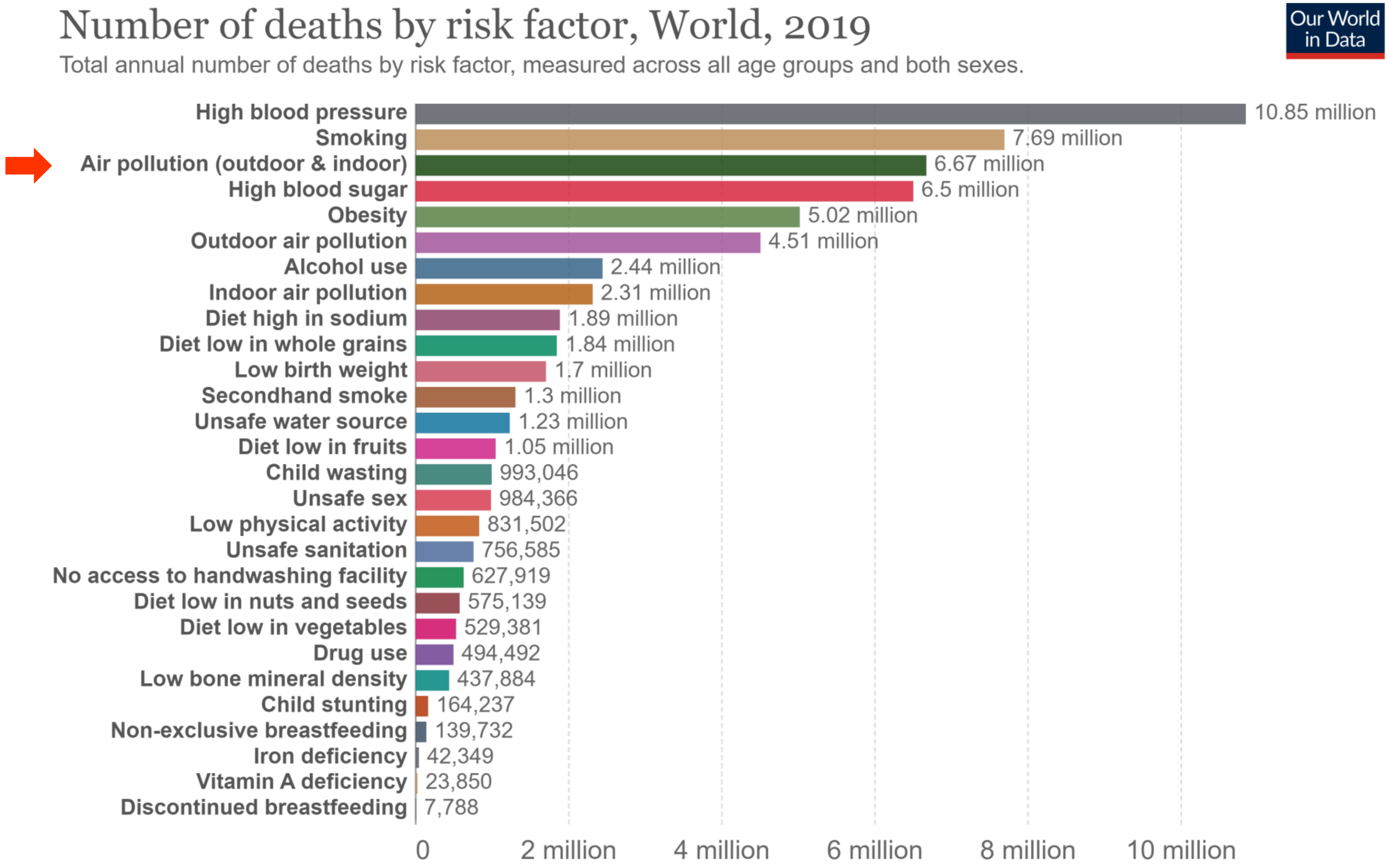
Air Pollution Effects of Short-Term Events:

Observing Structural Fires with a Dense Sensing Network

Ayina Anyachebelu
Undergraduate Research Intern
Urban Innovation @ MSR
Mentor: Madeleine Daepp

