Assessing Diurnal and Spatial Variations of $PM_{2.5}$ in Urban Environments: A Case Study with Low-Cost Sensors in an Environmental Justice Community

Inkyu Han, PhD

Associate Professor

Temple University College of Public Health

August 5, 2024

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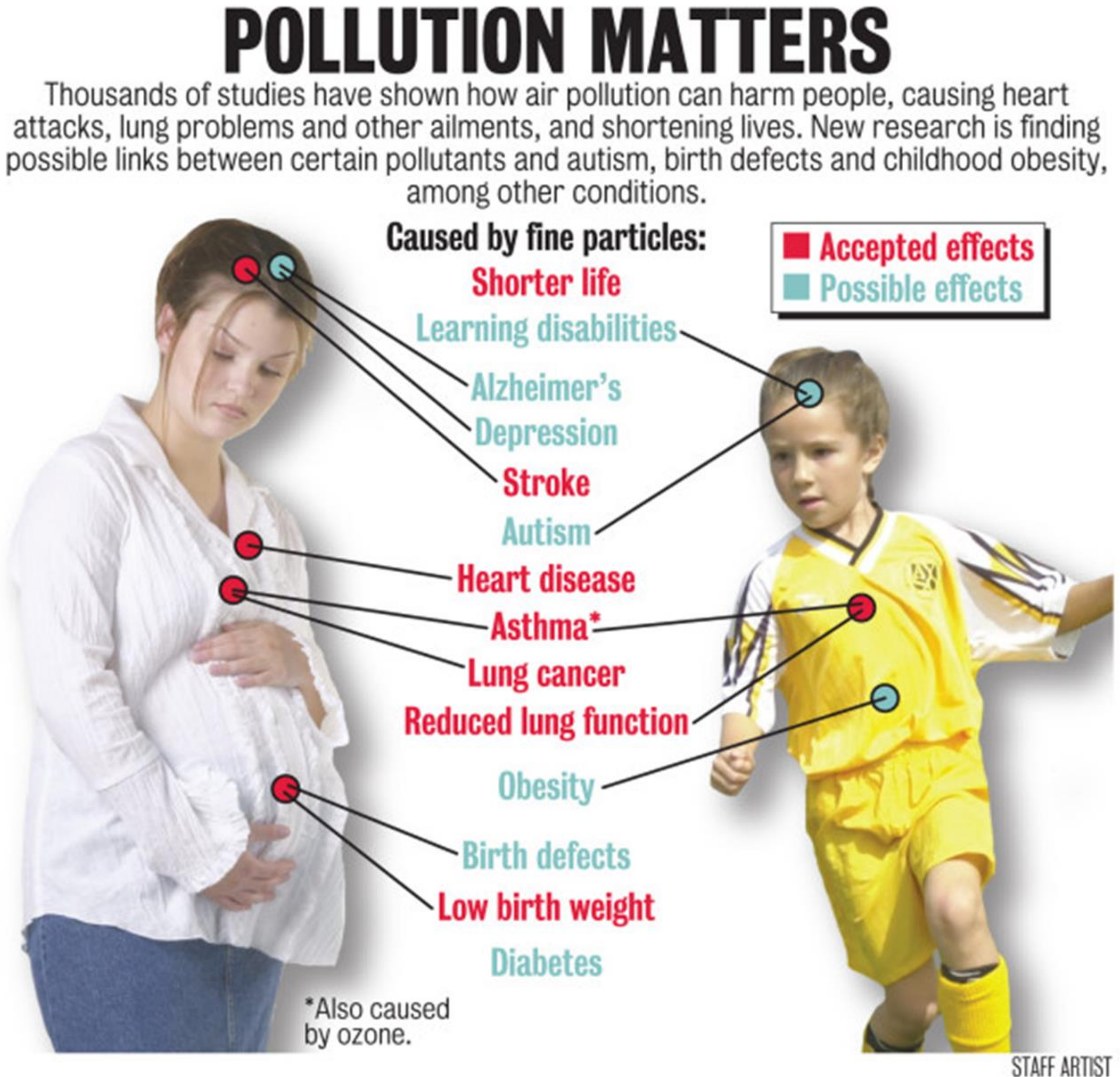
Contents

- Air pollution and health
- Background of low-cost air sensors
- Field evaluations
- Air monitoring with a low-cost air sensor in a community
- Summary
- Q & A

Air Pollution and Health Effects

- **Mortality**
  (Dockery 1993; Di 2017; Pope 2020)
- **Cardiovascular**
  (Brook 2008; Kaufman 2016; Drazen 2017)
- **Respiratory**
  (Dominici 2006; Adam 2015)
- **Neurologic disorders**
  (Dickerson 2015; Dickerson 2016; Jeremy 2018)
- **Reproductive**
  (Carre 2017; Rammah 2019)



Introduction

Increased focus on monitoring of $PM_{2.5}$ due severity of adverse effects

Suggested applications of the Low-cost Particulate Matter Sensor (LCPMS) to improve PM monitoring

