Air quality monitoring for pollutant mapping, co-benefits assessments, and exposure and health impact analyses

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UM SPH

Organization

Characteristics of air pollutant concentrations

… spatial & temporal variation, multiple pollutants of concern

Brief background on ambient monitoring

… background … history … health … significance …

Monitoring approaches

… types … Michigan networks … near-road and mobile monitoring

Fixed and mobile monitoring

… dispersion modeling with application to health study

Indoor monitoring

Summary

Air pollutant concentrations

Levels of air pollution are not uniformly distributed

- Communities with low to moderate incomes & communities of color more likely to have high levels of PM
- Traffic-related pollutants dominant emission & exposure source
- Exposure occurs in microenvironments (vehicles, homes, outdoor, workplace)
- Temporal variability driven by emissions, meteorological, air change rates and other factors

Some groups are more vulnerable to adverse effects

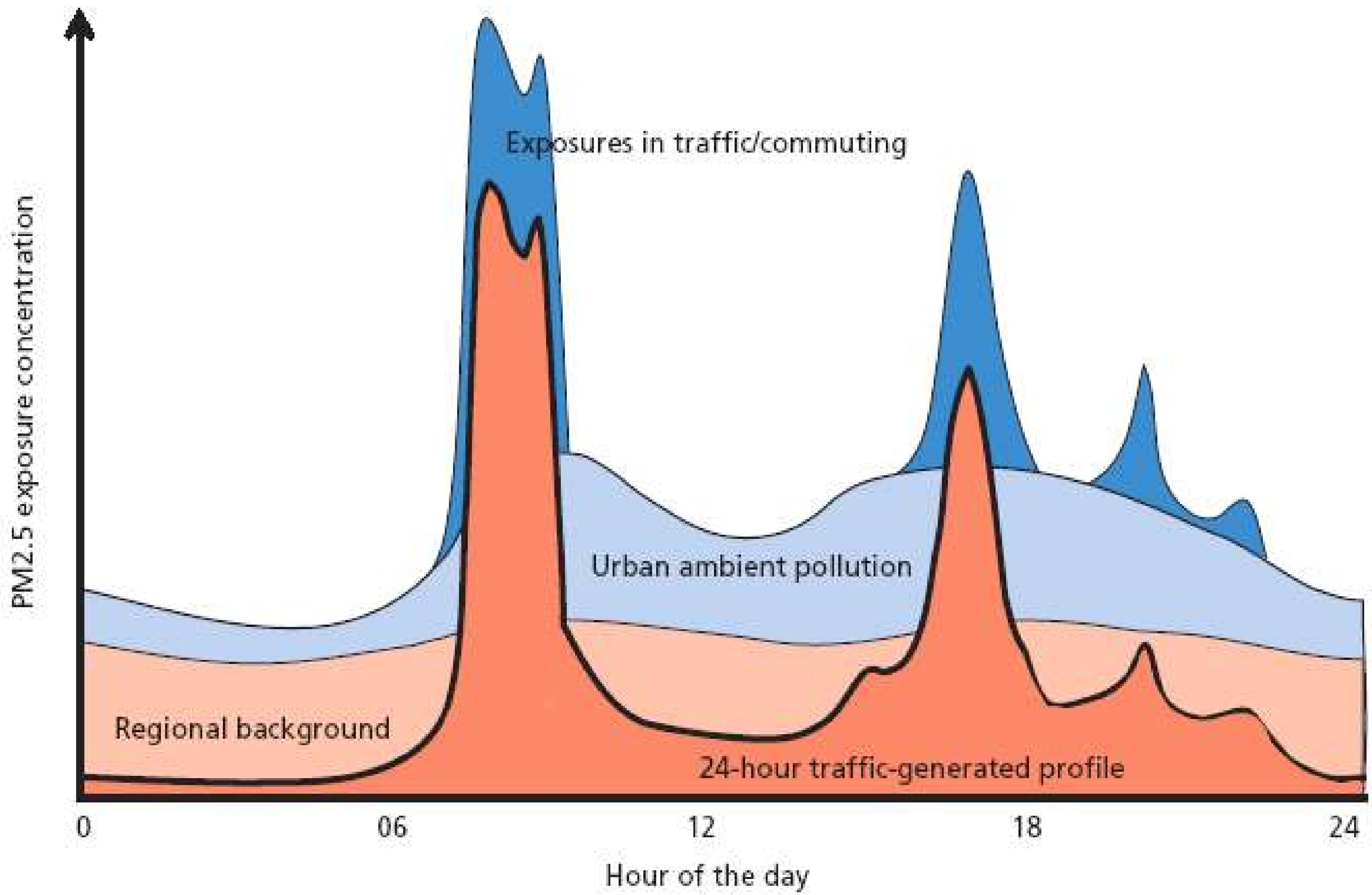
- Elderly, those with chronic conditions (e.g., heart disease, diabetes), pre-natal & children

Multiple pollutants are of concern for different reasons

- Criteria and toxic pollutants may be associated with asthma, pulmonary function, cardiovascular morbidity & mortality, prenatal & early childhood development, cognitive outcomes, cancer
- NAAQS compliance, with 1 hour to 1 year averaging time
- Greenhouse gases
- Indicators and tracers

Time of day effects, regional and local background

Relative exposure concentration of PM2.5
and the influence of traffic by time of day



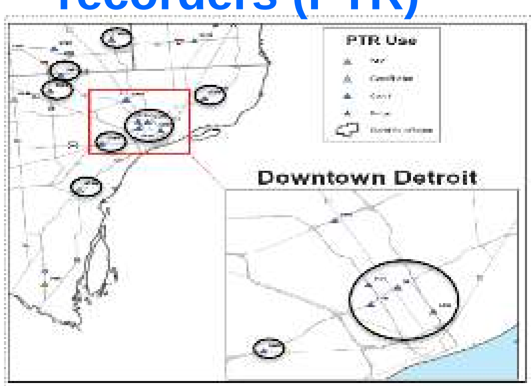
WHO, 2005

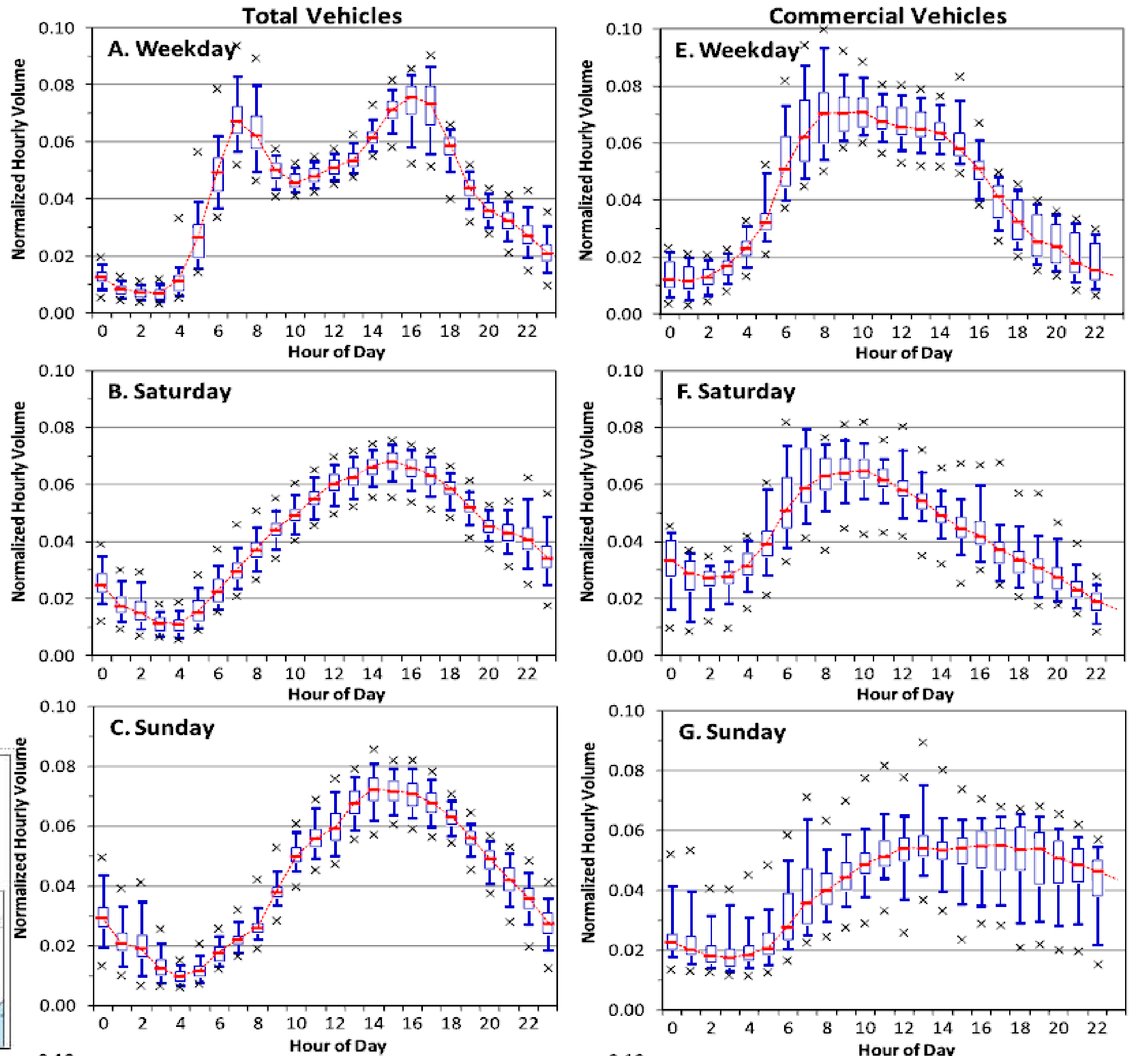
Link-based inventory – temporal allocation factors

Goal is to get correct hourly volume

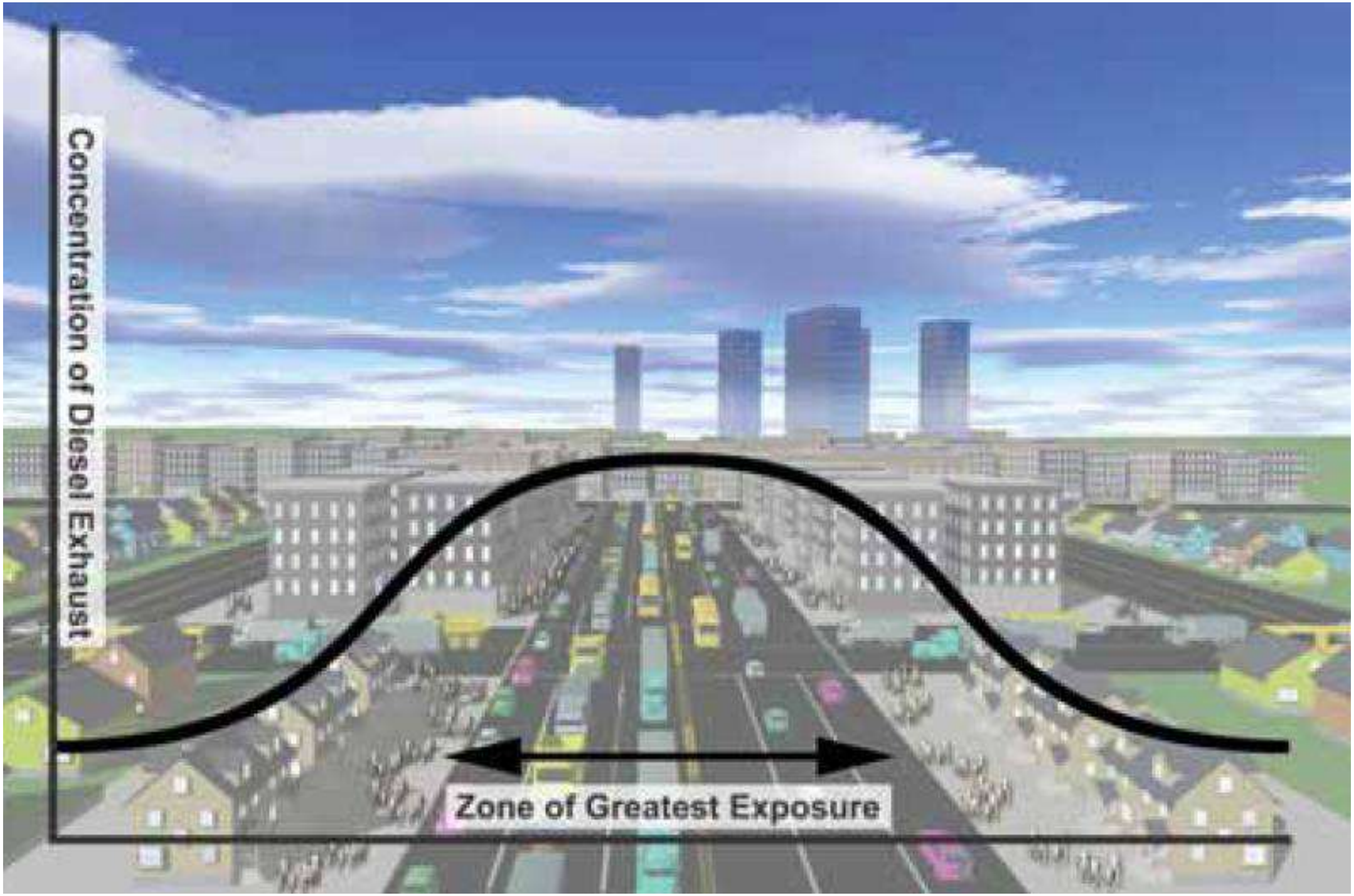
- Based on permanent traffic recorders & short-term counts
- Hourly factors shown with 1st, 5th, 25th, 50th (red bar), 75th, 95th and 99th percentiles'
- Also, day-of-week and month-of-year factors

Permanent traffic recorders (PTR)



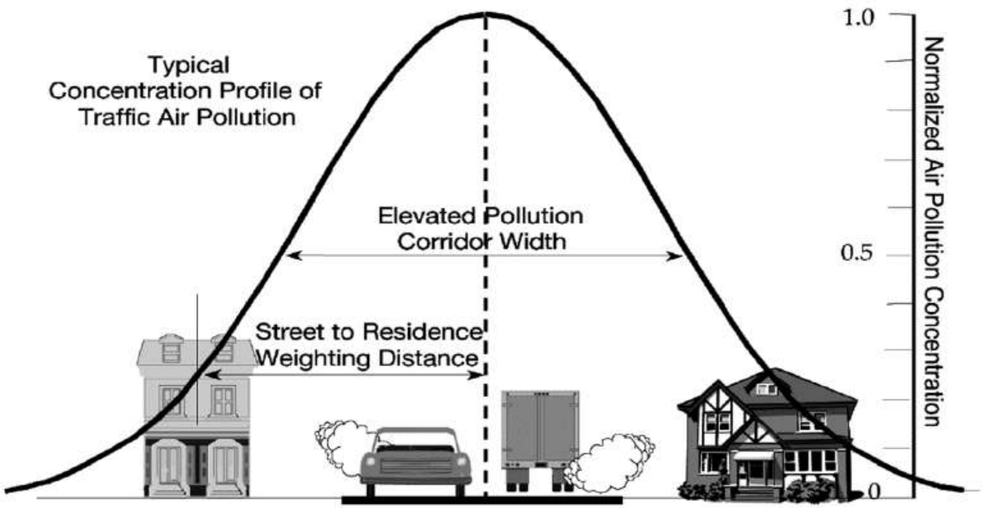


On-road, near-road, far-field zones, in-cabin



Diesel & Health in America. Clear Air Task Force, Feb. 2006

Predicted concentration gradients

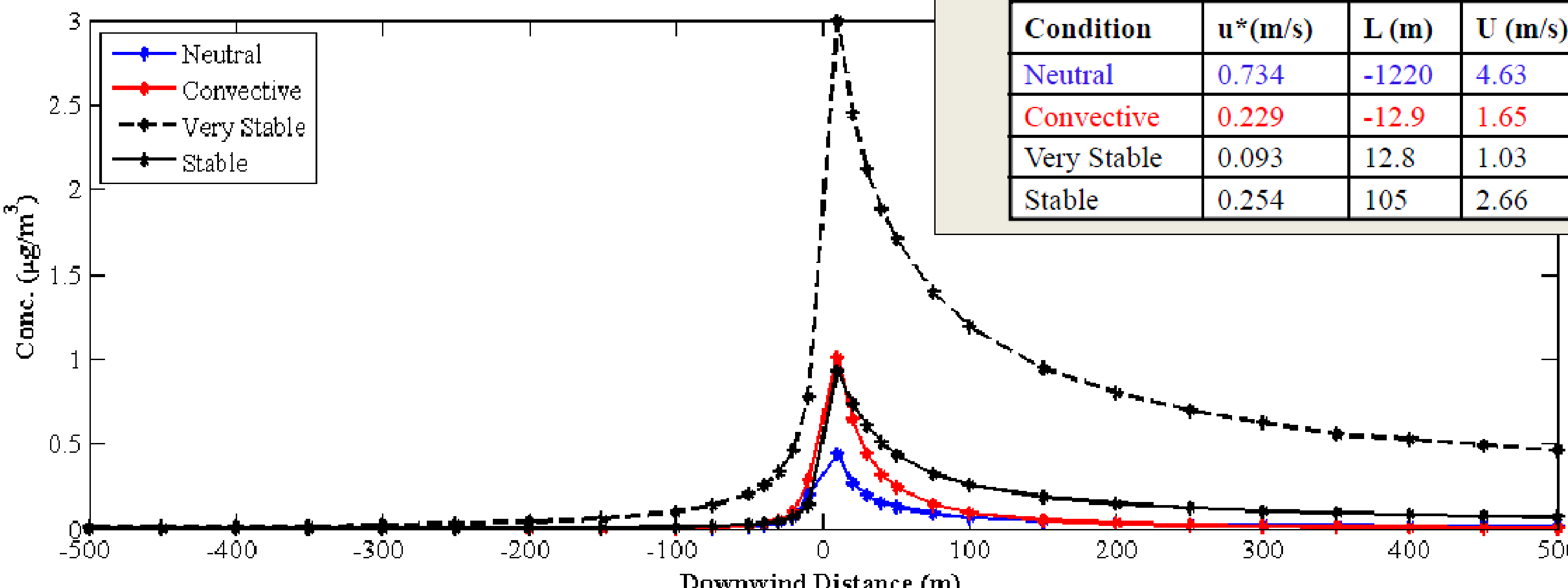


Concentration gradients predicted by RLINE for four representative meteorological conditions in Detroit

- Wind direction
- Atmospheric stability

Representative Met. Parameters from Fall 2010 in Detroit, MI.

