Hybrid Air Quality Modeling Approach for use in the Near-road Exposures to Urban air pollutant Study (NEXUS)

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16th International Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes
8 – 11 September 2014
Varna, Bulgaria

Background

- Epidemiologic studies are critical in establishing the association between exposure to air pollutants and adverse health effects

- Results of epidemiologic studies are used by U.S. EPA in developing air quality standards to protect the public from the health effects of air pollutants

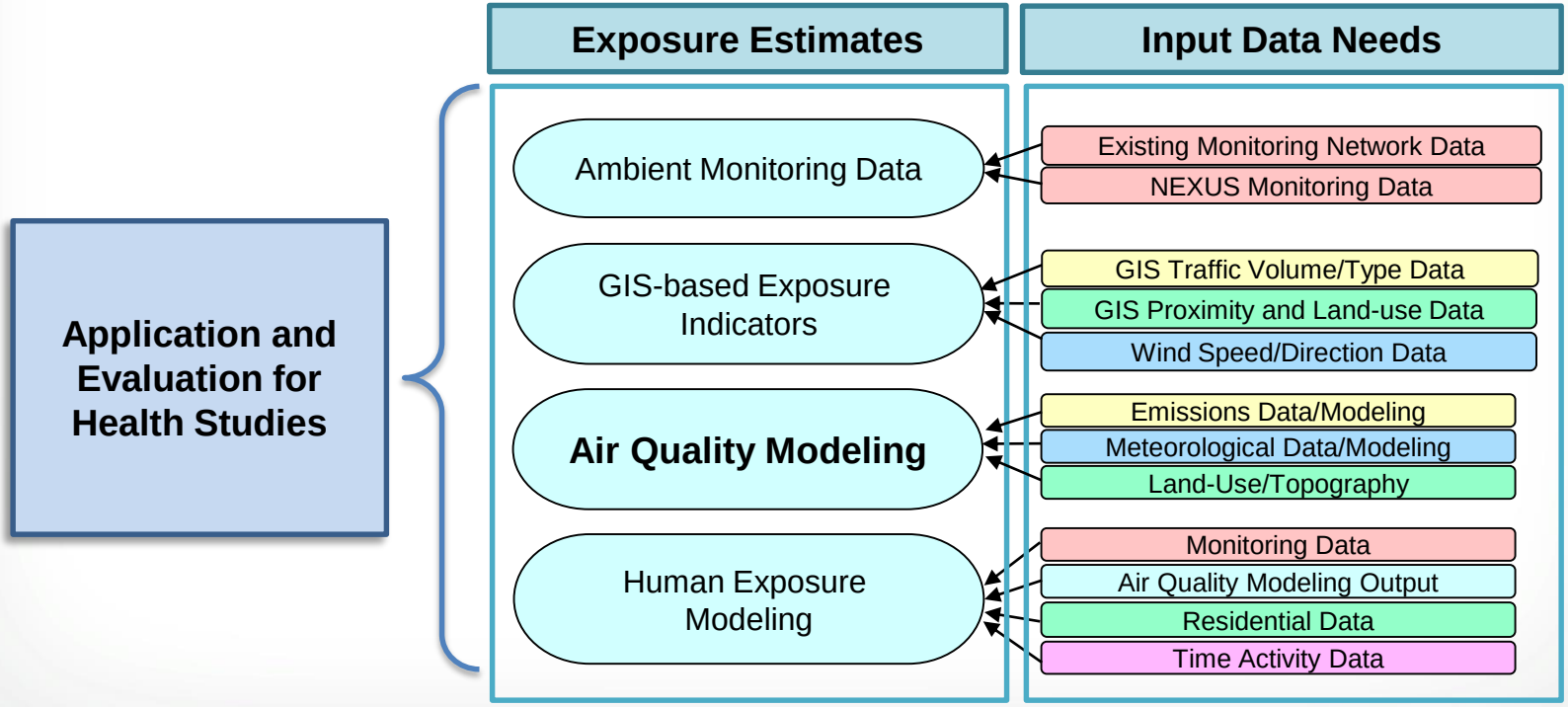
- A major challenge in environmental epidemiology is the adequate exposure characterization

Characterizing Exposures

- Measurements from central-site ambient monitors are typically used to characterize air pollution exposures
- Relying solely on central-site monitors does not account for spatial heterogeneity, temporal variability, or influence of infiltration and indoor sources.
- Statistical interpolation techniques and GIS models can provide additional spatial resolution in ambient concentration estimates.
- Models (e.g. CMAQ) estimate ambient concentrations by combining information on meteorology, source emissions, and chemical fate and transport.
- **Hybrid modeling approaches**, which integrate regional scale models with local scale dispersion models, provide new alternatives for characterizing ambient concentrations

Tiers of exposure estimates

Providing more detailed characterization of exposures for use in epidemiologic analyses is expected to help establishing association between air pollution and health outcomes



Near-road EXposures and effects from Urban air pollutants Study (NEXUS)