Air pollution is a leading global public health risk

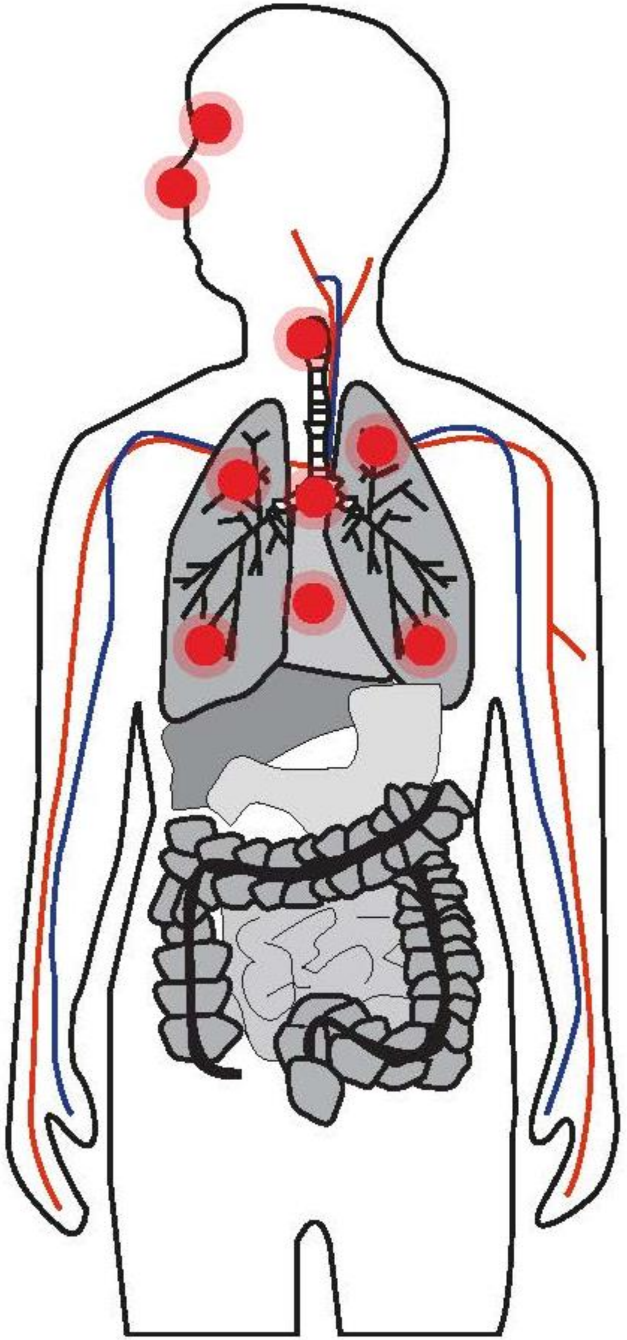


IHME, Global Burden of Disease (GBD), 2020

Acute and short-term effects of PM2.5 can be very harmful

Fine particulate matter (PM2.5): Particles small enough to enter the lungs and bloodstream

Even small increases **(6 – 10 µg/m³)** in PM2.5 for **2-3 hours** increases odds of adverse health outcomes for vulnerable populations.



Structural fires produce $PM_{2.5}$ but there is less known about their pollution contribution

