Oklahoma City

Air Quality Monitoring

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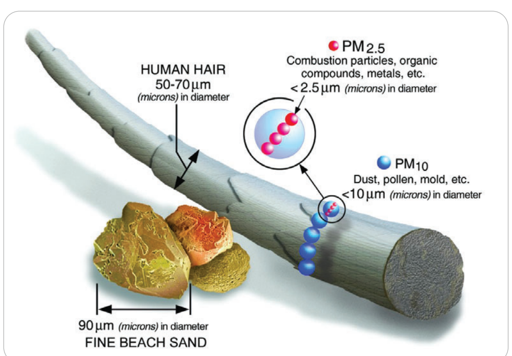
In addition to mapping heat, project members in Oklahoma City aimed to better understand the distribution of air pollution across the City using light-weight particulate matter sensors in both a combined mobile data collection (for a spatially-rich snapshot) and stationary data collection campaign (to observe temporal patterns). During the Heat Watch campaign, volunteers attached their AirBeam sensor alongside the CAPA heat sensor to collect mobile readings of a harmful pollutant class known as Particulate Matter ($PM_{2.5}$). The sensors were then installed for a two-week stationary phase outdoors at fire stations and public buildings spanning the region. The resulting maps and statistical summaries from these Mobile Campaign and Stationary Campaign are presented in this report.

AirBeam Air Quality Sensor

What is $PM_{2.5}$?

Particulate matter (PM) are tiny air particles that can be made of many different chemicals and are often produced through combustion processes of automobiles, construction equipment, industrial plants, and wildfires. PM particles smaller than 2.5 micrometers in diameter, known as $PM_{2.5}$, can be especially harmful to human health when breathed in elevated concentrations. By attempting to map these concentrations, we can better understand who is more or less exposed to $PM_{2.5}$, and to what degree.



US AQI Level	PM2.5 (ug/m3)	Health Recommendation
Good	0-12.0	Air quality is satisfactory and poses little or no risk
Moderate	12.1-35.4	Sensitive individuals should avoid outdoor activity as they may experience respiratory symptoms.
Unhealthy for Sensitive Groups	35.5-55.4	General public and sensitive individuals in particular are at risk to experience irritation and respiratory problems
Unhealthy	55.5-150.4	Increased likelihood of adverse effects and aggravation to the heart and lungs among general public
Very Unhealthy	150.5-250.4	General public will be noticeably affected. Sensitive groups should restrict outdoor activities.
Hazardous	250.5+	General public at high risk of experiencing irritations and adverse health effect. Should avoid outdoor activities.

Ranges of $PM_{2.5}$ sizes (left); $PM_{2.5}$ concentration levels (right), Source: EPA
$PM_{2.5}$ concentration levels and health recommendations based on 24-hour means

Mapping $PM_{2.5}$

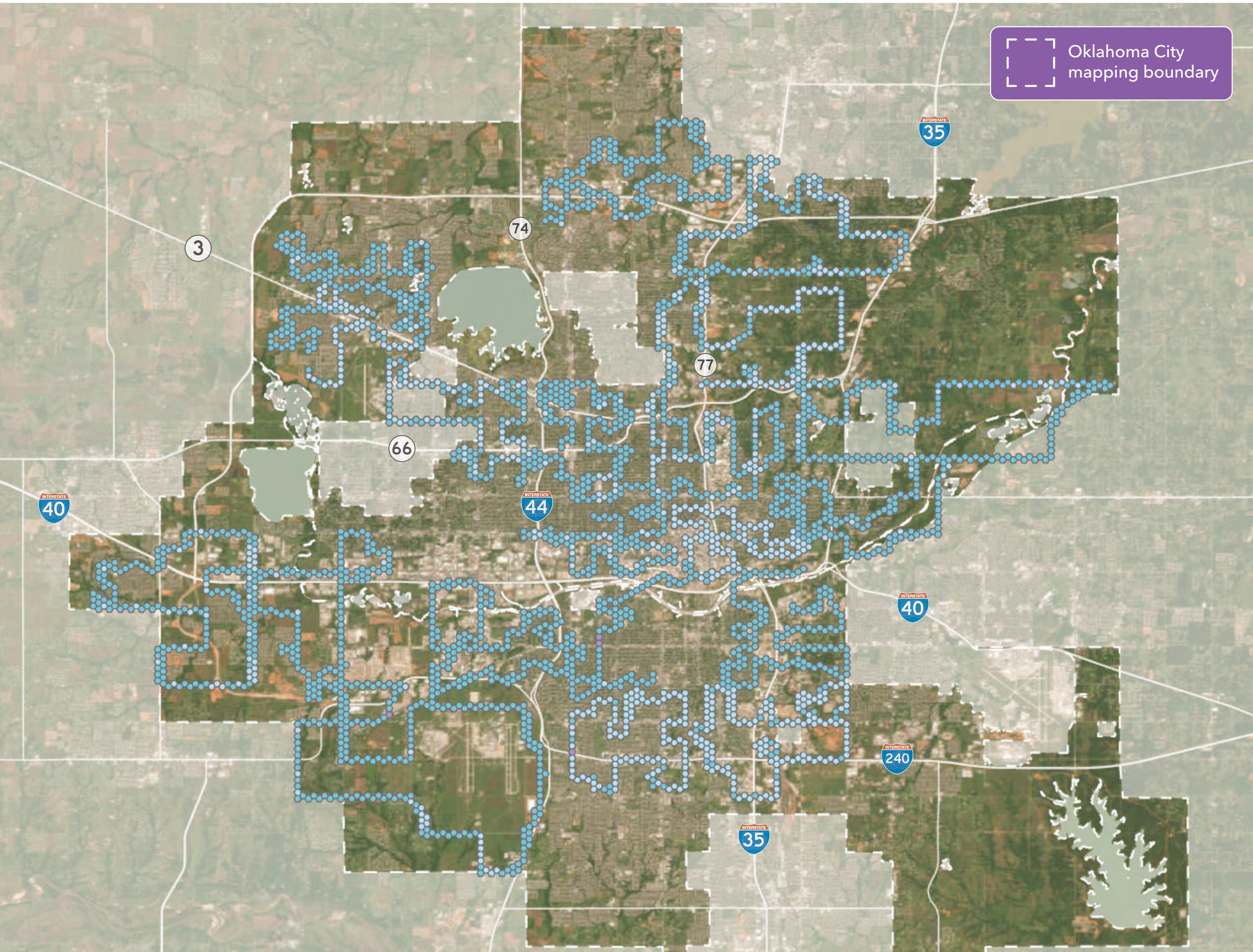
While the concentration and distribution of $PM_{2.5}$ across urban environments can vary with weather patterns day-to-day or even hour-by-hour, many sources of chronic pollution, such as industrial districts and high-traffic roadways, remain in relatively the same location and continue to emit pollution over time (in varying amounts). With mobile traverses we are able to gather a large amount of spatial information about these pollutants and further an approach for understanding patterns of $PM_{2.5}$ over time. The stationary data that follows provides a look at daily levels of air quality across several specific locations of interest.