Condition	u*(m/s)	L (m)	U (m/s)
Neutral	0.734	-1220	4.63
Convective	0.229	-12.9	1.65
Very Stable	0.093	12.8	1.03
Stable	0.254	105	2.66



M Snyder et al. 2013)

Which pollutants are the most important for health?

Ozone

- Summer time pollutant, affects broad areas (not localized), causes respiratory problems.

Particles (or particulate matter, PM)

- Can be year round problem, often localized (hot spot), causes many types of health problems
- Can cause acute air pollution episodes->
- Also hazardous at much lower levels

Donora, PA at noon on Oct. 29, 1948.
Photo source: Pittsburgh Post-Gazette

Diesel exhaust PM

- Carcinogen

Many others

- Toxics: NOx, SO_2, CO, etc.
- GHGs: CO_2, CH_4, etc.

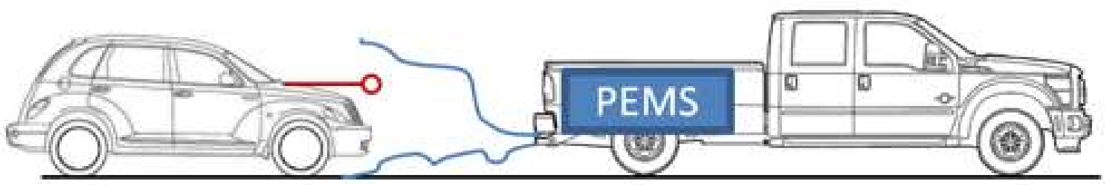
Air quality and exposure monitoring approaches

Remote sensing and satellite

- GOES, MODIS, Sentinel, etc.
- LIDAR, FTIR, etc.

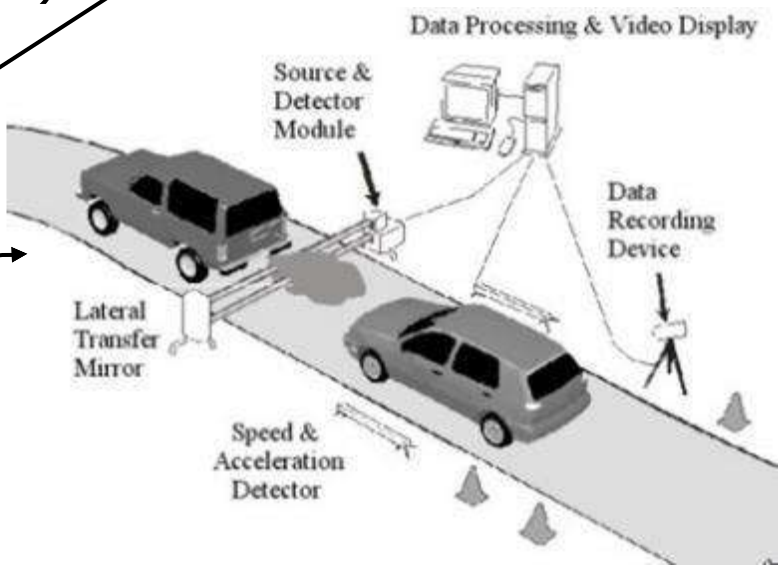
Fixed site

- Population-oriented
- Background
- Source-oriented (including near-road)
- Distributed – low cost



Mobile

- Vehicle chasing/following
- Cross-road
- Transect/mapping/hotspots



Indoor

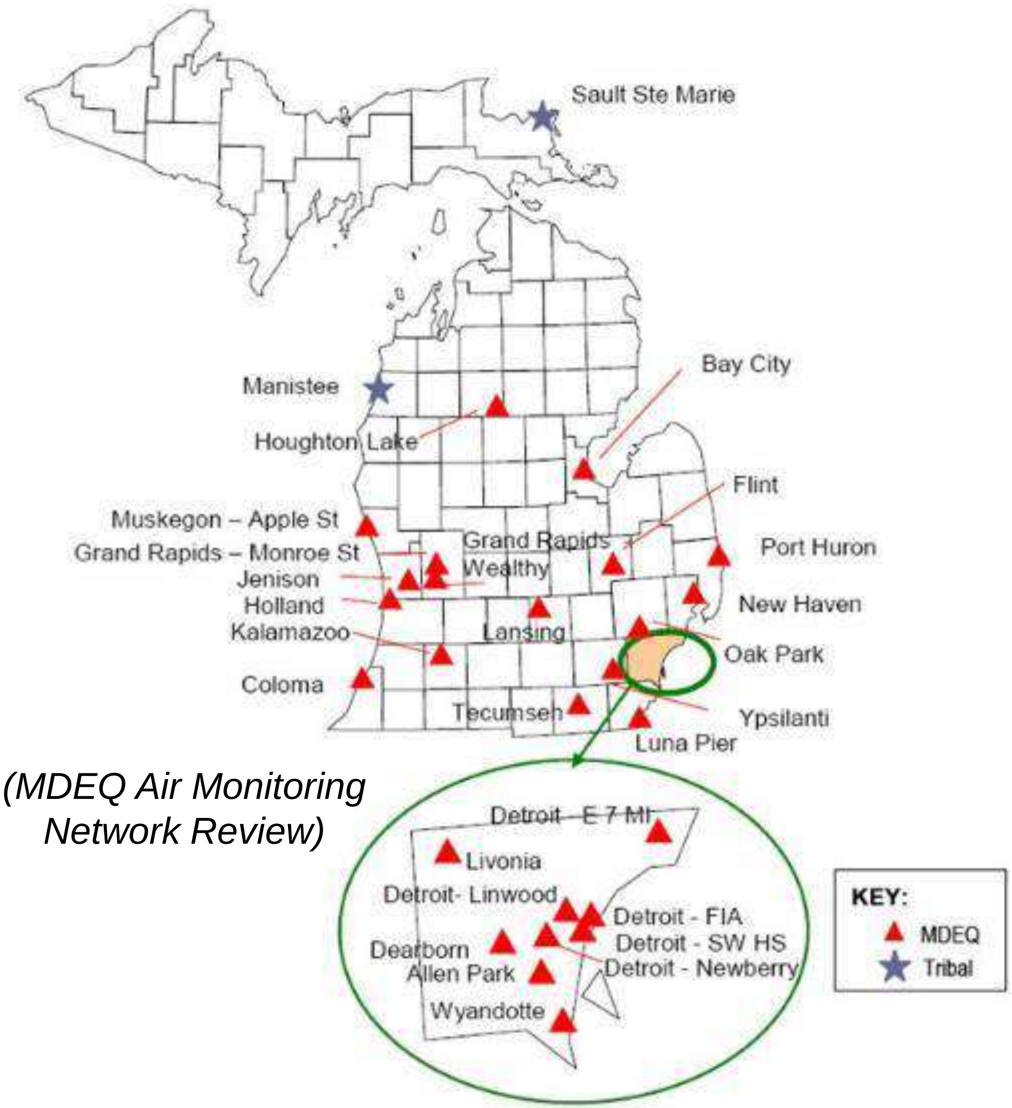
Personal

- Active & passive samplers in breathing zone, bikes, phones, etc.

Biological monitoring

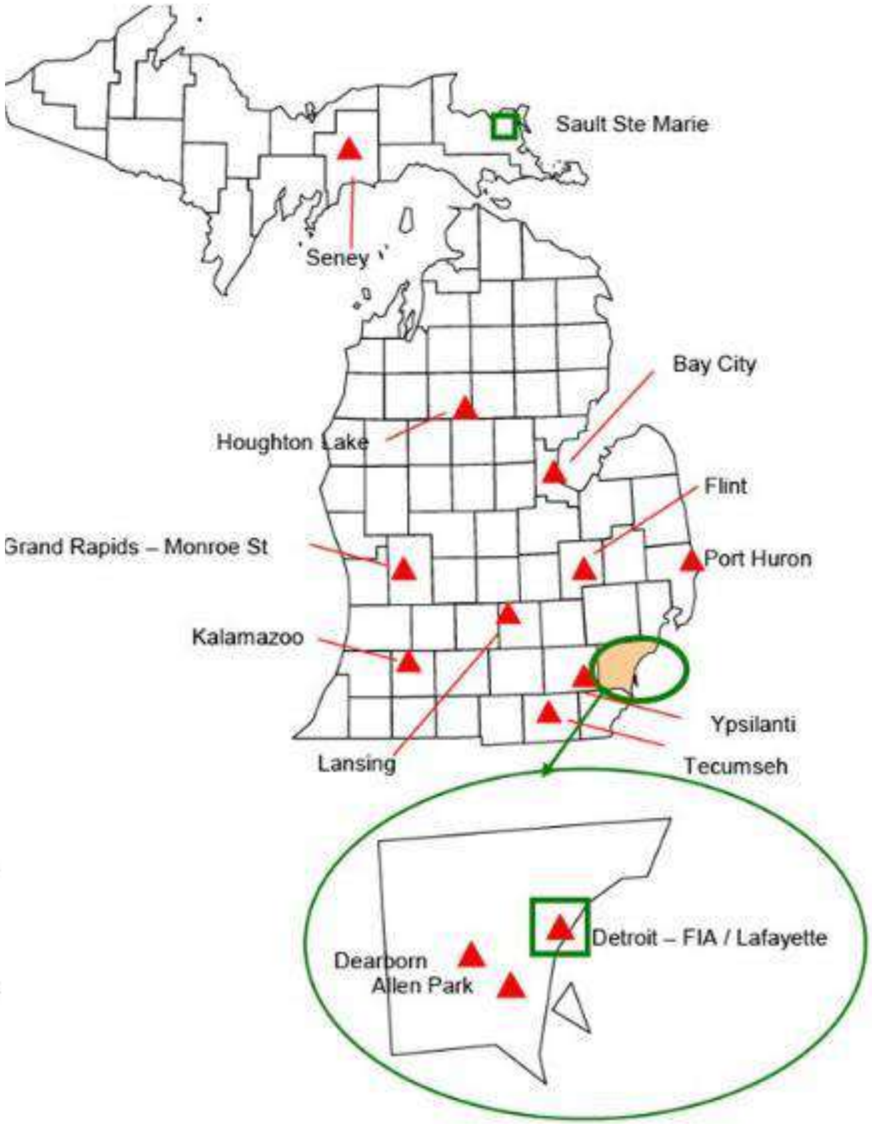
Air quality monitoring approaches – fixed site

AQS Monitoring - PM2.5 Ambient Air Monitoring Network



(MDEQ Air Monitoring Network Review)

Federal Reference Method (FRM)
(24-hr samples, every 3 days)



TEOM – continuous
(hourly)

Detroit-area monitoring

Some photos from Susan Kilmer, MDEQ, right from Motria Caudill,EPA

Near-road monitoring

2012 EPA requirements for near-road monitoring deployed about 120+ monitors for NOx, $PM_{2.5}$ and CO nationwide within 50 m of large roads.

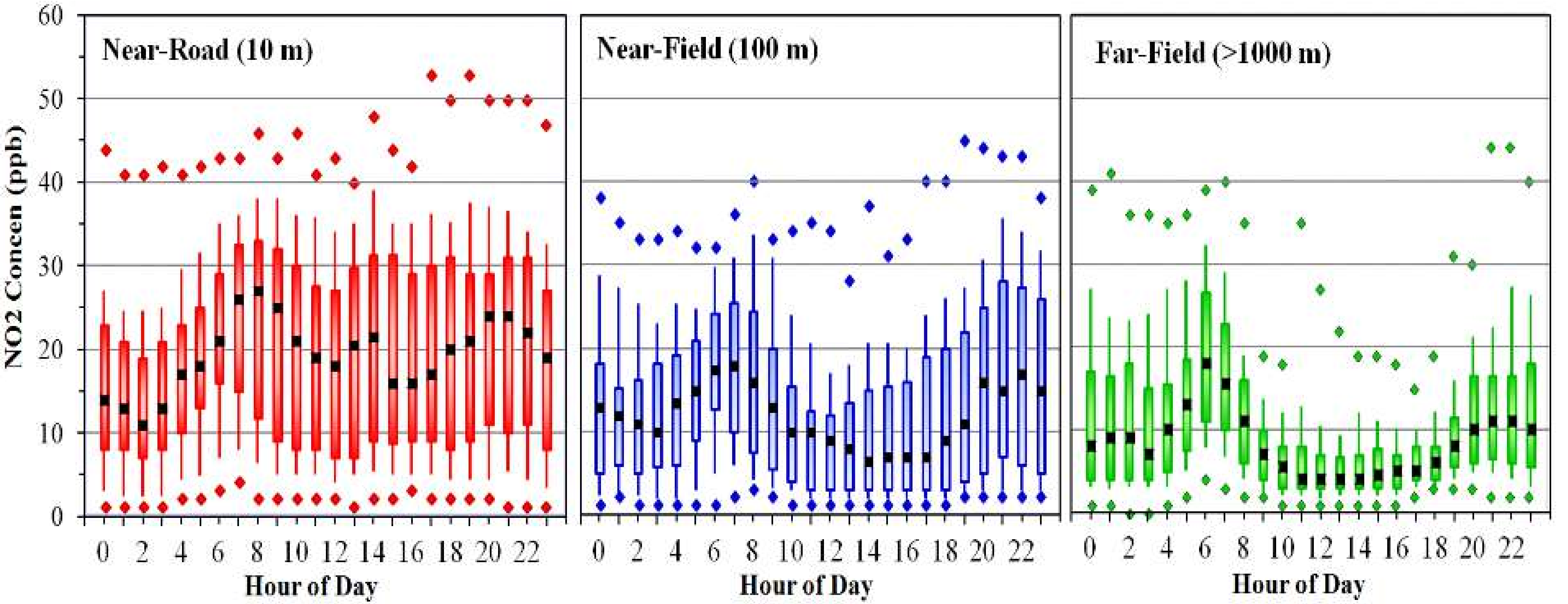
MDEQ with EPA support operates “near-road” monitoring sites

- Eliza Howell – site of major US EPA near-road experiments
- Livonia
- Allen Park almost a near-road site.