490,500

Structural Fires in 2020

2600 deaths & 1200 injuries

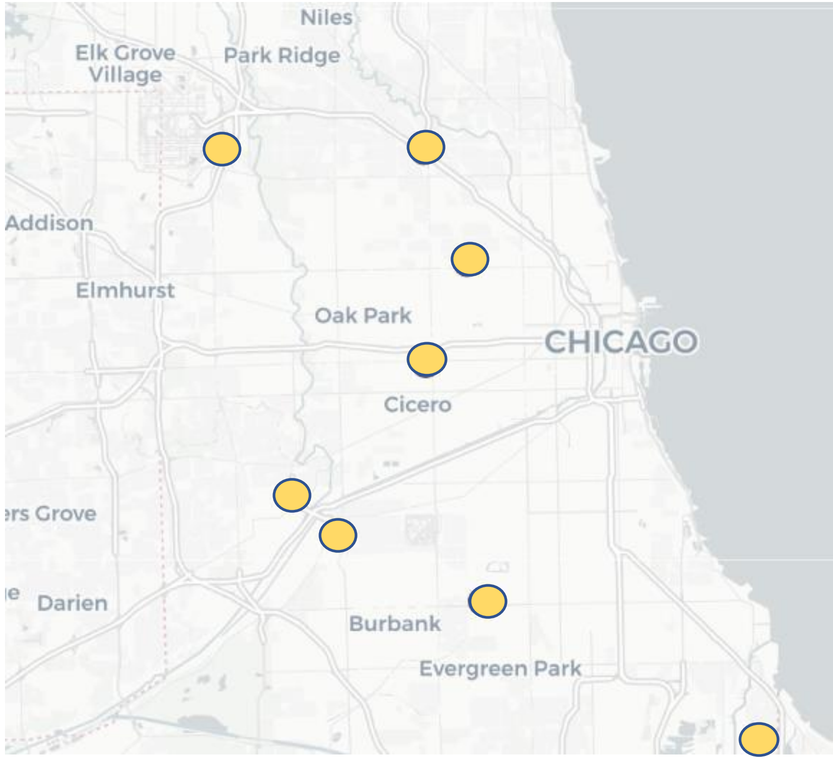
$12 million in property damage

??? Pollution

Scale, duration, and location and meteorological conditions of a fire affect its PM2.5 contribution, underscoring the need to characterize these events.

Regulatory Monitoring is not designed to detect short-term, hyperlocal events

- There are only 3 $PM_{2.5}$ EPA monitors in Chicago
- Monitors only provide daily averages
- This data is temporally and spatially sparse



Locations of EPA air quality sensors

Eclipse – a dense, low-cost sensing network that can fill regulatory monitoring data gaps

- Project by MSR Urban Innovation
- Deployed in July 2021
- 115 sensors across Chicago
- 5-minute, real-time readings
- Publicly available data

Dense sensing networks are yet to be applied to policy-relevant questions

We lack a causal understanding of spatio-temporal anomalies in network data.

Spatial calibration and $PM_{2.5}$ mapping of low-cost air quality sensors

Hone-Jay Chu, Muhammad Zeeshan Ali & Yu-Chen He

ADF: An Anomaly Detection Framework for Large-Scale PM2.5 Sensing Systems

Ling-Jyh Chen, *Senior Member, IEEE*, Yao-Hua Ho, Hsin-Hung Hsieh, Shih-Ting Huang, Hu-Cheng Lee, and Sachit Mahajan, *Graduate Student Member, IEEE*

Article

Building Low-Cost Sensing Infrastructure for Air Quality Monitoring in Urban Areas Based on Fog Computing

Ivan Popović [1], Ilija Radovanovic [1,2,*], Ivan Vajs [1,2], Dejan Drajic [1,2,3] and Nenad Gligorić [3,4]

Research Questions

1. What is the contribution of structural fires to pollution exposure?

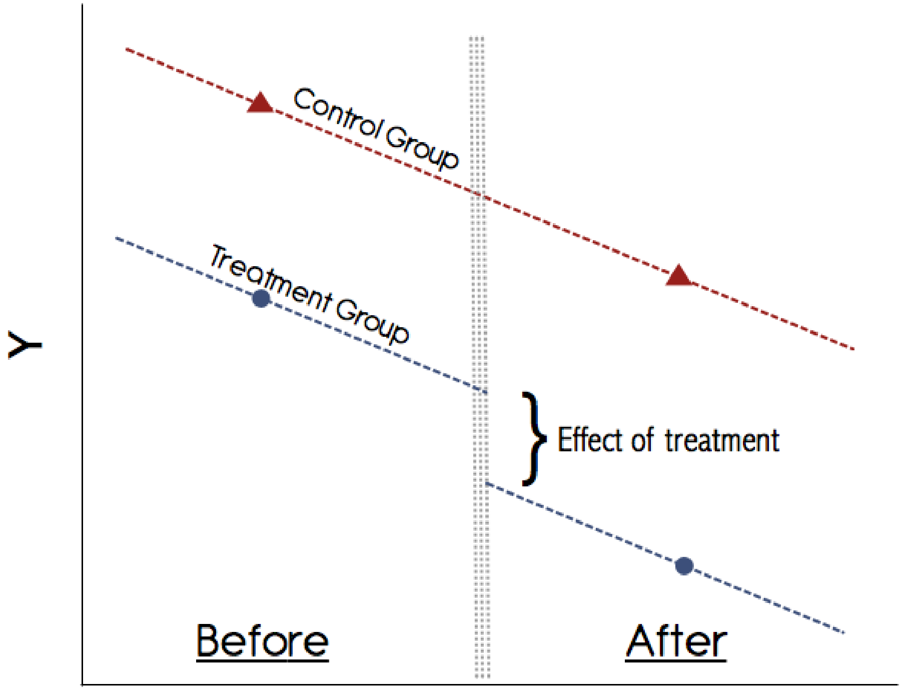
2. Can we characterize fires based on their emissions footprint?