Mobile Traverse Analysis

Air Quality Monitoring

Morning Air Quality Traverses

The following maps describe $PM_{2.5}$ data collected by mobile traverse on August 12th, 2023.

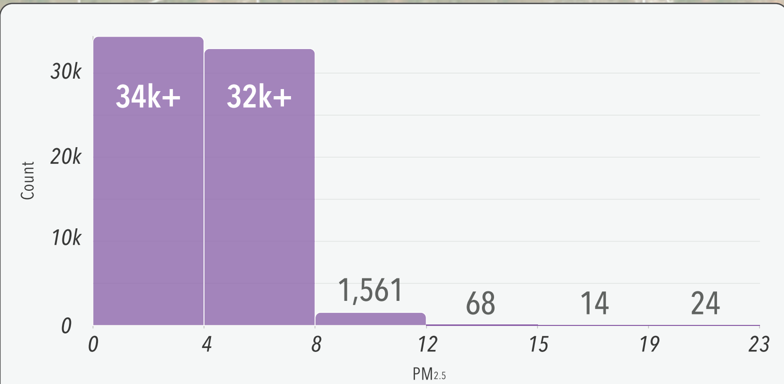


- Good 0-4 μg/m³
- Good-Moderate 4-12 μg/m³
- Unhealthy for Sensitive Groups 12-55 μg/m³
- Unhealthy 55-150 μg/m³
- Very Unhealthy 150-250 μg/m³
- Hazardous >250. μg/m³

Max $PM_{2.5}$ values are summarized into hexagons above from traverse point values.

Traverse Point Summary Stats

Min	Mean	Median	Max	Count
0	4	4	23	68,918



Notes

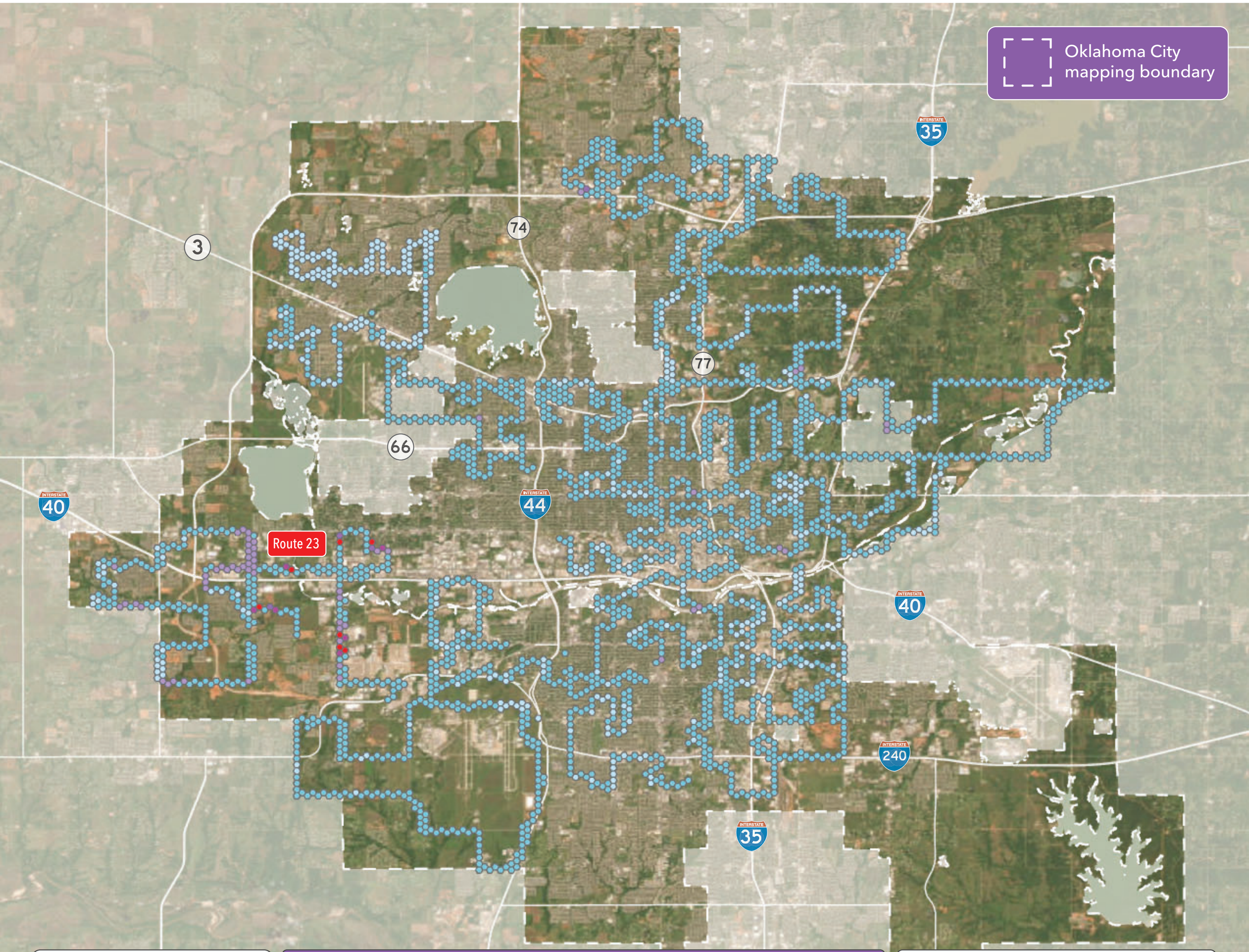
Particulate matter levels were relatively low across the Oklahoma City area during the mobile campaign, which may have been due in part to rainfall prior to and during the campaign day (2.33mm over previous 24hr period at WRWA station.)[1] In the morning, $PM_{2.5}$ levels were the lowest with an average of 4 ug/m^3. In areas with more dense vegetation to the northeast and south we see levels near 0 ug/m^3.

[1] WeatherUnderground.com

Afternoon Air Quality Traverses

The following maps describe $PM_{2.5}$ data collected by mobile traverse on August 12th, 2023.

HEAT WATCH



Good
0-4 μg/m³

Good-Moderate
4-12 μg/m³

Unhealthy for Sensitive Groups
12-55 μg/m³

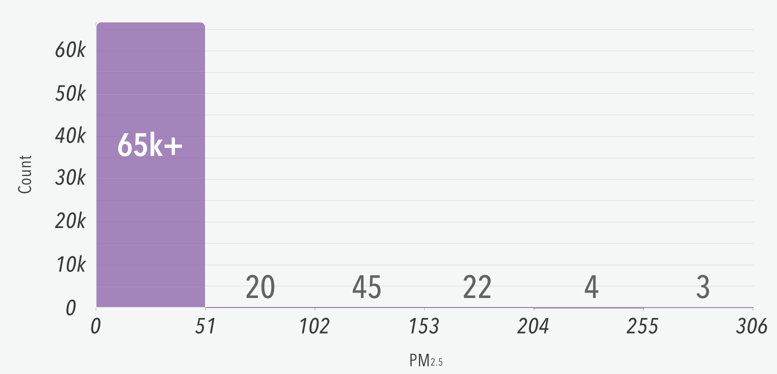
Unhealthy
55-150 μg/m³

Very Unhealthy
150-250 μg/m³

Hazardous
>250. μg/m³

Max $PM_{2.5}$ values are summarized into hexagons above from traverse point values.