No routine monitoring for near-road pollutants in Detroit and monitoring in bridge area is limited

Eliza Howell (top); Livonia (bottom) near road monitoring sites. MDEQ

NO_2 concentrations by time-of-day in Detroit spring 2012 (March - May) at near-road, near-field & far-field sites



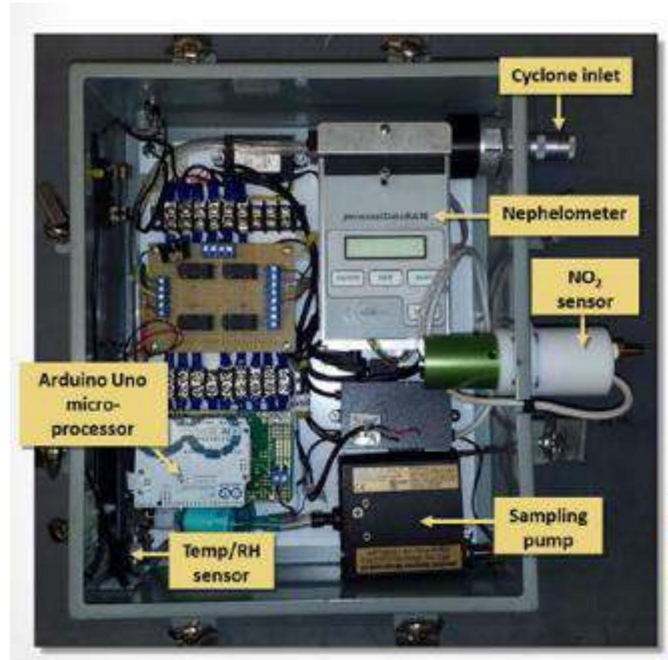
Based on Michigan Department of Environmental Quality data collected at Eliza Howell 1 and 2, and East 7 Mile sites. The first two sites are 10 and 100 m north of I96, an interstate with an annual average daily traffic (AADT) of about 135,000 vehicles per day and a fleet equivalent AADT of about 180,000. The third site is in a residential neighborhood in NE Detroit, downwind from the urban core, and over 3.5 km from freeways. Plots show hourly concentrations for minimum, maximum, 10th, 25th, 50th, 75th and 90th percentile concentrations.

Portable instrumentation

Portable, real-time, mid-tier cost sensors

Some compare favorably to MDEQ and laboratory-grade sensors.

A few integrated systems are under development.



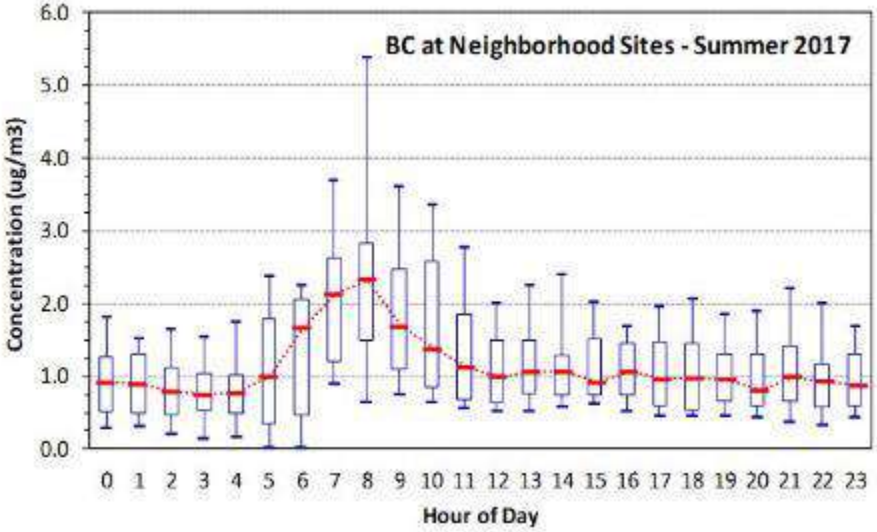
Measurement	Reporting Unit
NO_2 concentration	Parts per billion (ppb)
PM concentration	Micrograms per cubic meter (µg/m
Temperature	Degrees Celsius (°C)
Relative humidity (RH)	Percent (%) at °C

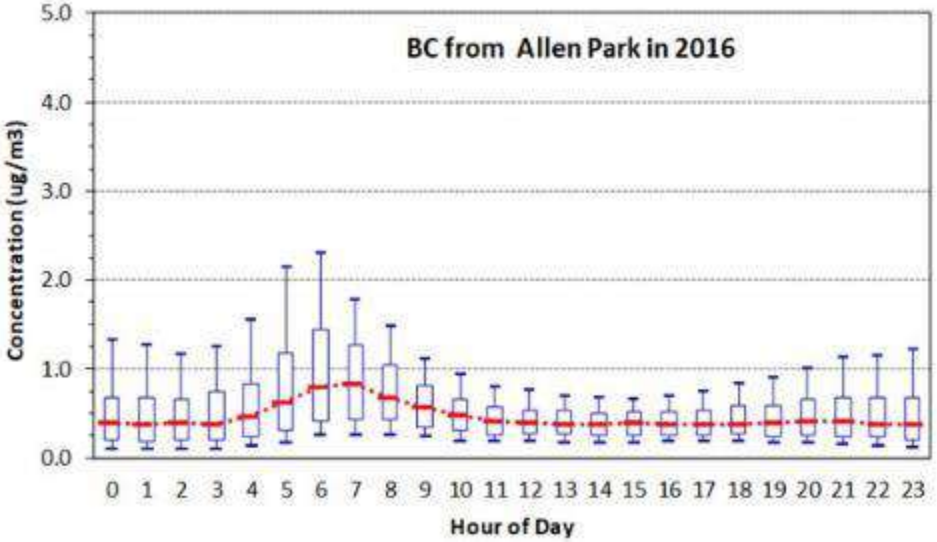
2B OEM-106 Ozone

DUSTTRAK DRX

I-75 Pilot study

Hour-of-day trends in **black carbon concentrations** at neighborhood and Allen Park sites. Plots show median, interquartile range (error bars), median, 10th and 90th percentile.





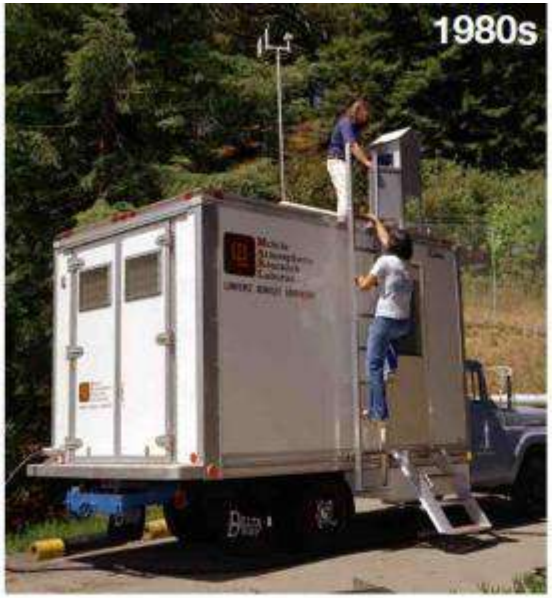
Mobile monitoring has evolved over the over past 50 years

Techniques evolving over the decades but still challenging.

Advances in measurement technology

Increasing mobility

Shift in emphasis from concentrations to exposure



Photos: D. Ensor, 2011, CARB, LBNL

Mobile monitoring to improve assessments

General approach

Use high quality instruments on both **programmed routes** and **specific locations** on a daily & seasonal basis

Measure various pollutants, e.g., **GHGs + toxic pollutants**

Use **repeated daily sampling** on each route

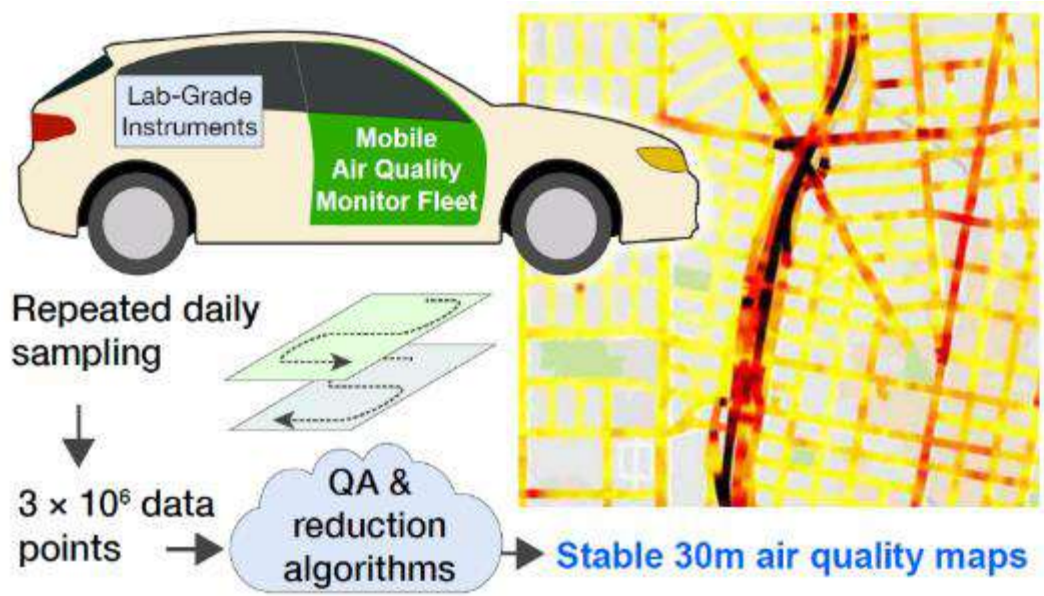
Capture the **spatial pattern of pollutants**, including "hotspots"

Evaluate concentration **trends** (seasonal & annual)

Compare **changes in GHG and toxics**

Derive emission estimates (or surrogates)

Evaluate **mitigation effectiveness** and evaluate **co-benefits**



Graphic: Joshua Apte, ES&T, 2017)

MPAL – Michigan Pollution Assessment Laboratory

Mobile air quality lab designed as part of an 10 year study of air quality levels in SW Detroit and impacts of the new Gordie Howe International Bridge.

- Area has potentially vulnerable populations, e.g., elderly and children.
- Inform health impact assessments and epidemiological studies
- Complement data collected from stationary regulatory sites.

MPAL consists of a 2018 Ford Transit truck equipped with fast-response air quality and meteorological sensors.

- Gases: CO_2, CO, CH_4, H_2S, H_2O, O_3, NO, NO_2, SO_2
- PM: PM10, PM2.5, PM (7 nm - 20 µm)
  PM composition: black/brown carbon, trace metals (e.g., Pb, Zn)
- Meteorological and other sensors, GPS, video, battery power (7+ kWh).

Inside MPAL


thermo scientific
SAMSON
PICARRO
PICARRO


HORIBA




victron energy
MultiPlus


MPAL – Instruments and Parameters

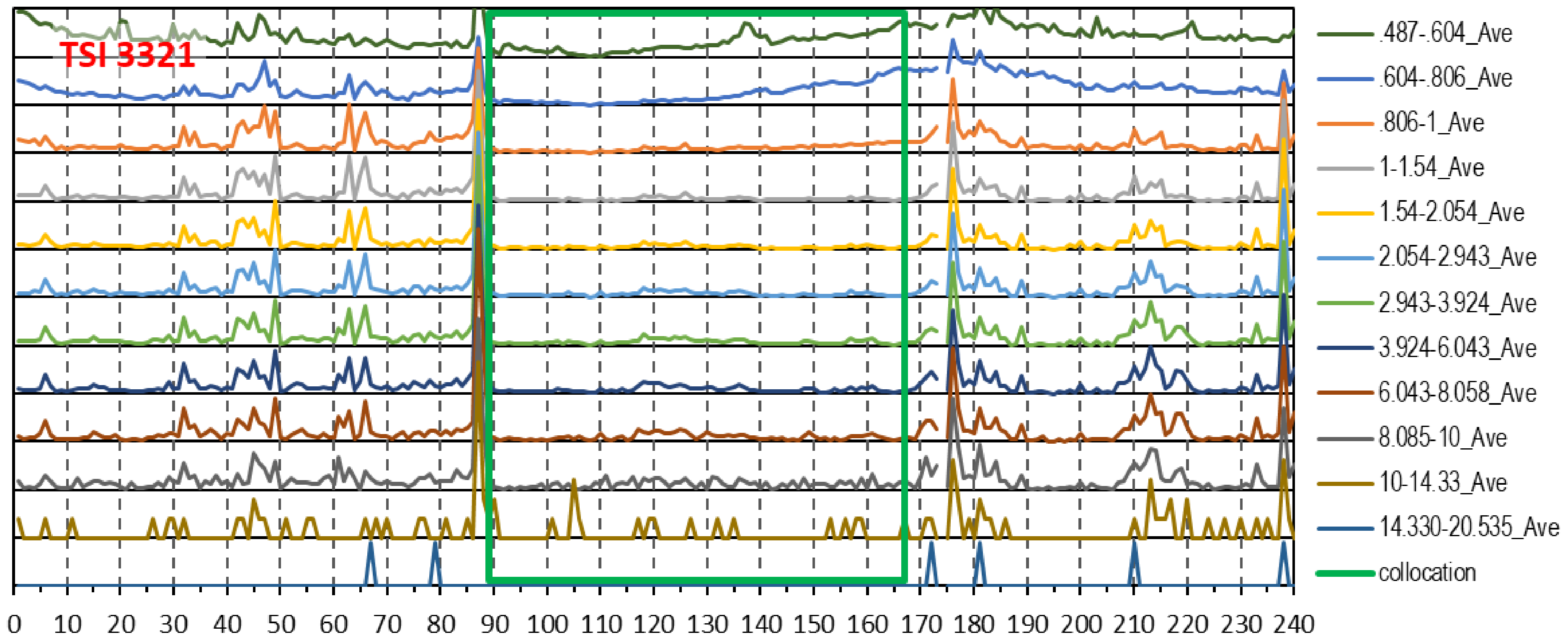
Instrument	Measured Parameters	Sampling Rate	Principle of Measurement	Channels	
				Total	Signal
Picarro G2401	CO_2, CO, CH_4, H_2O	1 s	Cavity ring-down spectroscopy	11	4
Picarro G2204	CH_4, H_2S, H_2O	1 s	Cavity ring-down spectroscopy	10	3
Horiba PX-375	Particle Matter (PM_{10})	1 min	Cyclone size separation, beta-ray attenuation	NA	1
	Trace metals in PM_{10}: Ti, V, Cr, Mn, Fe, Ni, Cu, Zn, As, Pb, Al, Si, S, K, Ca	30 min	Cyclone size separation, X-ray fluorescence	25	15
TSI 3910	PM 7 nm - 20 µm	1 min	Scanning mobility particle size (SMPS) + condensation particle	35	16
TSI 3321	PM 0.4 to 20 µm aerodynamic size	1 min	Time of flight sizing + light scattering	22	12
TSI 3330	PM 0.3 to 10 µm optical size & "mass"	1 s	Single particle counting + optical sizing	20	16
Magee AE-42 + others	Black, brown, yellow carbon (BC)	5 min	Absorption of collected particles at 370 - 880 nm	12	7
Eco Physics CLD 700 AL	NO_x, NO, NO_2	1 s	Chemiluminescence + UV absorption	8	3
API 400A	O_3	1 s	Absorption at 254 nm	7	1
Garmin 18x	Position, elevation, speed, direction	1 s	Geographic positioning system (GPS)	5	10
Young 92000	Wind speed/direction, atmospheric pressure,	1 s	Wind: ultrasonics + sensors	5	9
Spy Tec Mobius Action Camera	Front & back photos	2 s	1080P HD Wide Angle Edition	2	NA

6 hour run generates1.54M data points (excluding 43K images)

MPAL route on 4/16/19 (1 min locations)

Example 1 of PM Data: TSI 3321 APS

Uses bipolar charging, aerodynamic sizing, optical counting for size-specific measurements from 0.4 to 20 um dia. 1 min resolution.



