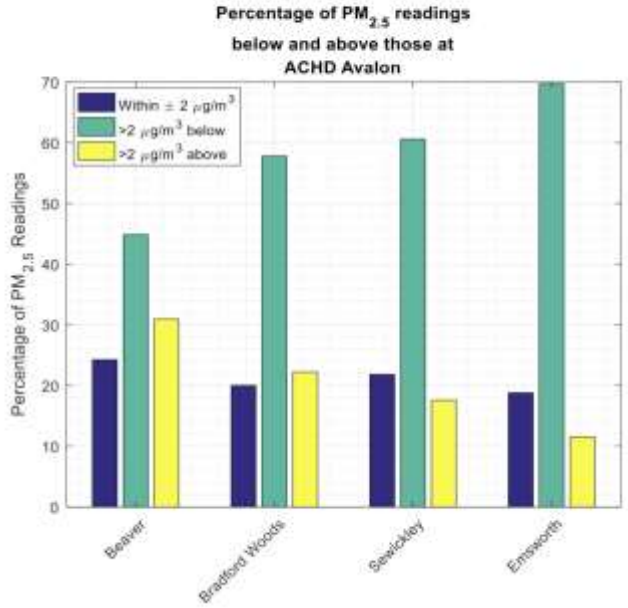
- Brighton Heights $PM_{2.5}$ data are unavailable for this week
- $PM_{2.5}$ data from Bradford Woods are unavailable from July 26th at 8:45 to July 19th at 13:00 due to sensors losing power

How Did the RAMP Sites Compare to ACHD Avalon?

Shown right is a plot of how well the $PM_{2.5}$ readings at northwest RAMP sites matched up with the nearby ACHD Avalon.
Shown in the plot are RAMP readings that are:

- **Within** ±2 µg/m³ of ACHD Avalon
- > 2 µg/m³ **below** ACHD Avalon
- > 2 µg/m³ **above** ACHD Avalon

- In the past week, all the Northwest RAMPs were most likely to read lower than the nearest ACHD site.
- The site that was most likely to be cleaner than ACHD Avalon was Emsworth.
- The site with most readings exceeding those at ACHD Avalon was Beaver.
- The RAMP in Beaver was also most likely to read close to ACHD Avalon in the past week.

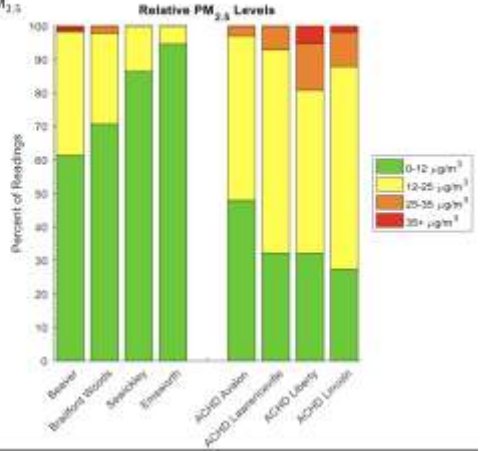


How Did the Site Readings Compare?

The bar graph represents the fraction of hours when the $PM_{2.5}$ concentration is in a certain range:

- low (0-12 µg/m³)
- moderate (12-25µg/m³)
- elevated (25-35 µg/m³)
- high (more than 35µg/m³)

- In the past week, all NW RAMP sites were reading "low" more often than any of the ACHD sites, indicating a cleaner background.
- However, Beaver saw a larger proportion of "high" concentrations than either ACHD Avalon or Lawrenceville.
  - This is the result of a recurring pollution event observed close to the mounting location of the sensor.
- It is worth noting that the two RAMP sites furthest north experienced the most particulate pollution in the past week, a trend that has not typically been observed.
  - It is possible that this is observed in Bradford Woods due to the $PM_{2.5}$ sensor being offline for much of the week when low readings were recorded.



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Three main points

- Low-cost sensors can meet EPA metrics for supplemental and exposure monitoring
- Citywide networks can be used to separate local emissions from regional climatology impacts and to evaluate environmental justice, but cannot capture all spatial variations
- Low-cost monitors are good candidates for monitoring in case of extreme or unexpected events

Was it worth the effort?