- Supplementing existing stationary air monitoring device
- Source identification (e.g., fence line community)
- Personal exposure assessment
- Research and awareness
- Information and awareness (general public and elected officials)

Introduction

Low-cost Particulate Matter Sensor (LCPMS)

- Direct reading instrument (DRI)
- Cheap cost
- Small size with increased portability

Dylos DC 1700 Air Quality Monitor (Dylos)

- Light scattering method to count particles in air
- Built in pump (flow rate: 1.08 L/min)
- Measurements in two size bins (>0.5µm and >2.5µm)
- 1 min data logging interval
- Full battery lasts about 6hrs

Current Knowledge

Several validation studies have been conducted

Good correlation between LCPMS and research grade monitors (R = 0.66 – 0.99)

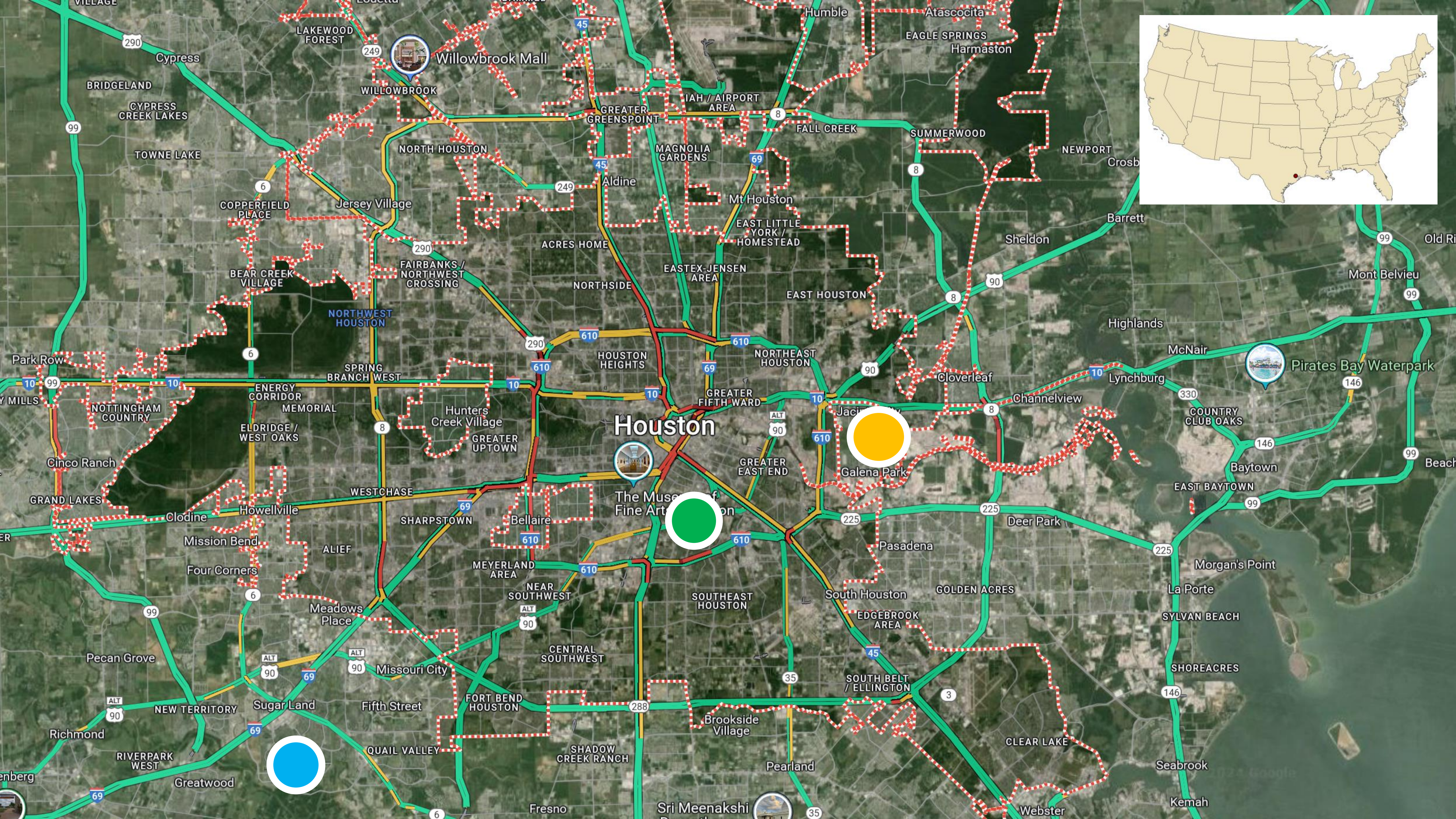
Calibration coefficients varied widely across studies (0.001 – 0.052)

Variation in calibration coefficients may lead to bias in converted measurements

Meteorological factors, Chemical and Physical properties of PM aerosols

Field Validation

- Effects of $PM_{2.5}$ emission source on the relationships between $PM_{2.5}$ measurements from
  - LCPMS (Dylos DC1700),
  - Gravimetric sampler ($PEM_{2.5}$) and
  - Research grade monitor (GRIMM 11R)



