Mapping the Concentration of Particulate Matter Pollution for Central Massachusetts:

A Step to Understanding Individual Exposure

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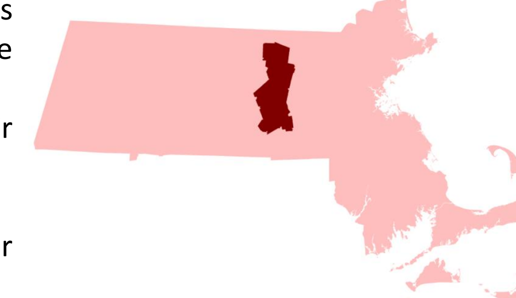
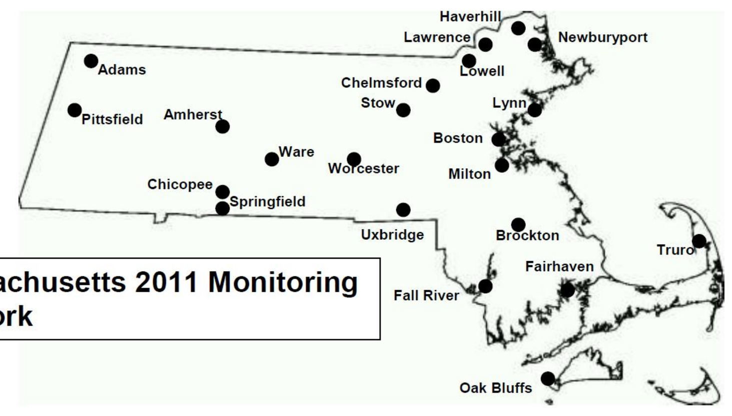
Introduction

Most cities in Massachusetts have been going through the process of post-industrialization in the past century. Numerous abandoned industrial buildings were left when manufacturers moved out. The descendants of minority laborers, who are relatively vulnerable to environmental hazards, still live in this area. It is vital to understand how the residents in this area are affected by environmental pollution.

To understand how air pollution affects human health, mapping the concentration of ambient air pollutants is indispensable. However, currently available monitoring data only available at 28 locations in Massachusetts (as shown in the map below), whereas most of EPA ambient air pollutants are not viable to conduct exposure modeling data. It is not viable to conduct analysis based on these data. Thus, in this project, we collected the air pollutant data of particulate matter (PM_{10} and $PM_{2.5}$) at 60 monitoring locations in Massachusetts. Such a density enabled us to create better concentration maps by means of spatial interpolation.

Although the ultimate goal is to measure six ambient air pollutants listed on the National Ambient Air Quality Standards (NAAQS) for the entire Commonwealth of Massachusetts, in this project we only focused on 14 cities and towns in central Massachusetts (refer to the study-area map above). Only $PM_{2.5}$ and PM_{10} were completely measured and analyzed, while the experience of this study would enable us to explore the greater area of Massachusetts, as well as include other pollutants in the experiment.





Massachusetts 2011 Monitoring Network

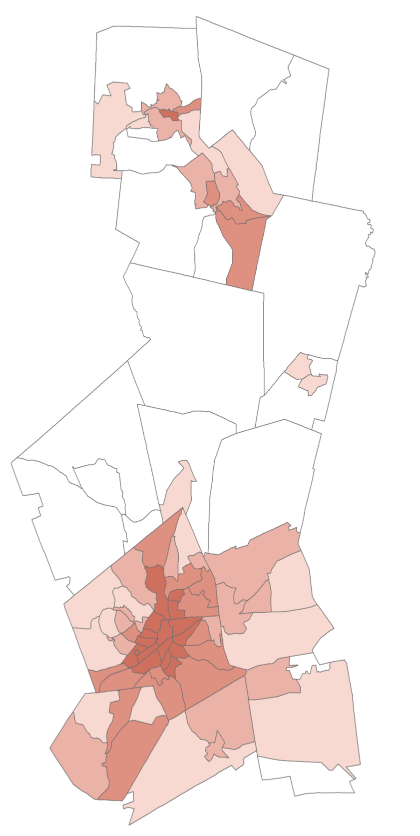
Research Objectives:

- To create a map showing the concentration of each ambient air pollutant in Massachusetts based on field data.
- To suggest candidate locations for additional ambient air pollution monitoring stations.

