National Assessment of Near-Road (NR) Air Quality: Requirements, Trends, and Analysis Insights

Work Sponsored by the Near-Road Air Quality Transportation Pooled Fund (TPF)

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Largely Based on Presentations Shared at the
Transportation Research Board 2019 Annual Meeting

STi Sonoma Technology

Washington State Department of Transportation

August 7, 2019

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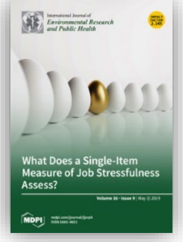
Material Drawn From

(Partial List):

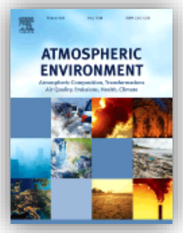


Brown et al., 2019: 2014-2016 data.

Conditions Leading to Elevated $PM_{2.5}$ at Near-Road Monitoring Sites: Case Studies in Denver and Indianapolis

Seagram et al., 2019: 2016 data.

National Assessment of Near-Road Air Quality in 2016: Multi-Year Pollutant Trends and Estimation of Near-Road $PM_{2.5}$ Increment



DeWinter et al., 2018: 2014 and 2015 data.

A National-Scale Review of Air Pollutant Concentrations Measured in the U.S. Near-Road Monitoring Network During 2014 and 2015

Reid et al., 2016: 2006-2035 modeled emissions.

Emissions Modeling with MOVES and EMFAC to Assess the Potential for a Transportation Project to Create Particulate Matter Hot Spots

Karner, Eisinger, and Niemeier, 2010: 1978-2008 global data.

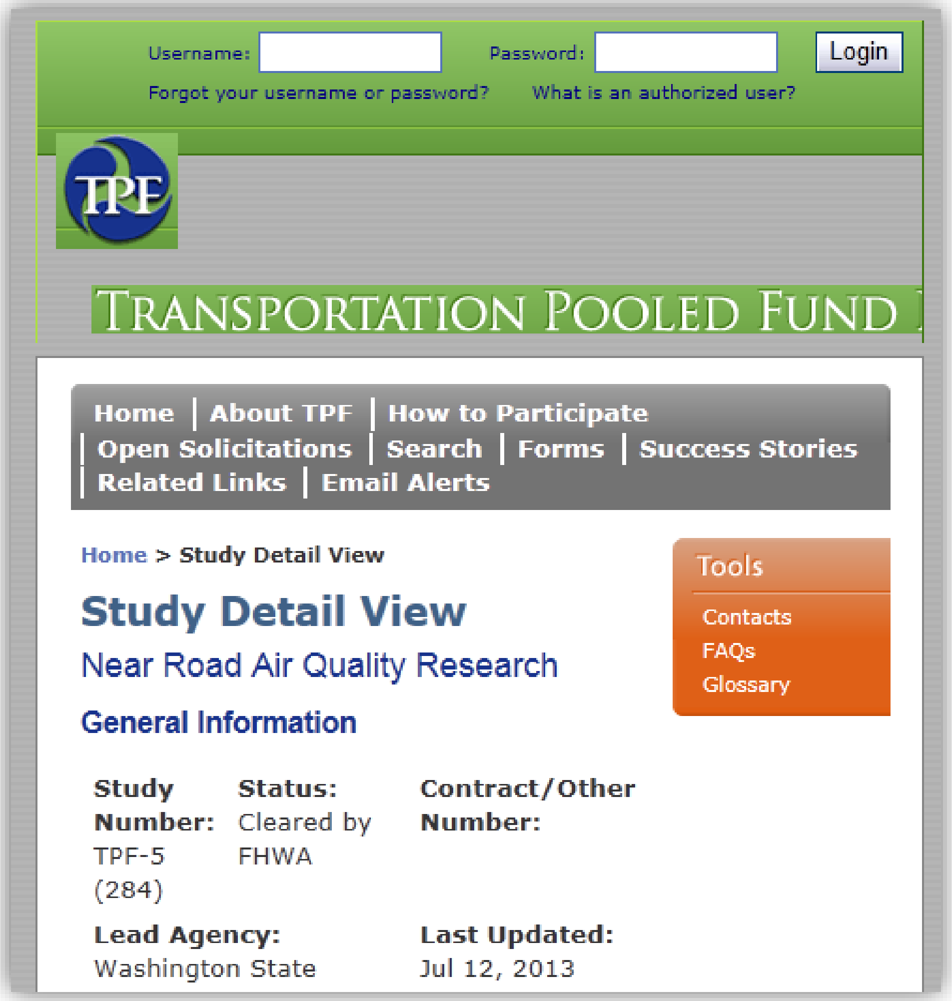
Near-Roadway Air Quality: Synthesizing the Findings from Real-World Data

Outline

1. Introduction: Pooled fund, motivation, EPA requirements
2. Data Overview: CO and NO_2 are not current problems; $PM_{2.5}$ is high at some sites
3. Near-Road $PM_{2.5}$: Increment varies across near-road (NR) sites
4. Trends: Starting to emerge, seem to be headed in right direction
5. Monitored Compared to Modeled: Disconnect between measured and modeled concentrations
6. Conclusions

Transportation Pooled Fund

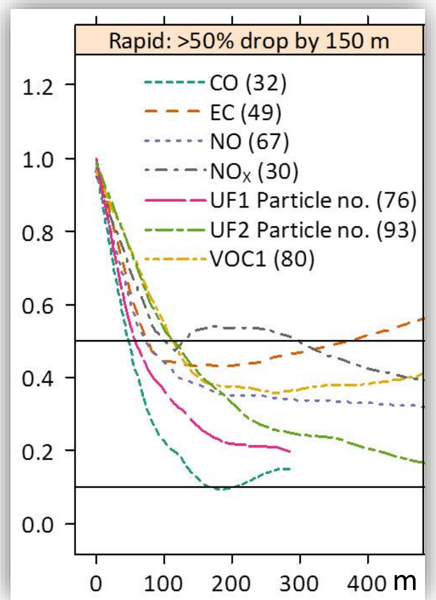
- Five-year program
- Sponsors
  - Arizona DOT
  - Caltrans
  - Colorado DOT
  - FHWA
  - Ohio DOT
  - Texas DOT
  - Virginia DOT
  - Washington State DOT, lead agency
- Research – STI



Objective: *"Improve the state of knowledge regarding, and the ability of state DOT staff to address, near-road air quality issues."*

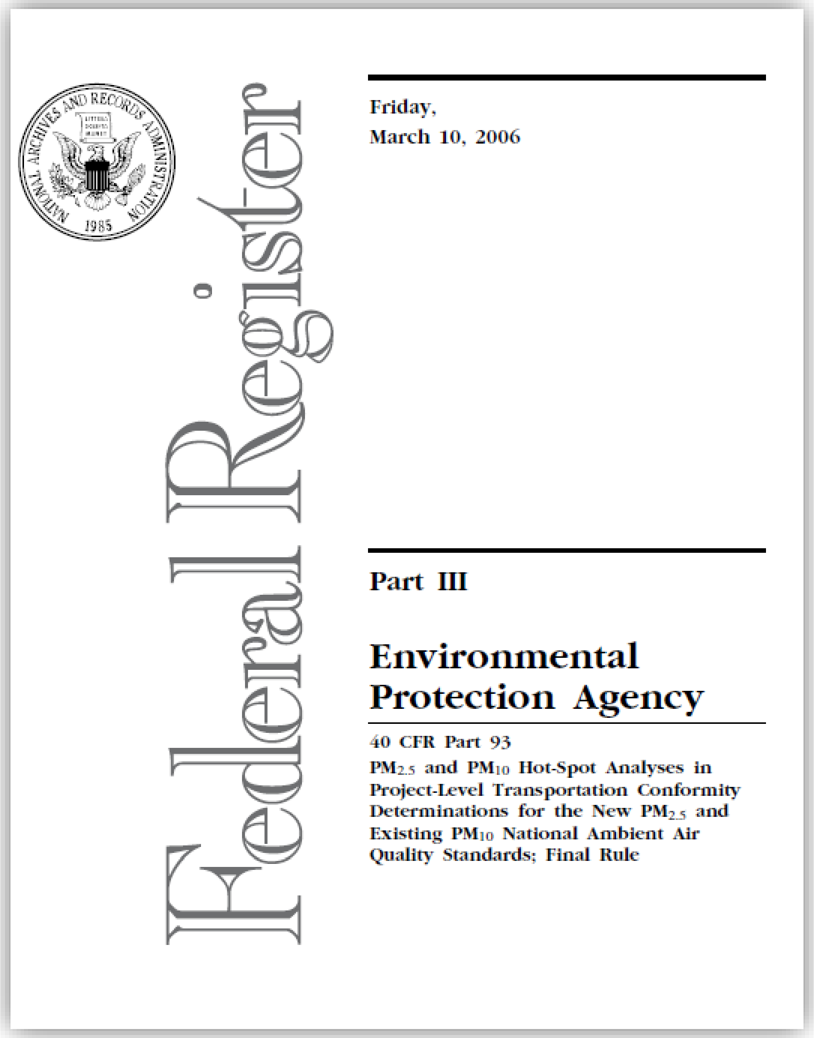
Motivation: NR Air Pollution

- CO, black carbon, NO_2, other pollutants are typically higher near major roadways
- HEI: traffic-related air pollution exposure linked to children's asthma (and other concerns)
- In 2010, EPA mandated air pollution monitoring near major roadways



Sources: Karner, Eisinger, and Niemeier (2010) *ES&T*, 44, 5334-5344; Health Effects Institute (2010); U.S. EPA NO_2 NAAQS 40 CFR Parts 50 and 58

Motivation: Required NR Analyses



Federal Register

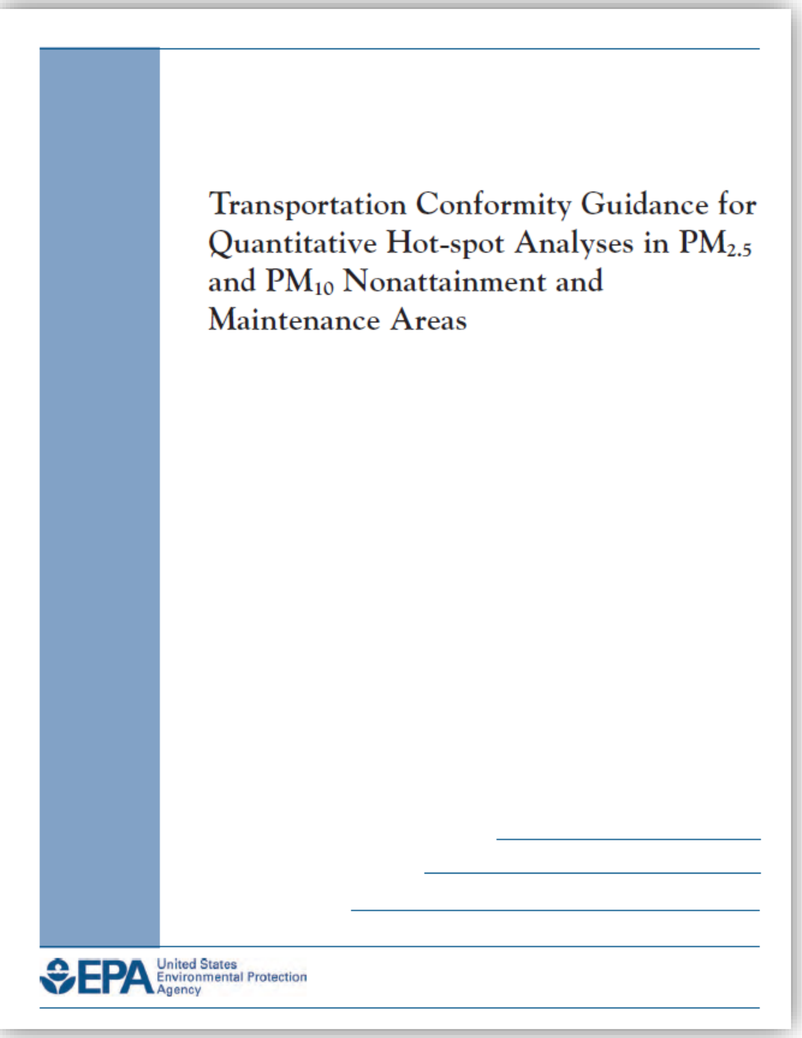
Friday,
March 10, 2006

Part III

Environmental Protection Agency

40 CFR Part 93

$PM_{2.5}$ and PM_{10} Hot-Spot Analyses in Project-Level Transportation Conformity Determinations for the New $PM_{2.5}$ and Existing PM_{10} National Ambient Air Quality Standards; Final Rule



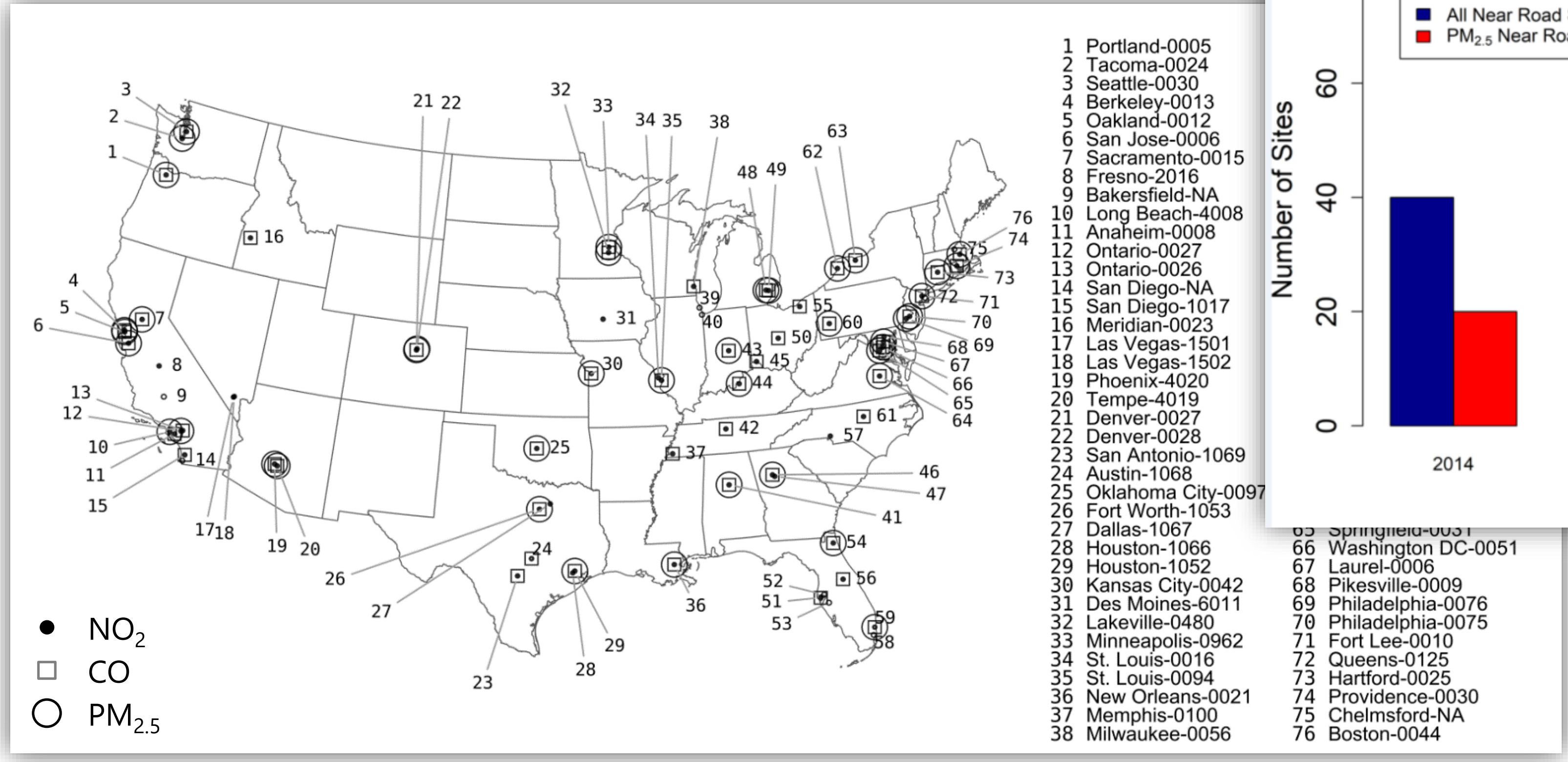
Transportation Conformity Guidance for Quantitative Hot-spot Analyses in $PM_{2.5}$ and PM_{10} Nonattainment and Maintenance Areas