Methodology

Difference in Differences (DID):

- Causal Method comparing the changes in outcomes over time between a treatment and control group with assumption groups would have moved similarly without intervention.

Difference-in-Difference estimation: graphical explanation



Treatment Group: Upwind Sensors
Control Group: Downwind Sensors
Effect: Change in $PM_{2.5}$

Model:

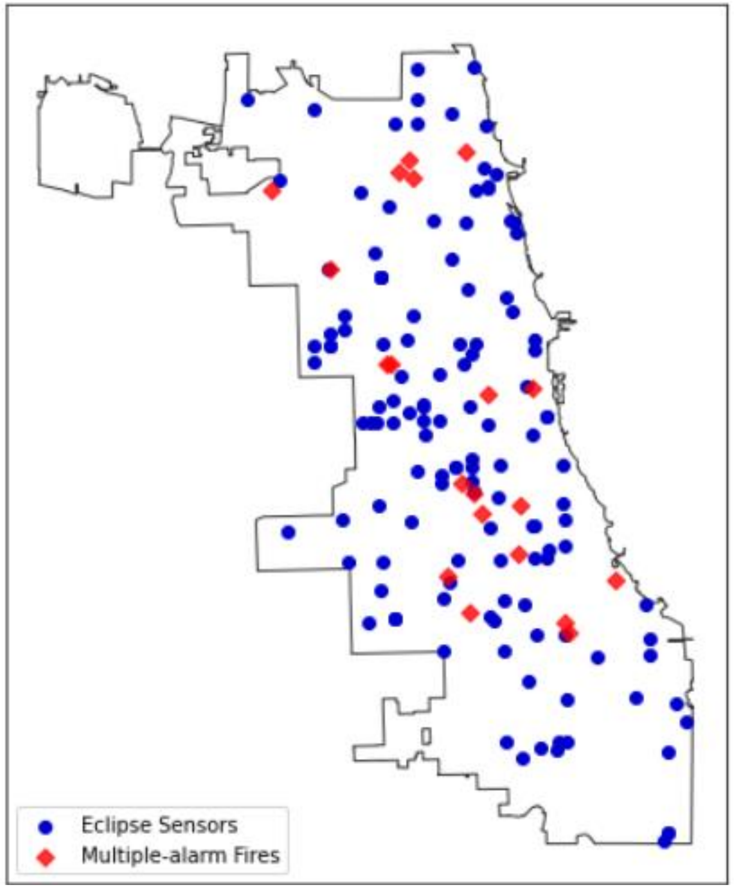
$$PM2.5_{it} = \alpha_0 + \sum_{k=-35}^{35} \beta_k \boldsymbol{Upwind}_{it} + X'_{it}\tau + \mu_i + \lambda_t + \epsilon_{it}$$

