Spatial and temporal patterns in air pollution in Pittsburgh: Traffic and point sources

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September 24, 2015
Acknowledgments

- **CMU:** Tim Dallmann, Yi Tan, Bob Gu, Hugh Li, Xiang Li, Allen Robinson, Andrew Hix, Richa Khosla, Jiesi Ma, Neil Donahue, Peter Adams

- **Financial Support:** Heinz Endowments

- This presentation reflects the views of the authors and not any of the funding agencies. No official endorsement should be inferred.
What you will learn

1. What air pollutants we care about and their relationships to health
2. Spatial and temporal variations in Pittsburgh air pollution
3. Contributions of traffic and industrial point sources to pollutant patterns
Obligatory slides of “smoky” Pittsburgh
1936
2006
However, Pittsburgh still does not meet national standards
PM$_{2.5}$ non-attainment
What pollutants?

Gases
- Carbon monoxide (CO)
- Nitrogen oxides (NOx)
- Sulfur dioxide (SO$_2$)
- Organic compounds

Particulate matter (PM)
- Black carbon (BC)
- PAHs
- Organic compounds
- Metals
# EPA National Ambient Air Quality Standards (NAAQS)

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Primary standard(s)</th>
<th>Allegheny County non-compliant?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ozone ($O_3$)</td>
<td>75 ppb (8-hr)</td>
<td>X</td>
</tr>
<tr>
<td>$PM_{10}$</td>
<td>150 µg/m$^3$ (24-hr)</td>
<td></td>
</tr>
<tr>
<td>$PM_{2.5}$ (Particulate matter &lt;2.5 µm)</td>
<td>12 µg/m$^3$ (annual) 35 µg/m$^3$ (24-hr)</td>
<td>X X</td>
</tr>
<tr>
<td>$NO_2$</td>
<td>53 ppb (annual) 100 ppb (1-hr)</td>
<td></td>
</tr>
<tr>
<td>CO</td>
<td>9 ppb (8-hr) 35 ppb (1-hr)</td>
<td></td>
</tr>
<tr>
<td>$SO_2$</td>
<td>75 ppb (1-hr)</td>
<td>X</td>
</tr>
<tr>
<td>Lead (Pb)</td>
<td>0.15 µg/m$^3$ (3-month avg.)</td>
<td></td>
</tr>
</tbody>
</table>
Air toxics

- ~190 species
  - Benzene, arsenic, etc
- Carcinogenic, mutagenic, teratogenic
- Regulated based on emissions
Air Pollution Impacts Health

At-risk people

PREGNANT WOMEN
HEART DISEASE
DIABETES
ACTIVES
SENIORS
CHILDREN & INFANTS

Health effects

ASTHMA
PRETERM BIRTH, AUTISM
HEART DISEASE
RESPIRATORY ILLNESS
EARLY DEATH

EVERYBODY BREATHEs!

Source: Breathe Project
Air Pollution and Health: Epidemiology

Harvard Six Cities Study

Mortality rate was **higher** in cities with higher PM$_{2.5}$ concentrations.

Result has been repeated for larger studies in more cities.

Limitation: Everyone in each city is assigned the same PM$_{2.5}$ concentration.
There is no safe limit

- EPA rules are set to protect human health
- Being below the limit does not make health risks zero
- Health risks persist
One major goal of our work

• Improve spatial fidelity relative to estimates from central site monitors
NYCCAS study: Sample sites
NYCCAS study: Pollutant maps
Mobile sampling in Pittsburgh
Sampling Domain: All Sites

2011-2012
2013-2014
Sample grouping: BC and Traffic

Summer 2013

Low Traffic

High Traffic

BC ($\mu$g m$^{-3}$)

- 75th %ile
- Mean
- Median
- 25th %ile

SUM_LOW

SUM_HIGH
Vehicle Plumes

[Graph showing various concentrations of pollutants over time, including PM$_{2.5}$, BC x 10, PAH, NO$_2$, NO, and CO$_2$. A note indicates that a MD truck passes the lab at 7:30 AM.]
The Contribution of High Emitting Vehicles (HEVs)

On-road emissions from HEVs

Non-plume background

Tan et al. *EST* (2014)
Plumes are from (diesel) vehicles

![Graph showing the relationship between PAHs and average daily truck traffic with a traffic tunnel noted as a reference point.]