Traverse Point Summary Stats				
Min	Mean	Median	Max	Count
0.0	4.7	5.0	306.0	66,884



Notes

In the afternoon, PM2.5 levels rose slightly across the area, with several "hazardous" level measurements in the industrial zone to the west of downtown (Route 23).

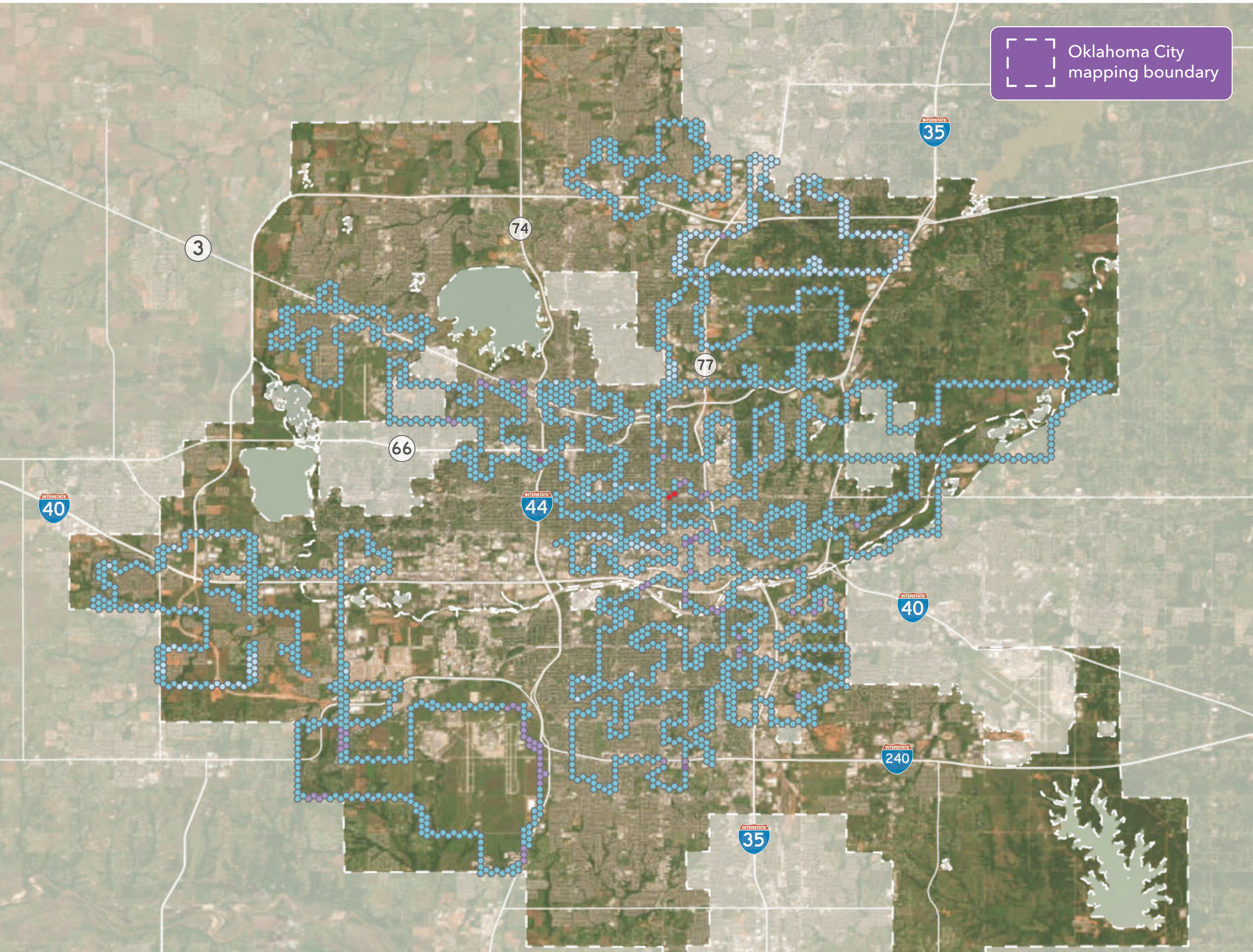
It is important to note here that extreme values, which may be related to roadway vehicles or point-source emissions, are not excluded from the mobile datasets, as they are considered accurate measurements and reflect real conditions observed along the traverses.

Evening Air Quality Traverses

The following maps describe $PM_{2.5}$ data collected by mobile traverse on August 12th, 2023.

CAPA

HEAT WATCH



Good
0-4 μg/m³

Good-Moderate
4-12 μg/m³

Unhealthy for Sensitive Groups
12-55 μg/m³

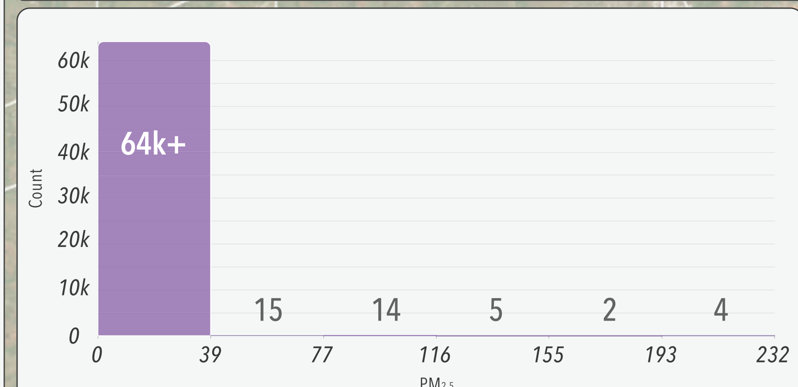
Unhealthy
55-150 μg/m³

Very Unhealthy
150-250 μg/m³

Hazardous
>250. μg/m³

Max $PM_{2.5}$ values are summarized into hexagons above from traverse point values.

Traverse Point Summary Stats				
Min	Mean	Median	Max	Count
0.0	6.0	6.0	232.0	64,160



Notes

In the evening time, particulate matter levels were at their highest of the three time periods, with near-zero concentrations in densely vegetated areas to the northeast and "unhealthy" levels measured in several locations in the central city and along roadways near the airport.