*** k ranges from -35 to 35, k=0 dummy is dropped as reference time*

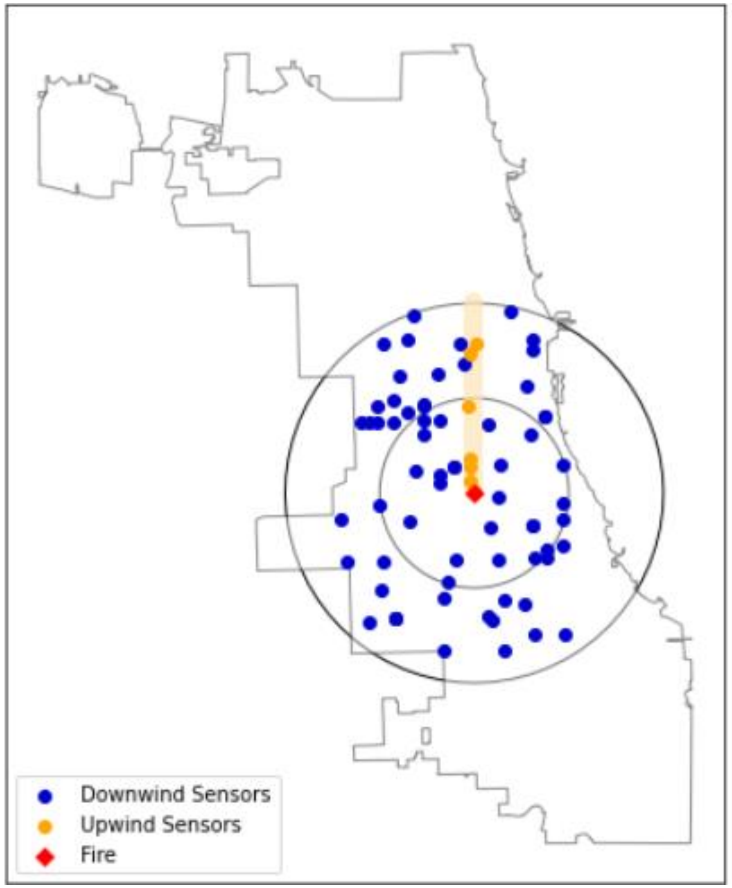
****k indexes 5-minute increments*

Identifying Upwind Sensors

Locations of Fires and Sensors



Identification of Upwind Sensors



Treatment Group: Upwind Sensors
Control Group: Downwind Sensors
Effect: Change in $PM_{2.5}$

Representation of Fire Plume:

- 1km - wide buffer in direction of the wind from fire
- Sensors in buffer are considered upwind
- Robustness checks using plume width variations

In right panel, circles are radii of 10 and 5km from the fire

Datasets: Fire Data

From July 2021 – July 2022:

Data Collection

Location
Start time
Alarm level (Intensity)

Data Validation

New Articles,
Communication with
Fire Dept media team

23 Multiple - Alarm Fires

****Comprehensive list**

100 Fires

with confirmed start times

Datasets: Meteostat

Weather Information:

Wind Direction
Windspeed
Temperature
Precipitation

From July 2021 – July 2022:

21 Multiple - Alarm Fires

With useable wind information

Datasets: Eclipse Network Data

July 2021 – July 2022
13 months -
3 hours before and after each fire

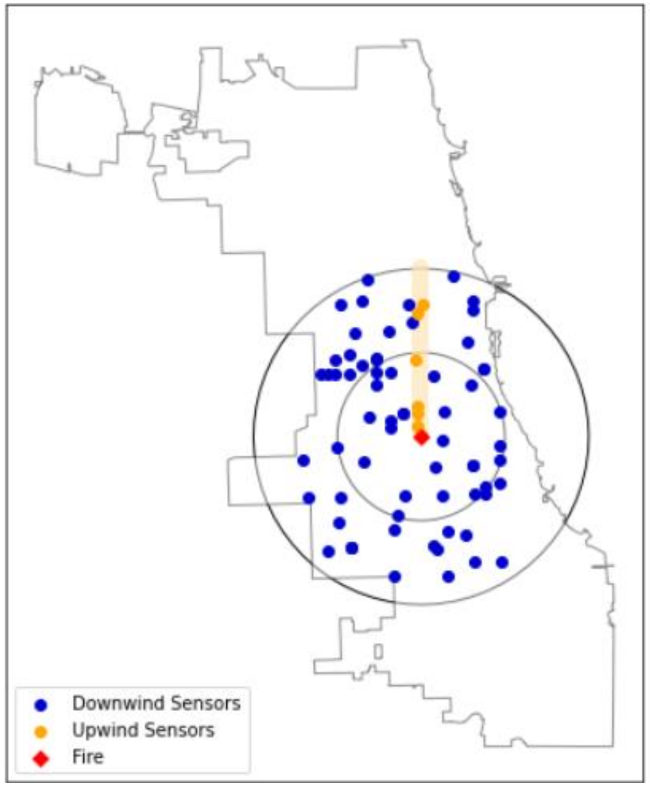
152,275
5-minute multiple-alarm fire readings from 675,64 readings