Humble
Atascocita
Lakewood Forest
Eagle Springs
Harmaston
Willowbrook Mall
Willowbrook
Cypress
Bridgeland
Cypress Creek Lakes
Greater Greenspoint
IAH / Airport Area
Fall Creek
Summerwood
North Houston
Magnolia Gardens
Newport
Towne Lake
Aldine
Mt Houston
Copperfield Place
Jersey Village
East Little York / Homestead
Barrett
Sheldon
Acres Home
Fairbanks / Northwest Crossing
Bear Creek Village
Eastex-Jensen Area
Northside
East Houston
Mont Belvieu
Northwest Houston
Highlands
Houston Heights
Northeast Houston
McNair
Pirates Bay Waterpark
Park Row
Spring Branch West
Cloverleaf
Lynchburg
Energy Corridor
Memorial
Greater Fifth Ward
Channelview
Nottingham Country
Hunters Creek Village
Country Club Oaks
Houston
Eldridge / West Oaks
Greater Uptown
Galena Park
Cinco Ranch
Greater East End
Baytown
The Museum of Fine Arts
East Baytown
Grand Lakes
Westchase
Clodine
Howellville
Sharpstown
Bellaire
Deer Park
Mission Bend
Alief
Pasadena
Four Corners
Meyerland Area
Morgan's Point
Near Southwest
Southeast Houston
La Porte
South Houston
Golden Acres
Meadows Place
Edgebrook Area
Sylvan Beach
Pecan Grove
Central Southwest
Missouri City
Shoreacres
South Belt / Ellington
Fort Bend Houston
New Territory
Sugar Land
Fifth Street
Brookside Village
Richmond
Clear Lake
Riverpark West
Quail Valley
Shadow Creek Ranch
Pearland
Seabrook
Greatwood
Fresno
Sri Meenakshi
Kemah
Webster

Locations

Clinton Drive Road

- Eastern part of the Houston metropolis, TX
- Higher number of HDDV (28%)
- Increased proportion of diesel particles

US59 Highway

- Southwestern to Northeastern part of Houston, TX
- Lower proportion of HDDVs (3%)
- Mainly from gasoline exhaust

Residential Home

- Suburban area in the Houston metropolitan, TX
- No significant sources of PM near the home

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- Dylos, PEM, GRIMM 11-R and a HOBO
- Logging intervals of 1 minute
- 20 days of sampling at each location
- Samples collected between 8am – 1pm
- Weekdays vs. Weekends
- October 2019 through January 2020
- Video recording of traffic for 10 mins every hour

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 (X_1 \times X_2) + \beta_5 (X_1 \times X_3) + \varepsilon$$

Y = LN of 3-hr $PM_{2.5}$ mass concentration from Grimm

X_1 = LN of 3-hr $PM_{2.5 - 0.5}$ number concentration from Dylos

X_2 = Binary Dummy variable: (1) US-59 and zero (0) other locations

X_3 = Binary Dummy variable: (1) Residential home and zero (0) other locations

β_4 = Interaction term: comparing Clinton *and US-59 slopes*

β_5 = Interaction term: comparing Clinton *and Res. Home slopes*

Overall Results

- Dylos count: 1439 ± 1053 #/0.01 ft^3
- PEM mass: 24.4 ± 24.4 $\mu g/m^3$
- Grimm mass: 13.7 ± 10.7 $\mu g/m^3$
- Temperature: 25.0 ± 6.5 °C
- $PM_{2.5}$ concentration varied by location