Experiment Design

Spatial Optimization

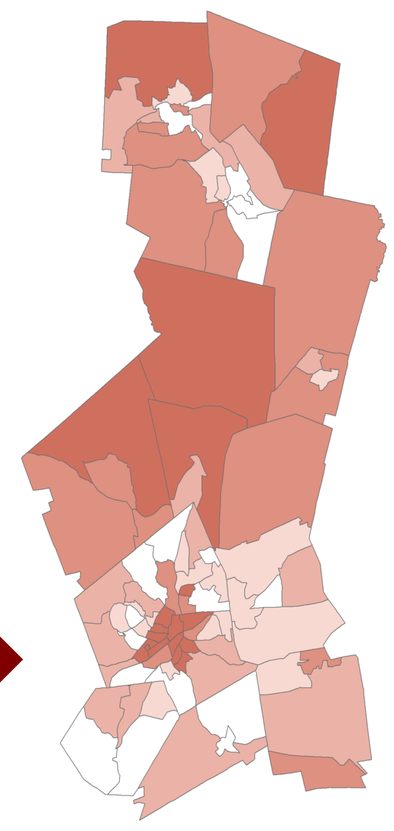
Distributing 60 monitoring locations optimally to capture the most spatial variation



Diesel PM Concentration (ppm)

From National-Scale Air Toxics Assessments NATA 2005 by Census Tract

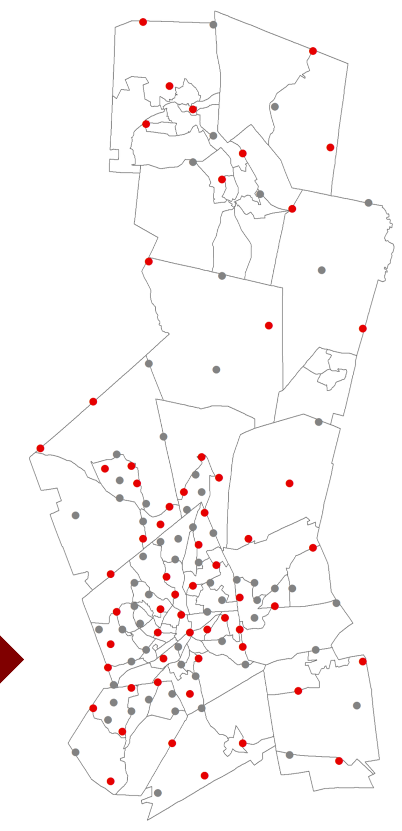
STEP 1



Monitoring Demand Surface

Autocorrelation-Adjusted Spatial Variance (gamma)

STEP 2



Selected Monitoring Sites

Autocorrelation-Adjusted Spatial Variation (gamma)

STEP 3

For tract i with concentration z_i, the autocorrelation-adjusted spatial variance (σ^2) is:

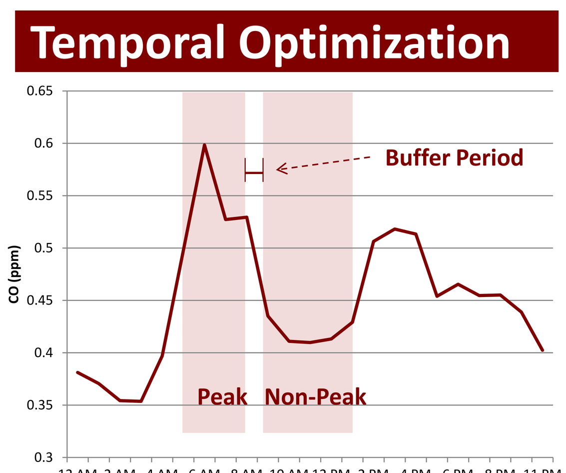
$$\sigma^2{}_i = \frac{1}{\sum_{j=1}^{k} \forall_{ij}} \sum_{j=1}^{k} (z_i - z_j)^2 \forall_{ij}$$

where j is a neighboring tract of i with concentration z_j; k is the number of neighbors around i; $i \neq j$; d_{ij} is the distance between I and j; h_i is the bandwidth for i determined by semivariance; $\forall_{ij}=0$ when $d_{ij}<h_i$, $\forall_{ij}=1$ otherwise.