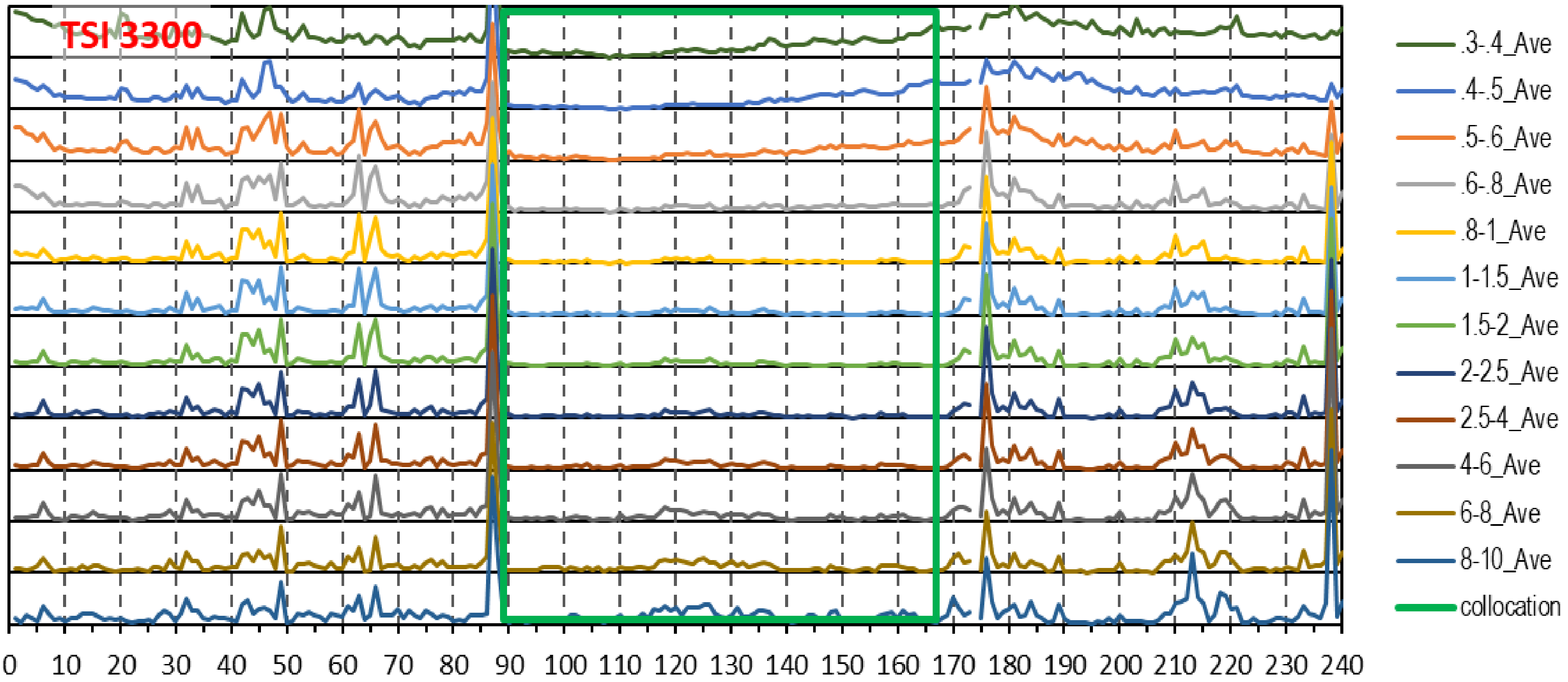
Plot shows 5/15/19 starting 8:20 am for 4 hours

Green shows collocation at EGLE DP4 starting 9:50 am

Collocation PM2.5 = 4.3 ug/m3   PM10 = 33.4 ug/m3

Example 2 of PM Data: TSI 3330 OPC

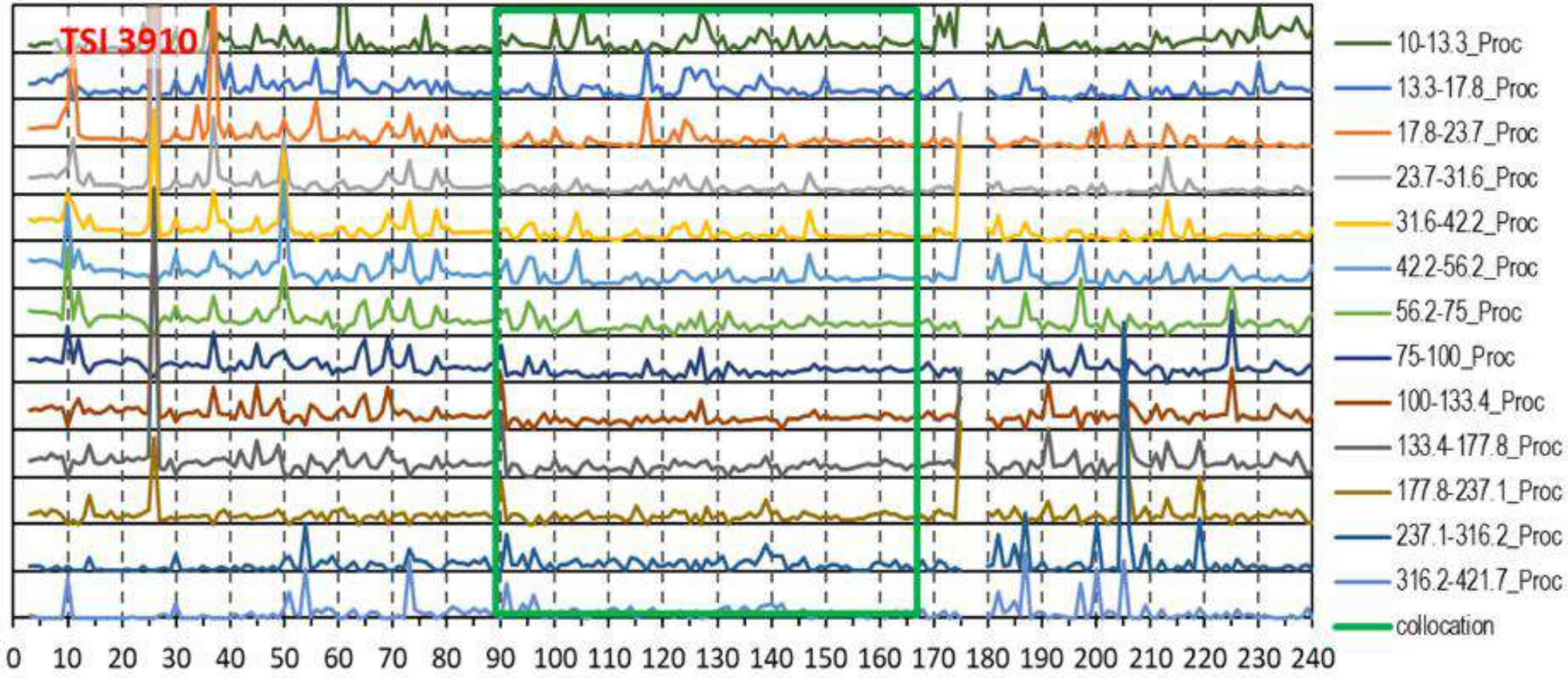
Uses optical particle counting for size-specific measurements from 0.3 to 10 um dia. 1 second resolution averaged to 1 min.



Plot shows 5/15/19 starting 8:20 am for 4 hours. Averaged to 1 min.
Green shows collocation at EGLE DP4 starting 9:50 am
Collocation PM2.5 = 4.3 ug/m3   PM10 = 33.4 ug/m3

Example 3 of PM Data: TSI 3910 Nanoscan

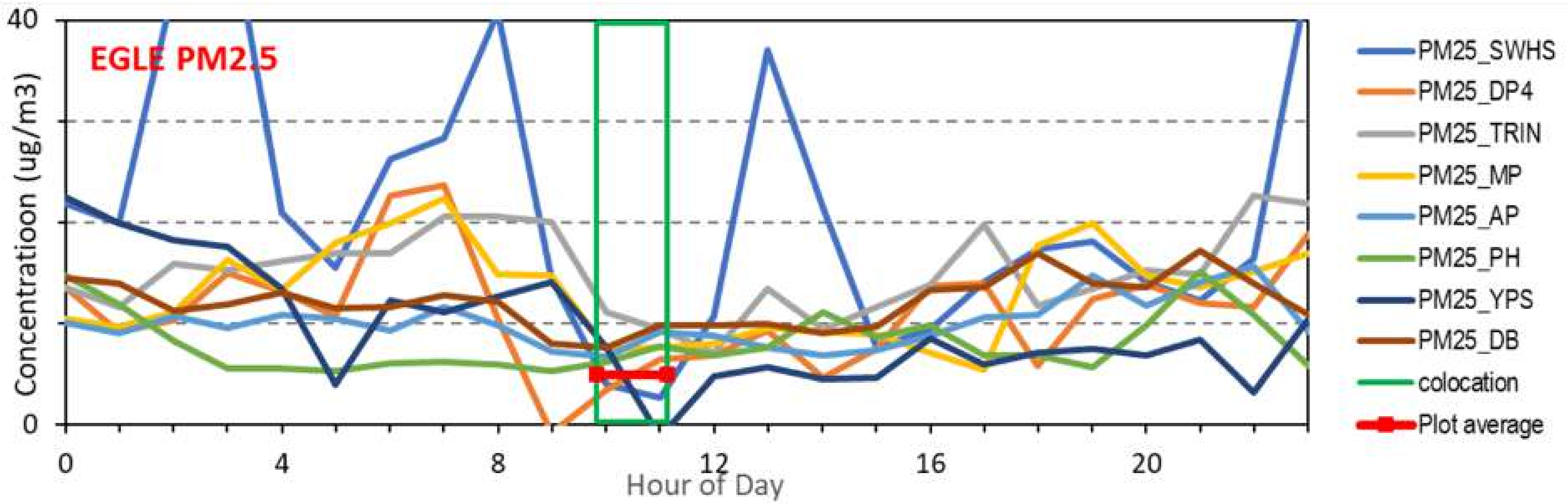
Uses electrical charging, sizing & condensation nuclei counter for size-specific measurements from 0.01 to 0.42 um dia. 1 min res.



Plot shows 5/15/19 starting 8:20 am for 4 hours. Averaged to 1 min.
Green shows collocation at EGLE DP4 starting 9:50 am
Collocation PM2.5 = 4.3 ug/m3 PM10 = 33.4 ug/m3

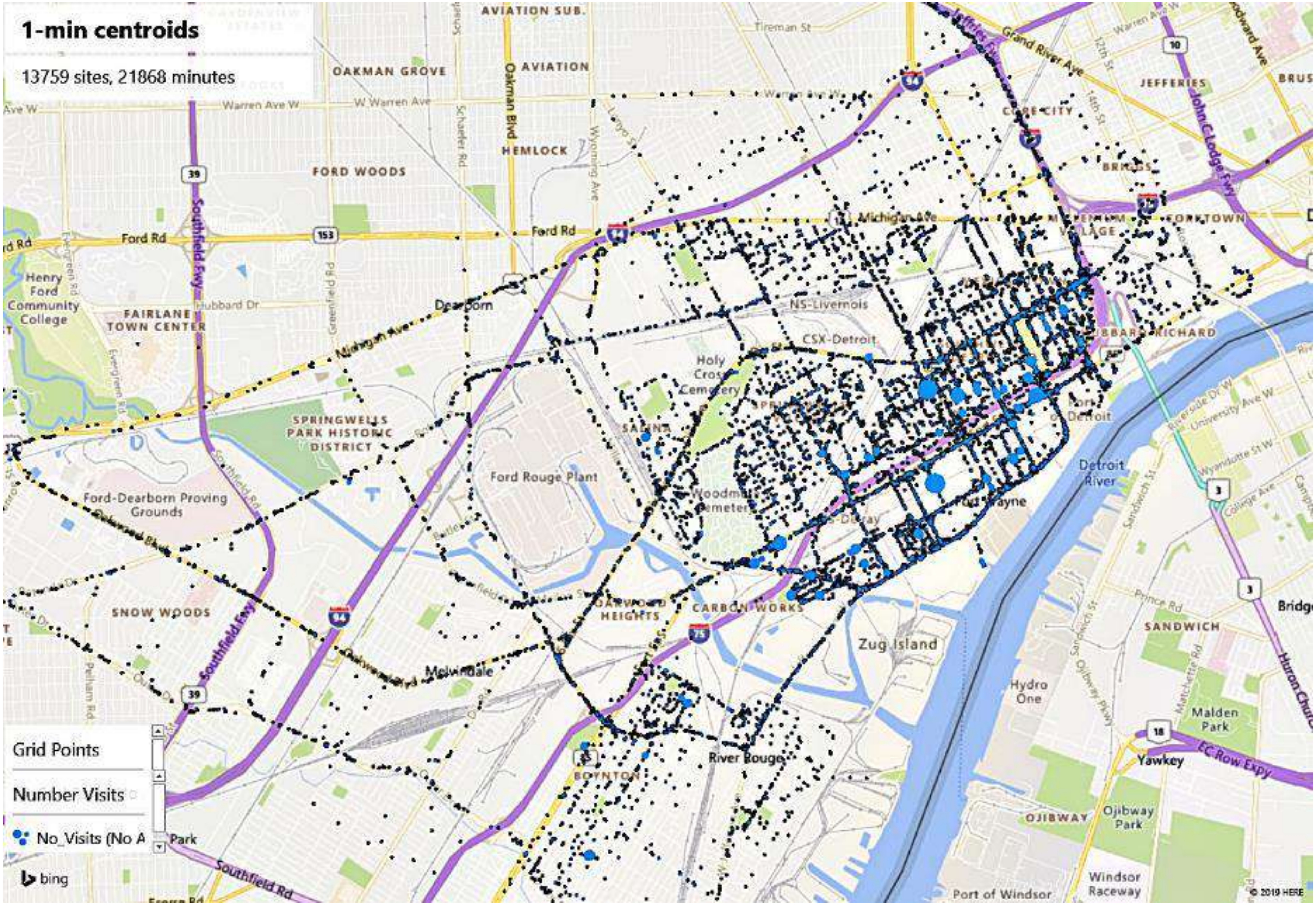
Example 4 of PM Data: TEOM & BAM

Operated by Michigan EGLE, Uses size selective inlet with either tapered element oscillating microbalance (TEOM) or beta attenuation monitoring (BAM). Typically 5 min res reduced to 1 hr.