EPA United States Environmental Protection Agency

Federal mandates: near-road “hot-spot” analyses

- Carbon monoxide (CO)
- Particulate matter ($PM_{2.5}$ and PM_{10})

Motivation: EPA-Mandated NR Monitoring, 2014+

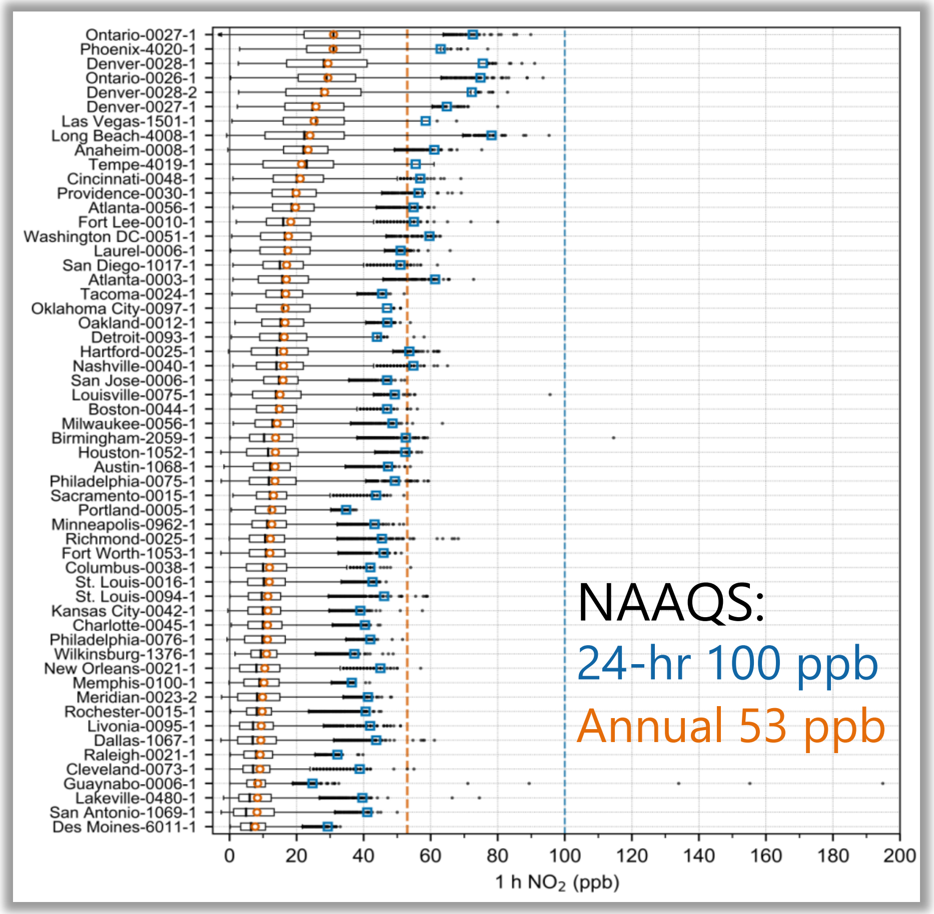


- NO$_2$ 68 locations
- CO 53 locations
- PM$_{2.5}$ 42 locations

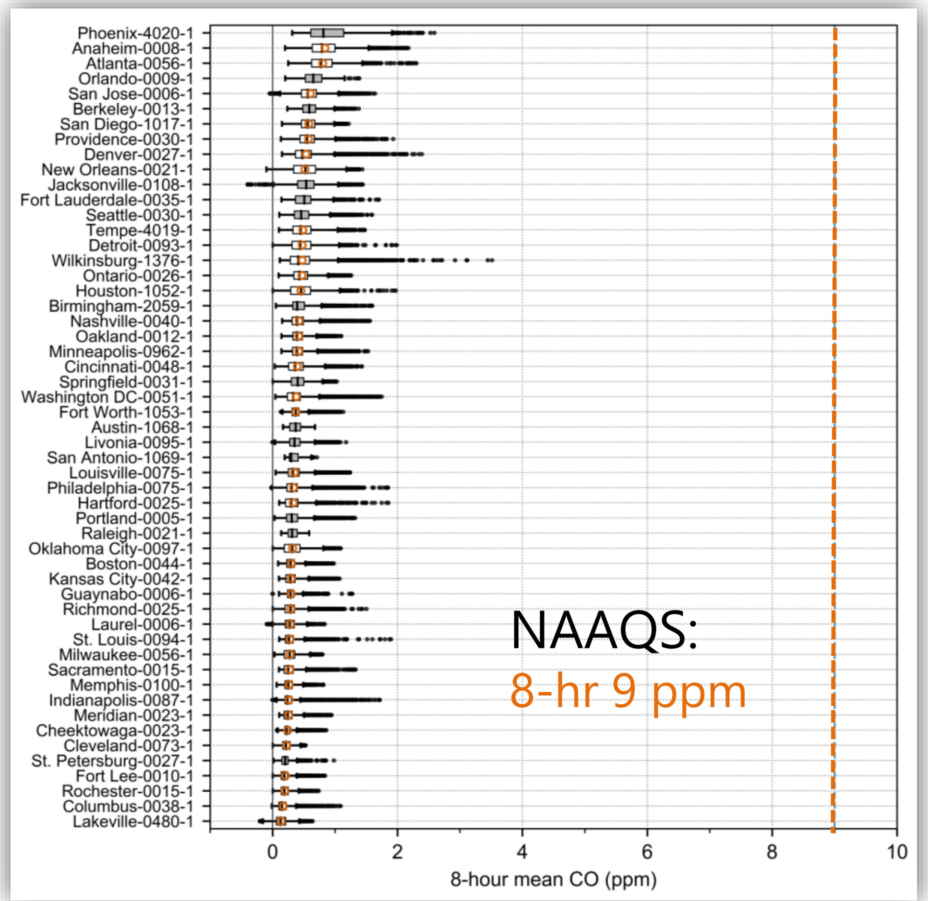
Site locations in 2016.
Source: Seagram et al., 2019, *Transportation Research Record*

Multiple Years of Data Show NR CO and NO_2 Are Well Below NAAQS

2016 NO_2



2016 CO



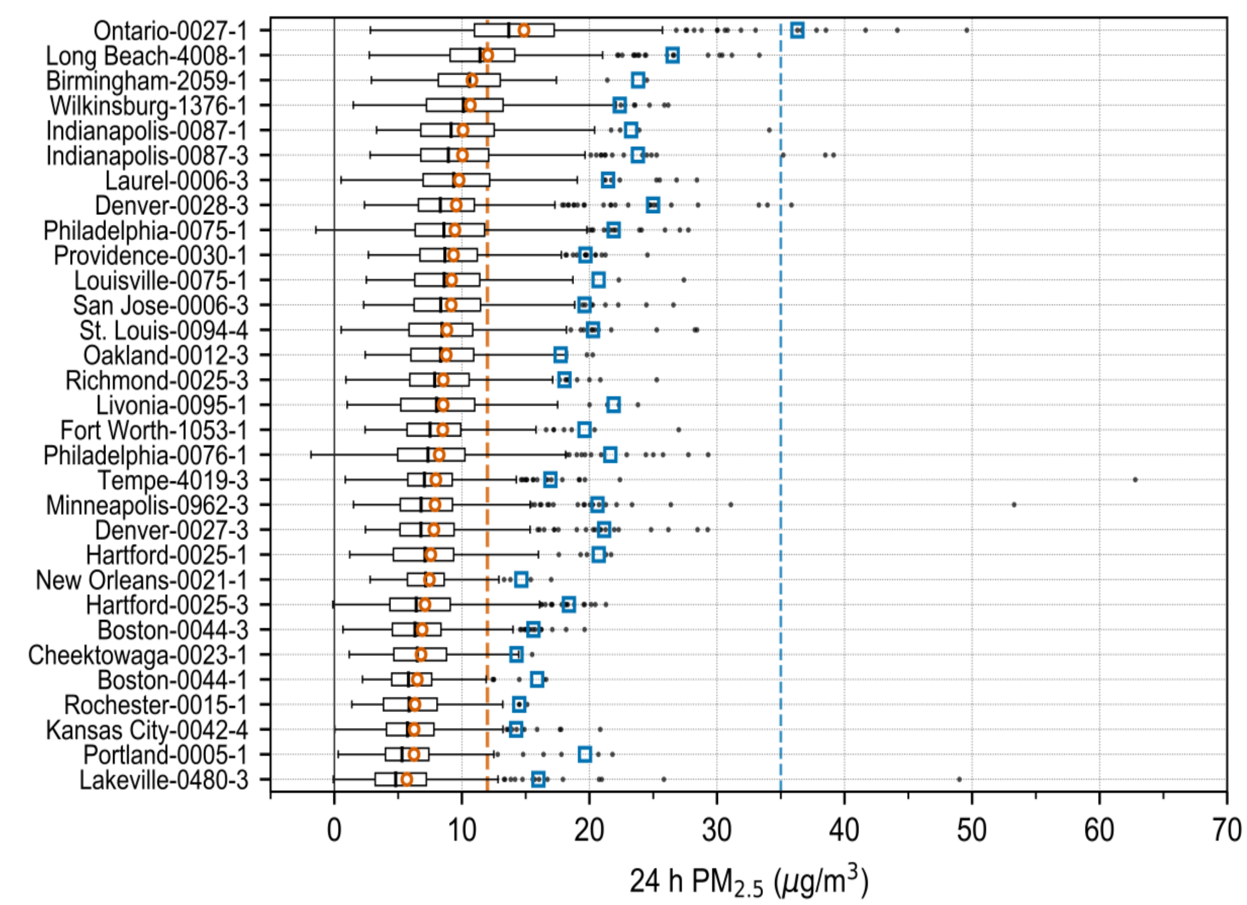
From Seagram et al., 2019, *Transportation Research Record*

These findings are for research purposes; do not use for determining attainment status.

2016 $PM_{2.5}$ – Most Sites Below NAAQS

<u>24-hr</u>: several sites > 35; Ontario 98th % > 35 μg/m³

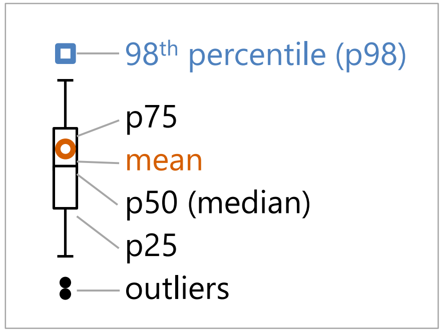
<u>Annual</u>: many sites near annual mean threshold, Ontario, Long Beach above it



NAAQS:

24-hr 35 μg/m³

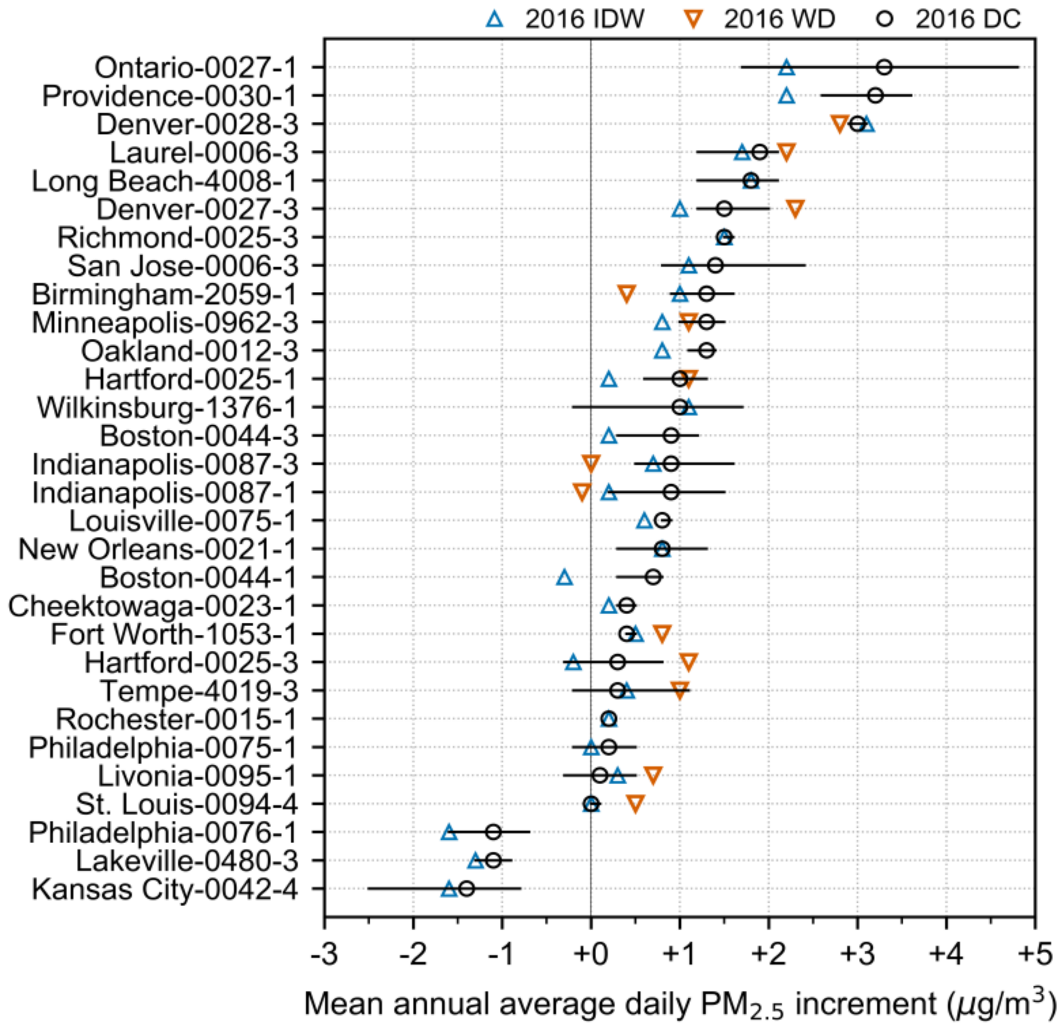
Annual 12 μg/m³



From Seagram et al., 2019, *Transportation Research Record*

These findings are for research purposes; do not use for determining attainment status.