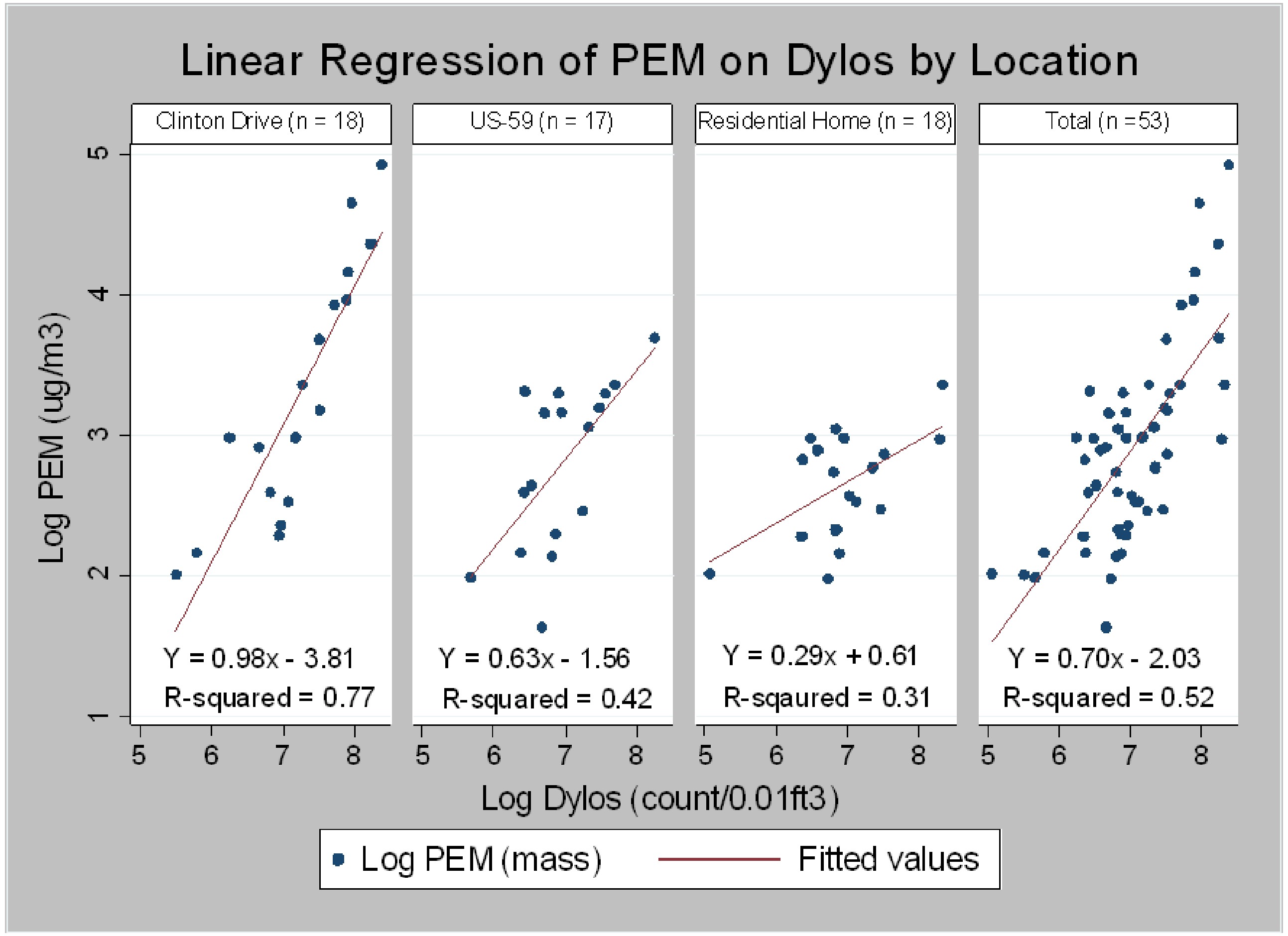
Location	Instrument	Measurement	N	Mean ± SD [a]	Median	Range
Clinton Drive	PEM	PM mass ($\mu g/m^3$)	18	39.9 ± 36.8	21.9	7.4 - 137.8
	Grimm 11R	PM mass ($\mu g/m^3$)	18	19.0 ± 14.7	12.5	2.6 - 47.6
	Dylos 1700	**PM number (particles/0.01ft^3)**	**18**	**1737 ± 1178**	**1138**	**246 – 4394**
	HOBO	Temp (°C)	18	27.3 ± 5.2	28.0	13.4 - 37.0
US-59	PEM	PM mass ($\mu g/m^3$)	17	18.9 ± 9.9	21.3	5.1 - 40.1
	Grimm 11R	PM mass ($\mu g/m^3$)	17	10.4 ± 5.2	8.2	3.2 - 21.5
	Dylos 1700	**PM number (particles/0.01ft^3)**	**17**	**1235 ± 854**	**1096**	**289 - 3844**
	HOBO	Temp (°C)	17	21.3 ± 5.9	22.1	10.9 - 32.6
Residential Home	PEM	PM mass ($\mu g/m^3$)	18	15.2 ± 5.6	15.7	7.2 - 28.8
	Grimm 11R	PM mass ($\mu g/m^3$)	18	11.6 ± 7.8	9.4	1.9 - 36.2
	Dylos 1700	**PM number (particles/0.01ft^3)**	**18**	**1332 ± 1082**	**1096**	**158 - 4144**
	HOBO	Temp (°C)	17	26.3 ± 7.1	26.6	12.7 - 37.3

[a] SD = Standard Deviation,

Dylos vs. PEM

Slopes differ by location

- Clinton: 0.98
- US-59: 0.63
- Residence: 0.29



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Bias

T-test showed mean bias between Dylos and PEM similar across locations (p = 0.89)

ANOVA test showed mean bias between Dylos and Grimm similar across locations (p = 1.0)

Location	PEM vs Dylos (Mean (%) ± SD)		Grimm vs Dylos (Mean (%) ± SD)		PEM vs Grimm (Mean (%) ± SD)	
	[a] General eqn.	[b] location eqn.	[a] General eqn.	[b] location eqn.	[a] General eqn.	[b] location eqn.
Clinton (n=18)	38 ± 22	37 ± 33	19 ± 13	14 ± 13	36 ± 23	35 ± 36
US-59 (n=17)	38 ± 45	37 ± 43	24 ± 17	19 ± 13	32 ±35	31 ± 33
Res. Home (n=18)	51 ± 35	27 ± 21	22 ± 19	19 ± 16	42 ± 39	25 ± 21
[c] Combined (n=53)	**42 ± 35**	**34 ± 33**	22 ± 16	17 ± 14	37 ± 33	30 ± 30