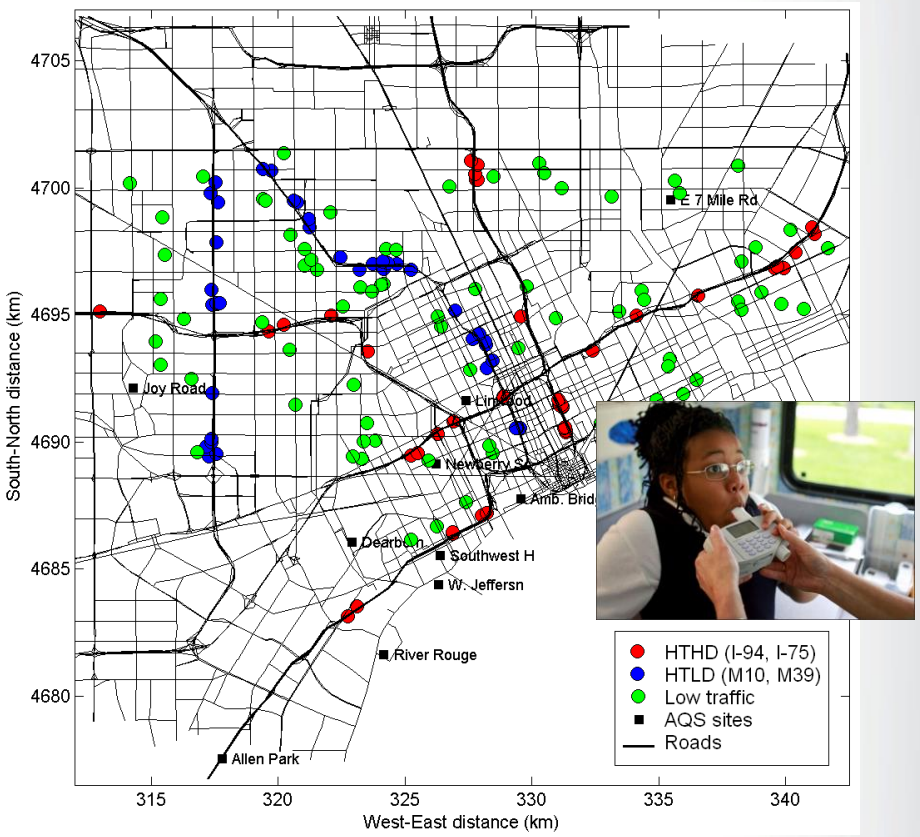
NEXUS Study

The NEXUS study is investigating whether children with asthma living near major roadways in Detroit, MI have greater health impacts associated with air pollutants than those living farther away, particularly near roadways with high diesel traffic

Study Design

Each sample location assigned an exposure class defined by proximity to roadways

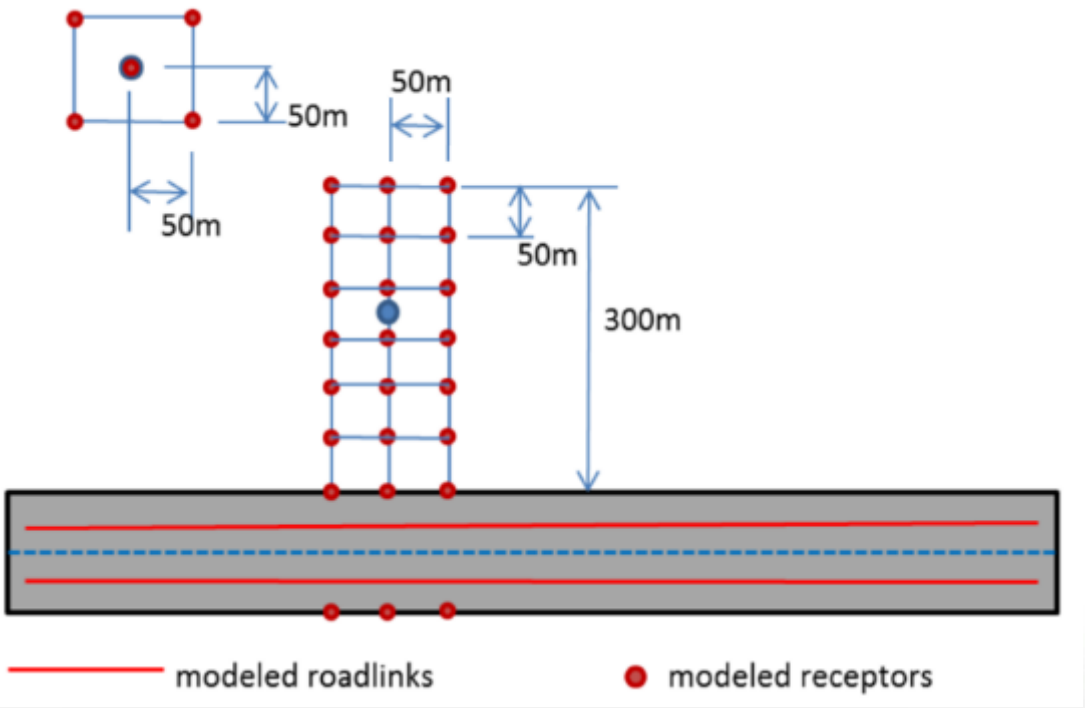
Exposure class	Distance to road (m)	Vehicles / day (annual average)
High-traffic, high-diesel (HD)	< 150	> 90000 total > 6000 commercial
High-traffic, low-diesel (LD)	< 150	> 90000 total < 4500 commercial
Low traffic (LT)	> 300	> 25000 total



- **Hybrid modeling** to estimate spatially & temporally varying exposures
- **Limited measurements** for evaluating and refining models