NR $PM_{2.5}$ Increment Results, 2016

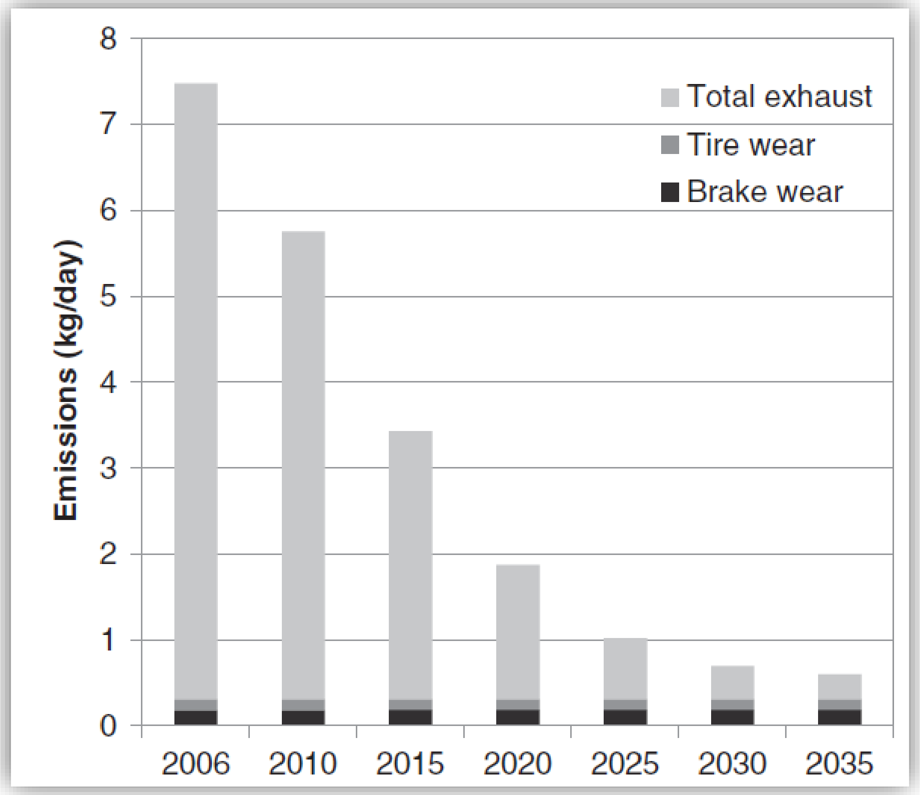


- Mean: 0.6 – 1.1 $\mu g/m^3$
- Most: 0.0 – 1.5 $\mu g/m^3$
- Increments vary widely among sites

Multiple methods used:
- Inverse distance weighting (IDW)
- Single upwind site (WD)
- Combination of nearby sites (Distance/Correlation, or DC)

(Seagram et al., 2019, Fig. 6)

On-Road Emissions and NR $PM_{2.5}$ Generally Trending Down



$PM_{2.5}$ emissions, hypothetical freeway, 125,000 AADT, 8% of which are HDDVs (Reid et al., 2016, Fig. 3, MOVES data).

These findings are for research purposes and should not be used for determining attainment status.

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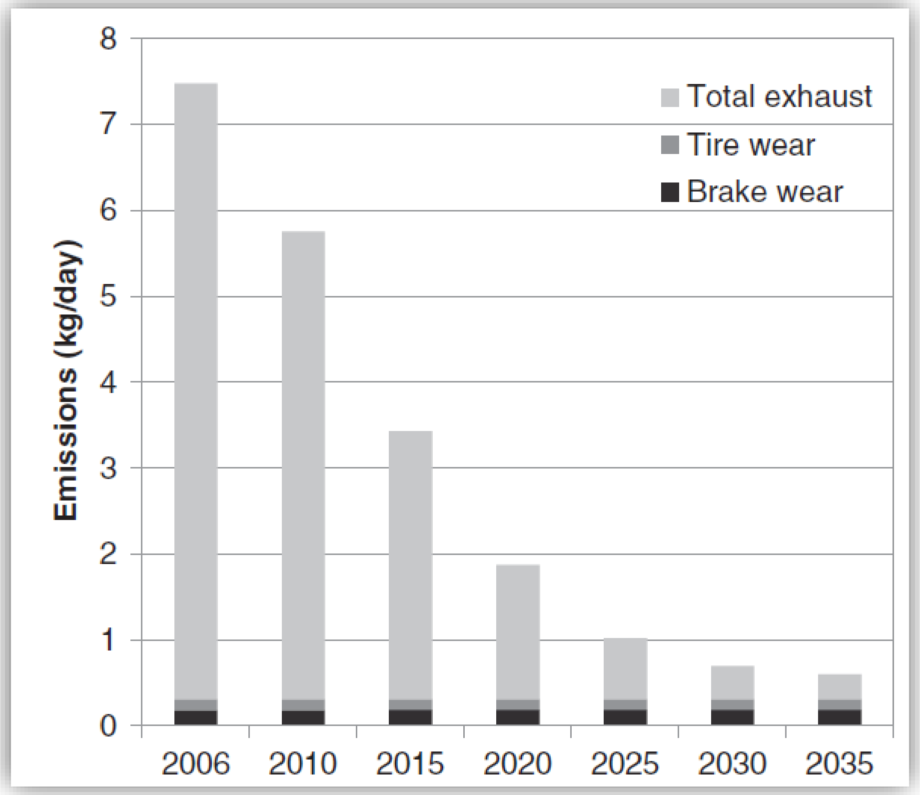

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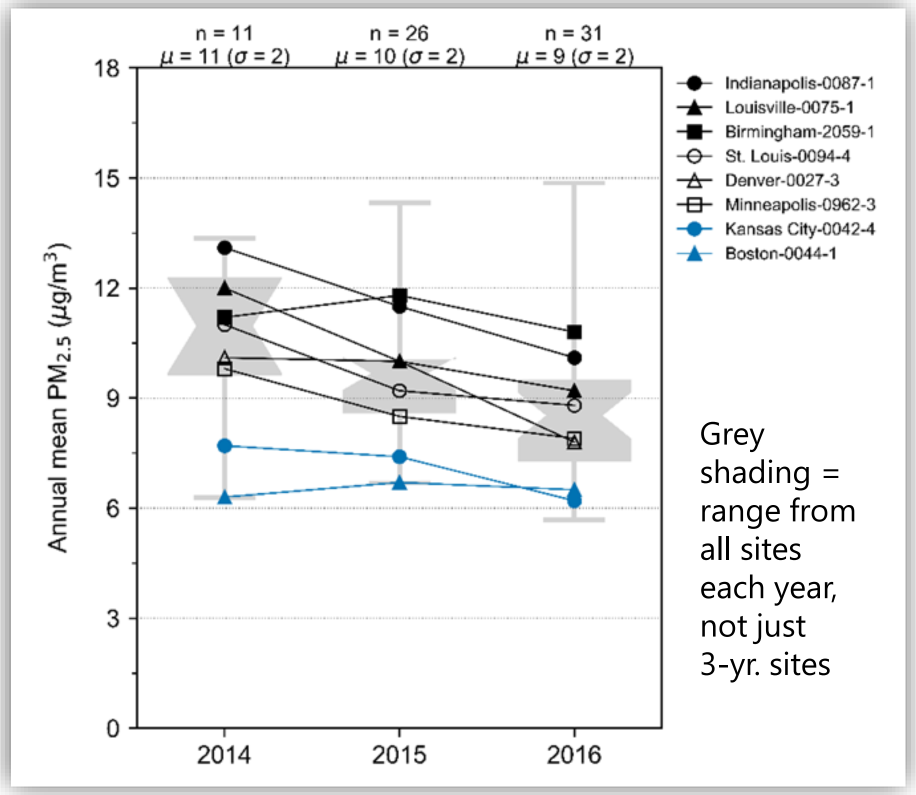
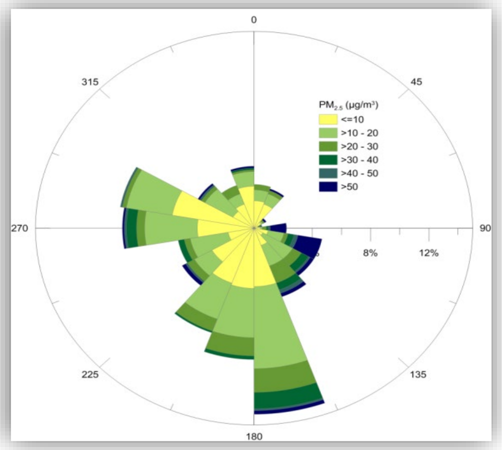


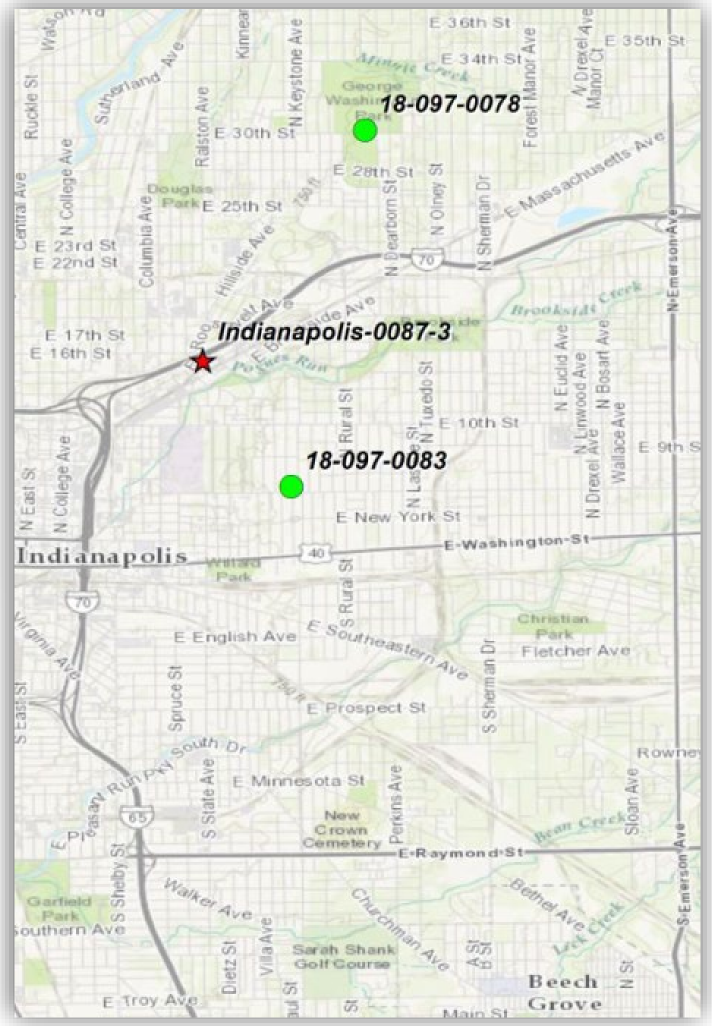
$PM_{2.5}$ annual mean 24-hr concentrations, NR sites, areas with three years of data (Seagram et al., 2019, Fig. 5).

Data for 8 areas; may not represent all sites.

These findings are for research purposes and should not be used for determining attainment status.