[a] *Absolute relative error estimated from a single regression line equation of total combined data*

[b] *Absolute relative error estimated from 3 regression line equations of data after grouping by sampling location*

[c] *Absolute error for all sampling locations combined together*

Community Monitoring

Galena Park

- 58% low-income population (86th)
- 42% less than high school education (96th)
- Annual average $PM_{2.5}$ in 2019 was 9.95 µg/m^3 (89th)
- Clinton Drive and Industrial Zone to the South

Method

- August 2020 – October 2020
- 15 Weekdays and 5 Weekends
    - 20 mins at 6 locations
    - Mornings (8pm and 12pm)
    - Evening (2pm and 6pm)
- Logging interval – 1 min
- PM, Temp & RH, Wind speed & direction

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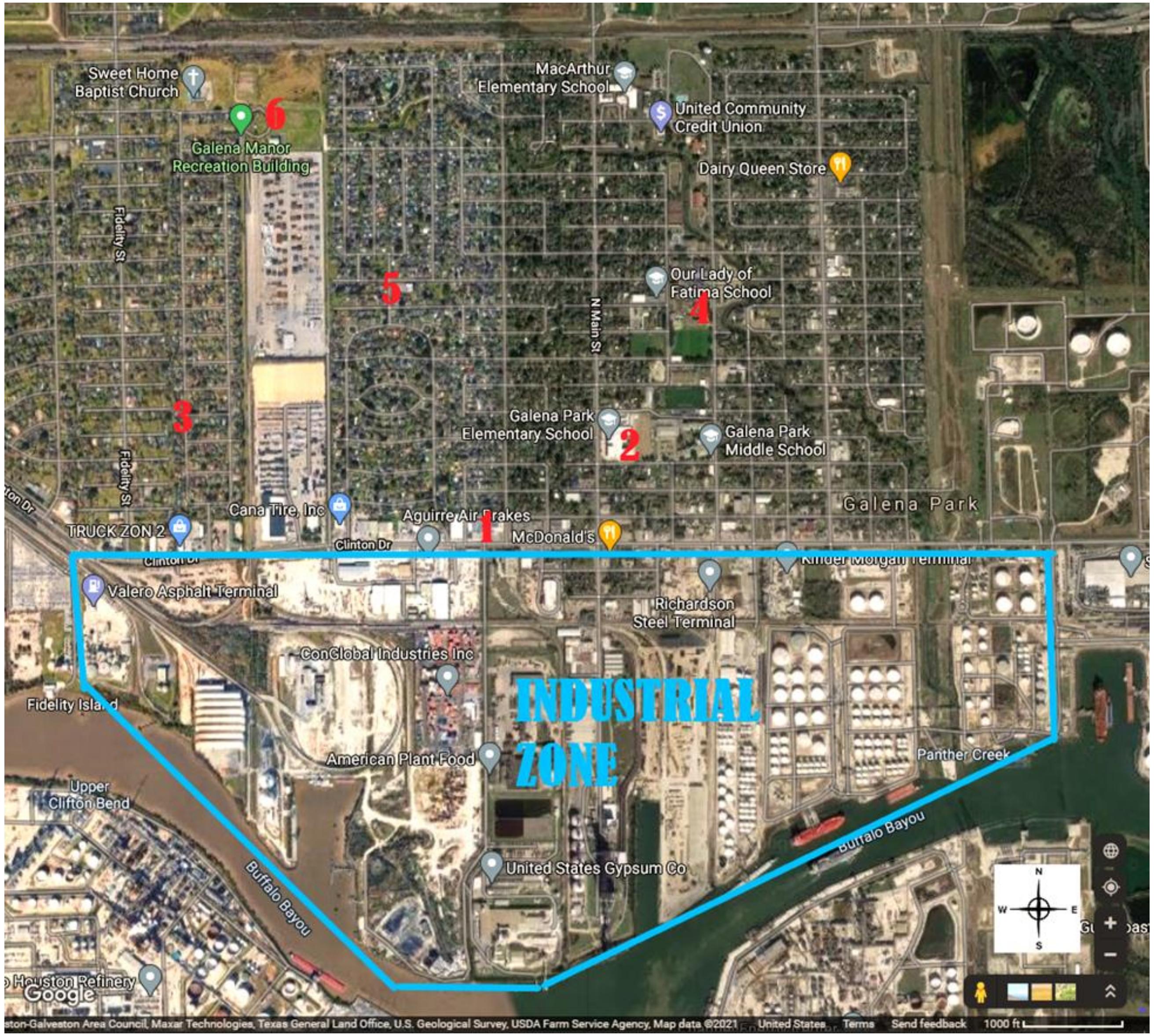
Locations