Near Road Gradients

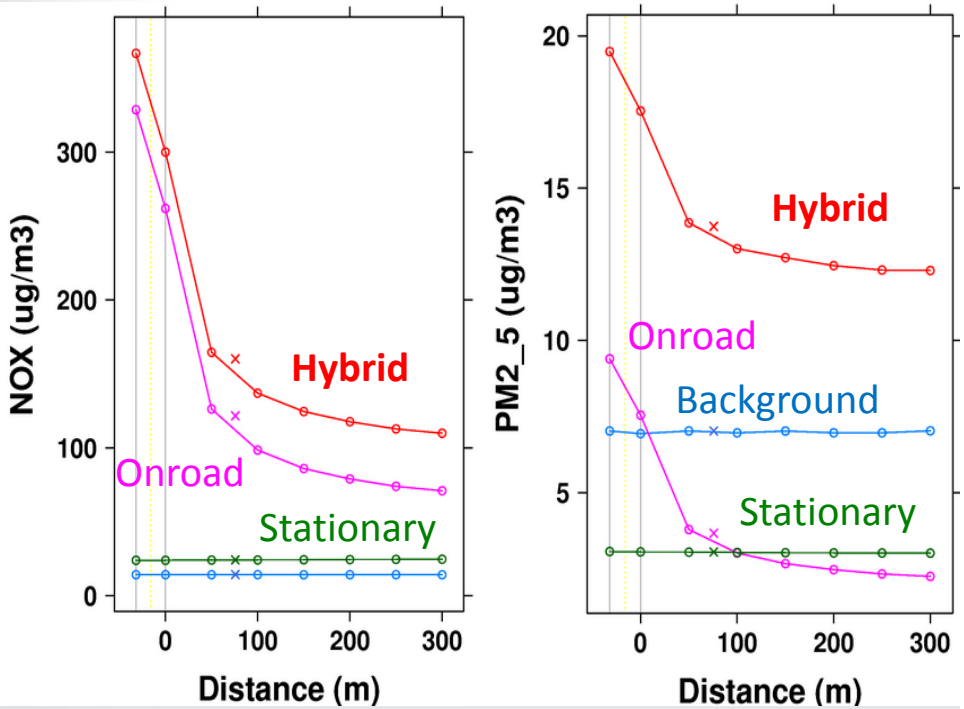
To evaluate differences in near-road pollutant gradients between the three traffic exposure groups (LD, HD and LT), receptor grids were refined within each NEXUS sub-area (including the participants homes and schools)



Key Elements in Air Quality Modeling

MOBILE SOURCES: RLINE model is used in conjunction with traffic activity and primary mobile source emission estimates to model hourly exposures at study participants' home and school locations.

STATIONARY SOURCES: Industrial sources such as stacks from manufacturing facilities are modeled using AERMOD using emissions from NEI 2008 and temporal profiles from SMOKE.



BACKGROUND: A space/time ordinary kriging (STOK) method combines AQS measurements and results from two CMAQ simulations: 1) using all emissions in a broad region and 2) all anthropogenic emissions in the Detroit study domain removed. The ratios of concentrations from two CMAQ simulations along with AQS data from background sites in the region, were used to estimate background concentrations.

Model Results

- Hybrid modeling provided hourly pollutant concentrations for Traffic-related air pollutants (primary $PM_{2.5}$, EC, NO_x, CO, benzene)

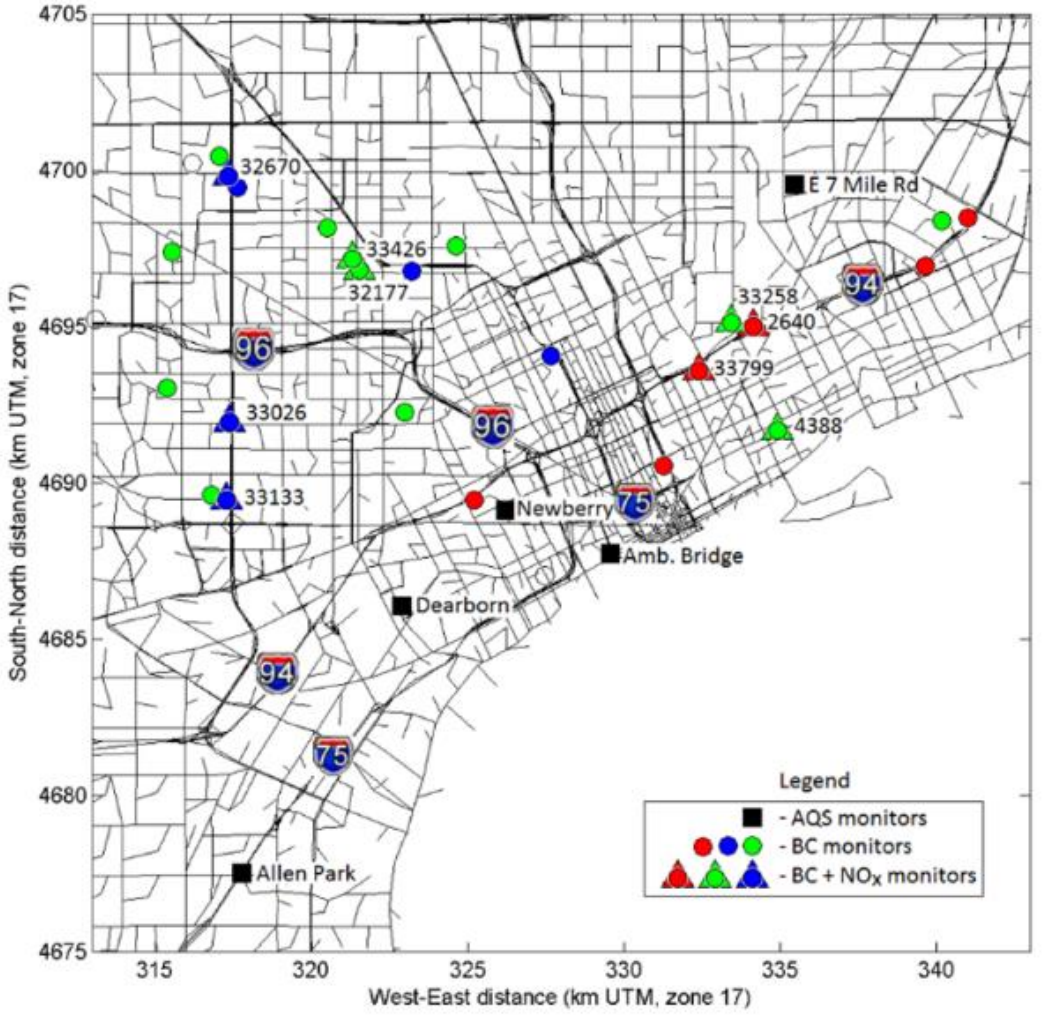
- Hourly concentrations were processed to calculate daily and annual average exposure metrics for each study participants' home and school locations