Indianapolis 2016 Case



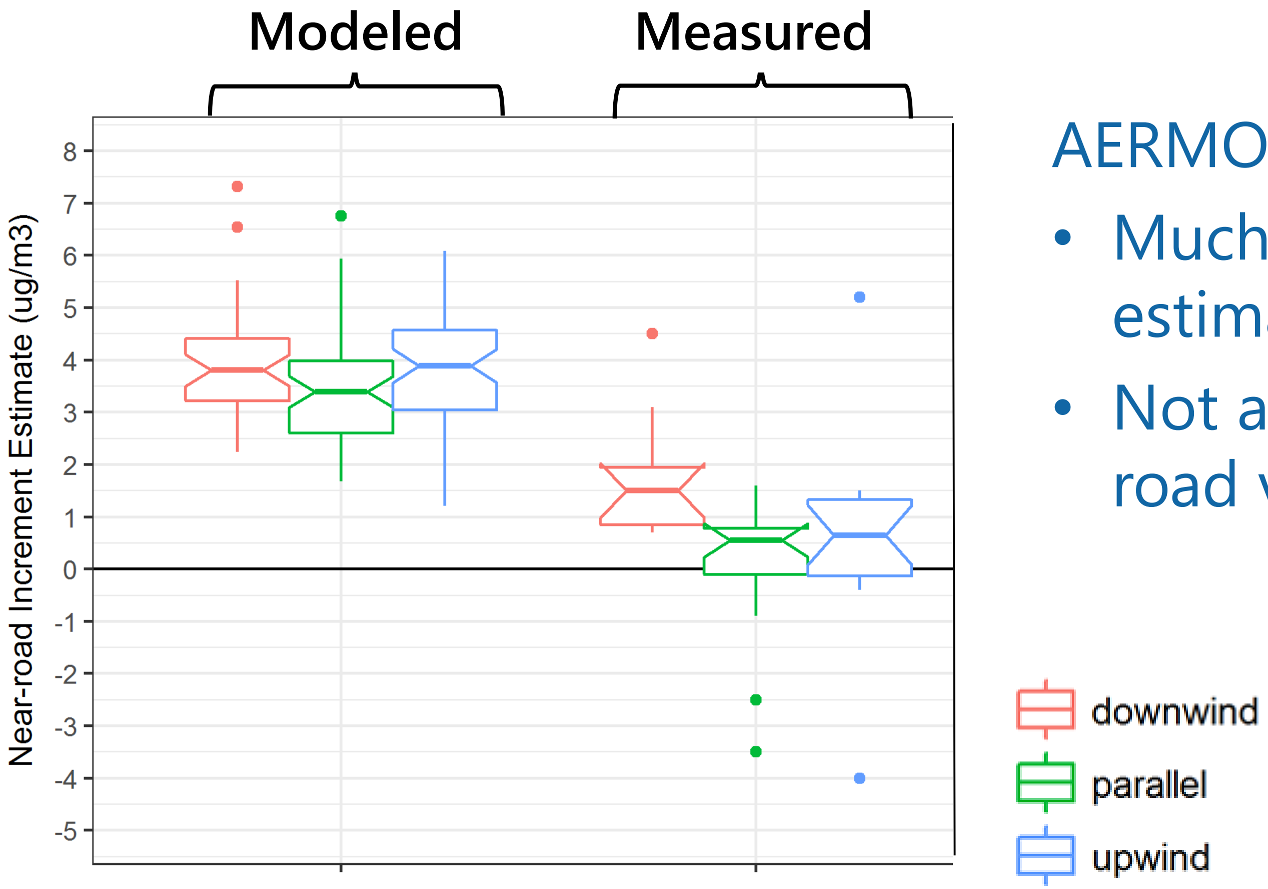


PM$_{2.5}$ Monitors

Near-road site (red star)

Background sites (green dots)

Modeled (AERMOD) Results Compared to Monitored Values (Preliminary Findings)



N=152;
24-hr $PM_{2.5}$

AERMOD results:

- Much higher (factor of 3, >2.5 µg/m^3) than estimates of monitored NR increment.
- Not as affected by wind direction relative to road versus measured concentrations.

More details available from TRB talk: Craig et al., 2019

Conclusions

1. CO and NO_2 are both well below NAAQS thresholds; $PM_{2.5}$ is below NAAQS at most sites
2. $PM_{2.5}$ increments vary widely. Average is ~0.6 - 1.1 µg/m^3, due to:
   - Meteorology (how often/when NR site is downwind)
   - Road geometry and near-road site characteristics (traffic, distance to road)
3. AERMOD modeling over-predicted monitored concentrations
4. Future research: investigate near-road increments
   - Refine understanding of what factors most influence NR $PM_{2.5}$ increments
   - Further sensitivity testing to understand uncertainty in the modeling chain, and what causes differences between modeled and monitored concentrations

Acknowledgments

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The Washington State Department of Transportation (WSDOT) is the lead agency. Other participants include the FHWA and the Arizona, California, Colorado, Ohio, Texas, and Virginia Departments of Transportation.

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http://www.nearroadaqpf.com/welcome

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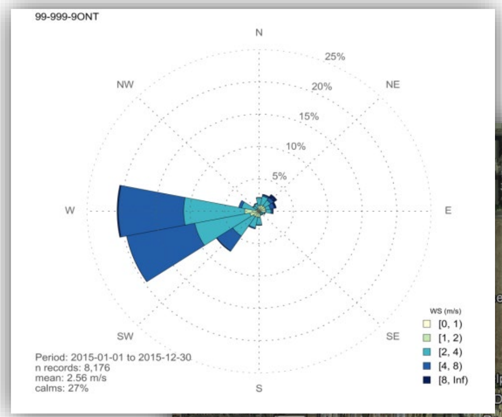
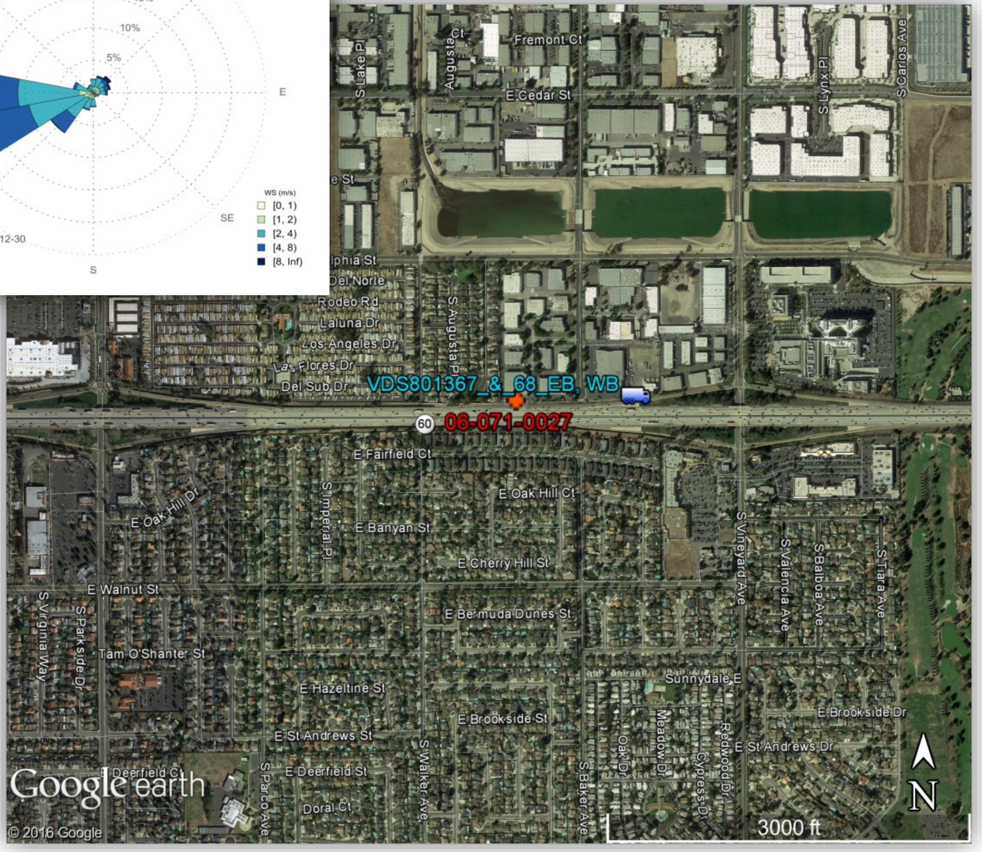
Supplemental Material

Ontario (Southern California) State Route 60





Google Earth view

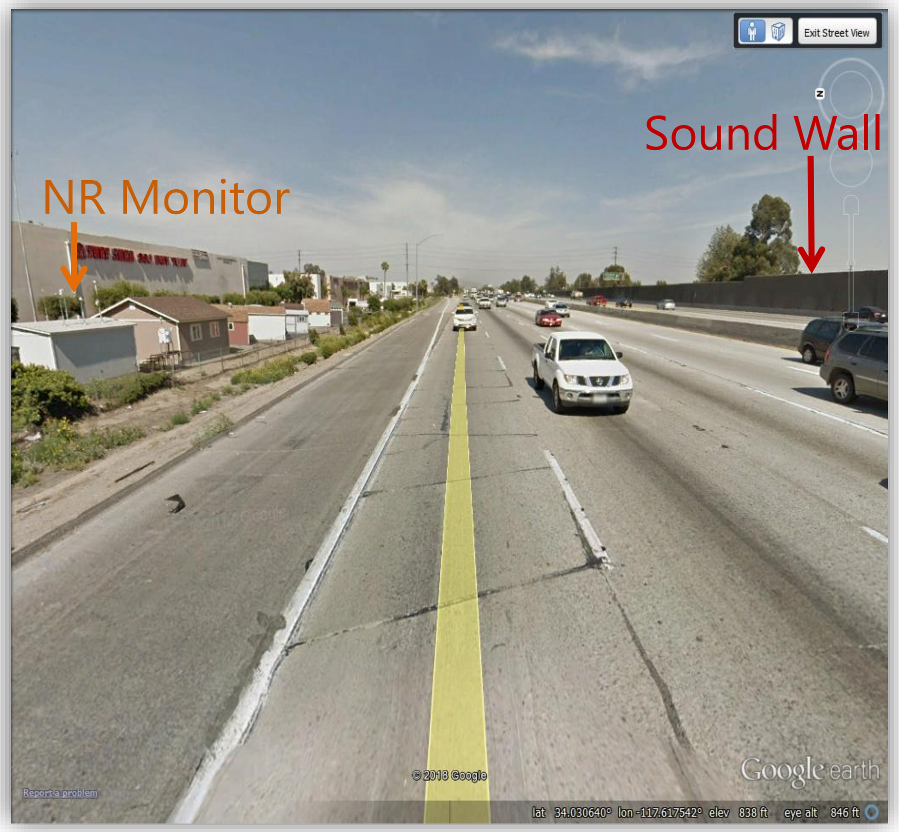
AADT: 215,000
FE-AADT: 625,736

- In top three highest FE-AADT, U.S. NR sites
- Only site above $PM_{2.5}$ 24-hr (98^{th} %) and annual NAAQS (2016)
- Highest 2016 $PM_{2.5}$ increment: $>3\ \mu g/m^3$

High Increment Illustration: Ontario, CA (SR-60)

Looking West

Looking East



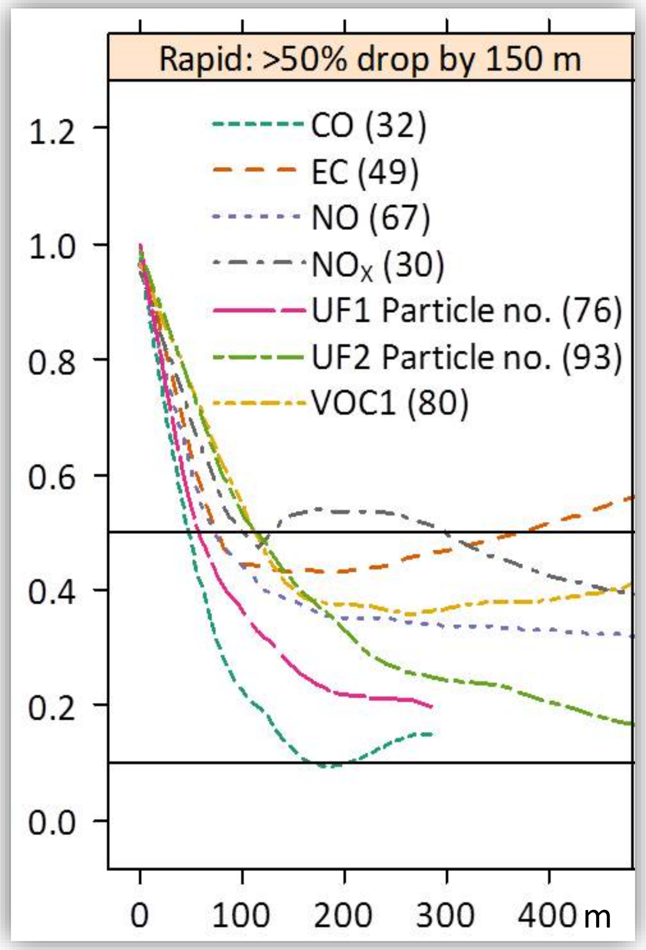
Motivation: Air Pollution Concentrations Higher Near Major Roads

Measured concentrations:
41 studies, 13 countries, 30 years

Key findings, by distance from road:

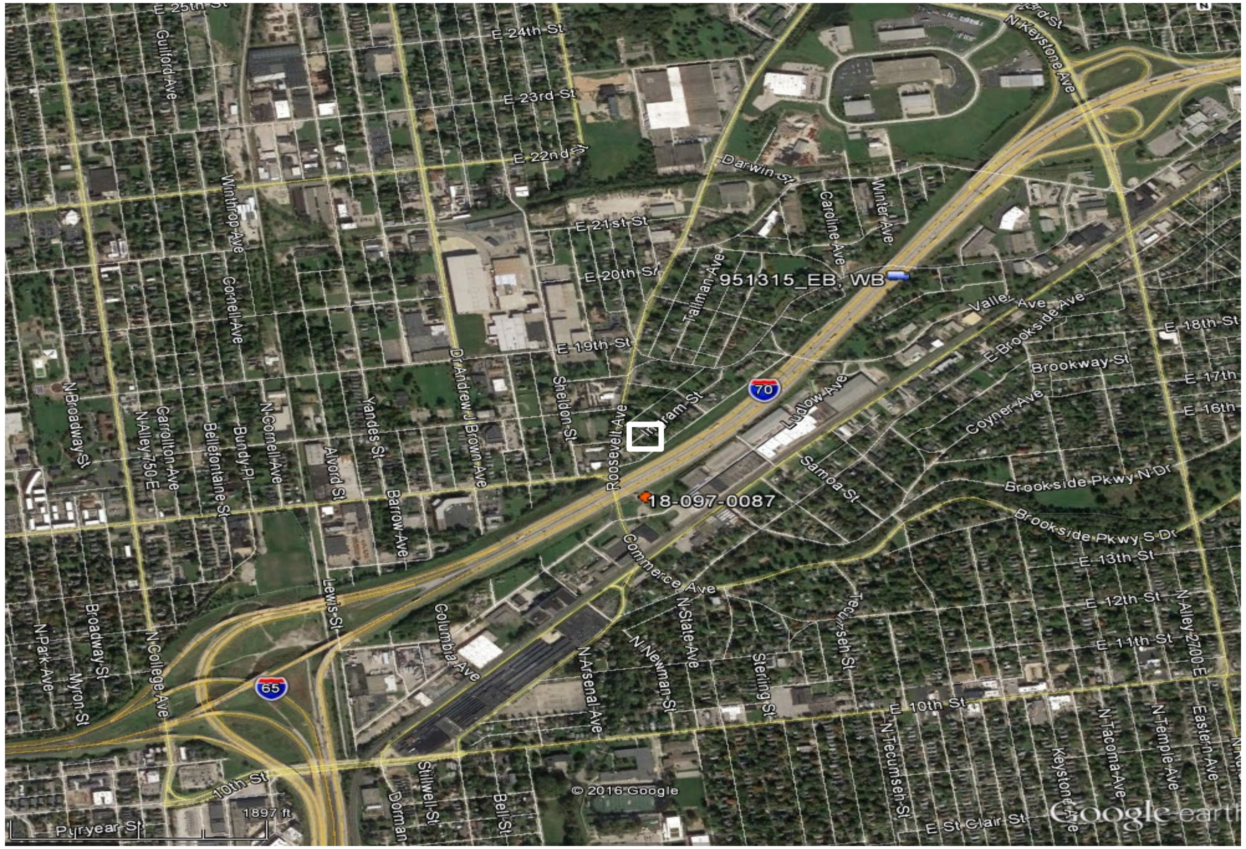
- 150 m – rapid (50%) decline
- 400 m – most at background
- 600 m – nearly all at background