- 50-node networks of low-cost sensors might not be ‘low cost’
  - Even reliable sensors break down
  - Should this be repeated at scale in multiple cities?
- Dense network is good at capturing:
  - Broad spatial gradients
  - PM plumes and other episodic events

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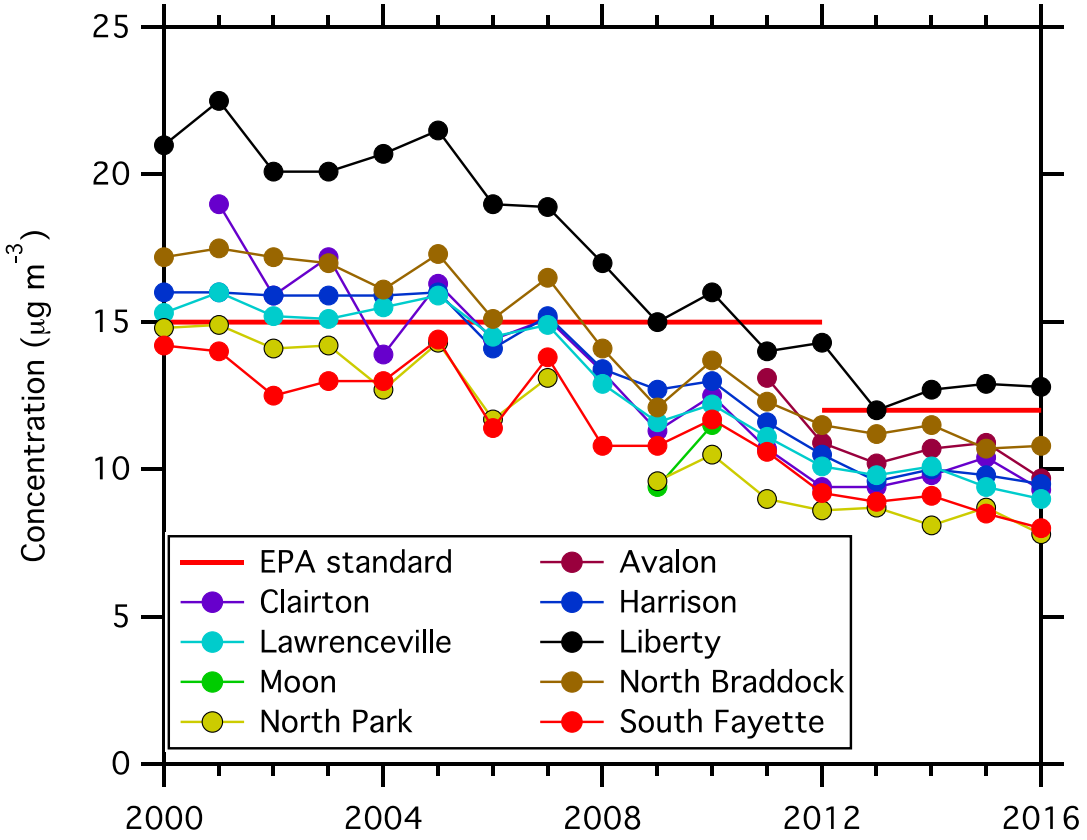
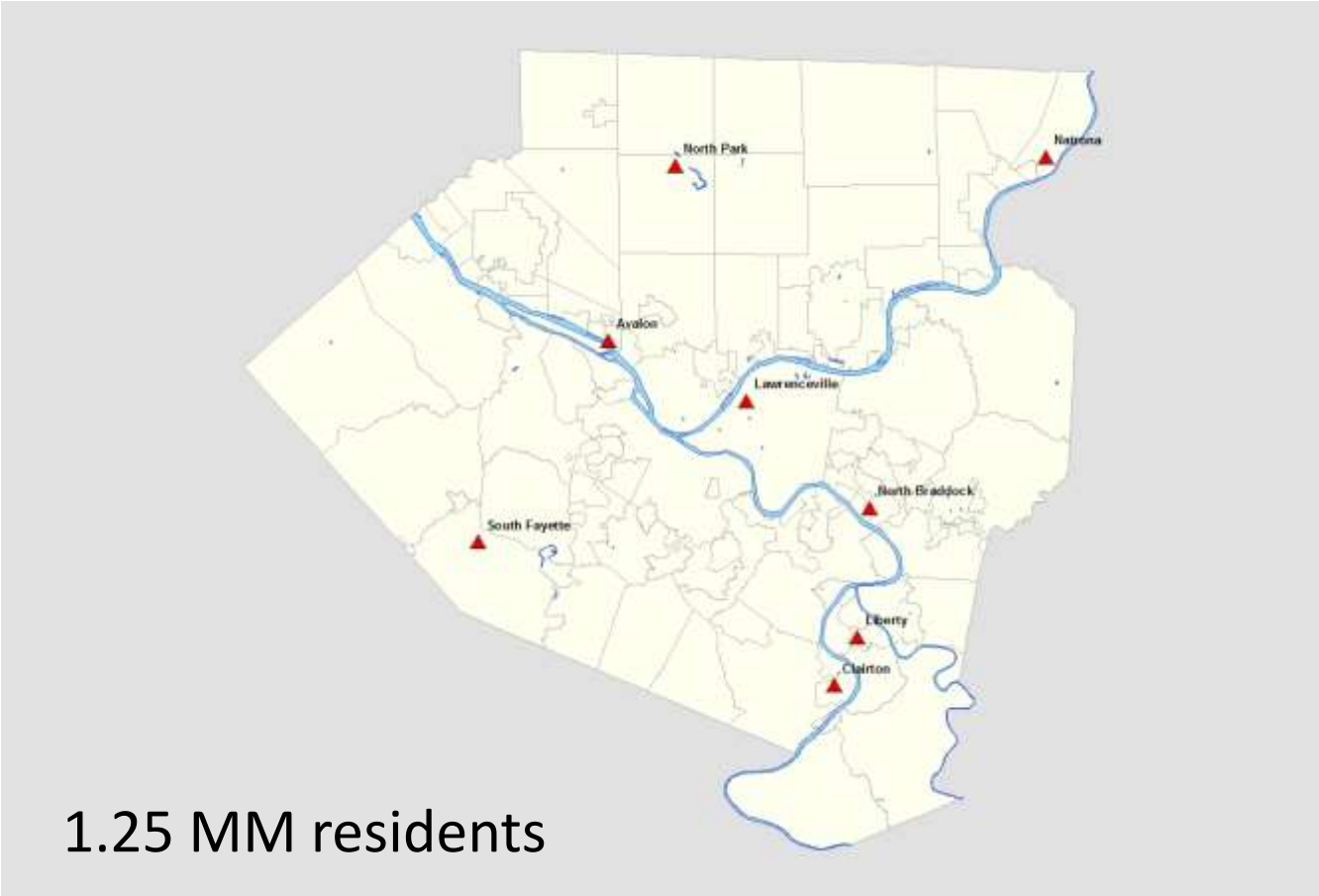
The policy focus has traditionally been on regional improvements