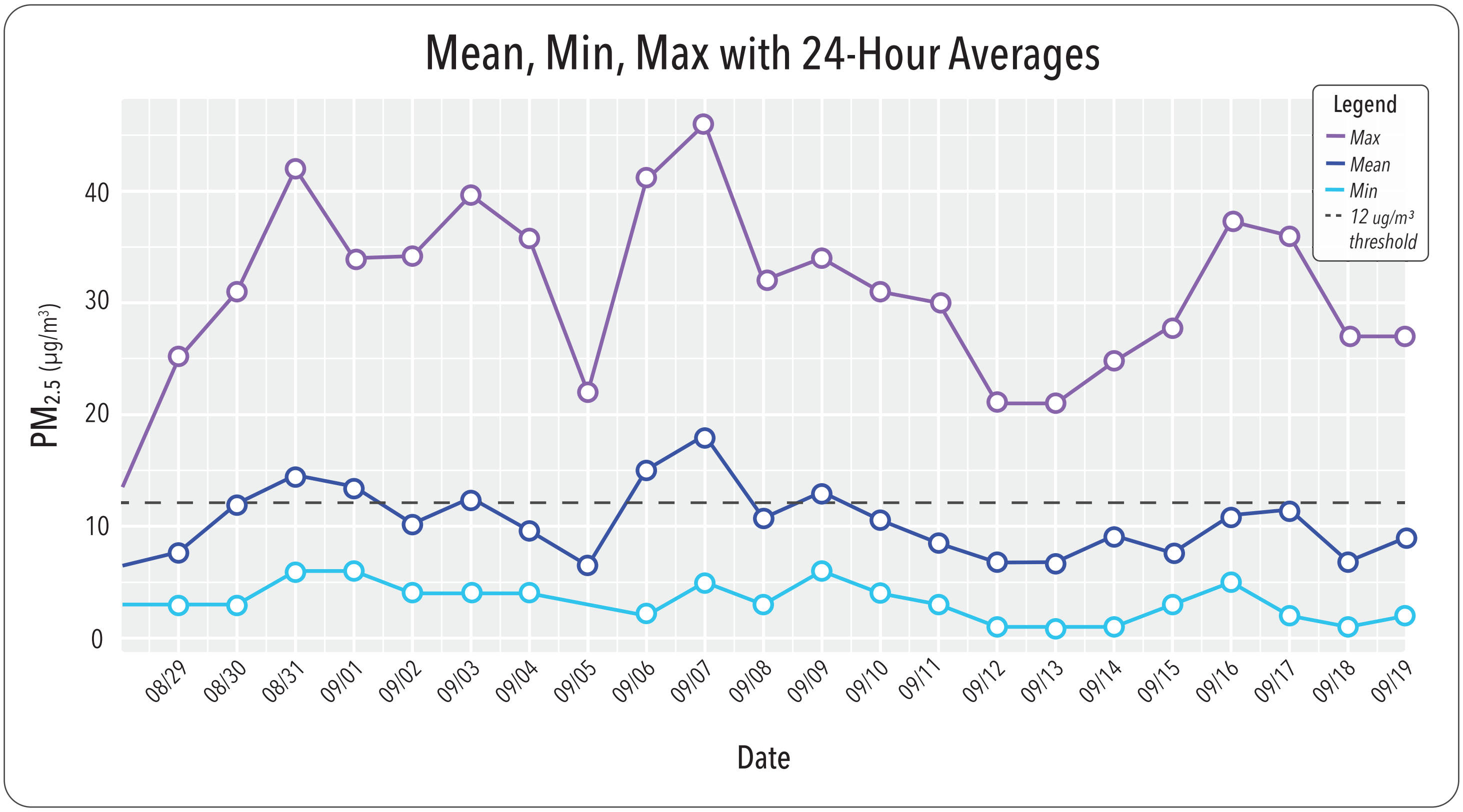
Stationary Analysis

Air Quality Monitoring

With the stationary mapping campaign we aimed to gather a geographically-diverse picture of trends in $PM_{2.5}$ distribution over a three week period between August 31st to September 19th, 2023. The AirBeam sensors were installed mostly behind local fire departments, which provided a geographic spread, secure public location, and power source, as well as at several DEQ (Department of Environmental Quality) regulatory monitoring sites for measurement validation. In this analysis we summarize the data gathered, examining trends by sensor, determine which locations reached elevated pollution levels (i.e. averaged >12 ug/m3 over a 24 hour period), and compare the AirBeams co-located with DEQ sensors. We also summarize the outlying measurements that were removed from analysis, determined as non-meaningful spikes in the data.

Stationary Air Quality Traverses

The summary below describes $PM_{2.5}$ data collected by stationary sensors from 8/31 - 9/19/23.



See appendix for full dataset by sensor.

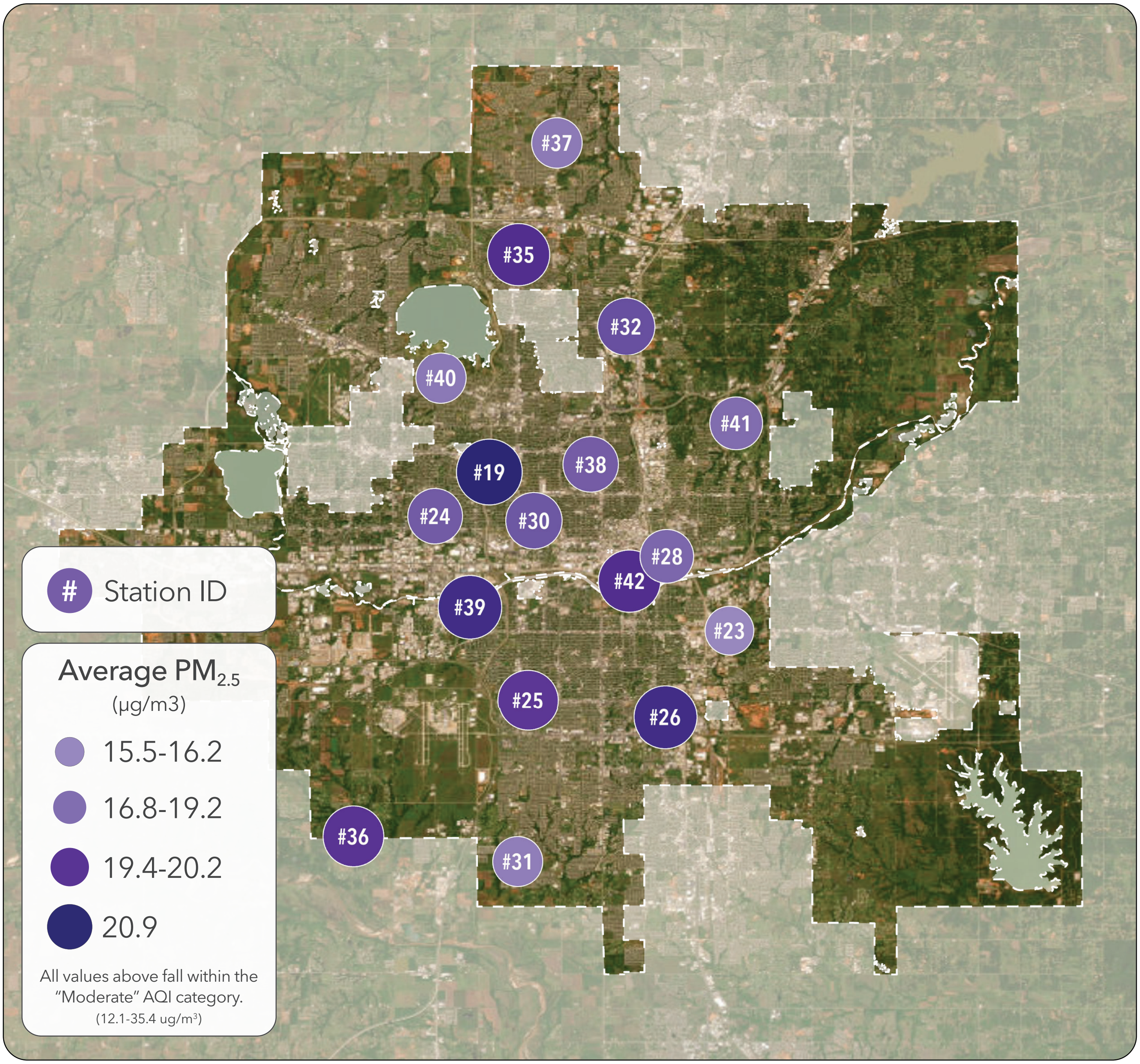
In this trend over time plot, we see the minimum, maximum, and average (mean) $PM_{2.5}$ measurements at each sensor over the two week period. Overall, average measurements were the highest on September 6th, while maximum levels peaked on September 7th. The lowest average measurements were collected on September 18th. On the following page we examine the spatial distribution of $PM_{2.5}$ on this peak day.