(nighttime exceptions)



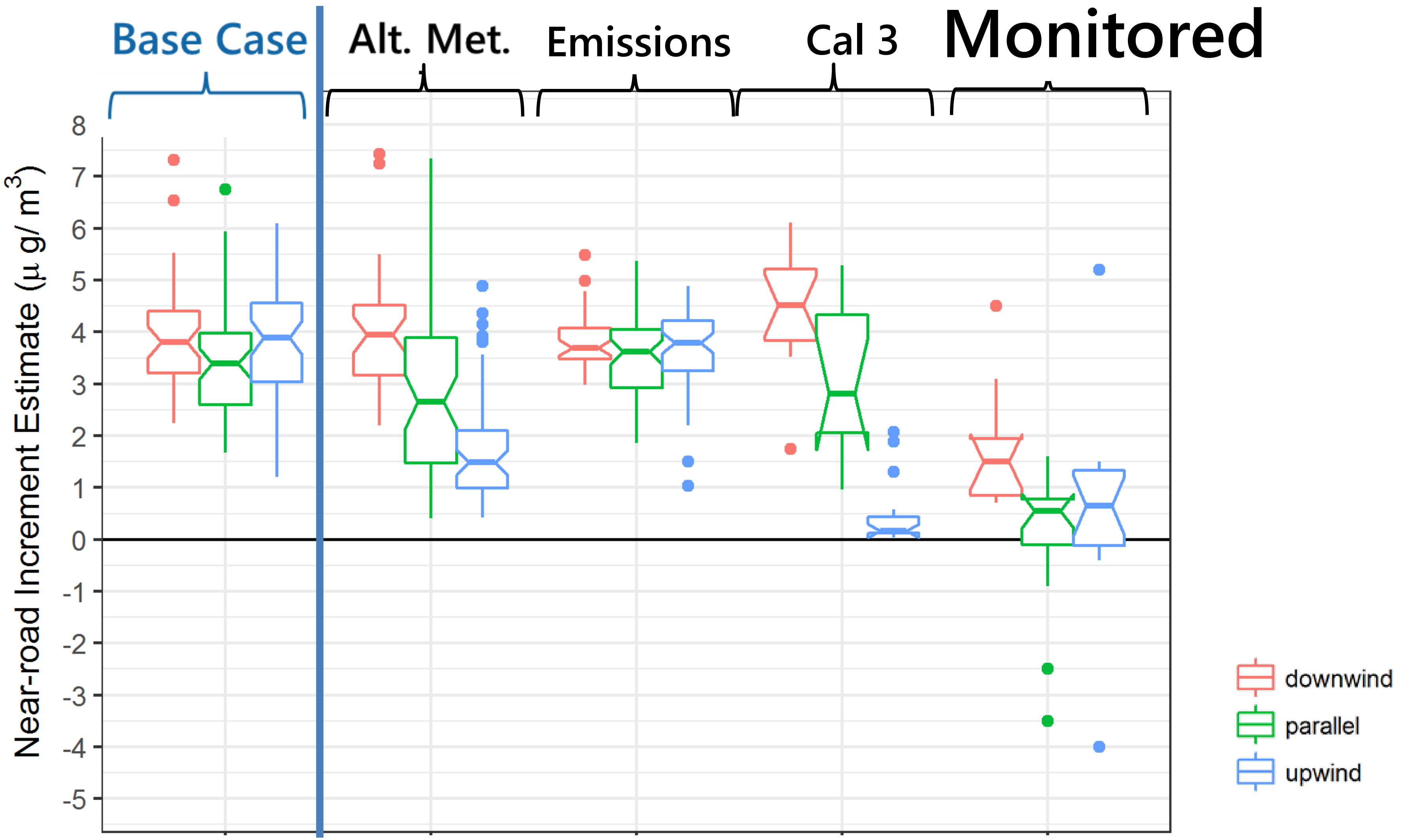
Source: Karner, Eisinger, and Niemeier (2010) *ES&T*, 44, 5334-5344.

Indianapolis Case Study



Site Information (2016)	
AQS ID	18-097-0087
$PM_{2.5}$ nonattainment	No
TPF	No
Road type	Freeway segment
Number of lanes	10
AADT	165,672 (14% HD truck)
FE-AADT	397,496
Distance to road	24.5 m
$PM_{2.5}$ 24-hr avg. increment	0.91 µg/m^3
$PM_{2.5}$	24-hour (1-in-3) + hourly
$PM_{2.5}$ max. 24-hr	39 µg/m^3
Annual mean $PM_{2.5}$	9.9 µg/m^3
CO max. 1-hr	1.9 ppm
NO_2 max. 1-hr	52 ppb
Collocated met.	Winds and temperature
Traffic Data	Hourly count/speed/fleet

Model Sensitivity Comparisons (see TRB talk for more details)



Indianapolis Case: Traffic Data Summary

http://indot.ms2soft.com

Parameter	Description
Year of monitor data used	2016 for freeway links 2013-2015 for certain local roads (scaled to 2016)
Interstate monitors	12 for I-70, I-65 (including ramps)
Arterial and local road monitors	22 for developing local roadway data
Speed data	Vehicle counts by speed bin (varying bins by monitor)
Class data	Vehicle counts by FHWA vehicle class

- Roadway links are mapped to monitors.
- Some links use data synthesized from multiple monitors.
- If speed or class information is missing, distributions are generated from local MOVES inputs and/or defaults.

Emissions Summary

Includes entire modeling domain (20 miles of roads).

Process	Average Daily $PM_{2.5}$ Emissions (pounds/day)	% of Total
Road dust (AP-42)	895	53
Running exhaust	677	40
Brake wear	74	5
Tire wear	35	2
Total	**1,681**	**100**

For comparison, a recent peer-reviewed measurement study next to Highway 401 in Toronto (~400,000 AADT) found, of total $PM_{2.5}$ mass measured:

- ~35% of traffic-related $PM_{2.5}$ was from non-exhaust
- ~64% of the non-exhaust was from brake wear, ~36% from road dust

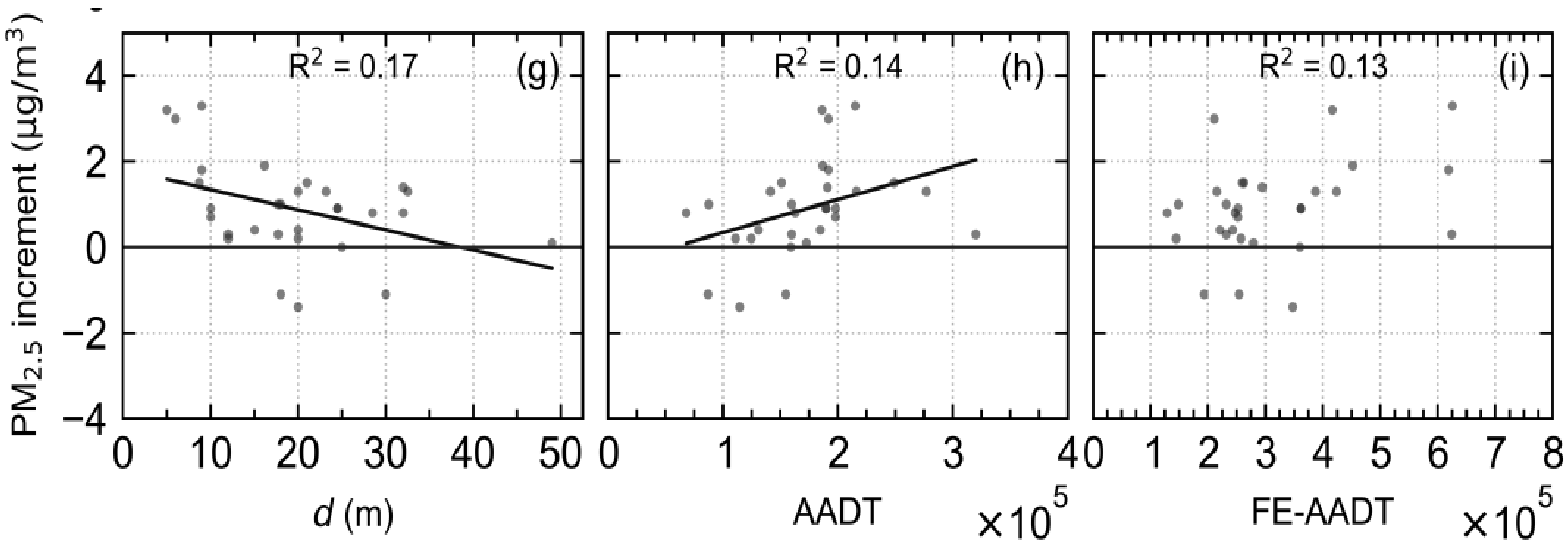
Source: Jeong et al., "Temporal and spatial variability of traffic-related PM2.5 sources: Comparison of exhaust and non-exhaust emissions." *Atmospheric Environment* 198 (2019) 55–69.

Indianapolis Case: AERMOD Setup

175 m

250 m

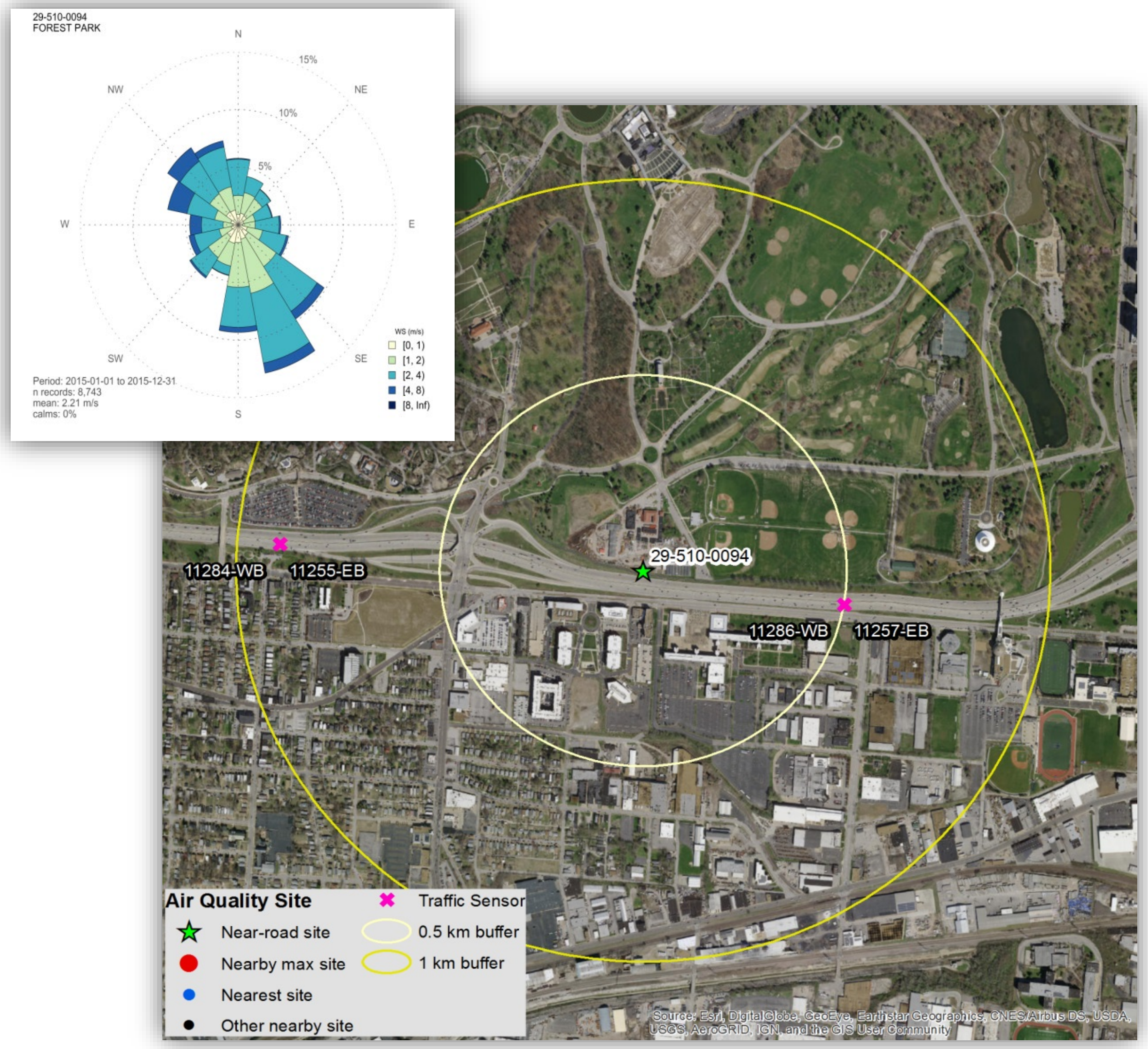
2016 $PM_{2.5}$ Increment Data:
Minimal Correlation vs. Distance or Traffic
Many Sites Have Confounding Factors (e.g., Ontario, St. Louis)



Lines show where relationships are significant, based on p-value ≤ 0.05

Source: Seagram et al., 2019, Fig. 7

St. Louis, I-64



AADT: 159,326

FE-AADT: 360,077

Estimated $PM_{2.5}$ increment:
0.0 - 0.5 µg/m^3 (2016)