1. Shopping mall
2. Galena Park Elementary School
3. Residence Home-1
4. Galena Park High School
5. Residence Home-2
6. Galena Manor Park



Regression Equation

$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_6 X_6 + \varepsilon$ (eqn 5)

Where,

Y = natural log of the estimated mean 20min $PM_{2.5}$ mass concentration from the Dylos

X_1 = Categorical variable for the sampling location coded as (1) Shopping Mall (2) Elementary School (3) Residence 5th (4) High School (5) Residence 9th (6) Park

X_2 = Categorical variable for Time of Day coded as (0) for Morning and (1) for Evening

X_3 = Categorical variable for wind direction coded as (0) for North, Northeast, and Northwest (1) for South, Southwest, Southeast

X_4 = Categorical variable for wind speed coded as (0) for <1 m/s (1) for 1 - 2m/s (2) for >2 m/s

X_5 = Categorical variable for distance from Industrial zone coded as (0) <500m and (1) >500m

X_6 = Continuous variable for temperature

X_6 = Continuous variable for relative humidity

ε = Residual error

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Results

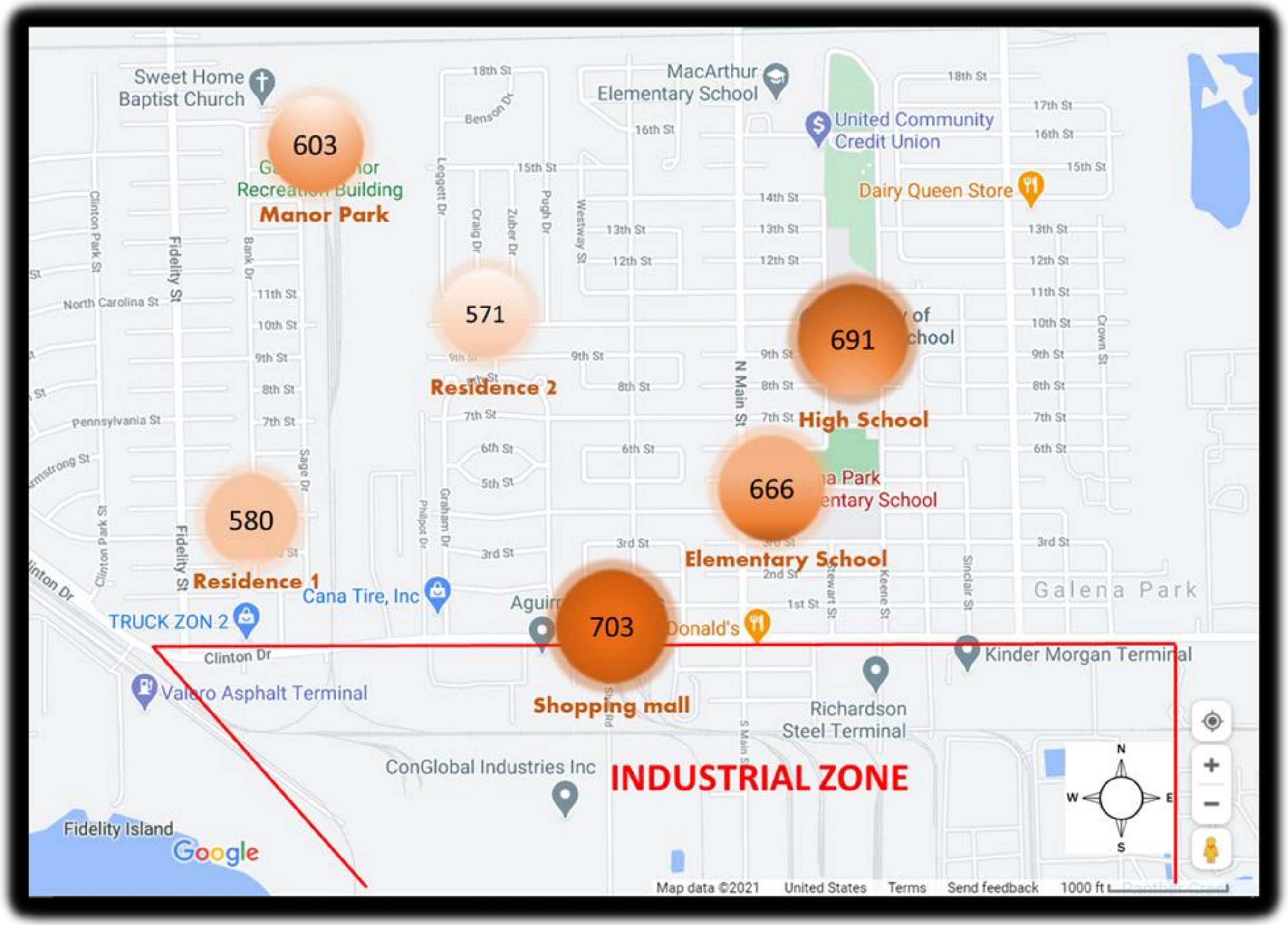
$PM_{2.5}$ number: 636 ± 385 #/0.01ft^3

Estimated $PM_{2.5}$: 12.3 ± 7.3 $\mu g/m^3$

Temperature: 29.4 ± 3.1 ^oC

RH: 52.8 ± 12.4%

$PM_{2.5}$ not vary by sampling locations ($p = 0.79$)