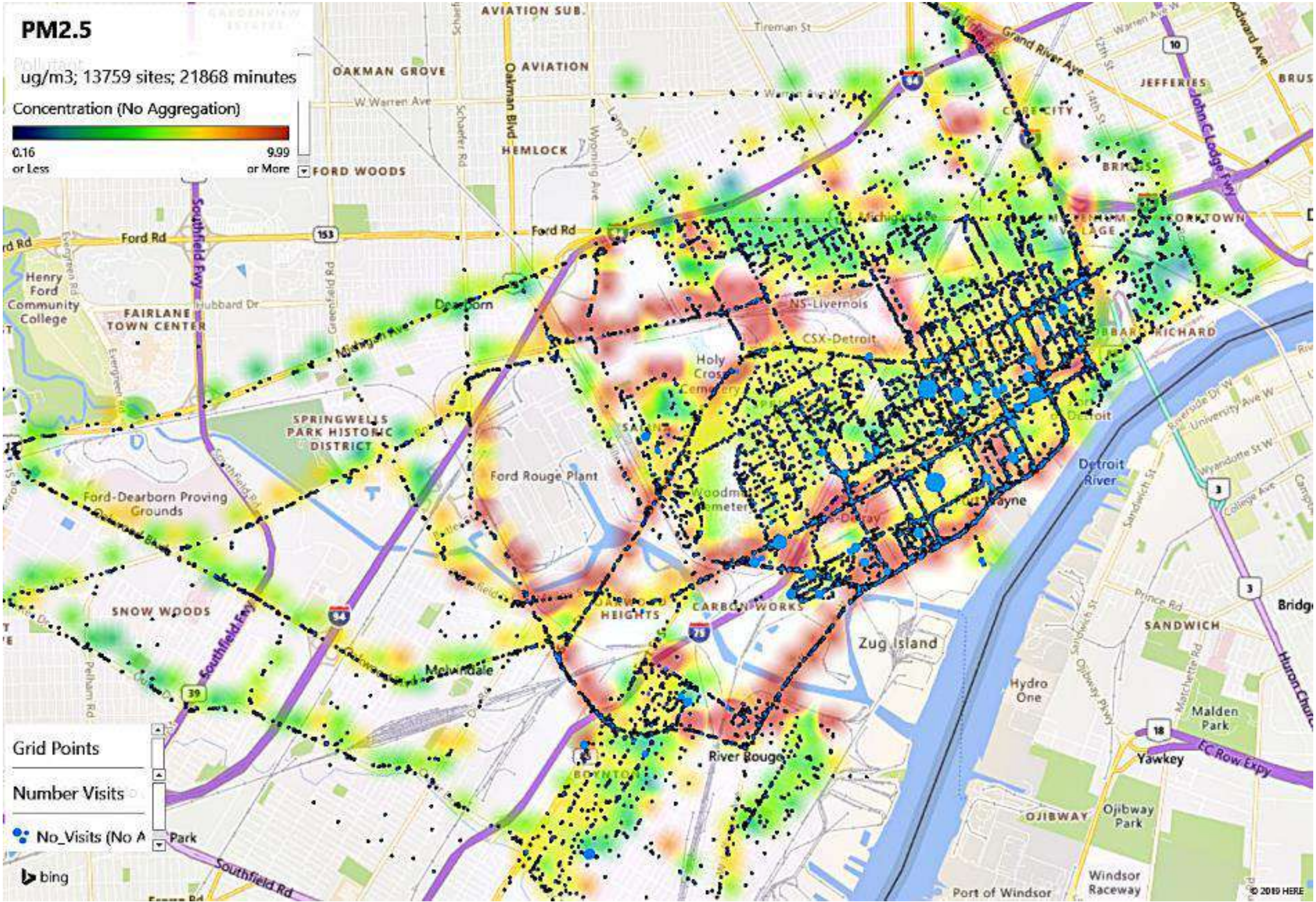
Plot shows 5/15/19 starting 8:20 am for 4 hours. Averaged to 1 min.
Green shows collocation at EGLE DP4 starting 9:50 am
Collocation PM2.5 = 4.3 ug/m3   PM10 = 33.4 ug/m3

MPAL sites May – November 2019 (1 min locations)



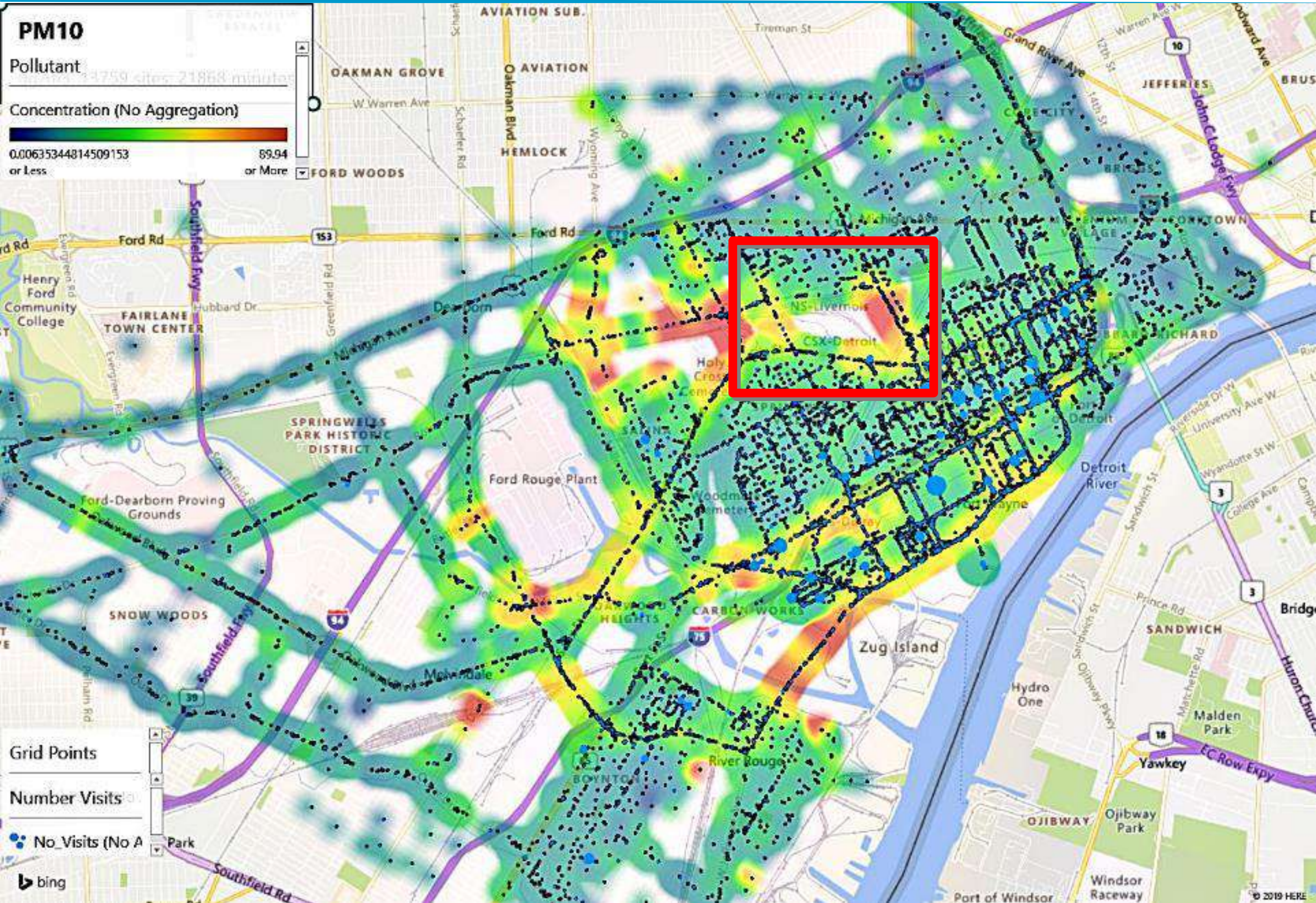
$PM_{2.5}$ mapping

No gridding, basic QA, 1 min measurements



PM_{10} mapping

1 m grid, 12965 locations, 20062 minutes.



PM_{10} mapping

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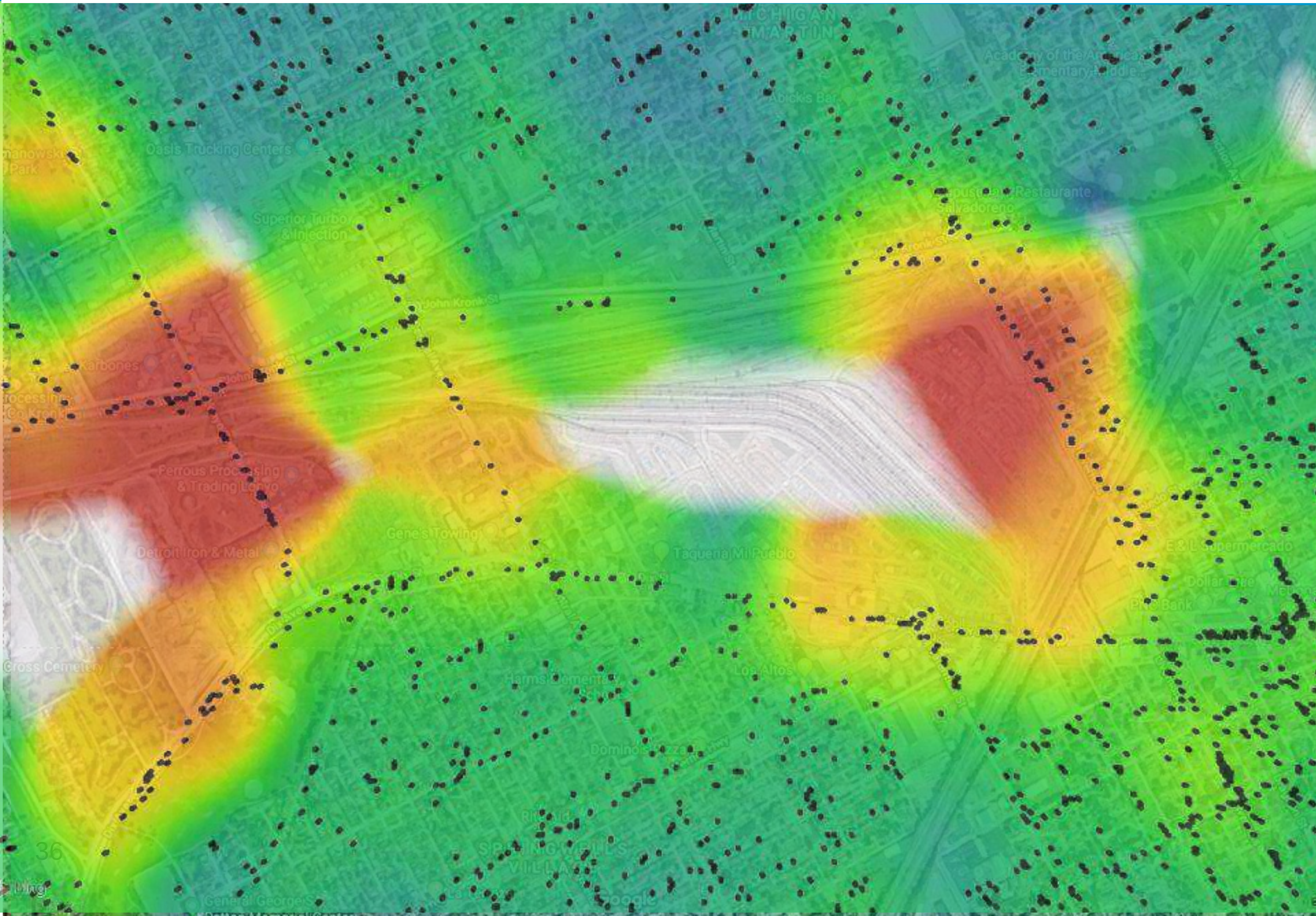
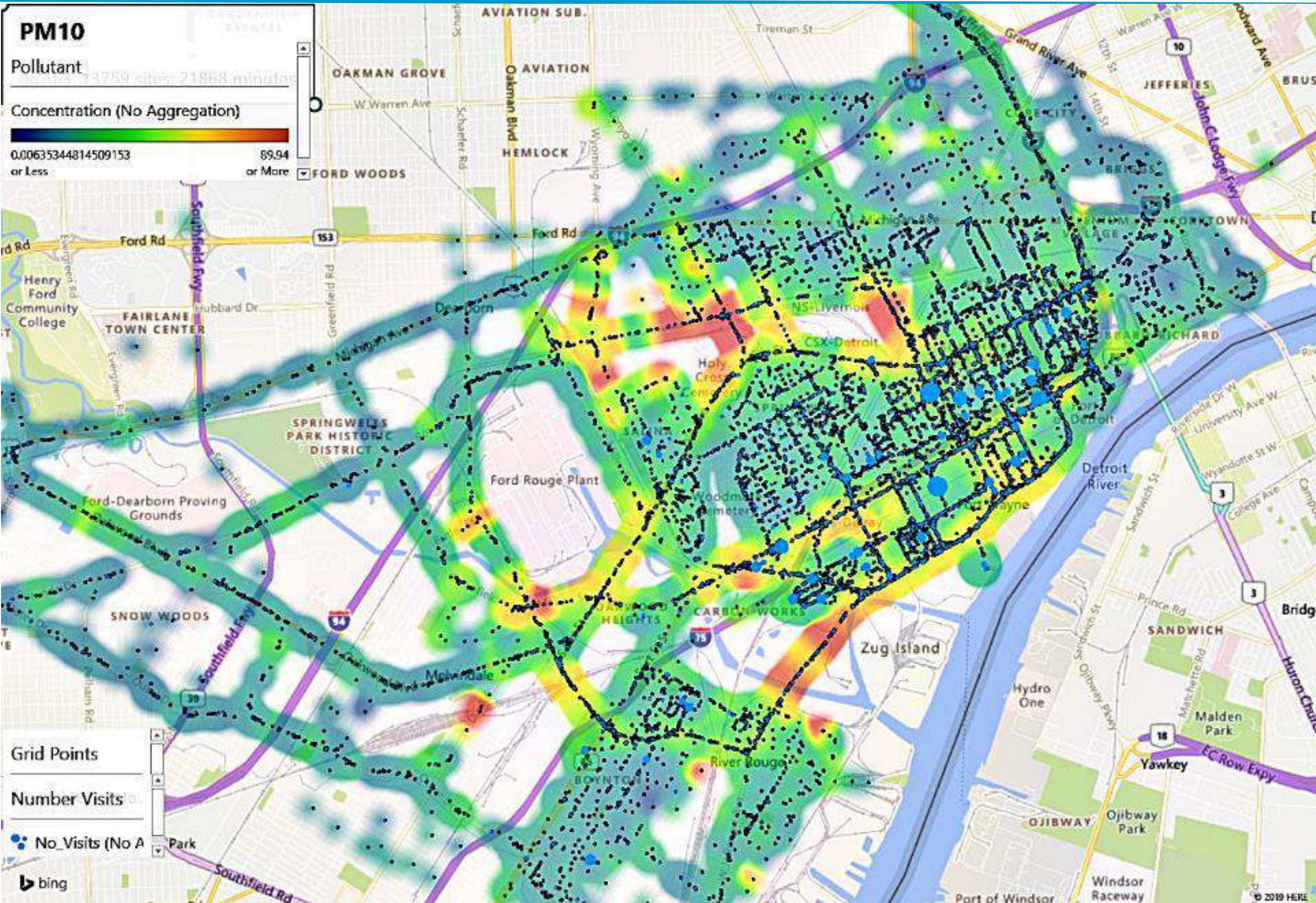


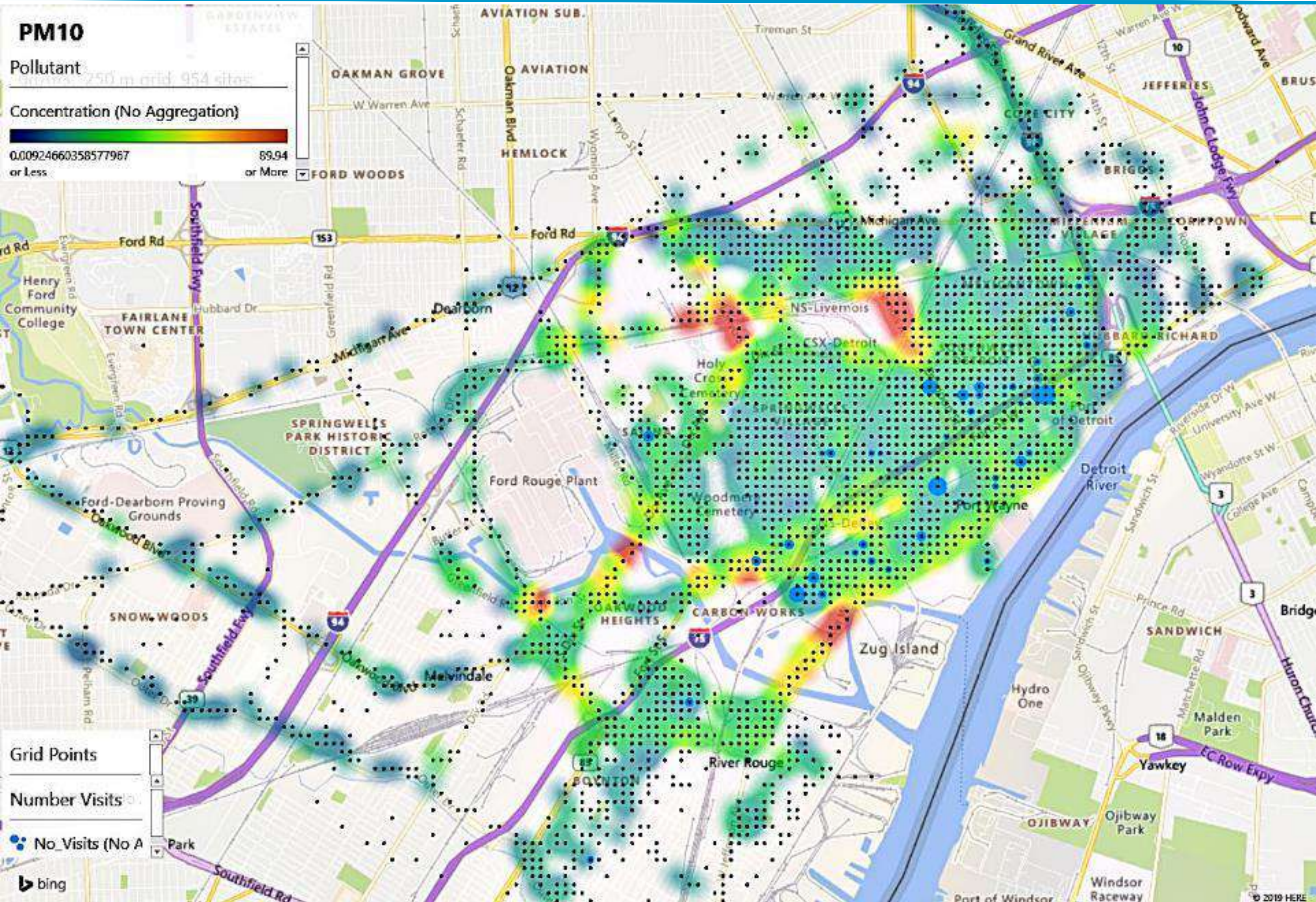
PM_{10} mapping

1 m grid, 12965 locations, 20062 minutes.