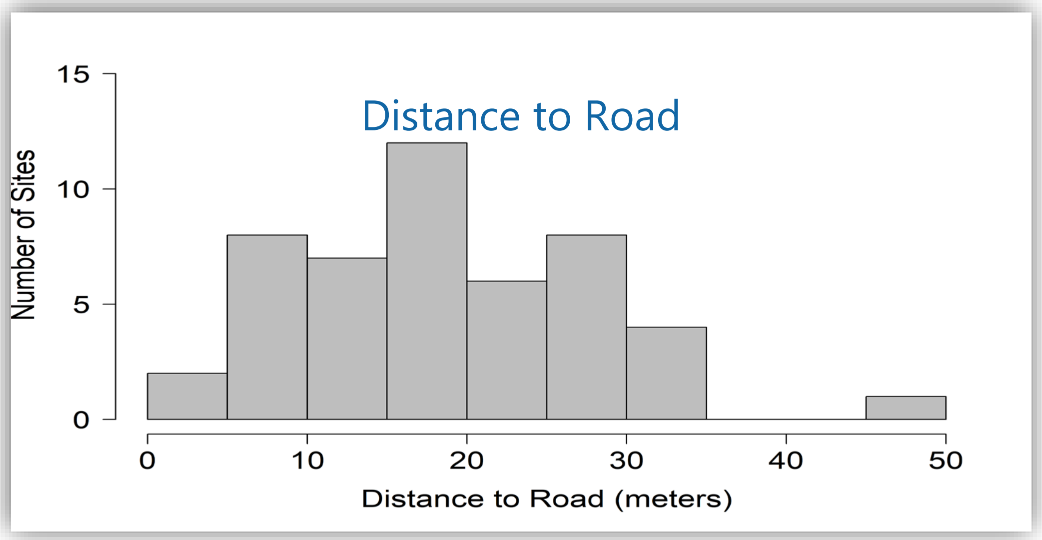
Google Earth view

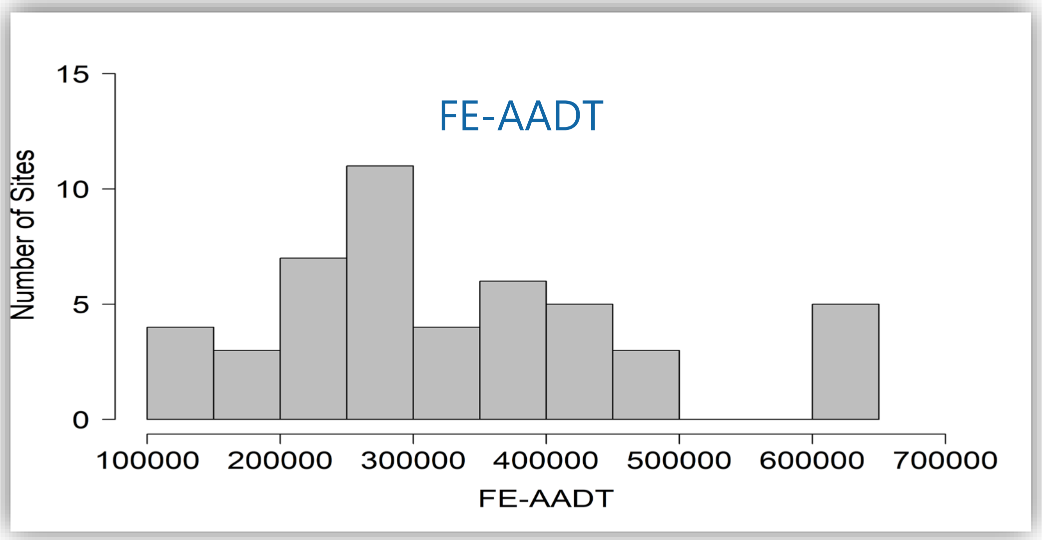
Looking North

For scale of depressed roadway, note height of jogger

2017 Near-Road $PM_{2.5}$ Sites

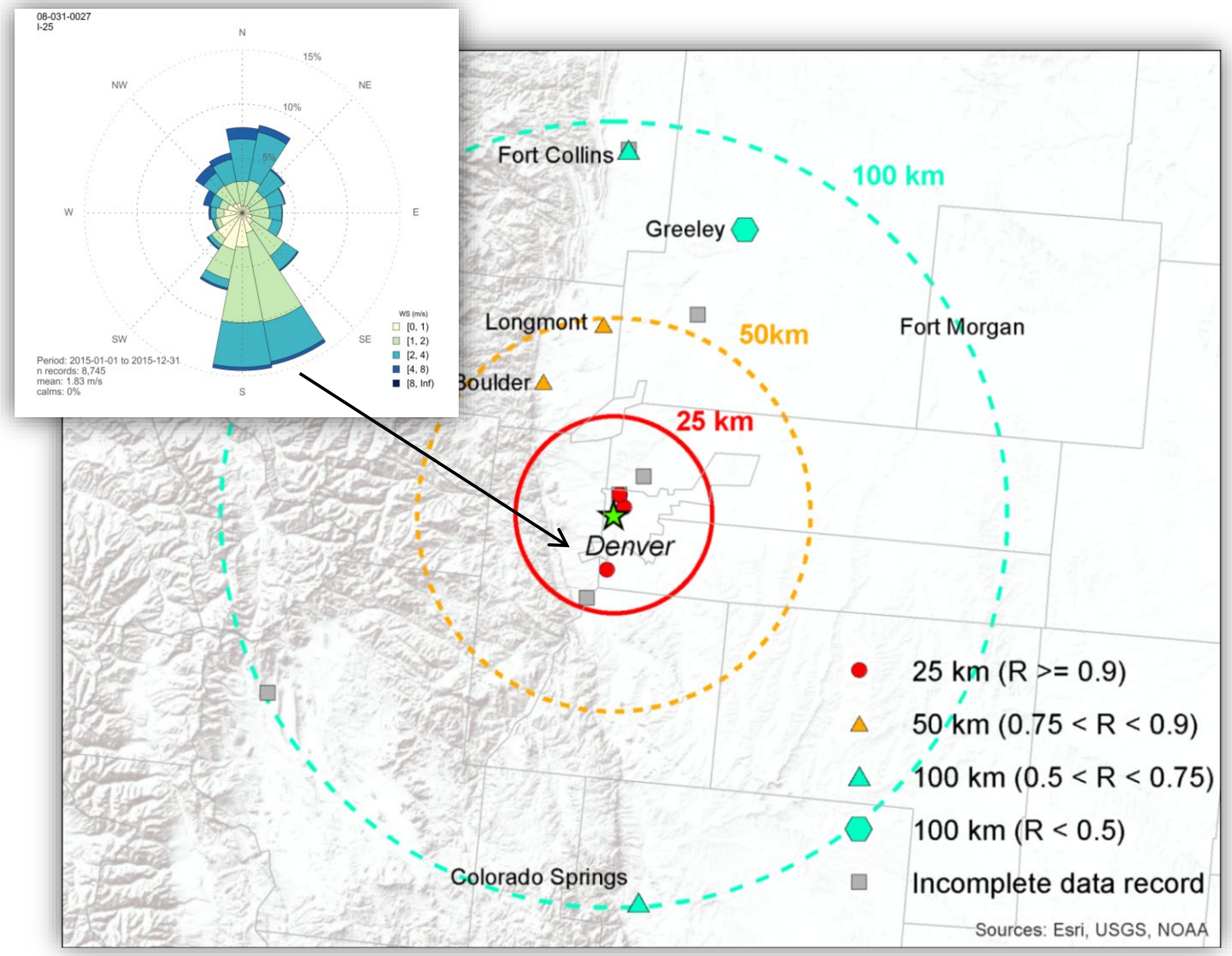
49 sites had complete near-road data





- Variety of site, traffic, meteorological conditions
- Distance to road ranges from 2 to 49 meters
- FE-AADT ranges from 129,229 to 625,736

Increments: Denver illustration



Key Issue: Near-Road $PM_{2.5}$ Increment

2015 example results, distance/correlation (DC), in ug/m3

- 25/50/100 km: 3.0/3.1/3.9
- r^2 of 0.5/0.75/0.90: 3.0/3.1/2.8
- Ave. all six DC methods: increment = 3.2

(DeWinter et al., 2018, Table 2)

Ongoing Research Needs

1. NO_2 and CO are well below NAAQS; at what point should CO results trigger a change to conformity hot-spot analysis requirements? Could further analysis of ambient and emissions trends help?
2. Will the (limited, ~8 areas) downward trending $PM_{2.5}$ values seen here be robust over time and geographic locations?
3. As more data become available on $PM_{2.5}$ values, trends, and near-road increments, how could that data be used to support screening-level (as opposed to quantitative) PM hot-spot analyses?

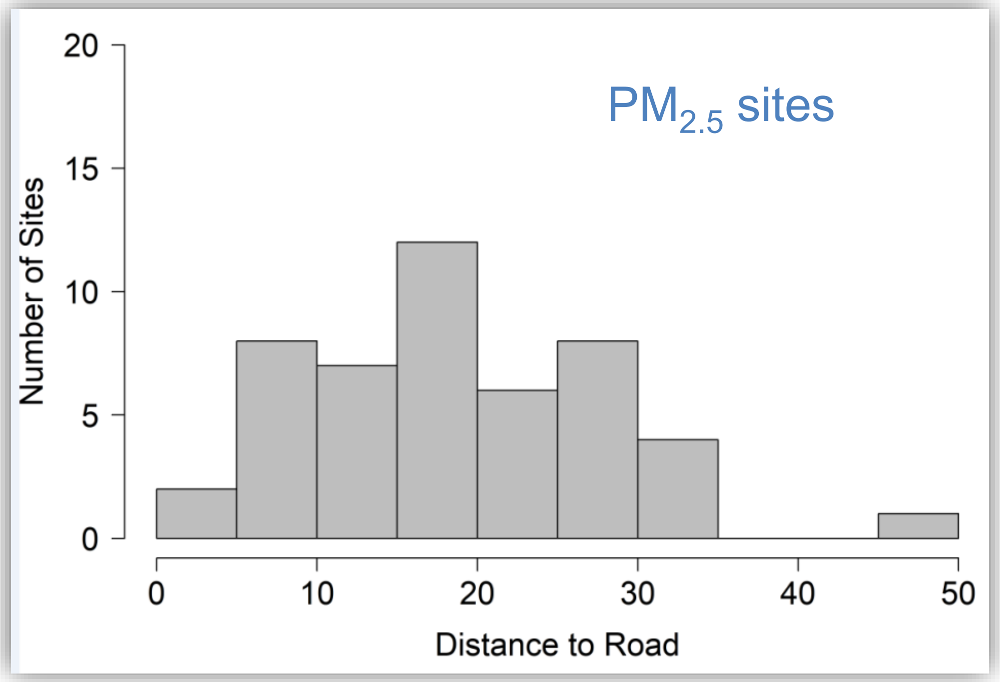
Key Issue: Near-Road $PM_{2.5}$ Increment

To estimate increments, we used three methods to compare the NR site to background sites:

1. **Distance/Correlation (DC)**: average of six metrics
   - Sites within 25 km, 50 km, and 100 km of NR site
   - Sites with correlations > 0.5, 0.75, and 0.90 with the NR site
2. **Inverse Distance Weighting (IDW):** inverse distance weighted values (squared) (sites within 40 km)
3. **Upwind Monitor (WD):** nearest single monitor predominantly upwind of NR site

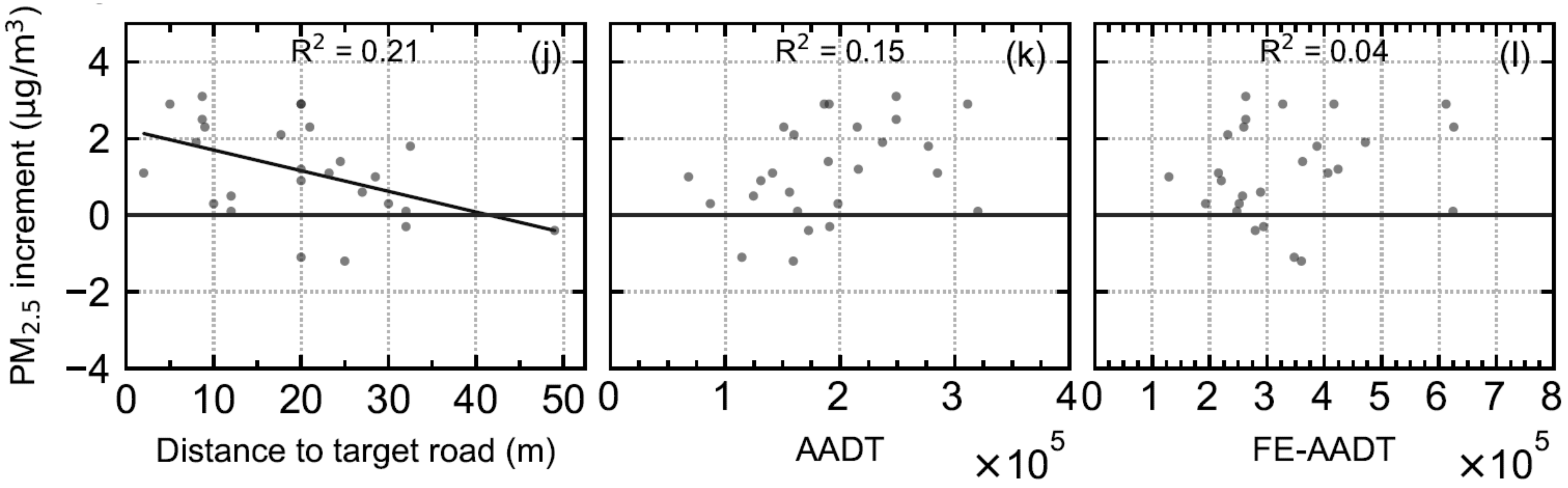
Factors to Weigh When Evaluating Increments (partial list)

- Distance to roadway
- Traffic volume
- Fleet mix (truck %)
- Meteorological conditions



Near-road sites by distance to roadway (m); 2017 data

2015 PM$_{2.5}$ Increment Data: Minimal Correlation vs. Distance or Traffic



Line shows where relationship is significant, based on p-value ≤ 0.05

Source: DeWinter et al., 2018, Fig. 6

Increment Summary: 2016 Data

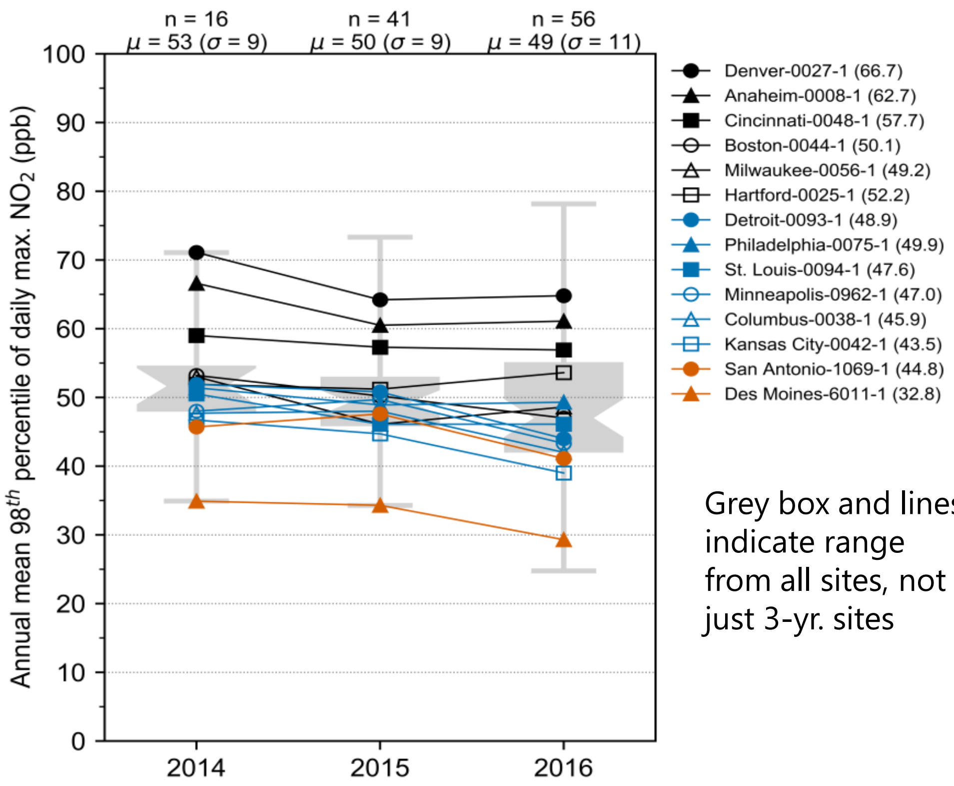
- Average $PM_{2.5}$ NR increment: 0.6-1.1 µg/m^3 Increment accounted for 6%-10% of total measured $PM_{2.5}$
- Findings consistent with literature:
  - *Karner et al. 2010* suggest 22% PM decrease from road edge and 500 m away (using data prior to 2010);
  - *Keuken et al. 2013* suggest 10%-15% increase in PM next to the roadway over urban concentrations;
  - *EEA 2011* found a maximum 10% increase in PM over background concentrations in European cities.