2.71 RMSE
For PM2.5 Calibration Model (compared to EPA monitors)

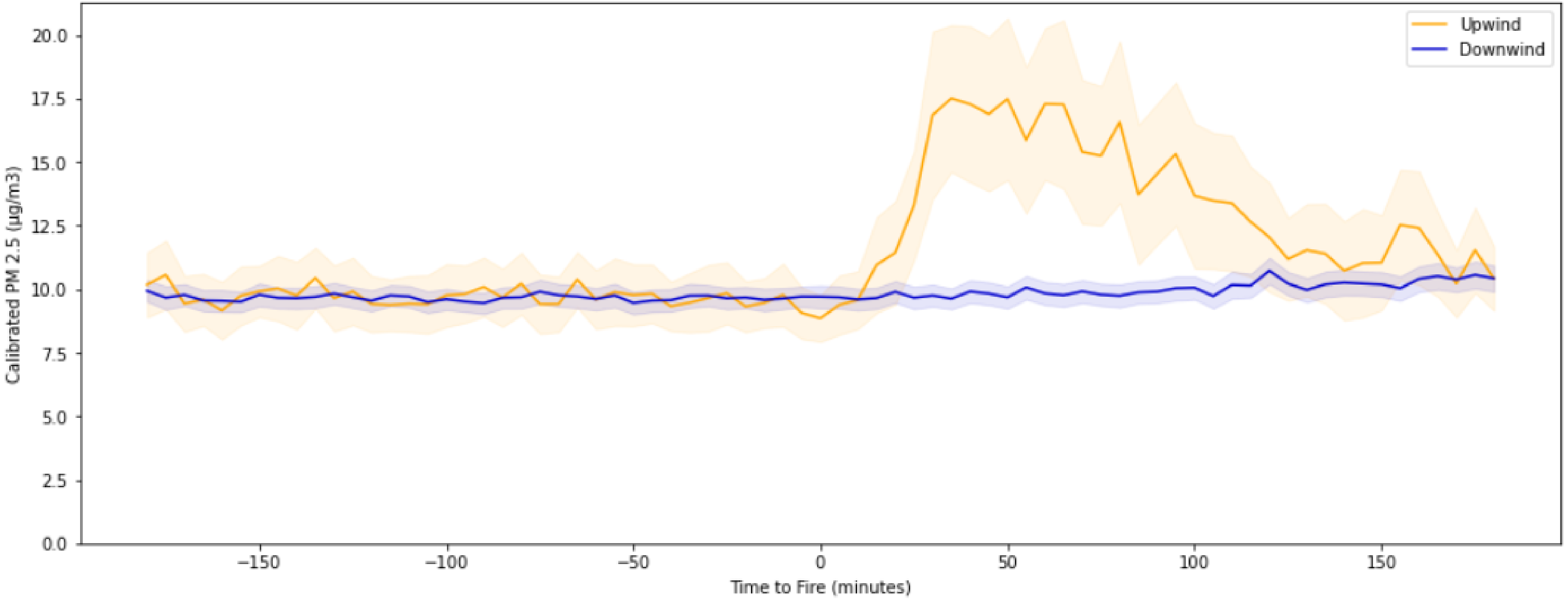
76% of Multiple Alarm Fires had an upwind sensor within 10 km