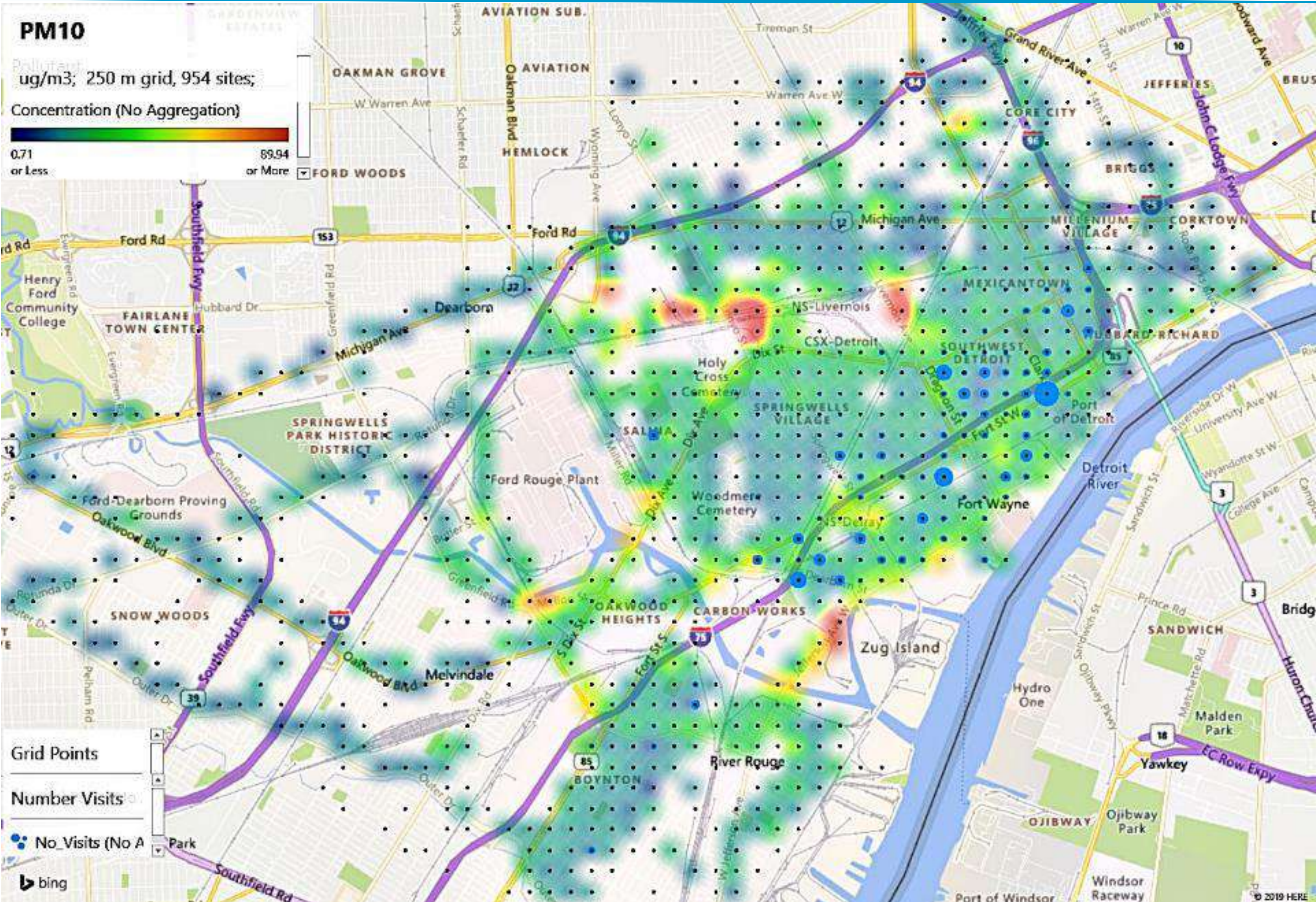
PM$_{10}$ mapping

100 m grid, 1732 locations, 20062 minutes.



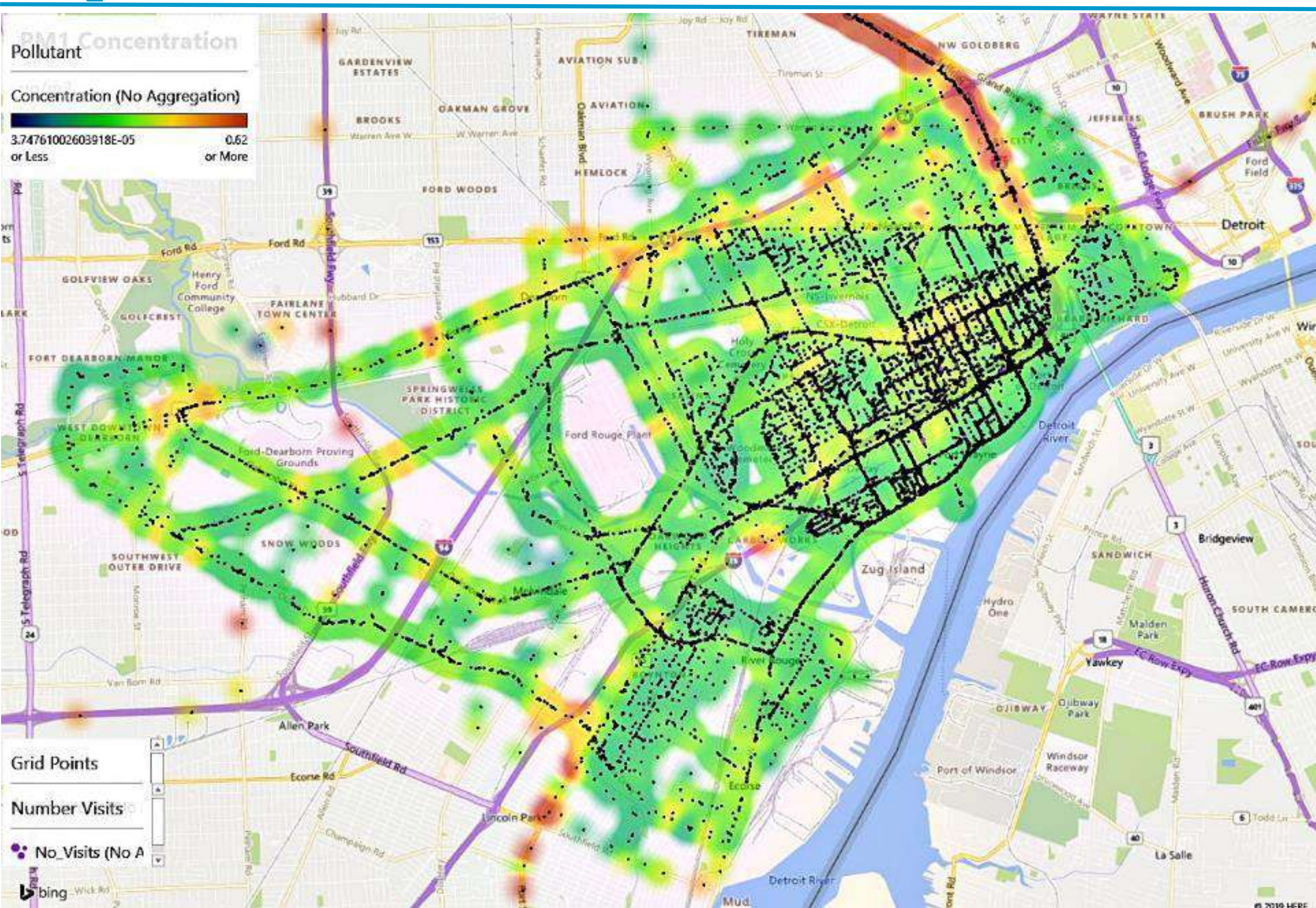
PM_{10} mapping

250 m grid, 954 locations, 20062 minutes



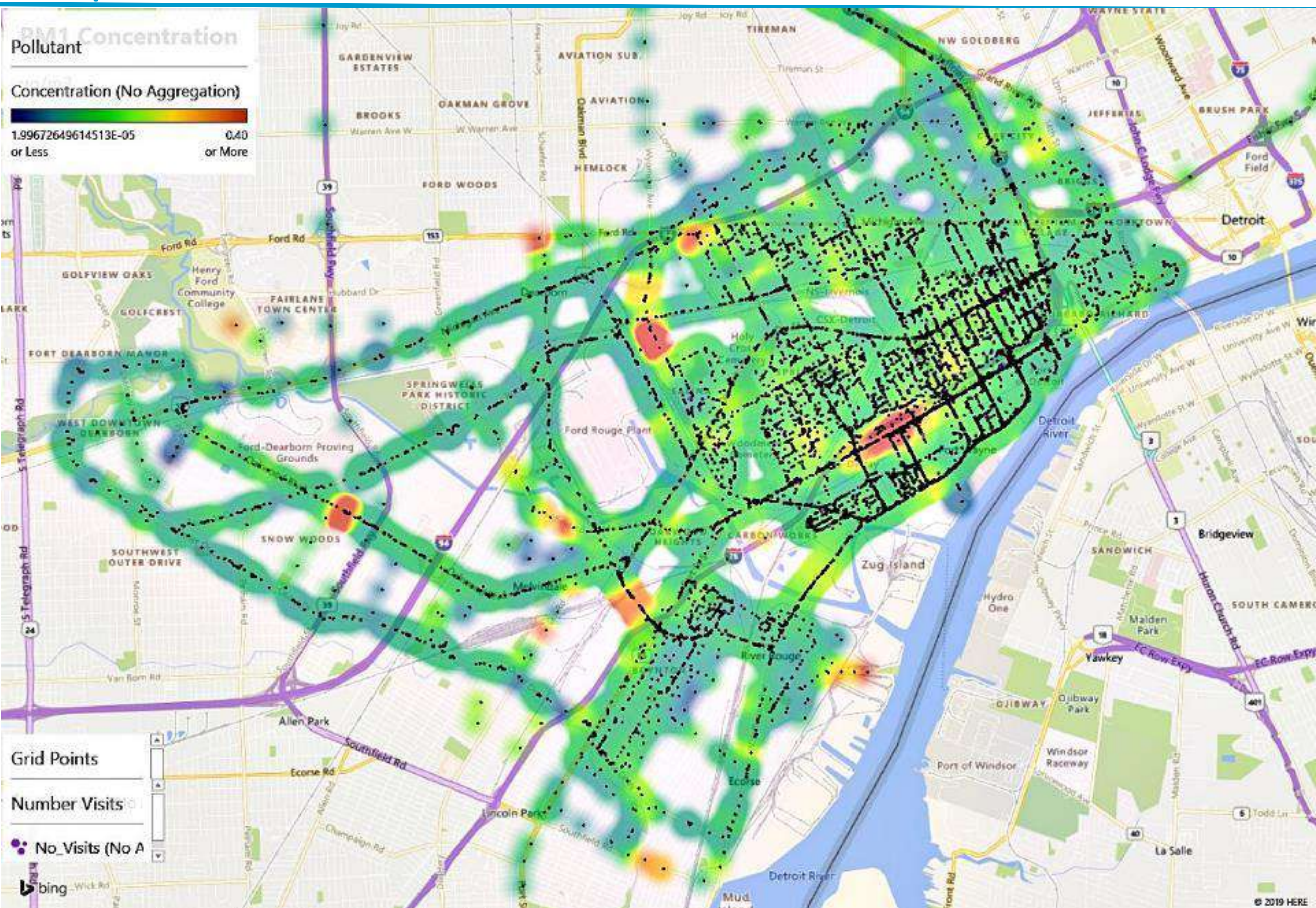
CO_2 mapping

Above 400 ppm, 20062 minutes (April – Nov, 2019)



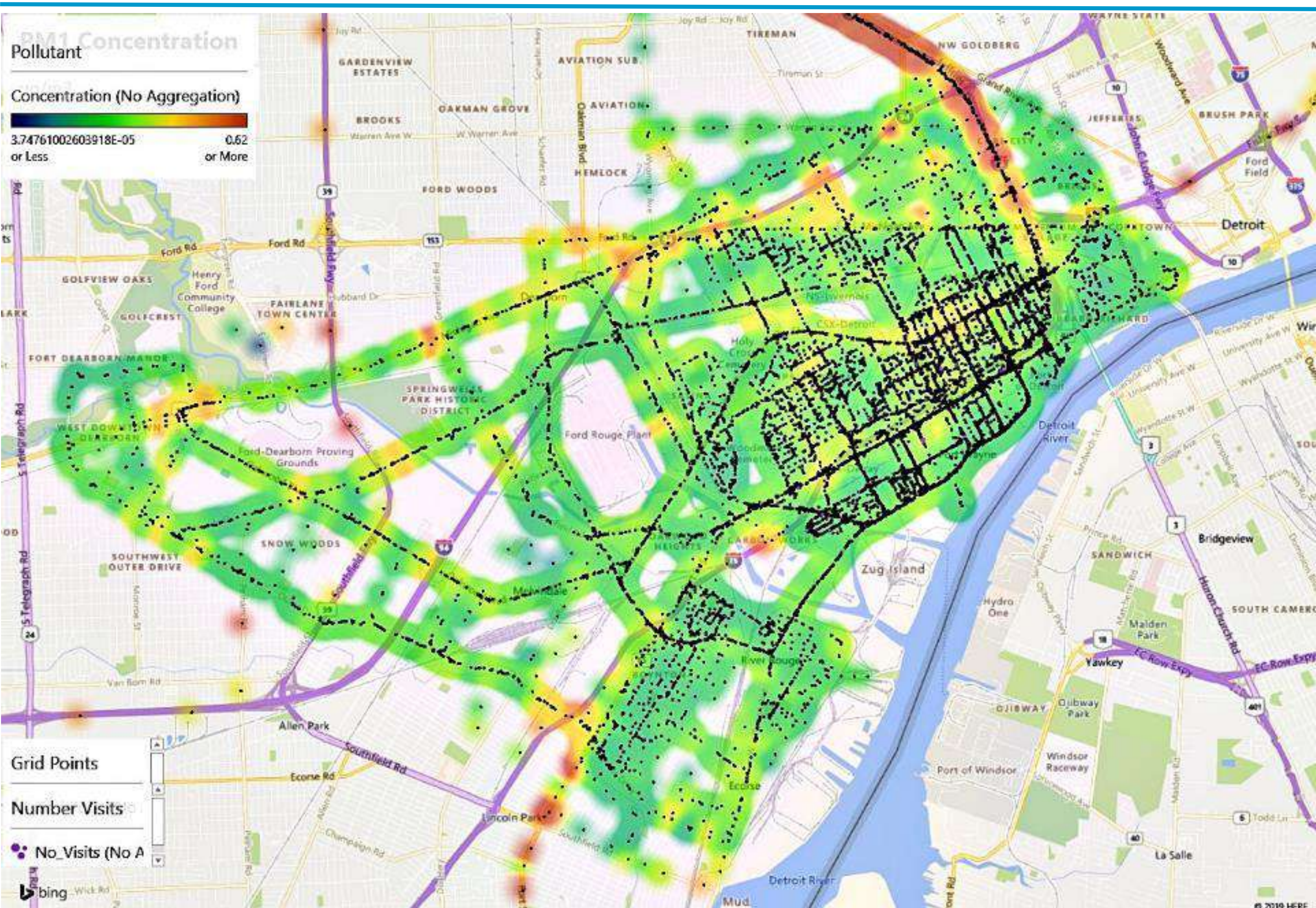
CH_4 mapping

Above 1.9 ppm, 20062 minutes (April – Nov, 2019)