2016 Near-Road Monitoring Sites Data Completeness

Pollutant	Measured (n sites[a])	Complete[b] (n sites[a])
NO_2	68	55
CO	53	39
$PM_{2.5}$	42	28

[a]*Number of unique sites by AQS ID (only one site is counted for any collocated monitors)*
[b]*Based on 75% completeness estimated by quarter*

3-Year Statistics: NO_2 (3-Year Sites)

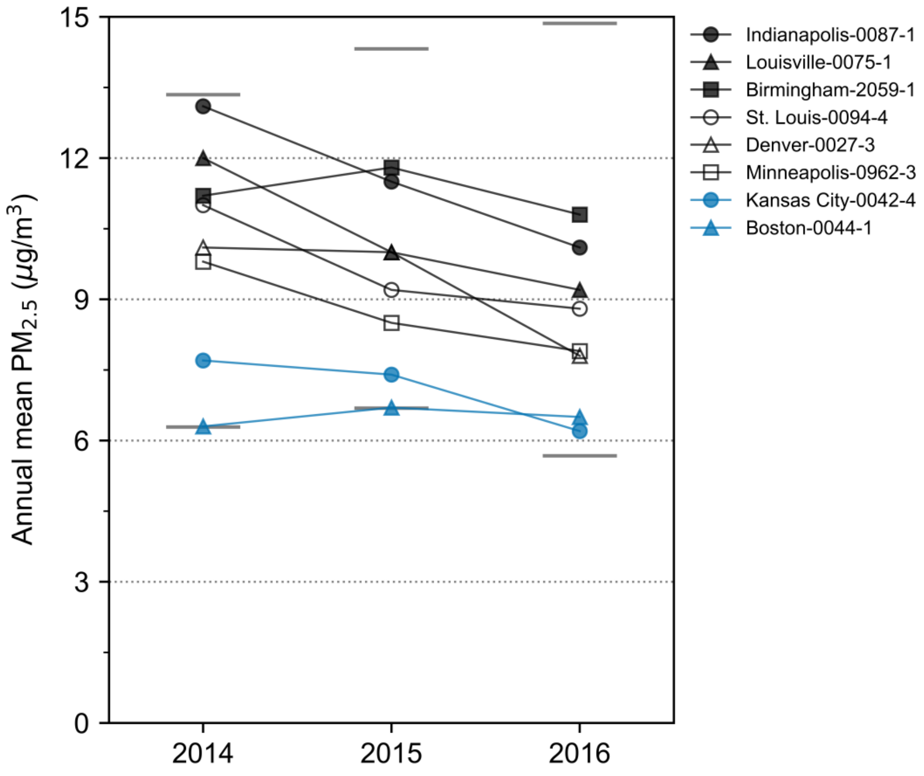


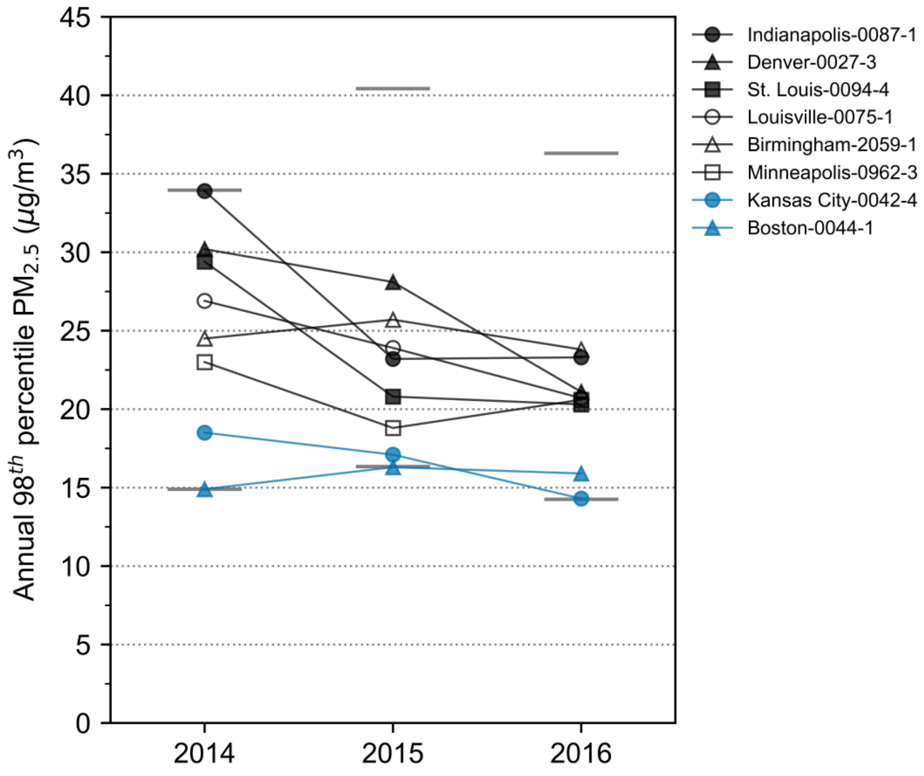
Grey box and lines indicate range from all sites, not just 3-yr. sites

For the 14 sites with complete data in all 3 years, concentrations at most sites were generally trending downward over the 3 years.

These findings are for research purposes and should not be used for determining attainment status.

3-Year Statistics: $PM_{2.5}$ (3-Year Sites)





Grey horizontal lines indicate range from all sites, not just 3-yr. sites

These findings are for research purposes and should not be used for determining attainment status.

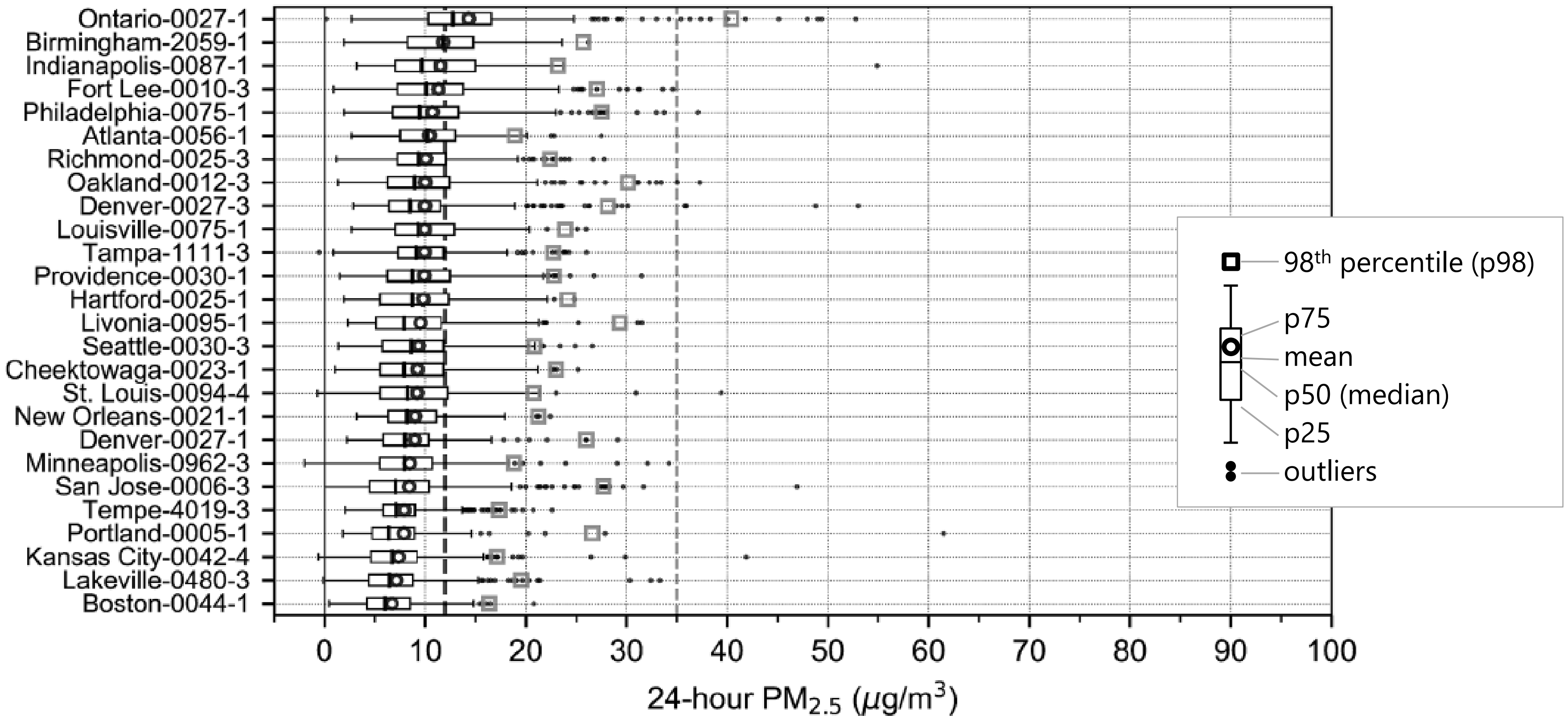
3-Year Statistics: $PM_{2.5}$ (3-Year Sites)

Monitor	Mean (µg/m^3)	p98 (µg/m^3)
Indianapolis-0087-1, IN	11.6	26.8
Louisville-0075-1, KY	10.4	23.8
Birmingham-2059-1, AL	11.3	24.7
St. Louis-0094-4, MO	9.7	23.5
Denver-0027-3, CO	9.3	26.5
Minneapolis-0962-3, MN	8.7	20.8
Kansas City-0042-4, MO	7.1	16.6
Boston-0044-1, MA	6.5	15.7

Data shown are the average of three years, for each site.

NAAQS:
24-hr 35 µg/m^3
Annual 12 µg/m^3

2015 $PM_{2.5}$



$PM_{2.5}$ concentrations at all near-road monitoring locations with at least 75% data completeness by quarter.

Source: DeWinter et al., 2018, Fig. 4

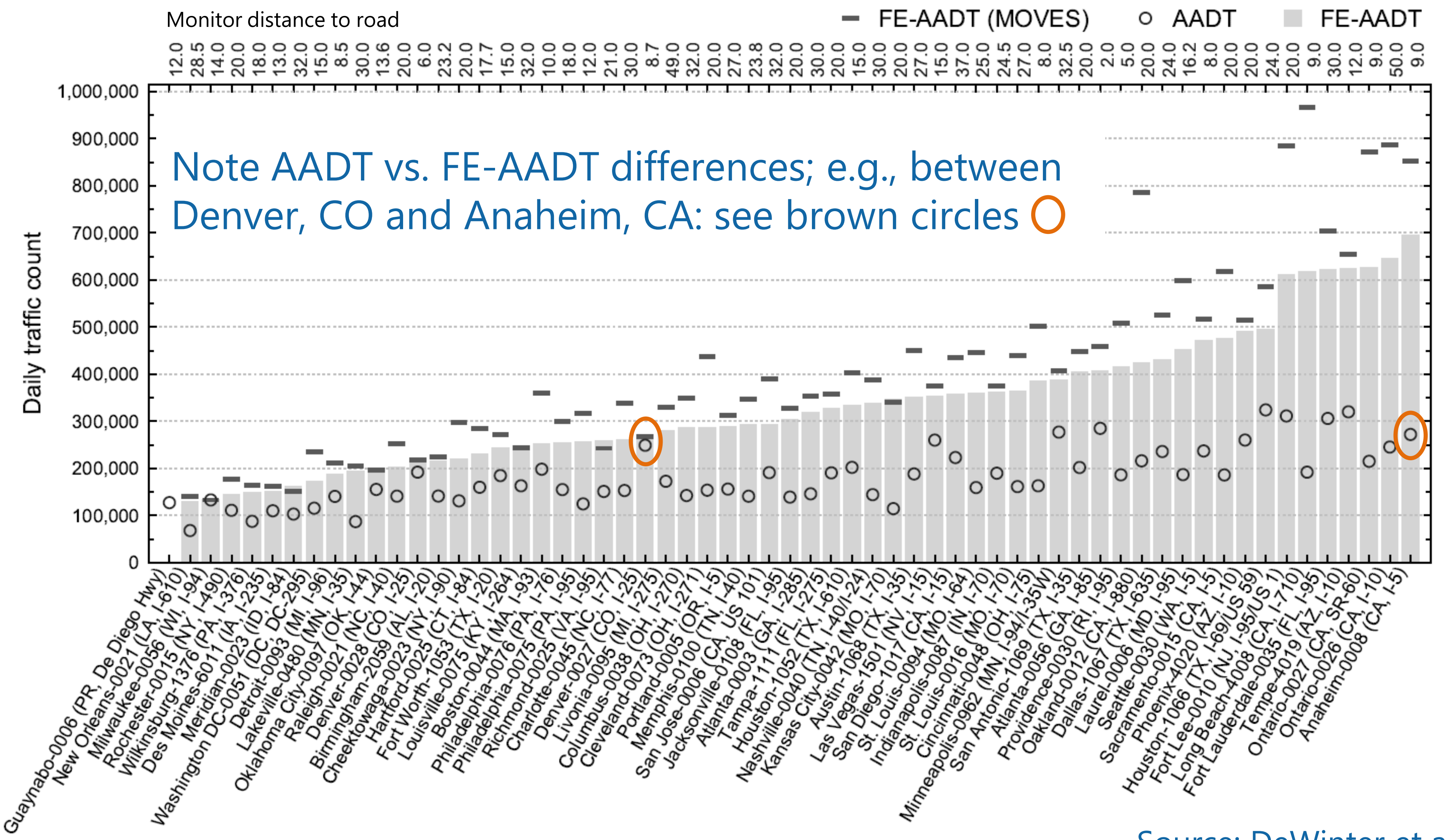
Data Sources

- Ambient $PM_{2.5}$, NO_2, and meteorological data acquired for all monitoring sites in U.S. from EPA Air Quality System (AQS) repository (>300 monitoring sites)
- Distance of monitor to roadway and AADT of adjacent roadway obtained from EPA at https://www3.epa.gov/ttnamti1/nearroad.html; also included fleet equivalent AADT (FE-AADT), defined as