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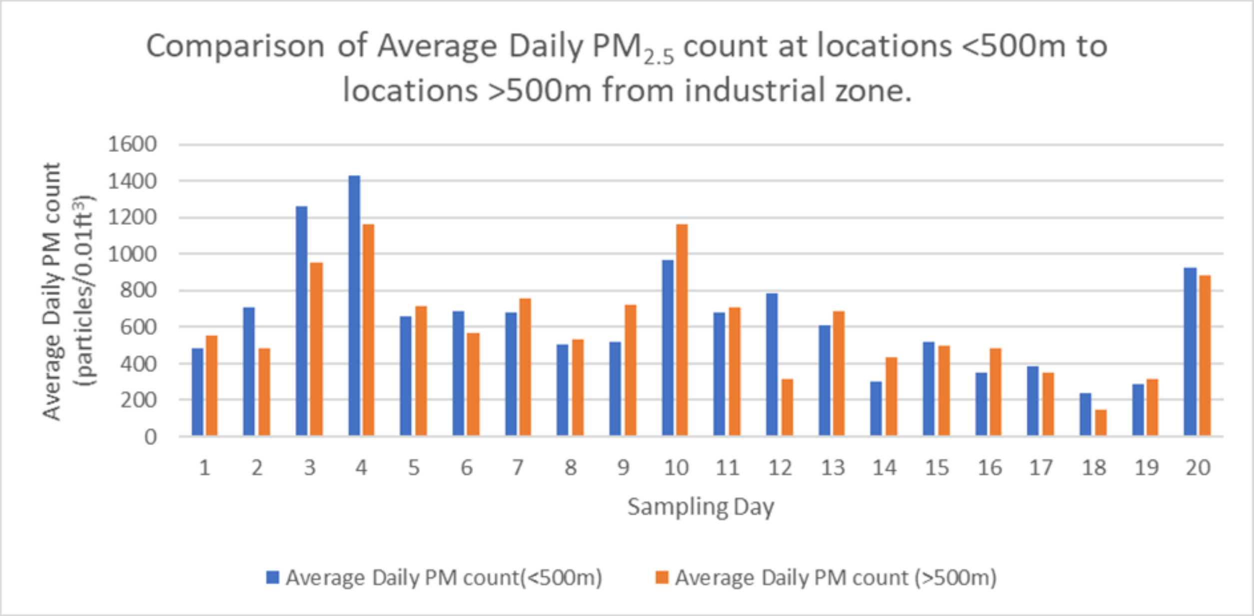
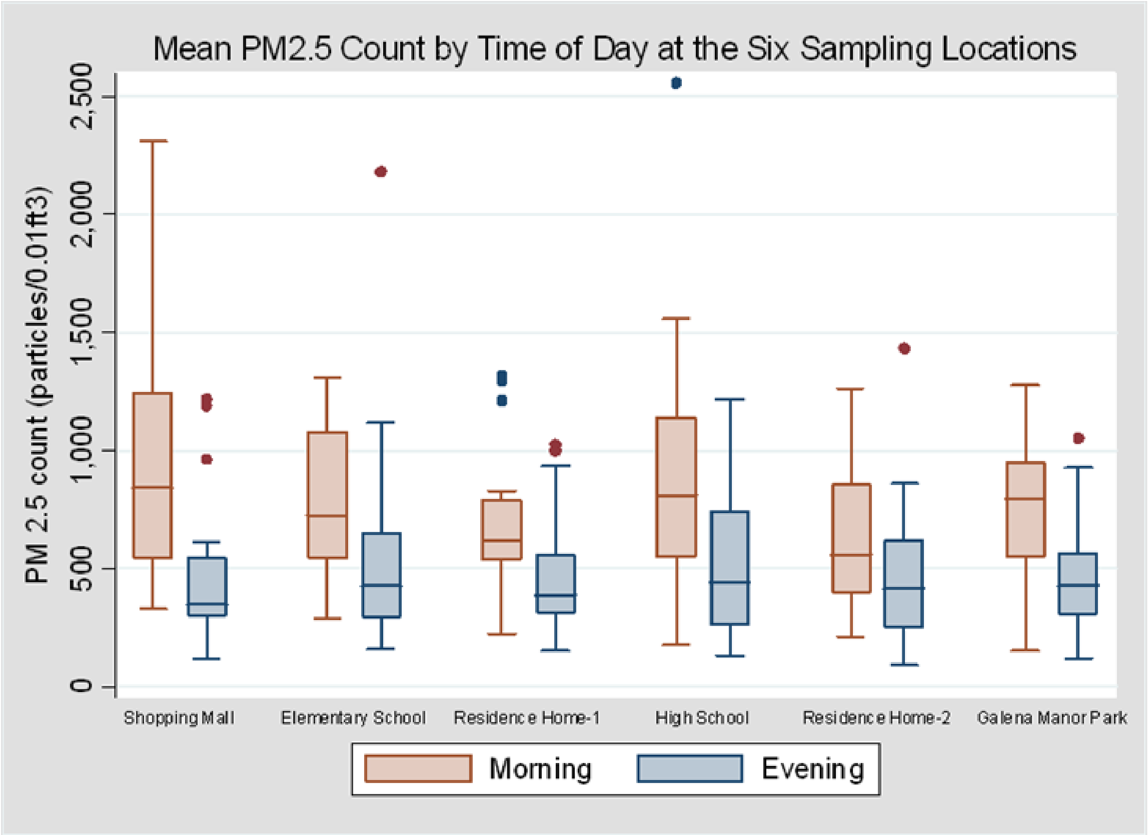
Spatial Variation