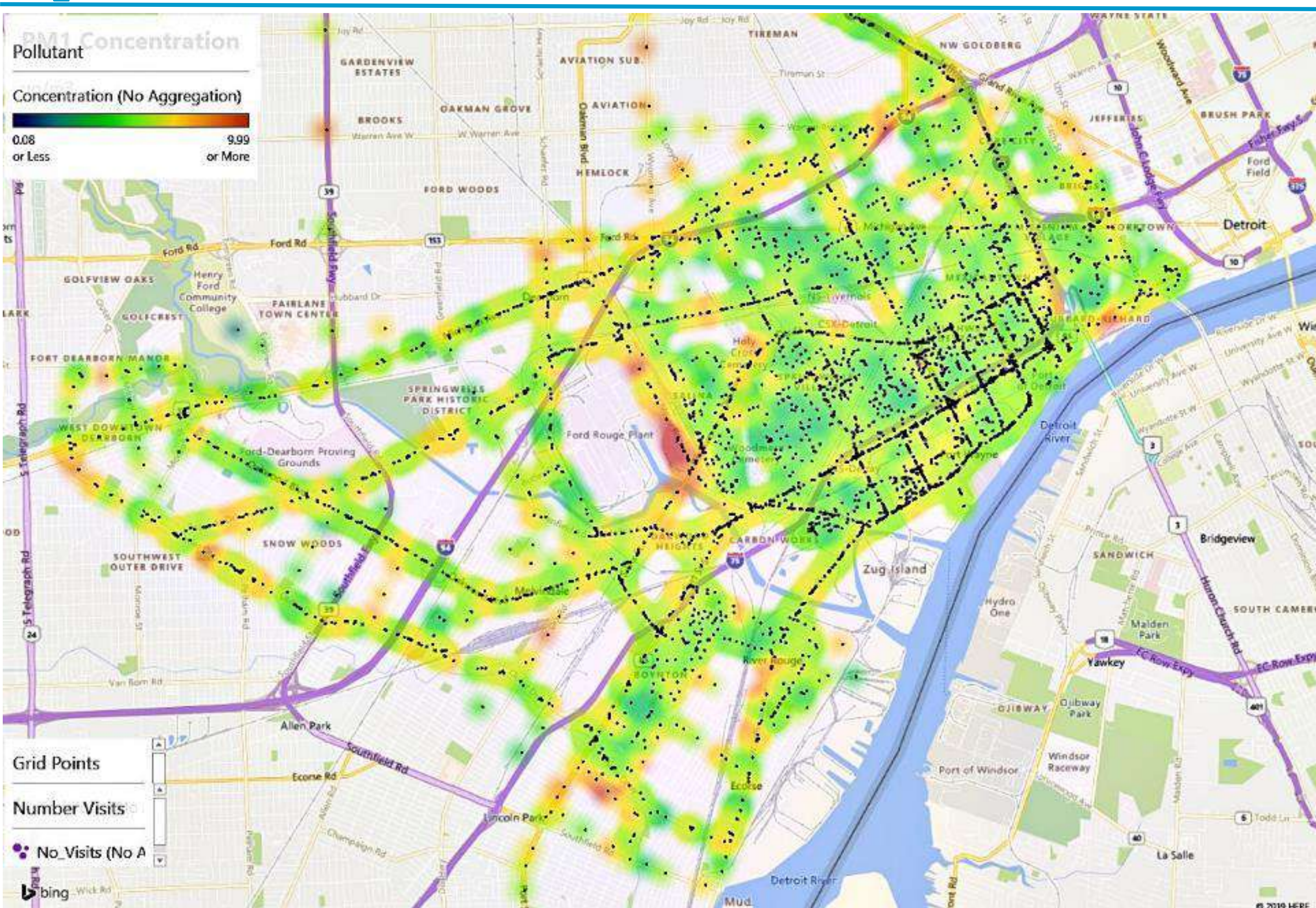
CO mapping

20062 minutes (April – Nov, 2019)



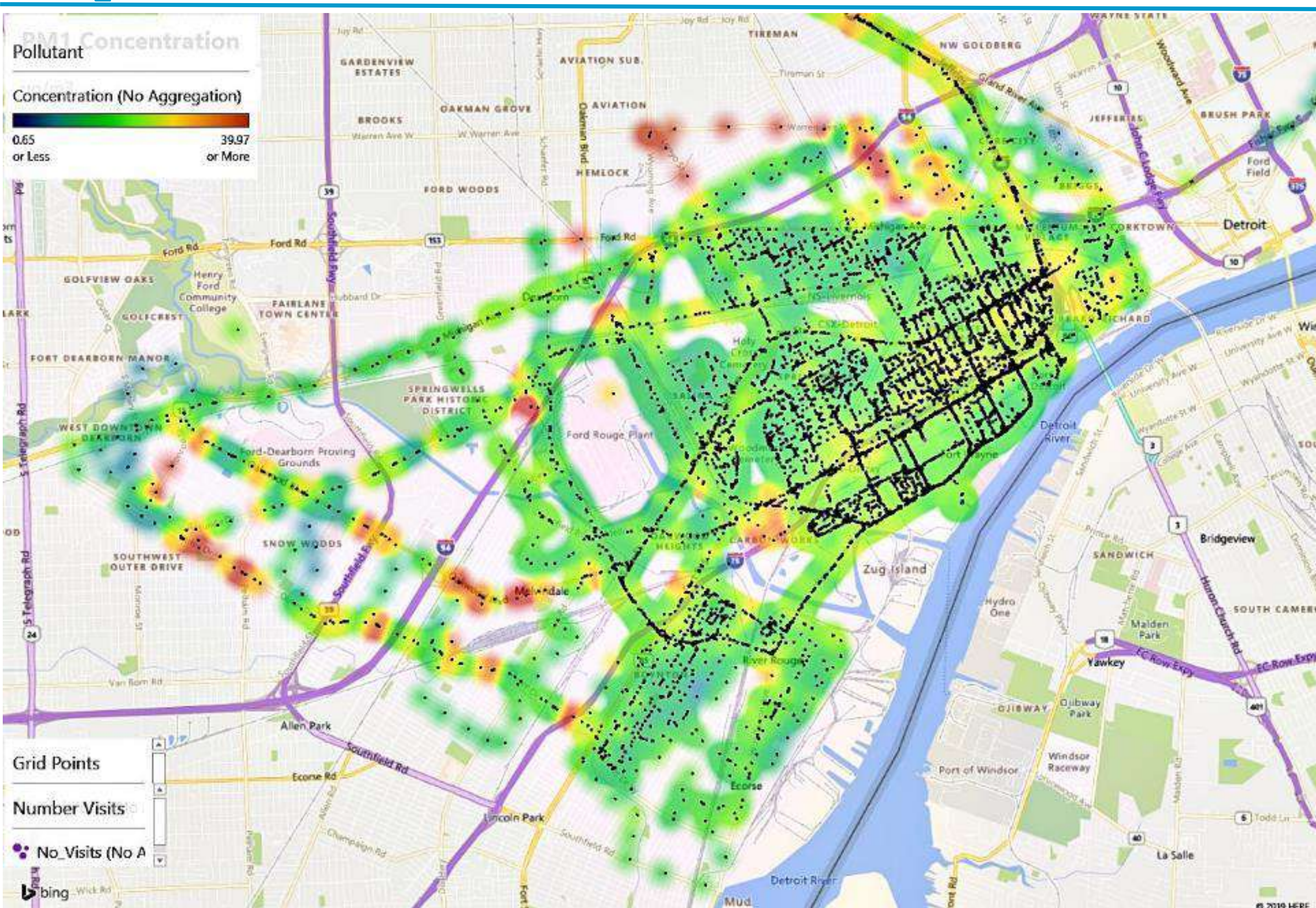
H_2S mapping

20062 minutes (April – Nov., 2019)



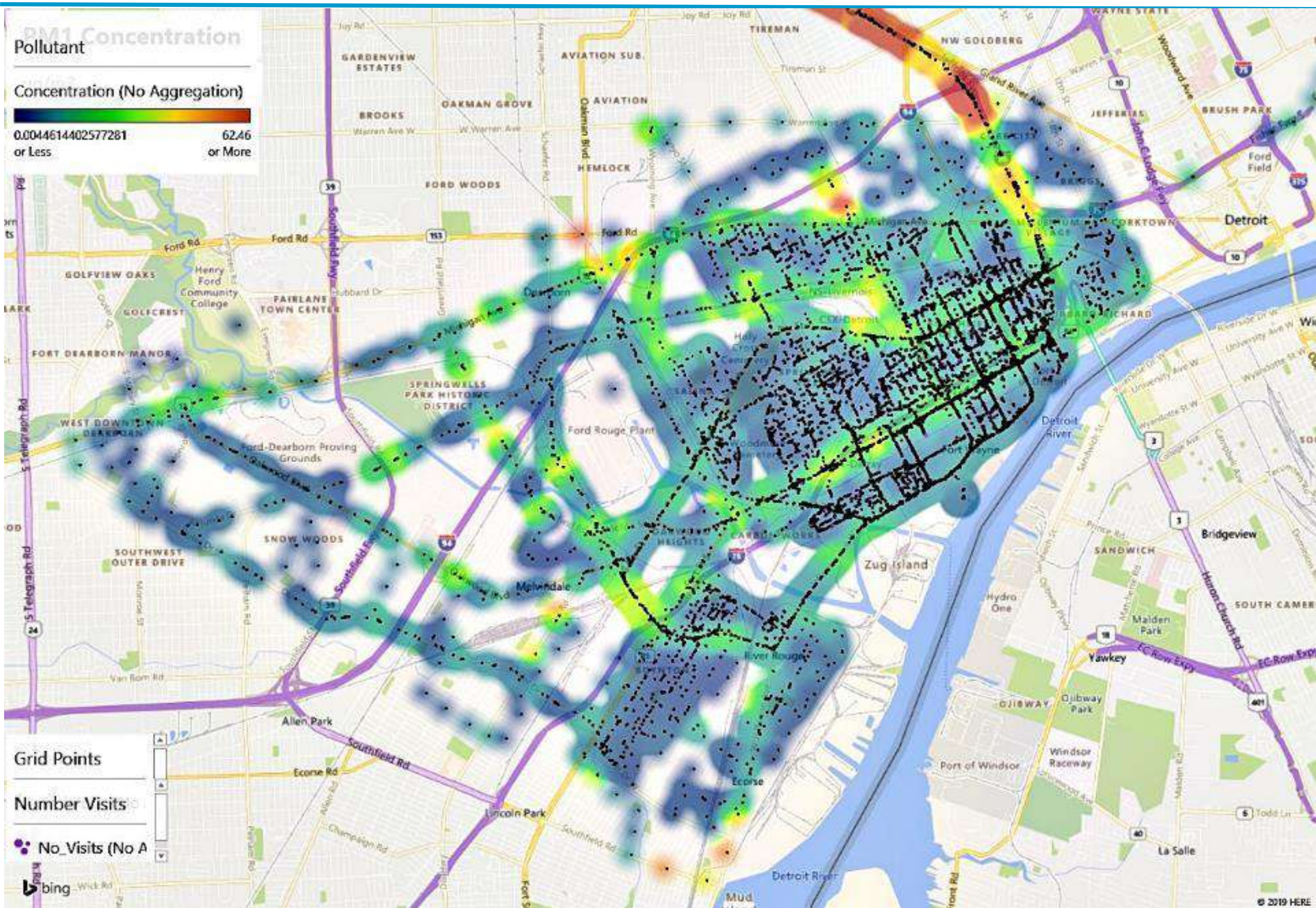
NO_2 mapping

20000 minutes (April – Nov., 2019)



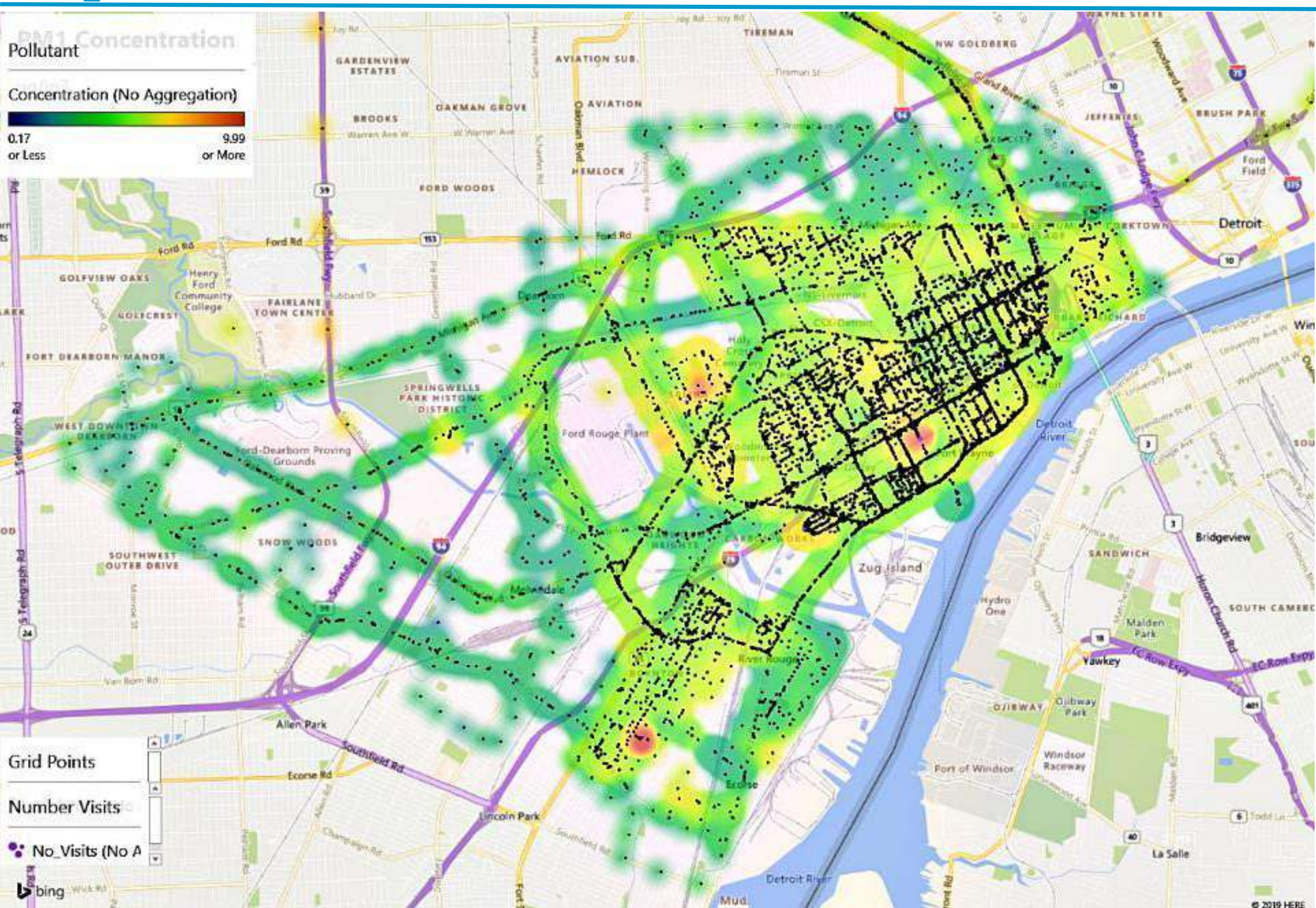
NO mapping

20062 minutes (April – Nov, 2019)



SO_2 mapping

20062 minutes (April – Nov, 2019)



Advantages of mobile monitoring

- **Multiple pollutants (GHG and toxics)** are simultaneously measured.
- Pollutant maps based on repeated measurements can reflect **long-term concentration patterns with high spatial resolution**
- Maps differ by pollutant, and can **show specific source areas** and can detect "unknown" sources
- Can show **hot spots, trends over time, exposures at sites** of interest
- High quality instrumentation shows small changes without drawbacks of low cost sensors, e.g., selectivity, sensitivity, precision.
- **Evaluate/verify mitigation policies and actions**, applicable to traffic, industry, commerce, fires, dusts, etc.
- **Make information accessible to communities**
- **Great outreach/public relations tool**