$$\text{FE-AADT} = (\text{AADT} - HD_c) + (HD_m \times HD_c)$$

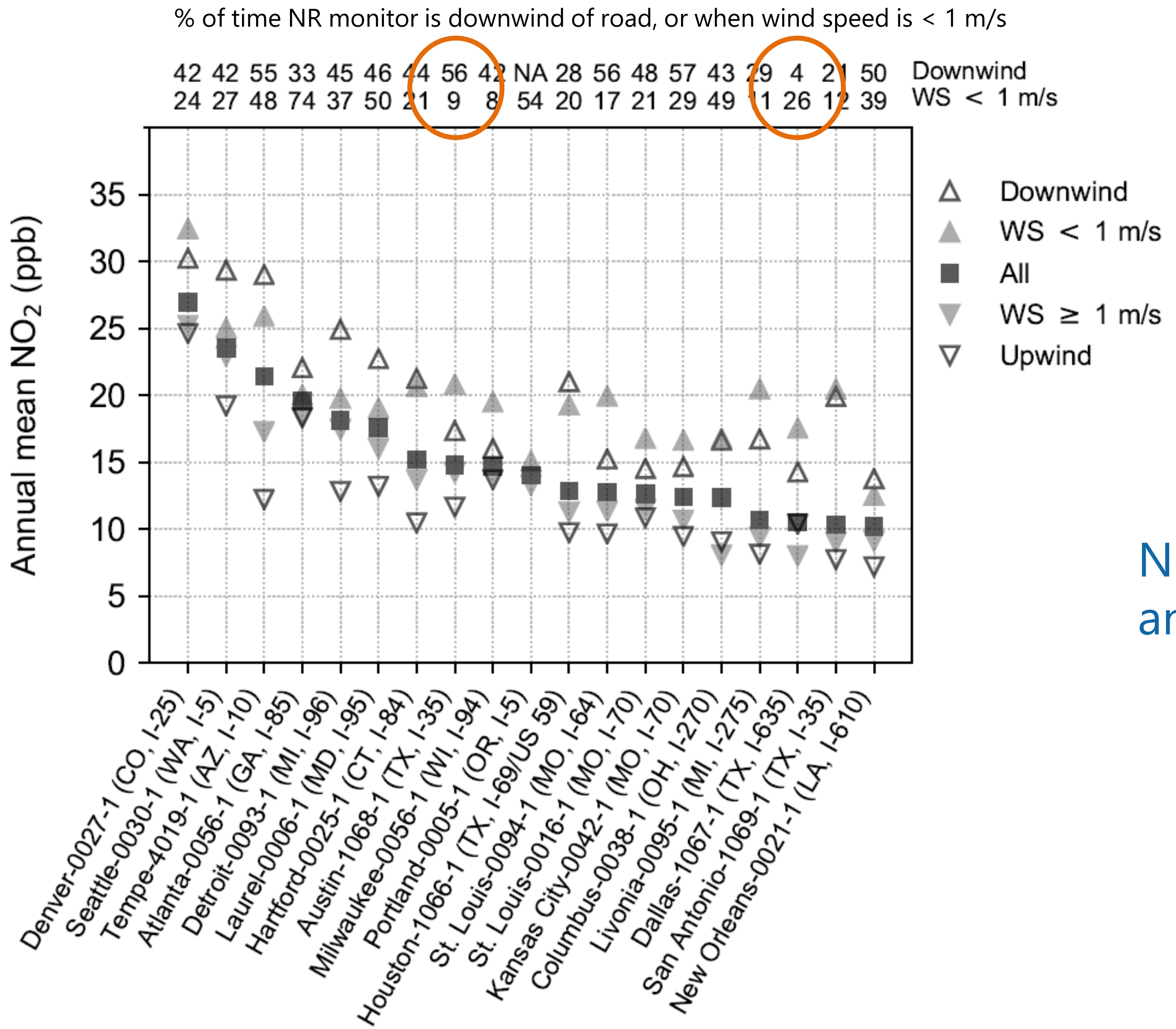
where HD_c is the volume of heavy-duty vehicles on the target roadway, and HD_m is a multiplicative factor that represents the ratio of heavy-duty to light-duty emissions of oxides of nitrogen (NO_x)

Factor: Varying Local FE-AADT



Source: DeWinter et al., 2018, Figure 2

Factor: Varying Wind Speed, Direction



Annual mean 2015 NO_2, five wind conditions.

Note differences between Austin and Dallas, Texas.

Source: DeWinter et al., 2018, Fig. 5

Additional Monitoring Analyses: Recent Published Work

International Journal of *Environmental Research and Public Health*

MDPI

Article

Conditions Leading to Elevated $PM_{2.5}$ at Near-Road Monitoring Sites: Case Studies in Denver and Indianapolis

Steven G. Brown [1,*], Bryan Penfold [1], Anondo Mukherjee [1], Karin Landsberg [2] and Douglas S. Eisinger [1]

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check for updates

Abstract excerpt: "At both sites, while the near-road site often had higher $PM_{2.5}$ concentrations than nearby sites, there was no clear correlation between traffic conditions (vehicle speed, fleet mix) and the high $PM_{2.5}$ concentrations."

Additional Information: Recent Published Work

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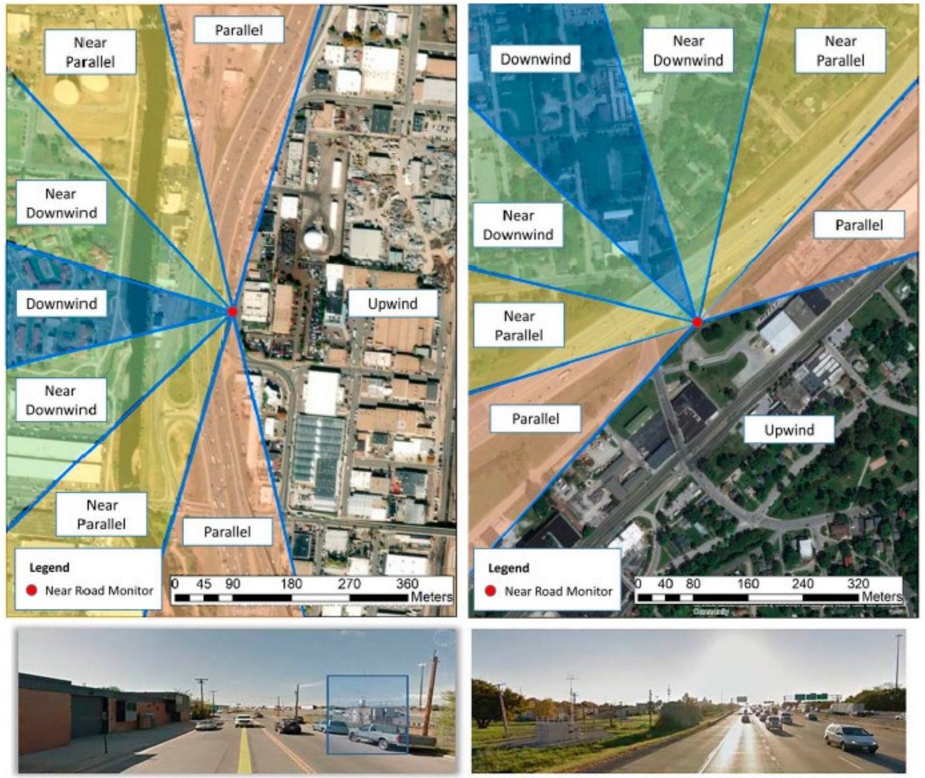
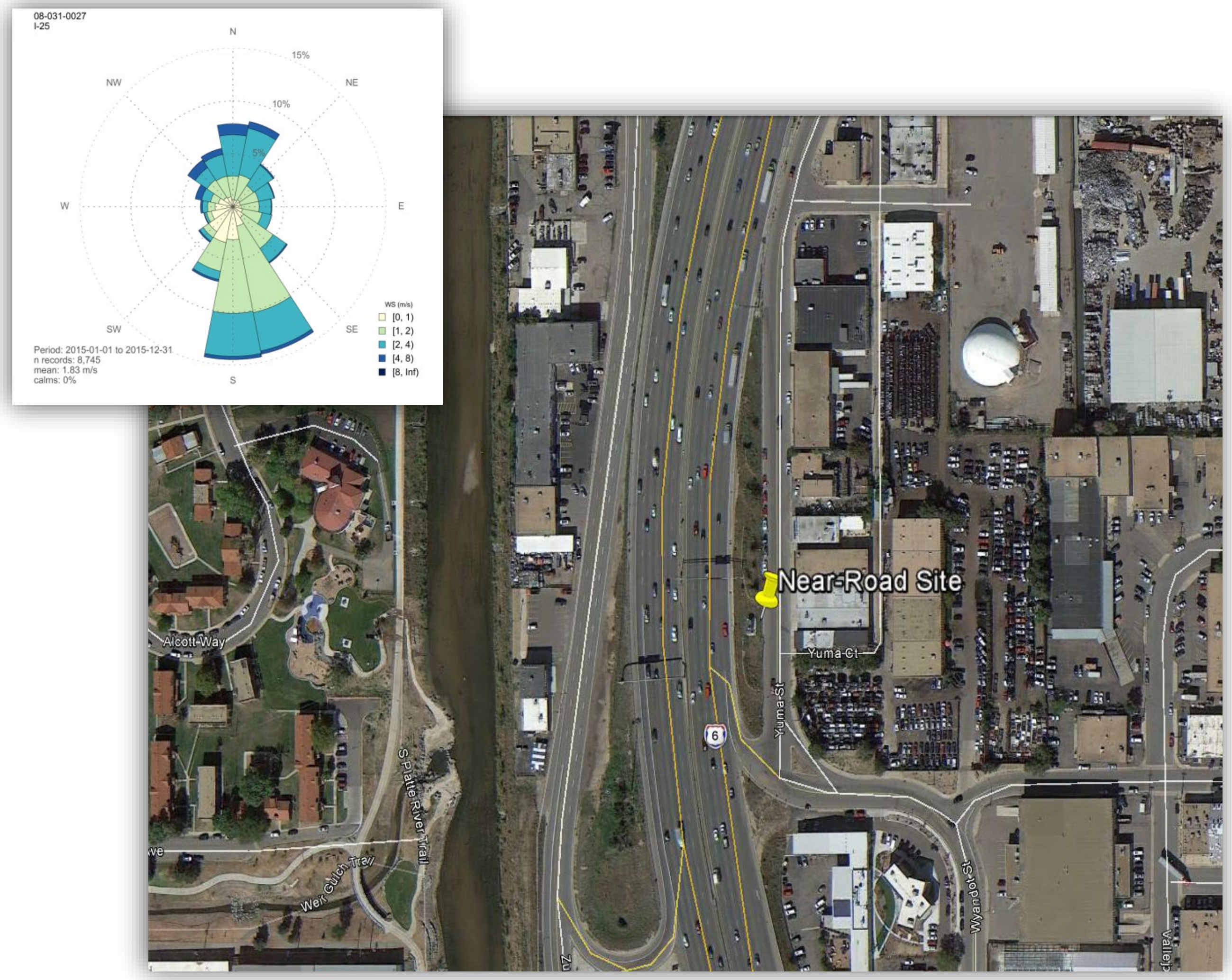


Figure 1. Satellite (**top**) and ground-level (**bottom**) views via Google Earth of the near-road sites at Denver (**left**) and Indianapolis (**right**); the Denver monitoring site is somewhat obscured by cars in the image, so the blue box denotes its location. In both satellite views, the angles used to determine wind direction bins (downwind, near downwind, near parallel, parallel and upwind) are also shown.

Denver I-25



AADT: 249,000
FE-AADT: 263,118

Note road curvature

Had one of the highest 2016 $PM_{2.5}$ increments in U.S. at ~3.0 $\mu g/m^3$

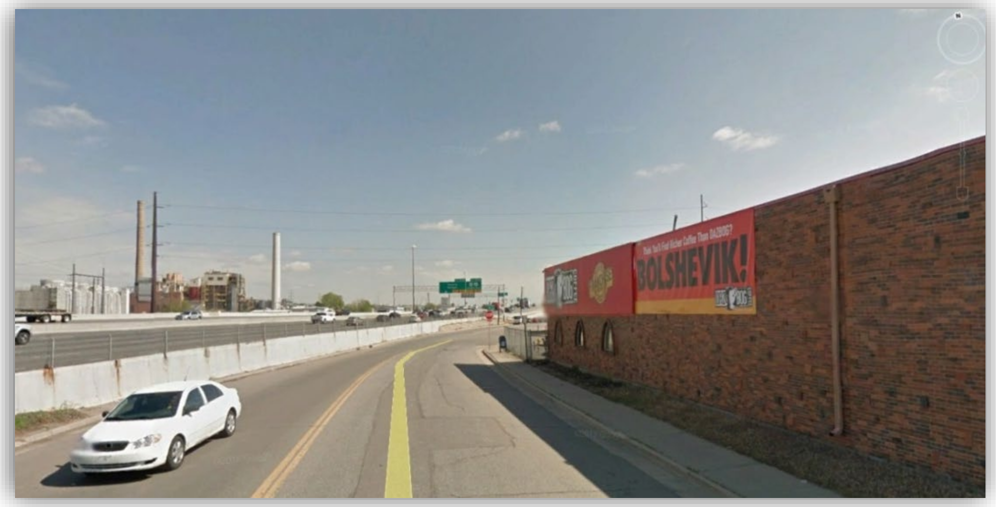
Google Earth view

Looking North

NR Monitor

Google street view.

Site Characteristics



Images of the Denver I-25 frontage road, taken from Google Earth.

Southbound view

- Near-road monitor (blue box)
- Road curvature
- Building "barrier"

Northbound view

- Road curvature
- Building "barrier"