Select a location with highest demand. When one location is selected, area within its bandwidth is excluded. The next location is selected from the remaining area. 127 representative locations were identified. 60 of them were selected manually.

Each location was measured for one minute each time. The point observations were interpolated to a surface using ordinary kriging. Refer to results for details of models.

Temporal Optimization

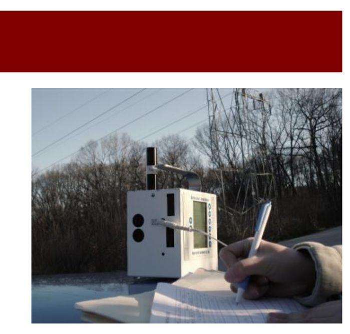


Distributing two monitoring times optimally to capture the most temporal variation

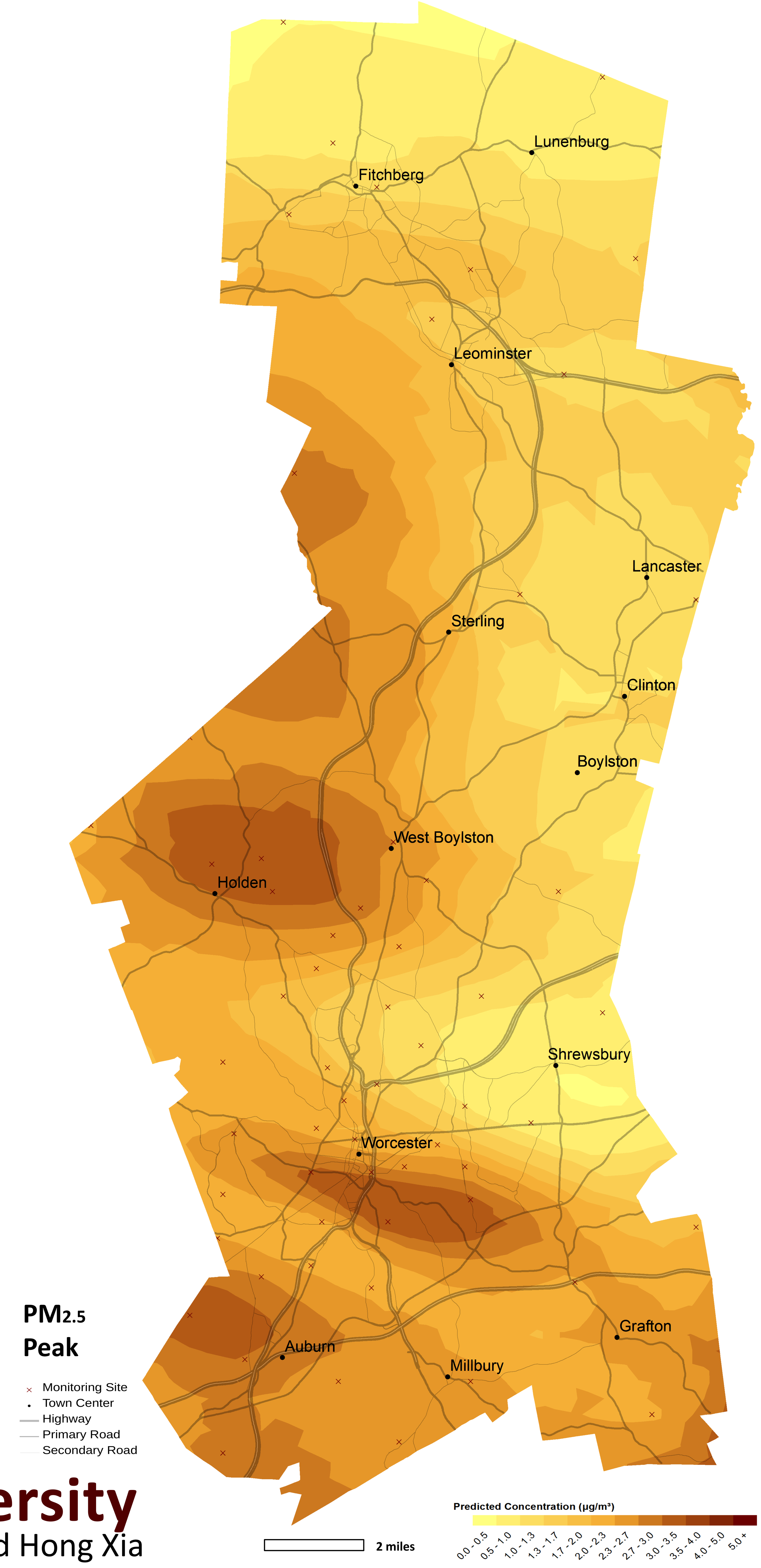
Each location was visited twice. One during peak hours and the other during non-peak. Based on previous daily carbon monoxide monitoring data in April, we identified peak/non-peak hours as the period when the concentration is above/below daily average. To prevent an overlap between peak and non-peak, a buffer period was defined as the period when the concentration is less than 0.5 standard deviation above/below the daily average. No measurement was taken during the buffer period. Thus, peak hours are from 5am to 8am and non-peak hours are from 9am to 1:30pm.