- Models provide pollutant surfaces capturing spatial and temporal variability across health study domain (Fall 2010 – Spring 2012)

Model Evaluation

Model results were compared to ambient monitoring data in Detroit:

- from routine AQS observational network
- from intensive monitoring campaign, part of the NEXUS study

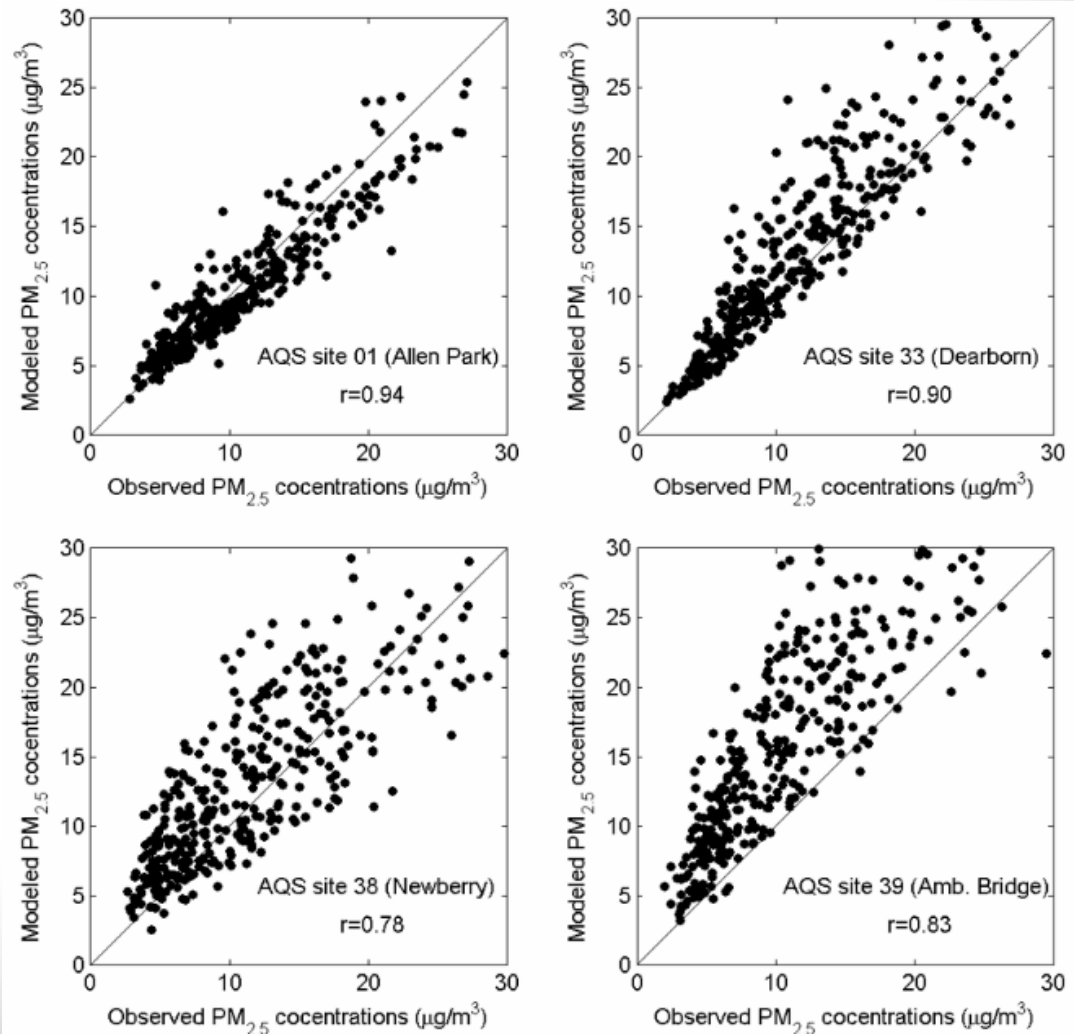


Locations of $PM_{2.5}$ and BC (●), NO_x (▲) monitors at NEXUS sites, and AQS sites (■)

Model Evaluation

Comparison between modeled daily average $PM_{2.5}$ concentrations for one-year period of 2010 at observed $PM_{2.5}$ concentrations at all four AQS sites