- **Y-axis**: PAHs/1000 BC
- **X-axis**: Average daily truck traffic

Tan et al. *EST* (2014)
Plumes are from (diesel) vehicles

\[ y = 0.0323x + 3.57 \]

\[ R^2 = 0.80 \]
Mapping Pollutant Concentrations

Kernel interpolation – Bottom-up estimation: “From Emissions to Concentrations”

On-road emissions from HEVs

Non-plume background
From On-road to Near-road

Kernel Interpolation

\[ C(d) = C_0 (1 - (d/100)^2)^2 \]

Distance to roadway (m)

Predicted concentration normalized by road edge
The Contribution of HEVs – Bottom-Up Estimation
Mapping the non-plume background

On-road emissions from HEVs

Non-plume background

Land Use Regression (LUR) – Top-down Estimation
“Link concentrations with independent variables”
## Non-plume Background BC

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>1.39</td>
</tr>
<tr>
<td>Average elevation (m)</td>
<td>-1.58E-3</td>
</tr>
<tr>
<td>The fraction of commercial land in the 200m buffer</td>
<td>0.77</td>
</tr>
<tr>
<td>The fraction of industrial land in the 200m buffer</td>
<td>1.13</td>
</tr>
</tbody>
</table>

\[ R^2 = 0.55 \]
\[ \text{LOOCV } R^2 = 0.44 \]
\[ \text{HV } R^2 = 0.23 \]
On-road emissions from HEVs

Non-plume background

BC: Traffic and industrial indicator

BC (μg/m³)

- High: 5.63
- Low: 0.52
NO$_2$: Traffic (and industrial) indicator
Cr: Industrial indicator

- 0 ug/m3
- 0 - 0.002 ug/m3
- 0.002 - 0.004 ug/m3
- 0.004 - 0.006 ug/m3
- 0.006 - 0.008 ug/m3
Residential Outdoor Exposure: BC
Environmental Justice: BC

Lower income homes are exposed to higher average BC
Constant $\sim 0.15 \, \mu g \, m^{-3}$ in plume layer
~150 deaths per year
Temporal patterns - Ozone

![Graph showing temporal patterns of ozone](image)

- Ozone (ppb) vs Hour
- Sun icon in the graph

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Point sources drive temporal changes

Overnight plume events
Point sources drive temporal changes

Automobile emissions
Industrial emissions
Point sources: Toluene
What you will learn

1. What air pollutants we care about and their relationships to health
2. Spatial and temporal variations in Pittsburgh air pollution
3. Contributions of traffic and industrial point sources to pollutant patterns
The Contribution of HEVs – Bottom-Up Estimation

The Contribution of High Emitting Vehicles

BC (μg/m³)
- 0.13 - 0.25
- 0.26 - 0.50
- 0.51 - 0.75
- 0.76 - 1.00
- 1.01 - 2.41

Kilometers

The Contribution of High Emitting Vehicles

BC (μg/m³)
- 0 - 0.25
- 0.26 - 0.50
- 0.51 - 0.75
- 0.76 - 1.00
- 1.01 - 2.28

Kilometers

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Sites are skewed

Particle-bound PAH (ng m$^{-3}$)

- Mean = 16 ng m$^{-3}$
- Median = 9 ng m$^{-3}$

Summer 2013
LUR 101

• Observations

• Independent land use variables from GIS
  • Areas zoned commercial or green space
  • Road length, total traffic

• Stepwise regression

• Leave-one-out cross validation (LOOCV) & Hold-out validation (HV)

Eeftens et al., *ES&T* (2012)
Total BC
Fraction from high emitting (diesel) vehicles
LUR for Mobile Monitoring