Instrument

We used DustScan Aerosol Monitor 3020 to measure the concentration of both $PM_{2.5}$ and PM_{10} at each monitoring location. The ranges and errors are shown in the table to the right (unit: mg/m³).



Range	Error
0-0.5	0.002
0-1	0.002
0-10	0.010
0-99.999	0.100



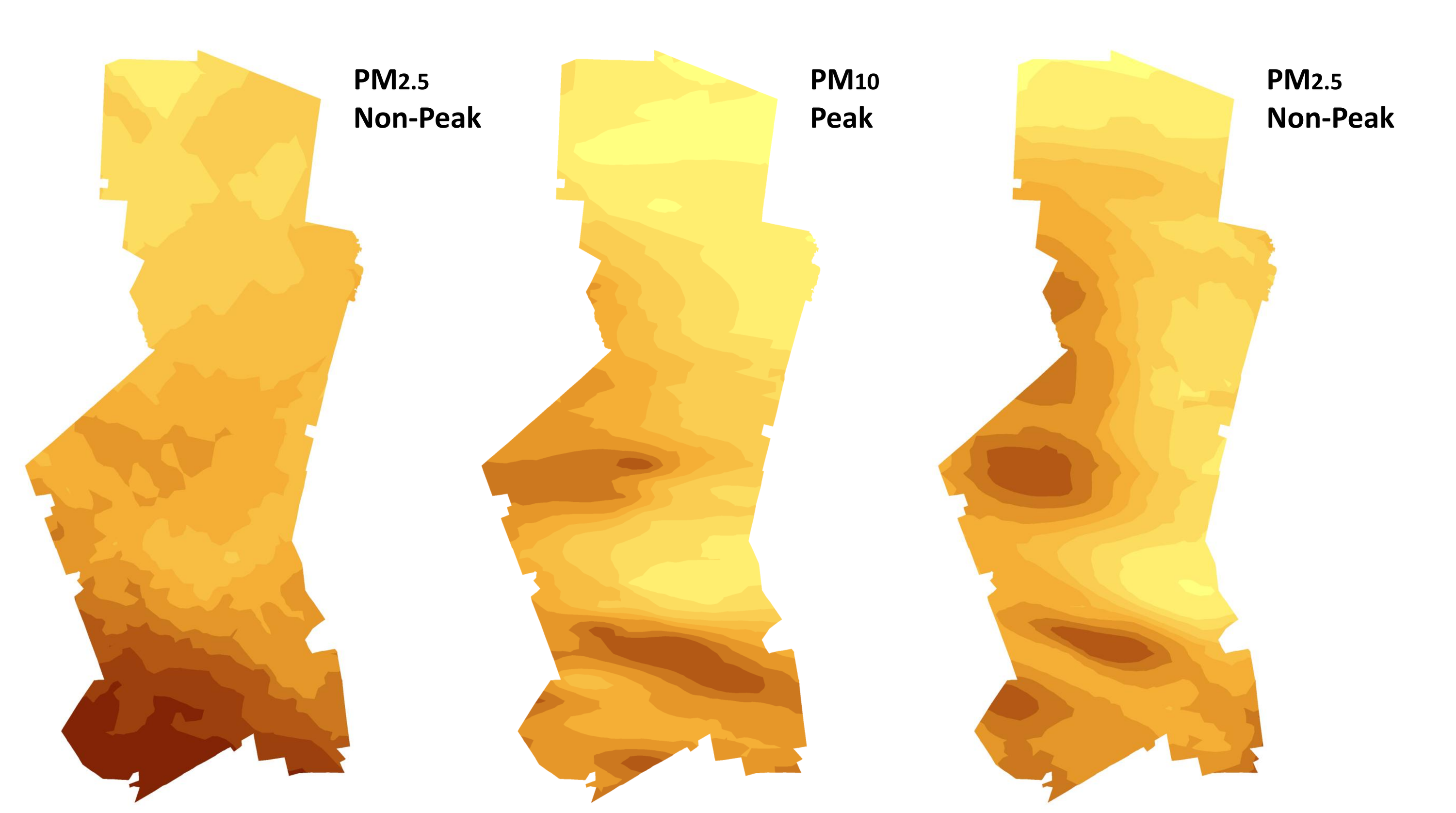
Results

Several high concentrations of $PM_{2.5}$ during peak hours. These hot spots are located at the Main South area in Worcester, I-90 near Grafton, and the center of West Boylston. The concentration of PM_{10} increased gradually from Worcester to the southern boundary of Auburn. During non-peak hours, both $PM_{2.5}$ and PM_{10} formed two strips of high concentration, one stretched from Holden to West Boylston and another from Worcester to Grafton.

No observation was comparable to the EPA standard. Through the process of model optimization, the cross-validation results of kriging yield fairly small analytical errors, which are around or less than 0.001 mg/m³. Since the spatial patterns of non-peak hours were more spread out, anisotropic models are fairly suitable to map non-peak concentrations.

The sources of error in this study include: (1) Process errors associated with experiment design, including short sampling period at one location, limited number of monitoring sites and times, and fluctuation in temperature. (2) Measurement errors associated with the sensitivity and accuracy of the DustScan and Garmin GPS. (3) Analysis errors that came from the kriging method we chose.

Data		$PM_{2.5}$ (Peak)	PM_{10} (Peak)	$PM_{2.5}$ (Non-Peak)	PM_{10} (Non-Peak)
Sample Size		59	59	60	59
Model Summary (unit of input data: mg/m³)					