Upwind and Downwind Sensors Follow Parallel Trends

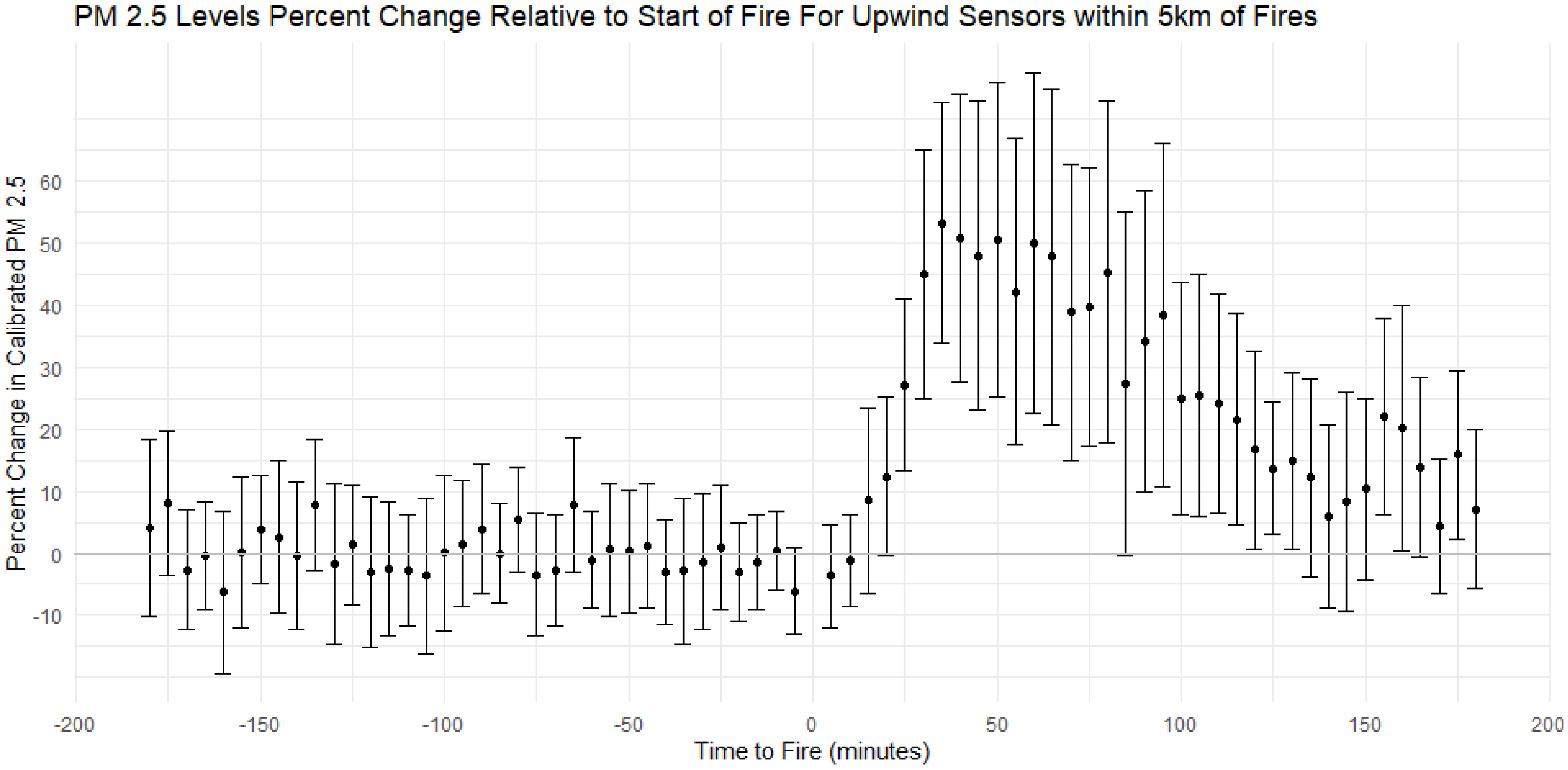
Identification of Upwind Sensors



Our plots bolster the assumption that upwind and downwind sensors would have had similar trends in the absence of a fire.



