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

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• 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.

Exposure Estimates
- Ambient Monitoring Data
- GIS-based Exposure Indicators
- Air Quality Modeling
- Human Exposure Modeling

Input Data Needs
- Existing Monitoring Network Data
- NEXUS Monitoring Data
- GIS Traffic Volume/Type Data
- GIS Proximity and Land-use Data
- Wind Speed/Direction Data
- Emissions Data/Modeling
- Meteorological Data/Modeling
- Land-Use/Topography
- Monitoring Data
- Air Quality Modeling Output
- Residential Data
- Time Activity Data

Application and Evaluation for Health Studies
Near-road EXposures and effects from Urban air pollutants Study (NEXUS)
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.
Each sample location assigned an exposure class defined by proximity to roadways

<table>
<thead>
<tr>
<th>Exposure class</th>
<th>Distance to road (m)</th>
<th>Vehicles / day (annual average)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High-traffic, high-diesel (HD)</td>
<td>&lt; 150</td>
<td>&gt; 90000 total &gt; 6000 commercial</td>
</tr>
<tr>
<td>High-traffic, low-diesel (LD)</td>
<td>&lt; 150</td>
<td>&gt; 90000 total &lt; 4500 commercial</td>
</tr>
<tr>
<td>Low traffic (LT)</td>
<td>&gt; 300</td>
<td>&gt; 25000 total</td>
</tr>
</tbody>
</table>

- **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).
**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 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
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$_x$. 
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

Legend
- HT/HD: modeled (black), observed (red)
- HT/LD: modeled (blue), observed (green)
- LT: modeled (black), observed (green)
• 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 $\text{NO}_x$ 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)
• 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
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.*