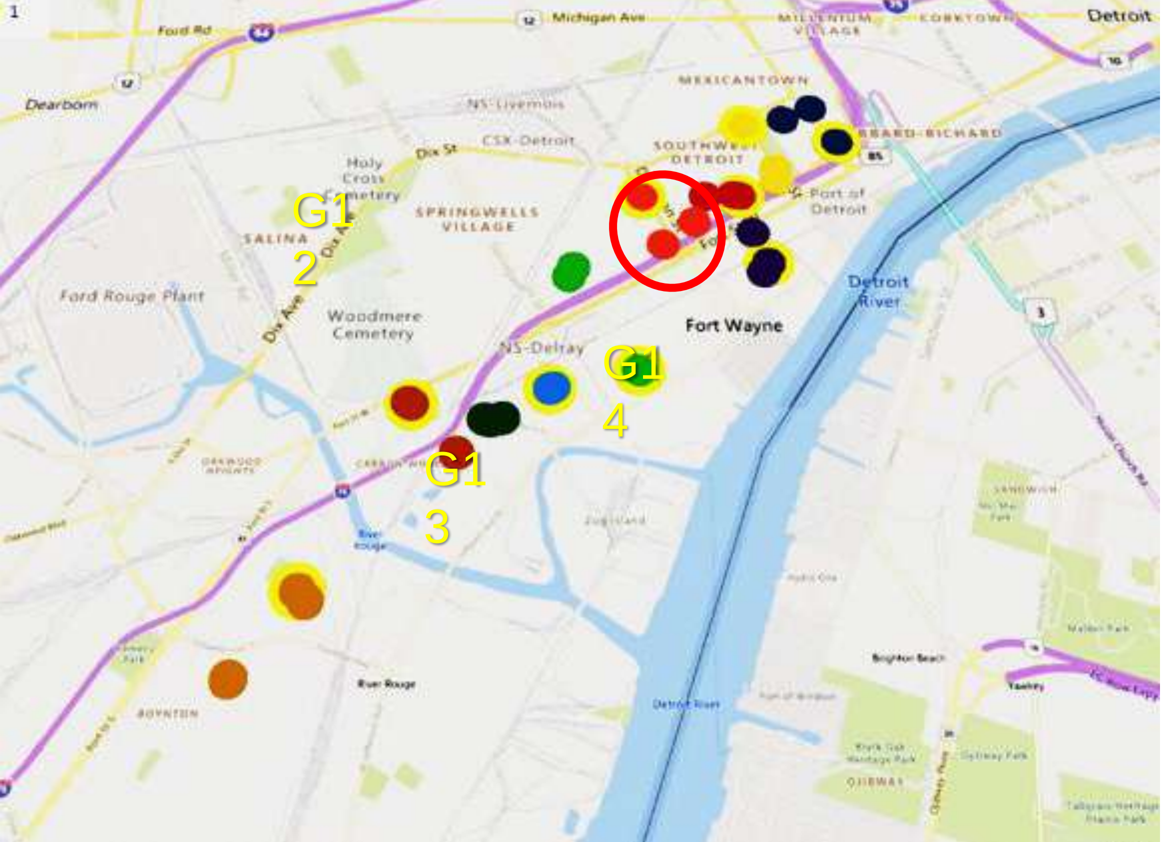
Indoor Sampling

Investigate baseline & project effects

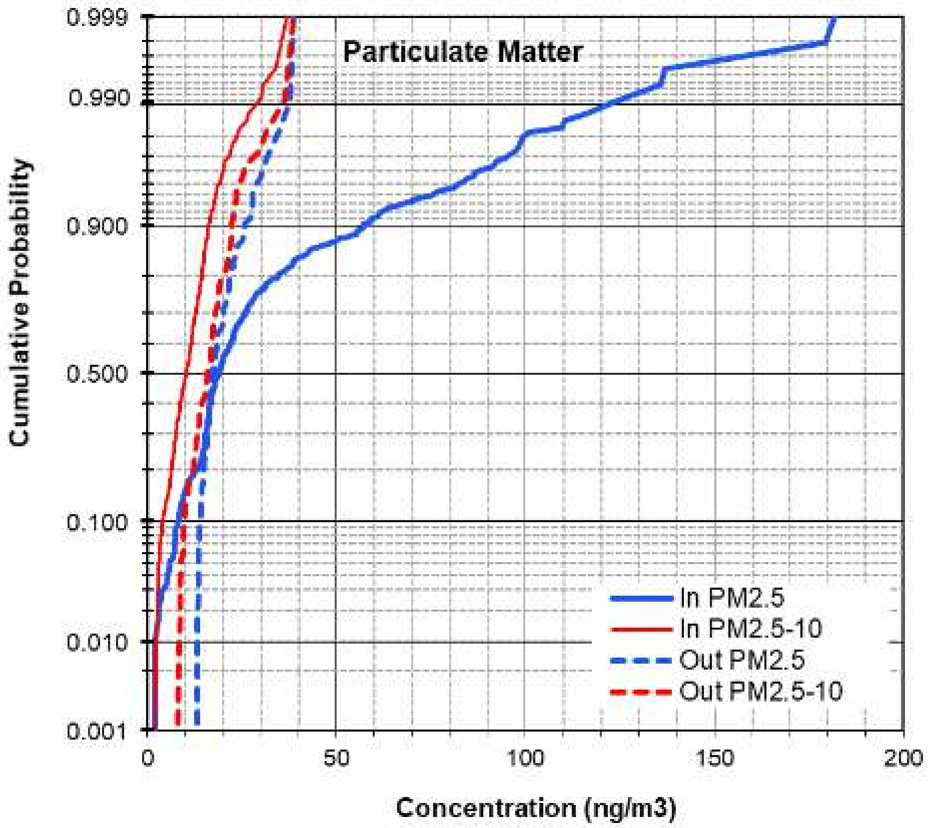
Assess pollutant penetration (I/O ratios; informs HIA)

Assess mitigation effectiveness

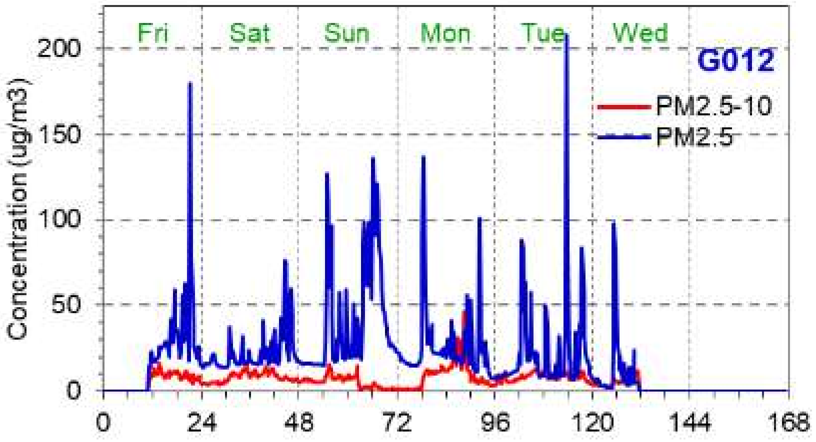
- Recruit ~30 households within about 500 m of I75
- Sample quarterly indoors and outdoors
- Sample in clusters of homes, some near, some far from I75



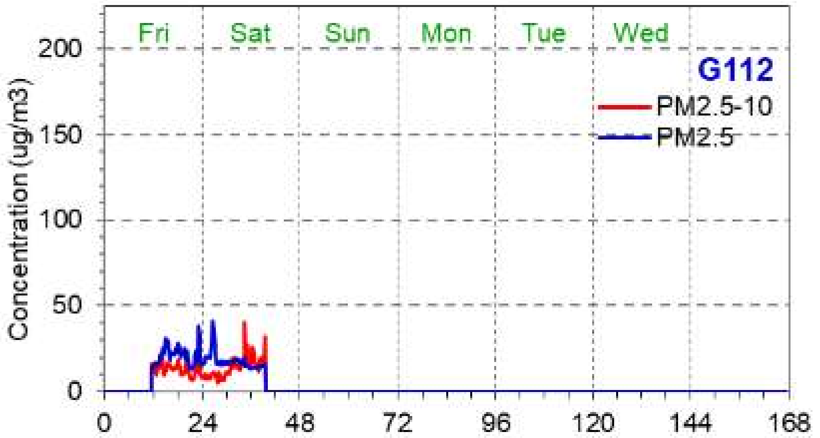
Indoor & Outdoor PM



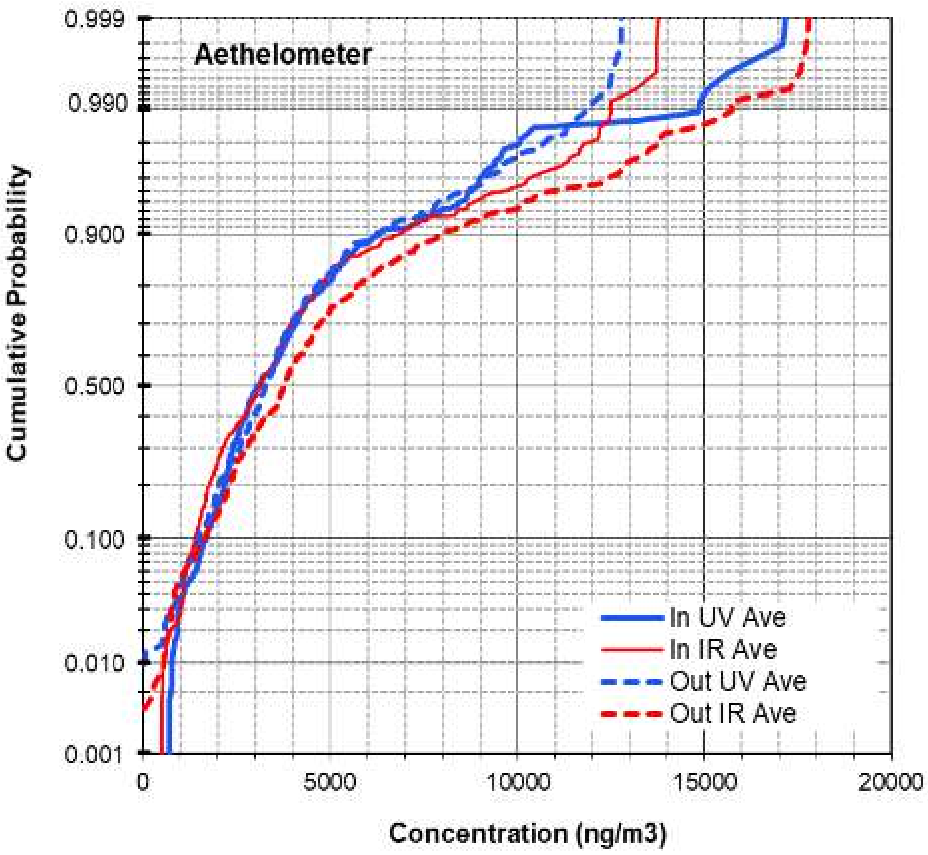
Indoor



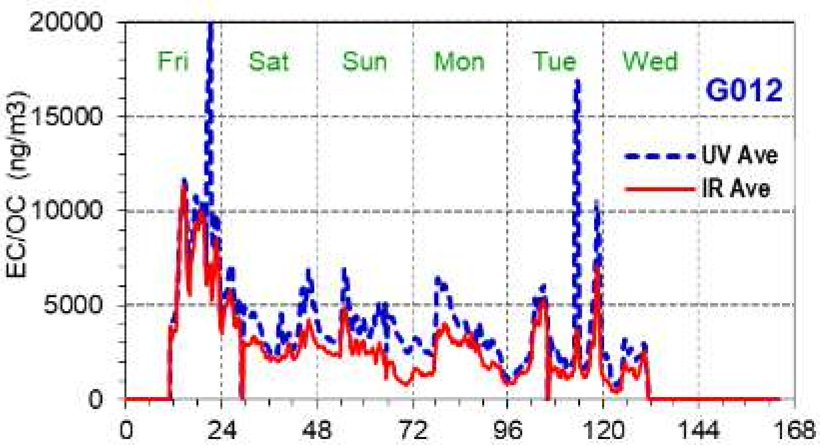
Outdoor



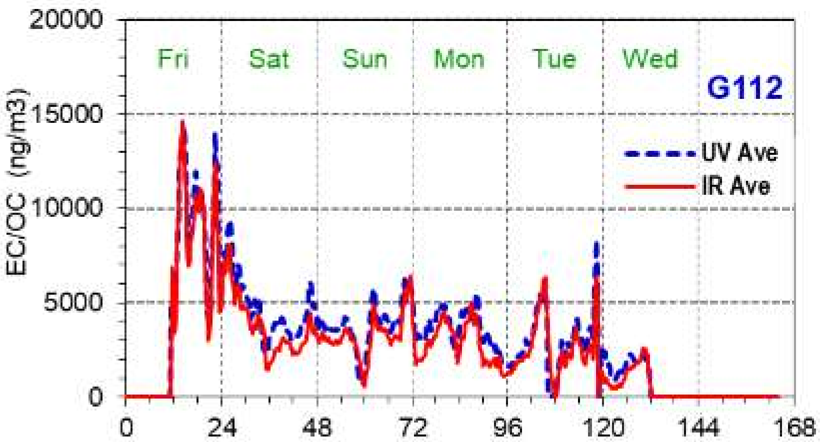
Indoor & Outdoor Black Carbon



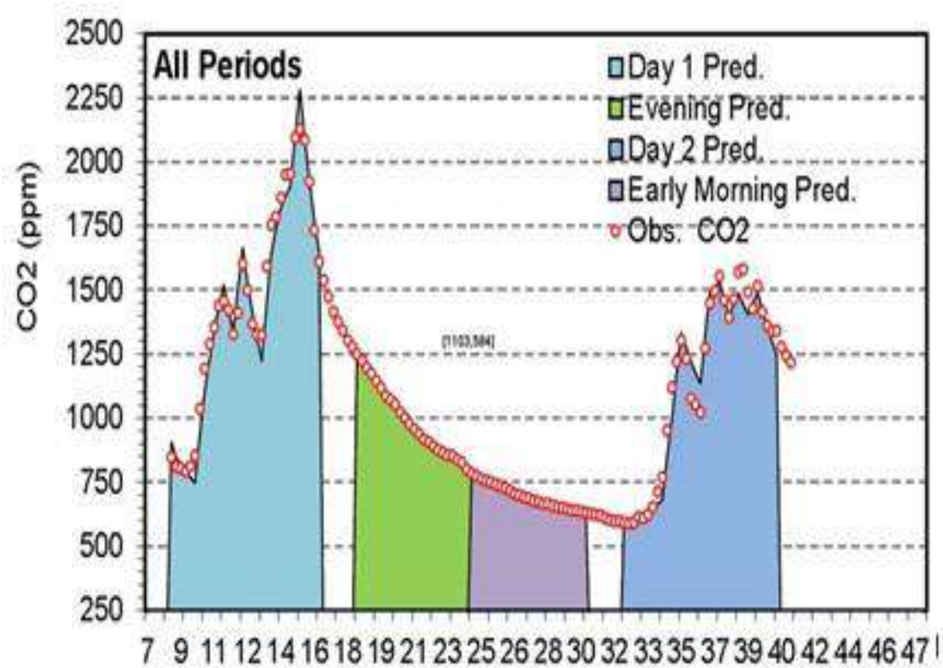
Indoor



Outdoor



CO_2: derived air change rates



Observed and simulated CO_2 concentration trends over 36-h periods in a school classroom. ACRs obtained using transient mass balance approach.

Red circles show observed (15-min) levels. Colored areas show predicted CO_2 levels using simulated air change rate estimates fitted for the school day (blue), evening (green), and early morning (yellow) periods. Time axis shows hour of day (starting at 07:00). Uses 1-min CO_2 and 15-min occupancy data

Environmental Quality, Health and Learning in Conventional and High Performance School Buildings

EQUALS

CONVENTIONAL	ENERGYSTAR	LEED	OTHER
10	15	9	3

A few key points about monitoring

Concentrations of traffic-related air pollutants (TRAP) and diesel exhaust pollutants represent from about 15 to 30% of total $PM_{2.5}$

- TRAP share due to mobile sources is stable or increasing.
- Near-road monitoring is limited
- PM2.5 has high background level (not specific to TRAP)

Compliance with the National Ambient Air Quality Standards is based on fixed site monitoring using EPA methods

- Based on a very limited number of sites, which may not reflect fine-scale spatial gradients of concentrations and true exposure of the population.

For exposure & health assessments, need spatially-resolved information

- Concentrations of TRAP vary at fine scales
- Vulnerability of subpopulations also varies spatially
- Health effects occur over a continuum of dose, and no single threshold (like the NAAQS concentration) is necessarily protective when no threshold for exposure (i.e., levels below which health effects do not occur) has been identified.

Thanks! Questions?