- Distance from industrial zone
  - Mean daily $PM_{2.5}$ was similar between groups
  - >500m group larger on 11 days
  - Wilcoxon signed rank test p-value = 0.88

Temporal variations



- Time of Day
  - Morning median $PM_{2.5}$ >500 particles/0.01ft^3
  - Evening median $PM_{2.5}$ <500 particles/0.01ft^3
  - Mean $PM_{2.5}$ higher in mornings
  - Wilcoxon signed rank test p-value < 0.01

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Regression Analysis

Time of Day

- Morning 0.54 µg/m³ > Evening

Wind Direction

- Downwind 2.29 µg/m³ > Upwind

Wind Speed

- WS (>2m/s) 2.32 µg/m³ > Calm

No spatial difference

	[a] Model 1			[b] Model 2			[c] Model3 with Interaction		
	Coef.	95% CI	P(t)	Coef.	95% CI	P(t)	Coef.	95% CI	P(t)
Constant	**2.71**	2.13 , 3.28	0.00*	**2.63**	2.11 , 3.16	0.00*	**2.78**	2.31 , 3.26	0.00*
Time of Day	**- 0.60**	- 0.75 , - 0.45	0.00*	**- 0.60**	- 0.75 , - 0.45	0.00*	**- 0.63**	- 0.78 , - 0.48	**0.00***
Temperature	**- 0.004**	- 0.02 , 0.01	0.62	**- 0.004**	0.22 , 0.50	0.60	**- 0.002**	- 0.02 , 0.01	0.68
WD	**0.36**	0.22 , 0.50	0.00*	**0.36**	0.22 , 0.50	0.00*	**0.83**	0.60 , 1.08	**0.00***
WS									
• **1 – 2m/s**	**0.20**	0.03 , 0.36	0.02*	**0.20**	0.03 , 0.36	0.02*	**0.57**	0.37 , 0.77	**0.00***
• **>2m/s**	**0.67**	0.48 , 0.87	0.00*	**0.68**	0.48 , 0.87	0.00*	**0.84**	0.62 , 1.05	**0.00***
WD*WS									
• **1 – 2m/s**			**N/A**			N/A	**- 0.84**	- 1.13 , 0.55	**0.00***
• **>2m/s**							**- 0.24**	- 0.62 , 0.14	0.21
Location									
• **Elementary**	**- 0.05**	- 0.28 , 0.17	0.65						
• **Residence 1**	**- 0.11**	- 0.34 , 0.12	0.35		N/A			N/A	
• **High School**	**- 0.004**	- 0.23 , 0.23	0.97						
• **Residence 2**	**- 0.17**	- 0.39 , 0.06	0.15						
• **Manor Park**	**- 0.06**	- 0.29 , 0.16	0.59						
df		11			6			8	
R^2		0.43			0.42			0.51	
AIC		273			267			236	

[a] Model with variables sampling location, time of day, wind direction and windspeed and temperature.
[b] Sampling location dropped from model 1.
[c] Model 2 with interaction term included
df = degrees of freedom, WD = wind direction (baselevel = North), WS = wind speed (baselevel = <1m/s)
Time of day (baselevel = Morning), Location (baselevel = Shopping mall)

Summary and Conclusions

Effects of $PM_{2.5}$ Particle size and $PM_{2.5}$ emission source on linearity between Dylos and research grade monitors

Particle size and emission source affected the linearity

May lead to bias on converted Dylos mass measurements

Particle size and emission source considered during calibration of Dylos

Application of Dylos as a citizen science tool to evaluate spatial and temporal variation in a low-income community

Within small study area (~2.5km^2), one monitor required for ambient $PM_{2.5}$ assessment

Dylos can determine peak periods and meteorological factors affecting ambient $PM_{2.5}$

Dylos can be used as a tool to determine outdoor activities for community members (e.g., school children)

Thank you

Contact Information

Inkyu Han, PhD
Associate Professor
Human Exposure Assessment
Department of Epidemiology and Biostatistics
Temple University College of Public Health
Inkyu.han@temple.edu