Trend Removal	Type	Local Polynomial Interpolation	Local Polynomial Interpolation	Local Polynomial Interpolation	Local Polynomial Interpolation
	Power	2	2	2	3
Kriging Model	Type	Gaussian	Stable	Exponential	Spherical
	Nugget	$6.74 \cdot 10^{-7}$	$1.36 \cdot 10^{-6}$	$3.07 \cdot 10^{-7}$	$4.58 \cdot 10^{-7}$
	Parameter	N/A	0.2	N/A	N/A
	Range	3228	56640	14000	10000
	Partial Sill	$1.46 \cdot 10^{-6}$	0	$7.80 \cdot 10^{-7}$	$5.18 \cdot 10^{-7}$
	Function	0.346x+0.001	0.353x+0.002	-677.144x+1.326	0.379x+0.001
Anisotropy	Minor Range	N/A	N/A	4685	3386
	Direction	N/A	N/A	95°	107°
Results of Cross Validation – Prediction Error (unit of input data: mg/m³)					
Mean		$3.45 \cdot 10^{-6}$	$2.19 \cdot 10^{-5}$	$-5.74 \cdot 10^{-6}$	$-6.23 \cdot 10^{-6}$
Root-Mean-Square		0.001253	0.001208	0.000957	0.000912
Mean Standardized		0.005398	0.017915	-0.001899	-0.002566
RMS Standardized		0.865121	1.006222	0.988293	0.946582
Ave. Std. Error		0.001455	0.001204	0.000976	0.000976



Refer to the upper-right corner for legend and the results of **$PM_{2.5}$ Peak**

Conclusion

We clearly identified certain areas with higher concentrations, such as areas near major highways and intersections. Certain hot spots stood out more during peak hours. The kriging models we employed also indicated that anisotropic models are more suitable for non-peak hours. Although the highest concentrations in the results never exceeded the NAAQS, the actual human exposure might be quite different from our results since our network was not able to characterize small-scale and indoor exposure. Further studies on the effect of pollution on human health are needed to verify the applicability of the NAAQS.

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