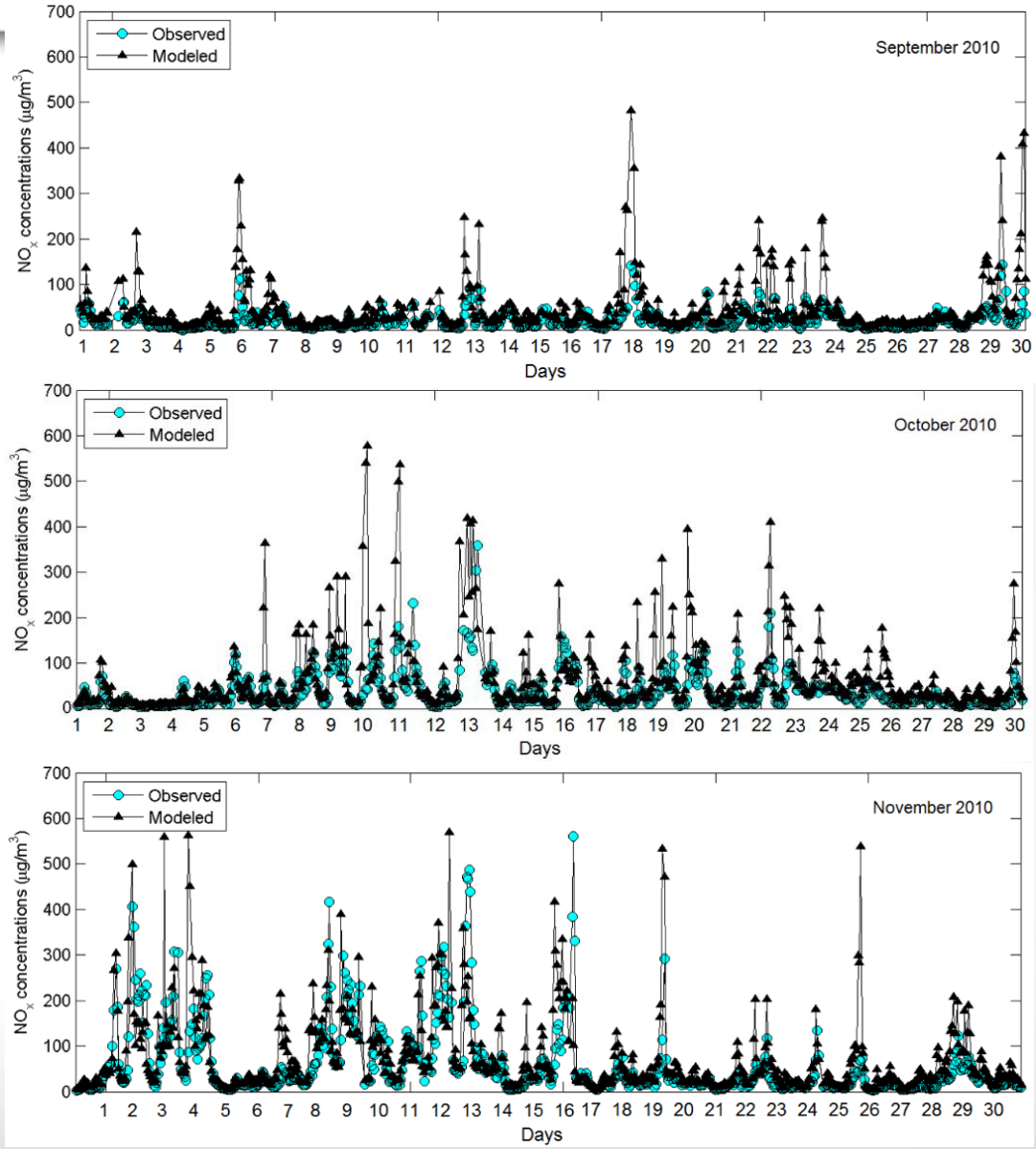
- Model results correlate well with observed data
- The Allen Park site near I-75 has best comparison
- There is more scatter at the "Newberry" and "Ambassador Bridge" sites, likely due to uncertainties in spatial allocation of emissions near these locations (modeled as 1km x 1km area sources)
- In contrast, the "Dearborn" site is impacted by industrial sources modeled as stacks with their known locations



Time series of hourly NOx concentrations at AQS site 26-163-0019 (E. 7 Mile Road)

Modeled concentrations generally follow the time series of observed data, however there are some over-predictions at certain hours likely due to uncertainties in emissions from traffic.

The monitoring site is away from major highways, therefore the observed concentrations are influenced by emissions from local roads and regional sources

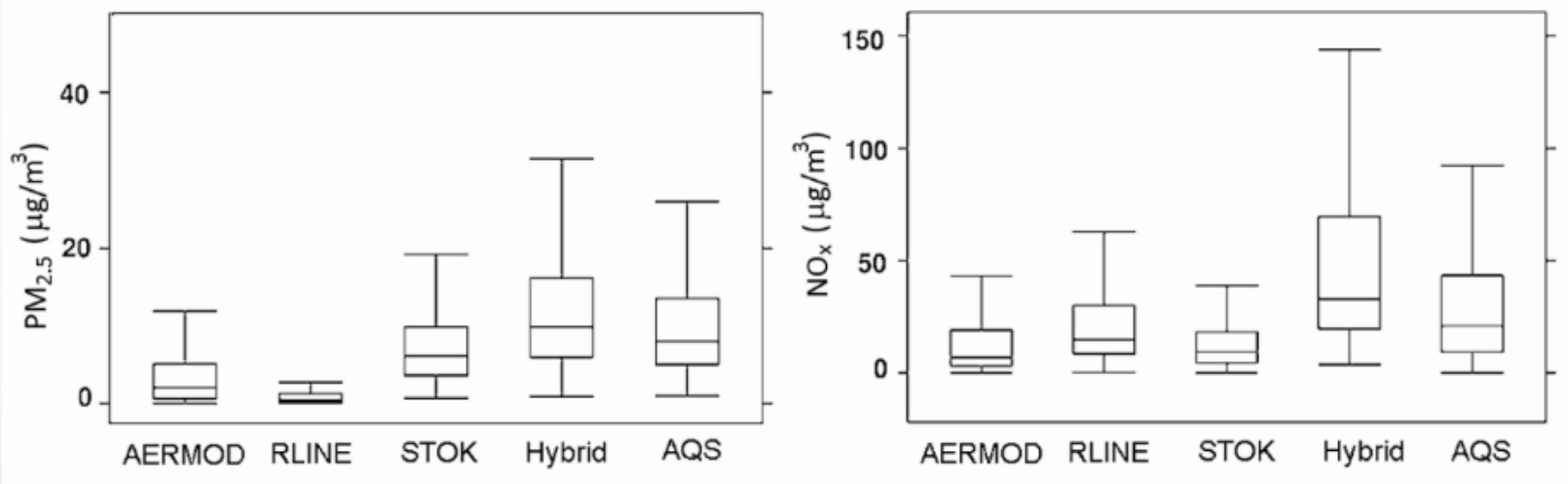


Relative contribution of various source categories

Hybrid modeling provides contributions of various sources:

- stationary sources (i.e. AERMOD)
- roadways (i.e. RLINE)
- urban background (i.e. STOK)
- and total (Hybrid)

Distributions of modeled and observed $PM_{2.5}$ and NO_x concentrations for 2010 at the AQS monitoring sites. (all four $PM_{2.5}$ averaged, and one NO_x site)



Relative contribution of roadways is very small for $PM_{2.5}$ but quite high for NO_x, whereas urban background is more significant for $PM_{2.5}$ than for NO_x.

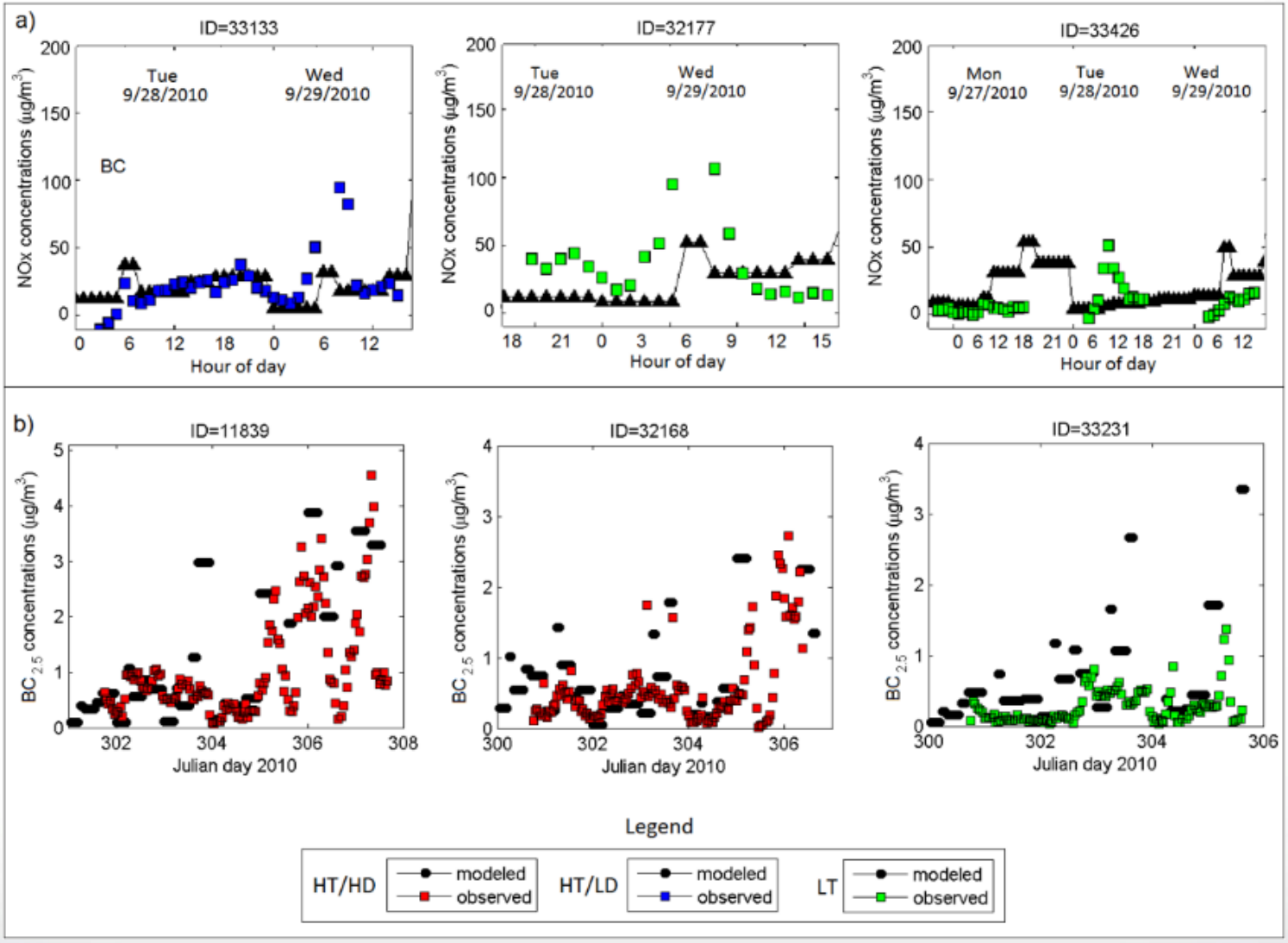
Model Evaluation

In addition to observational data from the routine monitoring network, we also used monitoring data from the 2010 intensive monitoring campaign of the NEXUS study:

- ✓ Black carbon (BC) measurements at 25 NEXUS homes
- ✓ NO_x at 9 NEXUS homes

- Model generally captures the time series of observed NO_x and BC concentrations.
- However, at some sites and for some specific hours, the model under- or over-predicts concentrations at some locations due to uncertainty in hourly traffic activity at the road link level.
- Nevertheless, except for some events, the model can capture the magnitude and time patterns of near road pollutant concentrations, critical for the exposure and health studies