Note that outliers were removed from the stationary data analysis in order to focus on longer-term fluctuations, rather than the short-term spikes that may be associated with vehicle traffic or aberrant sources. The removed outlier measurements are summarized in the appendix at the end of this report.

Peak Day Sensor Averages

Average $PM_{2.5}$ on 9/7/2023

Let's examine the distribution of $PM_{2.5}$ on the peak day from the period:

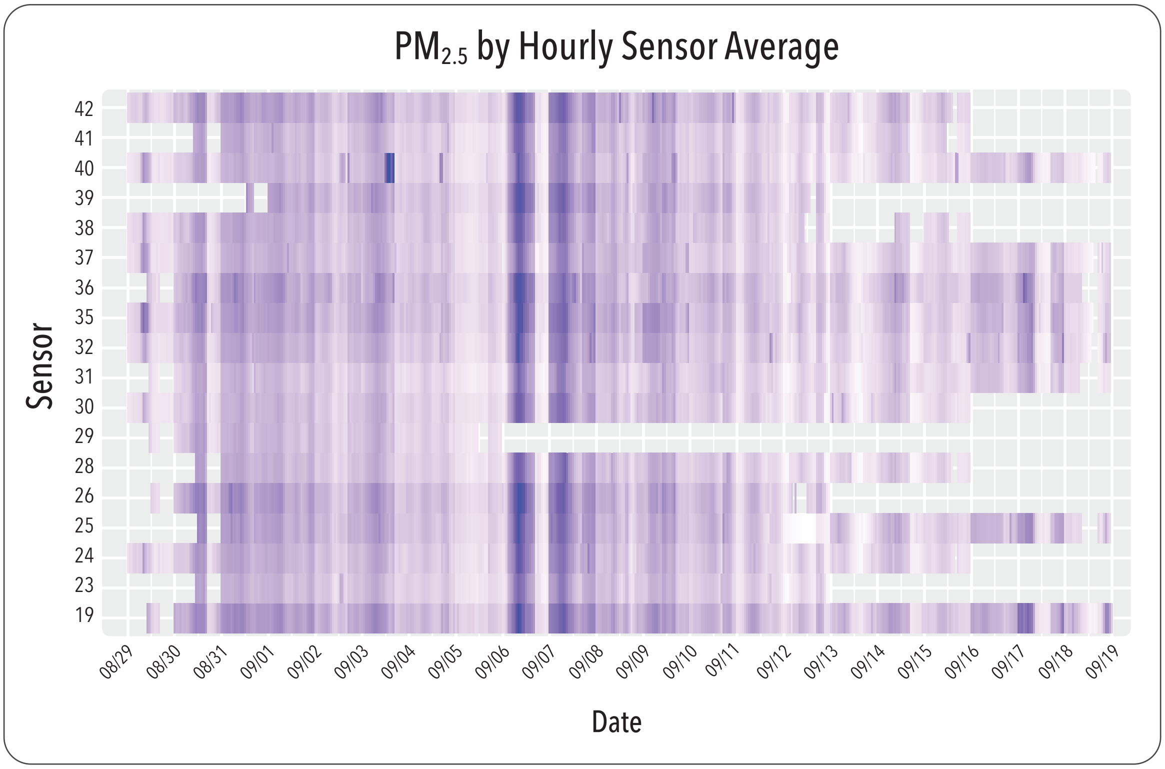


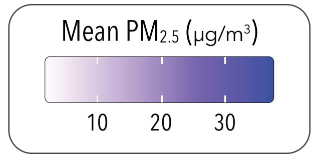
Color scheme here not comparable to color scheme in mobile traverse maps

Individual Sensor Summary

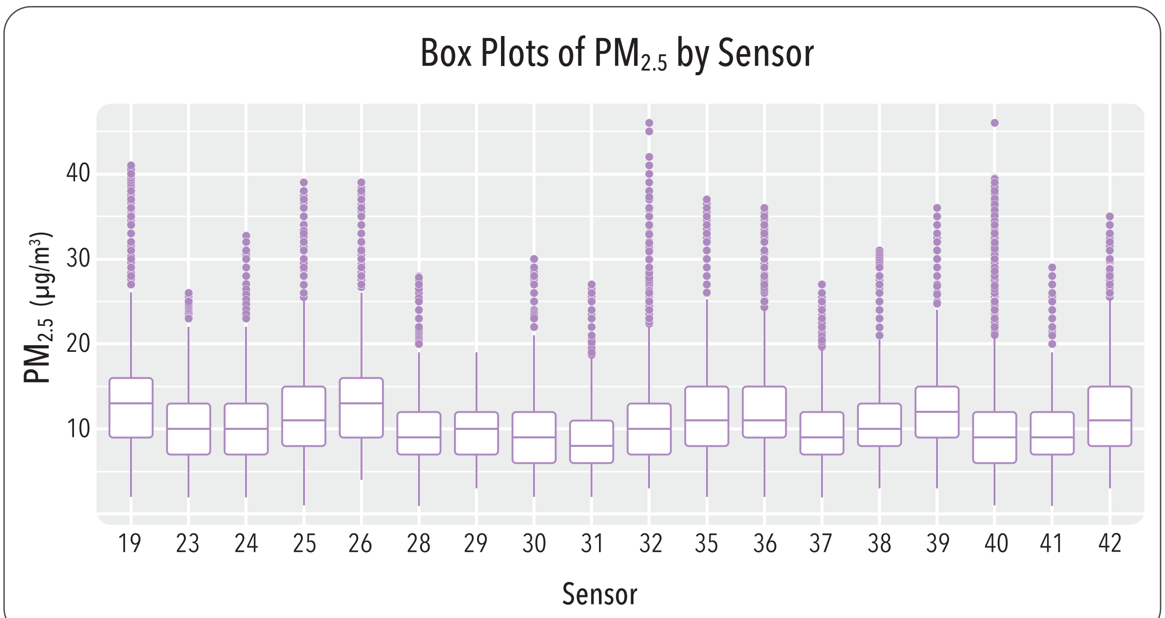
The below describes $PM_{2.5}$ data collected by stationary sensors from 8/31 - 9/19/23.