Data: Allegheny County Health Dept.



1.25 MM residents

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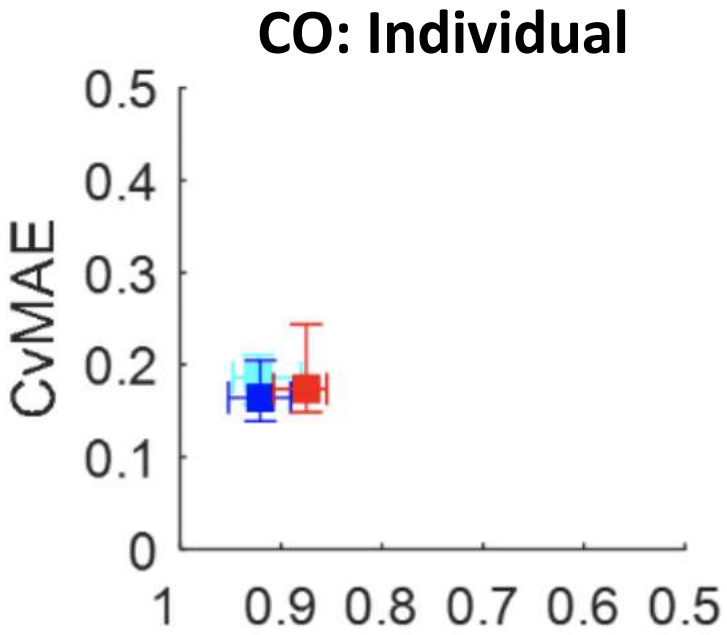
Generalized calibrations perform nearly as well as individual ones



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Malings et al, *AMT*, 2019