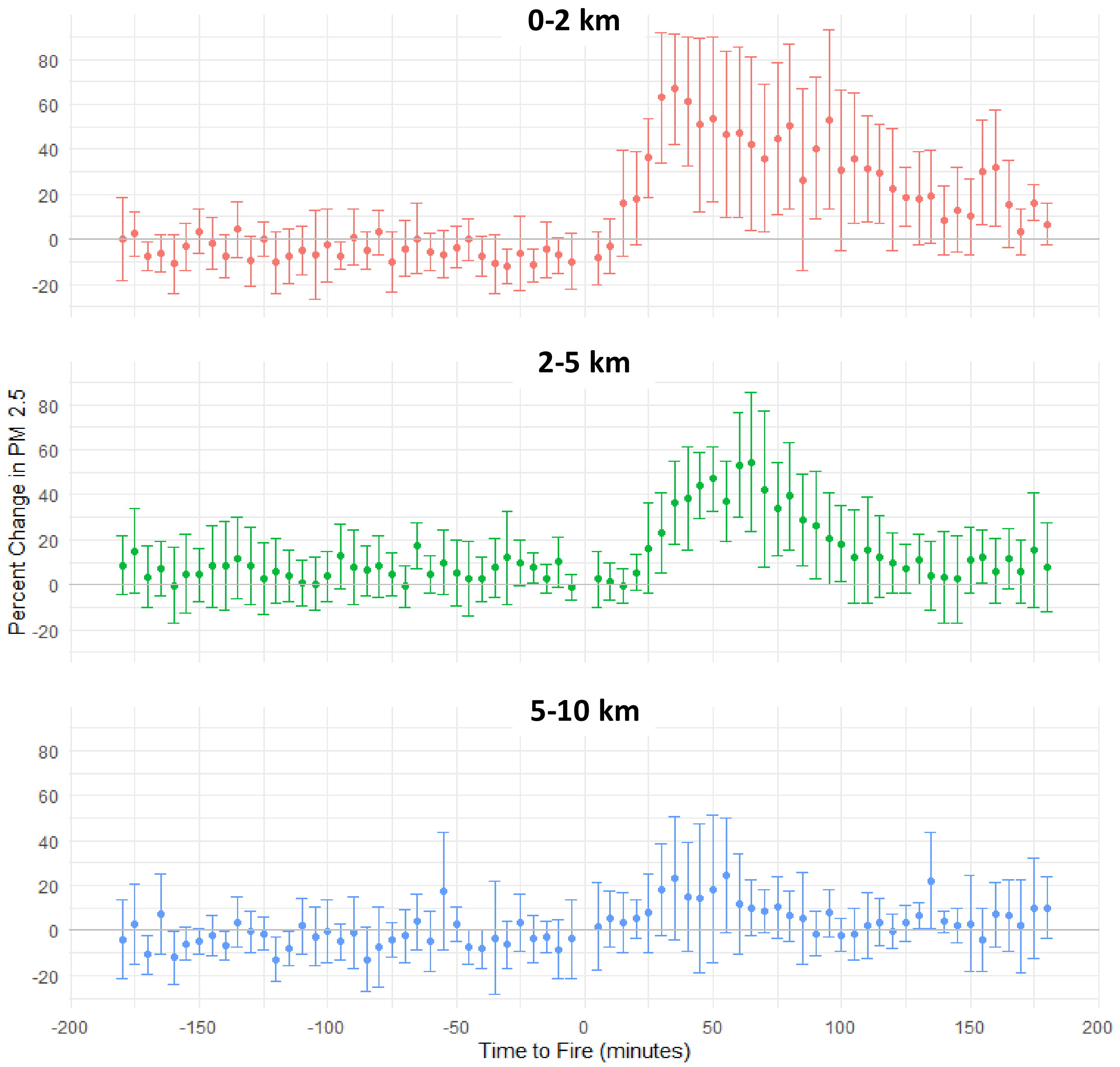
We can characterize fire effects on PM2.5 temporally



- Up to 53% increase in PM2.5 (~7.8 μg/m^3)
- Greatest exposure 35 minutes after fires start
- Elevated levels for about 2 hours

We can characterize the distance of fire emission spreads

- **Significant effects for sensors within 5 km but not farther away**
- 67% increase for 0-2km (peak after 35 mins)
- 55% increase for 2-5km (peak after 65 mins)
- Again, effect lasts for about 2 hours



Limitations

Limited to Twitter fire dataset

Comprehensive list of Multi-alarm fires and thorough validation

Low-cost sensors subject to error

Effective Calibration in line with EPA recommendations

Simple fire plume dispersion representation

Robustness checks with varying plume width sizes

Potential wind direction changes after first hour of fire

Reasonable assumptions given clear, significant results

Implications

Public Health

- We estimate that on average **23,000 people** are affected by each fire
- Vulnerable Populations will be affected by:
  - 2-hour exposure and even small increases in PM2.5
  - Increased hospitalizations, medical spending and mortality

Future Sensing Work

- Low-cost, real-time sensing networks are effective in detecting and quantifying neighborhood-level pollution events.
- This study informs early fire detection/classification systems and warning systems for the public

Summary

- Regulatory monitoring cannot detect short-term, hyperlocal pollution events like structural fires, but low-cost dense networks like Eclipse can fill those gaps

- Structural fires have statistically significant impacts on PM2.5
  - Increases by 67%
  - Heightened exposure for about 2 hours
  - Effects as far as 5km away – affecting 23,000 people

- Novel dense networks of low-cost sensors enable us to characterize previously undetectable urban phenomena which could improve public health outcomes

Thank you!

To the Urban Innovation Team
And all attendees!

$$\text{PM2.5}_{it} = \alpha_0 + \sum_{k=-35}^{35} \boldsymbol{\beta_k Upwind}_{it} + X'_{it}\tau + \mu_i + \lambda_t + \epsilon_{it}$$

*** k ranges from -35 to 35, k=0 dummy is dropped as reference time*

****k indexes 5-minute increments*