Model-to-monitor comparison at NEXUS monitoring sites



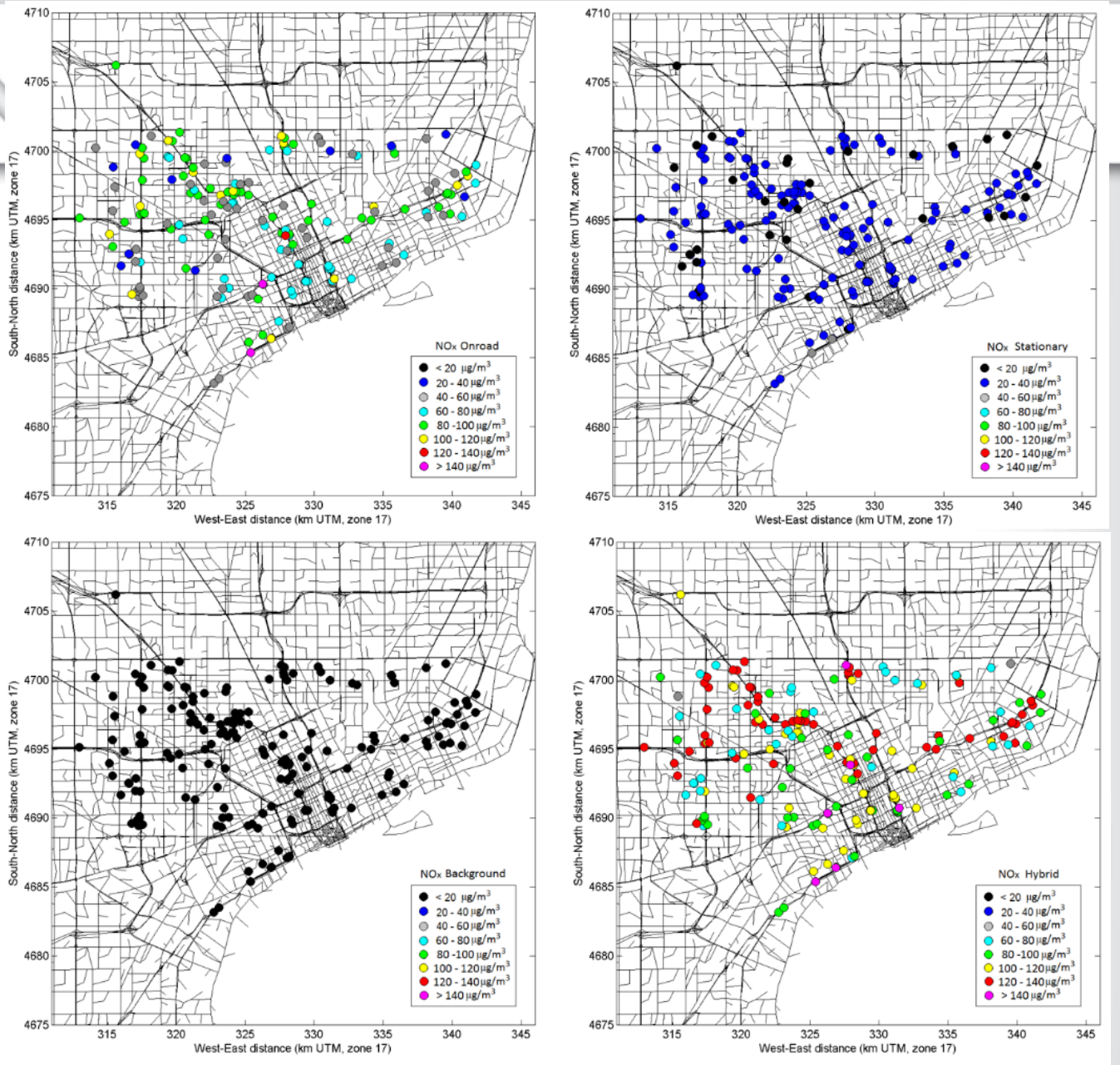
Model Results: Exposure Metrics

- The model-based exposure metrics for CO, NO_x, $PM_{2.5}$ and its components (EC and OC), were calculated from hourly predictions and were able to capture the spatial and temporal variability across the health study domain

- The hybrid modeling approach also allowed estimating relative contributions of roadways versus stationary sources and urban background

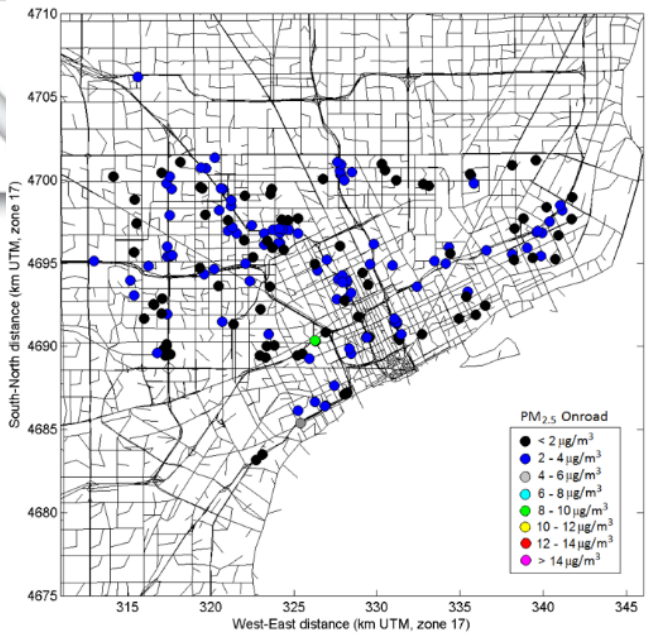
Modeled daily NO_x concentrations averaged during Sep-Oct 2010