Measuring the highest in $PM_{2.5}$ concentration over the two week period was AirBeam 26, installed at Fire Station #16 at McCracken Park in the Cloverleaf neighborhood, with an average $PM_{2.5}$ reading of 13.2 μg/m³. Following closely was AirBeam19, installed at the DEQ West regulatory site in Will Rogers Garden, located by the interchange between interstate I-44 and Highway 66, with an average $PM_{2.5}$ reading of 13.1 μg/m³ over the two week period. The lowest measuring sensor was AirBeam 31, at Fire Station #35 located in the Rivendell neighborhood, with an average reading of 9.0 μg/m³.





The graph here displays $PM_{2.5}$ levels over the multi-week period and also displays the duration of data collection for each sensor. Several sensors like AB #29 stopped collecting data early, potentially due to a disconnected power source of sensor malfunction.

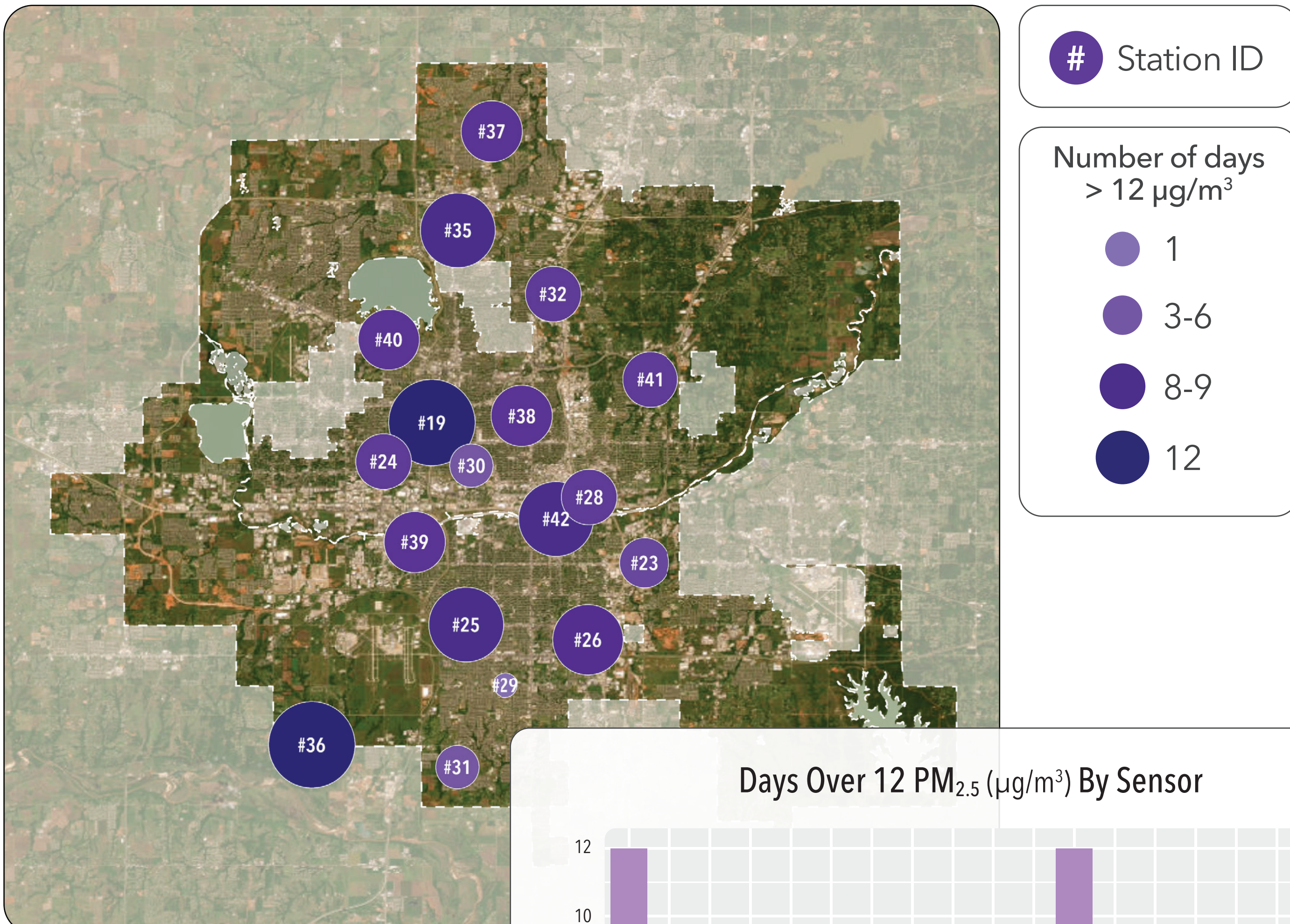


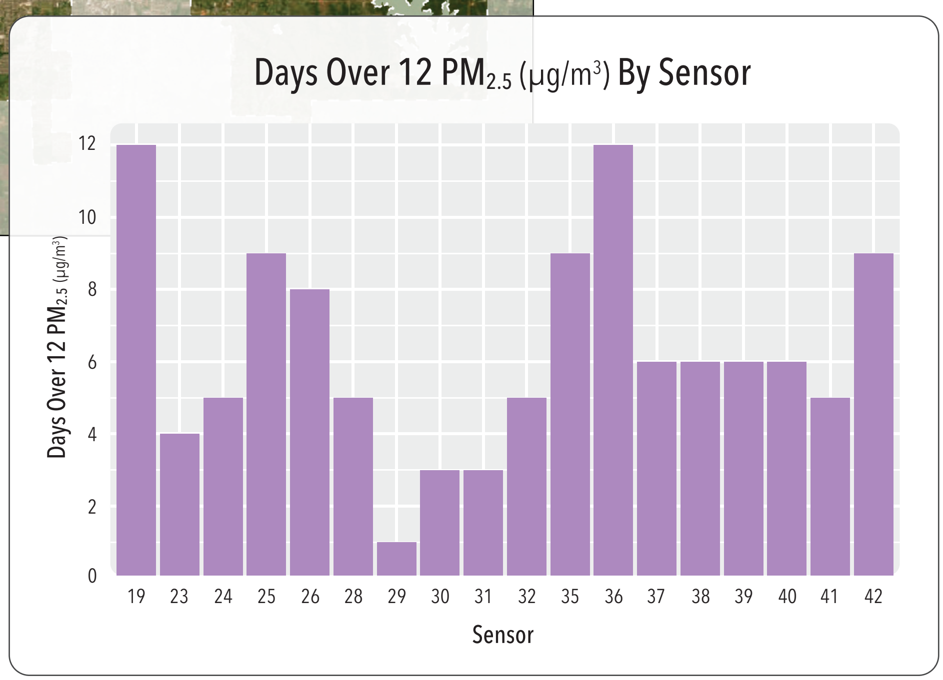
Box and whisker plots show for each sensor the median measurement across the two week period (middle horizontal bar) and interquartile range (lower bar to upper bar), with values outside of this range depicted as points along the whiskers.

Elevated 24-Hour Averages

Number of Days with Average $PM_{2.5}$ over 12 µg/m³

According to the EPA, when $PM_{2.5}$ measurements reach a 24-hour average between 12-35 µg/m³, sensitive individuals should avoid outdoor activity as they may experience respiratory symptoms. We here tabulated the number of days that each sensor measured 24-hour means of over 12 µg/m³. AirBeams #19 and #36 both measured 12 days out of 21 with an average concentration in this range. For sensitive individuals that reside or spend the majority of their time in these areas, $PM_{2.5}$ pollution poses a health risk over half of the time of this measurement period.

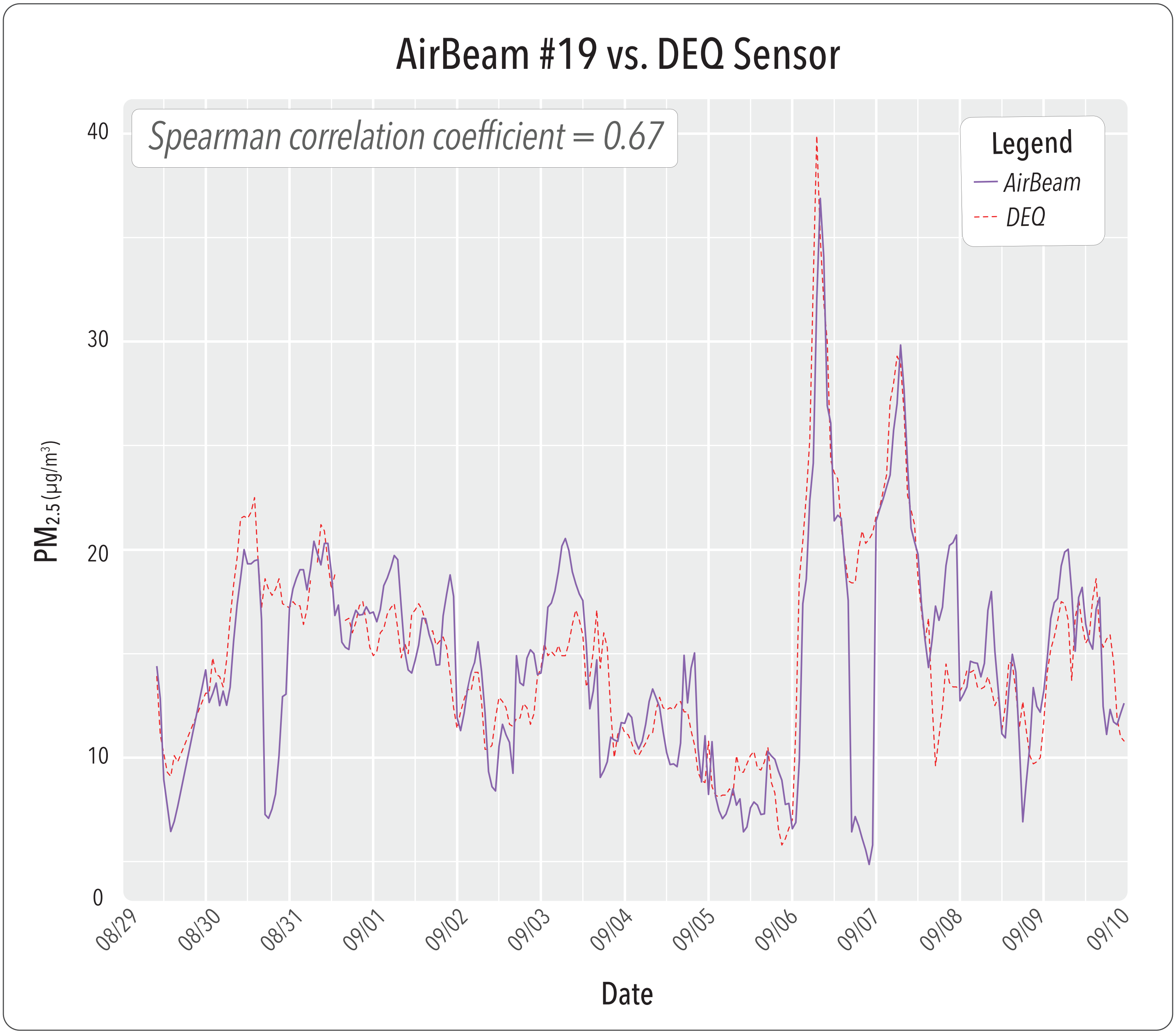




Co-Location Assessment

$PM_{2.5}$ 8/29/23 - 9/10/23

Co-location is a method of comparing low-cost sensors with reference stations to assess their performance and establish calibration equations for long-term monitoring. In this study AirBeam #19 was positioned, or "co-located", nearby to the DEQ West regulatory site in Will Rogers Garden at the intersection of interstate I-44 and Highway 66. We then plotted $PM_{2.5}$ readings from each sensor and calculated the Spearman correlation coefficient, which is a measure of the strength and direction of relationship between two variables.



Overall, AirBeam 19 and the DEQ West sensor indicated a strong correlation and close relationship with a Spearman's correlation of 0.67. As seen in the plot, the two sensors track within a similar range of concentrations over a two-week co-location period. With wider variation, the AirBeam in general appears to be more sensitive than the DEQ station. This could be due to several differences including design and casing of the two sensor types; functional differences such as response time and measurement increment; and, processing methods like filters for noise or corrections.