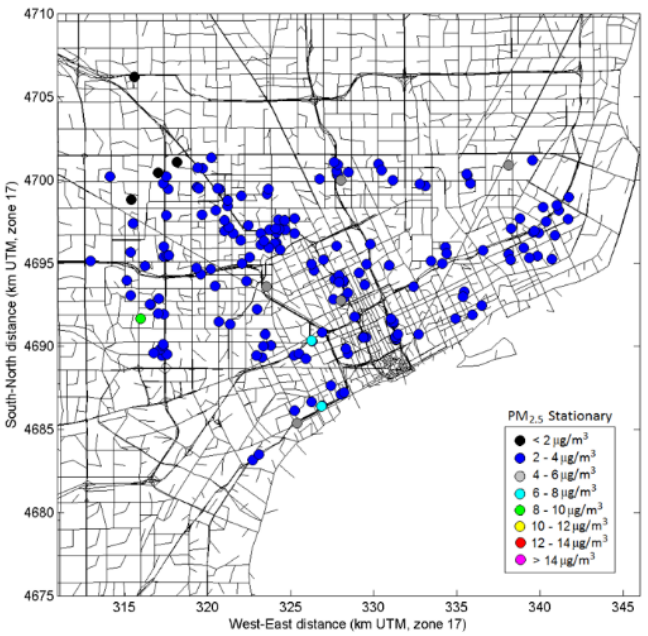
Contributions from
- mobile sources (top left)
- stationary sources (top right)
- urban background (bottom left)
- total (bottom right)

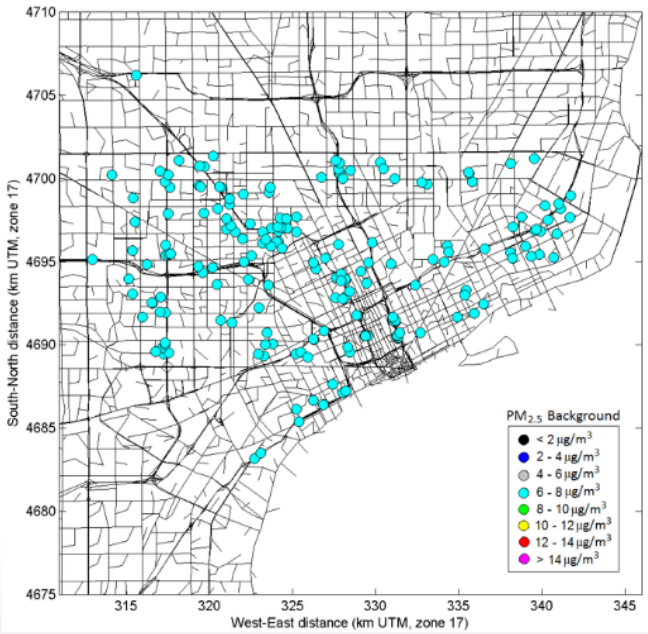


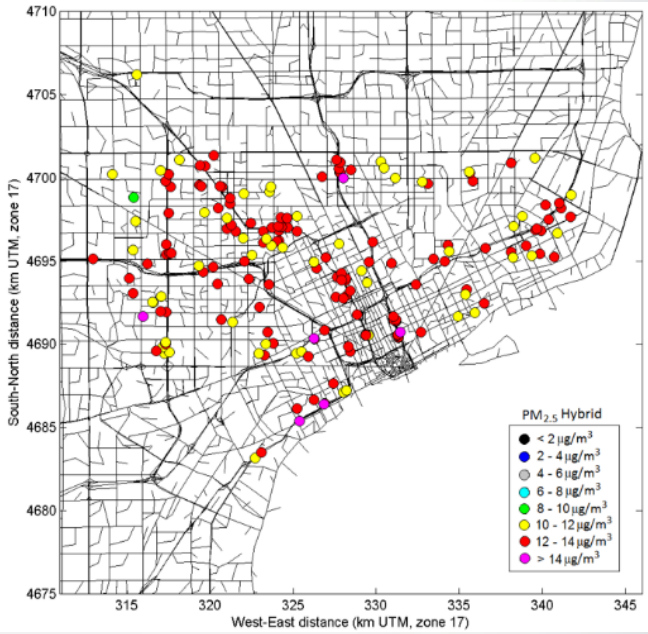
Modeled daily $PM_{2.5}$ concentrations averaged during Sep-Oct 2010

Contributions from
- mobile sources (top left)
- stationary sources (top right)
- urban background (bottom left)
- total (bottom right)









Model Results: Exposure Metrics

- For both NO_x and $PM_{2.5}$, the urban background was nearly uniform across the domain, while mobile source contributions varied across the domain – with higher concentrations next to major roadways and lower concentrations away from roads.

- The overall mobile source contribution, however, was not the same for NO_x and $PM_{2.5}$.

- For NO_x, urban background contributes less than half of total concentrations, whereas for $PM_{2.5}$, the urban background dominated and the local impact of mobile sources was less than 30%.

- Stationary source contributions for $PM_{2.5}$ were of similar range to mobile sources

Summary

The hybrid modeling approach used in NEXUS provides new information regarding exposure to traffic-related air pollutants that is not captured by simpler exposure metrics (such as traffic intensity and distance to roads) commonly used in environmental epidemiology studies of traffic-related air pollution

- ✓ Using a novel mini-grid approach, the modeling was able to resolve near-road air pollutant gradients
- ✓ The hybrid modeling approach also provided an opportunity to compare relative contributions of various sources: stationary sources, roadways, urban background, and total
- ✓ While near-road gradients of roadway emissions within 300 meters were strong for all pollutants, their relative contributions to the total concentration varied by pollutant.

Disclaimer: Although this work was reviewed by EPA and approved for publication, it may not necessarily reflect official Agency policy.