Conclusion

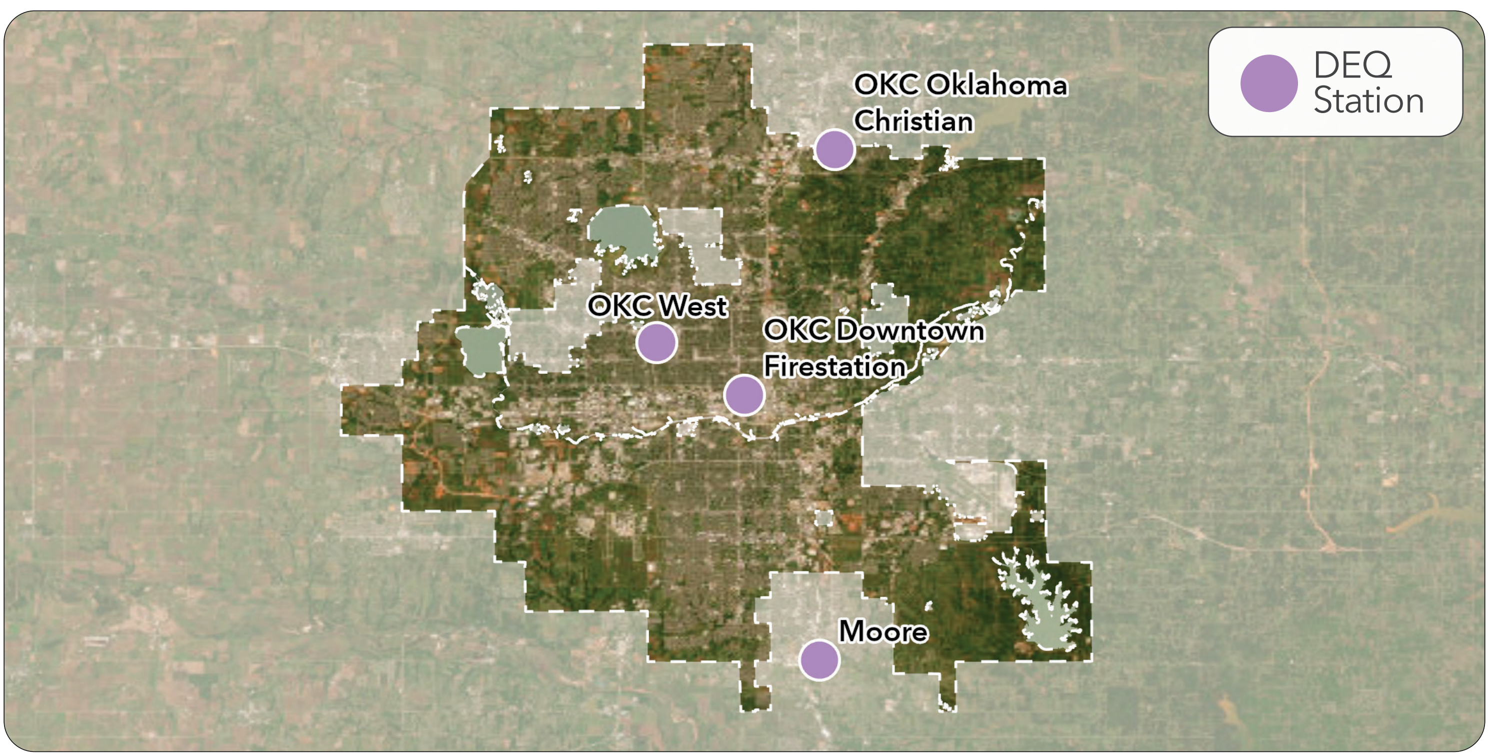
In this study we explored the capabilities of low-cost air quality monitoring across Oklahoma City to provide valuable and accurate information across a three week period in September, 2023. As evidenced by the mobile traverses, on relatively low air pollution days (mean < 8 ug/m3) concentrations of particulate matter do vary across the area by location and time of day. On-road mobile monitoring reached locations outside of established Department of Environmental Quality (DEQ) reference station areas, highlighting areas experiencing elevated concentrations of particulate matter that may not have otherwise been detected (such as along the industrial area near Route 23 in the afternoon).

During the stationary monitoring period we saw temporal fluctuations in $PM_{2.5}$ concentrations at select sites across the region and through analysis derived several key findings:

1. Certain locations consistently saw elevated levels of air pollution more often than others, contributing to disparate levels of exposure by location;

2. The co-located AirBeam and DEQ West regulatory station tracked closely in $PM_{2.5}$ measurements (correlation coefficient of 0.67); and,

3. Given the evidence of spatial variability in $PM_{2.5}$ concentrations across the area, significant gaps persist in the long-term air quality monitoring network across Oklahoma City, hindering the ability of planners to sufficiently strategize long-term adaptation actions as well as short-term response activities during poor air quality events.



Department of Environmental Quality regulatory stations that monitor $PM_{2.5}$

Conclusion

Given these findings we recommend increasing the presence of long-term stationary monitoring networks across Oklahoma City, specifically in areas that indicated higher levels of $PM_{2.5}$ concentrations in the mobile study as well as the peak-day and 24-hour mean exposure maps from the stationary study. Combining these insights along with population vulnerability data (provided by tools such as the U.S. Climate Vulnerability Index) can help to identify areas facing the highest risk of impacts from degraded air pollution and most in-need of long-term monitoring.

Low-cost sensors can provide a well-tested and integrative solution for long-term monitoring (AQ - SPEC). The widespread platform PurpleAir, which employs the same sensing technology in its products as AirBeam (along with additional redundancy for improved accuracy) provides a publicly accessible mapping dashboard for installed monitors. Data flows from such networks can be used for a variety of purposes, such as better informing regional forecasting models like those provided by IQ Air, and providing more granular insight to planners and public health officials and public health officials. Including additional pollutants such as CO, NO2, CO2 and VOCs could also be achieved with relatively low-cost devices in future studies.

Findings and recommendations in this study comprise a direction for improved monitoring, a key element for managing and addressing the health risk that particulate matter poses in Oklahoma City. Collaborative studies that span governance structures are key for raising public awareness and a valuable touch point for continued efforts in co-creating mitigation and adaptation solution strategies, and guiding further research. Studies such as these need also to be integrated with existing work by local researchers for a robust understanding of the effects of other pollutants and patterns with particulate matter. We hope that this study provides a stepping stone in such directions.

Thank you to all participants of the mobile and stationary monitoring campaign, including mobile data collection teams as well as hosts of the stationary sensors at Fire Stations and other buildings across Oklahoma City.

Appendix

Air Quality Monitoring

CAPA

Sensor Summary Statistics

HEAT WATCH

$PM_{2.5}$ Summary Statistics

Sensor ID	Mean (µg/m³)	Min (µg/m³)	Max (µg/m³)	SD (µg/m³)	Median (µg/m³)	Mode (µg/m³)
19	13.1	2.0	41.0	5.3	13.0	13.0
23	10.1	2.0	26.0	4.1	10.0	10.0
24	10.3	2.0	33.0	4.6	10.0	9.0
25	11.4	1.0	39.0	5.3	11.0	12.0
26	13.2	4.0	39.0	5.5	13.0	13.0
28	9.8	1.0	28.0	4.6	9.0	9.0
29	9.7	3.0	19.0	3.2	10.0	10.0
30	9.5	2.0	30.0	4.5	9.0	6.0
31	9.0	2.0	27.0	4.0	8.0	7.0
32	10.5	3.0	46.0	4.8	10.0	10.0
35	11.9	2.0	37.0	5.1	11.0	10.0
36	12.3	2.0	36.0	5.1	11.0	10.0
37	9.7	2.0	27.0	4.1	9.0	8.0
38	10.9	3.0	31.0	4.5	10.0	10.0
39	12.5	3.0	36.0	5.4	12.0	12.0
40	9.6	1.0	46.0	5.2	9.0	5.0
41	10.0	1.0	29.0	4.4	9.0	8.0
42	11.9	3.0	35.0	5.2	11.0	8.0

Outliers

PM$_{2.5}$ Statistical Outliers

The following table summarizes the interstitial outliers removed from the main dataset. A visual representation is available in the delivery datasets.

Sensor ID	Count	Min (µg/m³)	Mean (µg/m³)	Max (µg/m³)
19	603	0	12.7	97
23	246	0	19.3	198
24	159	1	48	479
25	2109	0	7.6	318
26	279	1	23.4	261
28	222	1	29.7	45
29	45	3	112.7	457
30	180	1	39.5	800
31	178	0	12.1	137
32	331	1	47.7	383
35	253	0	29.7	126
36	218	1	38.9	84
37	326	0	110.6	585
38	199	1	32.4	220
39	251	1	28	80
40	672	0	222.2	784
41	128	17	30.5	37
42	366	1	43.3	472