DEVELOPMENT OF MODEL-BASED AIR POLLUTION EXPOSURE METRICS FOR USE IN EPIDEMIOLOGIC STUDIES

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Abstract

Population-based epidemiological studies of air pollution have traditionally relied upon imperfect surrogates of personal exposures, such as area-wide ambient air pollution levels based on readily available concentrations from central monitoring sites. U.S. EPA in collaboration with University of Michigan is developing and evaluating several types or tiers of exposure metrics for traffic-related and regional pollutants that differ in their modeling approaches for addressing the spatial and temporal heterogeneity of pollutant concentrations. We hypothesize that using more refined exposure estimates will provide greater power to detect associations with health outcomes, particularly for traffic-related pollutants that can vary considerably over short distances and time scales. The Near-road Exposures to Urban air pollutant Study (NEXUS) design is focused on determining if children in Detroit, MI with asthma living in close proximity to major roadways have greater health impacts associated with air pollutants than those living farther away, particularly for children living near roadways with high diesel traffic. One tier for estimating exposures to traffic-generated pollutants uses local-scale dispersion modeling. Temporally and spatially-resolved pollutant concentrations, associated with local variations of emissions and meteorology, were estimated using a combination of the AERMOD and RLINE dispersion models, local emission source information from the National Emissions Inventory, detailed road network locations and traffic activity, and meteorological data from the Detroit City Airport. Hourly pollutant concentrations for CO, NO_x, $PM_{2.5}$ and its components (EC and OC) were predicted at each study participant location (n=160). The exposure metrics were evaluated in their ability to characterize the spatial and temporal variations of multiple ambient air pollutants across the study area. This research will be used for improving exposure assessments in future air pollution epidemiology studies, and for informing future multipollutant exposure analyses.

Keywords: air pollution, epidemiologic studies, exposure, air quality modeling

1. Introduction

Through the Clean Air Act (CAA), the U.S. Environmental Protection Agency (EPA) develops air quality standards to protect the public from the health effects of criteria air pollutants (ozone, carbon monoxide, oxides of nitrogen, particulate matter, lead and oxides of sulfur) and hazardous air pollutants (HAPs). These Congressional mandates have led to a systematic risk assessment approach that encompasses hazard identification, dose-response assessment, exposure assessment, and risk characterization. As this field of risk assessment has evolved, so has the reliance on epidemiologic studies for identifying hazards to air pollutants, quantifying the relationship between dose, exposure, or concentration and the response, and determining and assessing mitigation strategies. In the absence of personal exposure measurements, epidemiologic studies have traditionally relied upon alternate indicators of exposure, such as area-wide ambient air pollution concentrations from central monitoring sites. For the criteria air pollutants, epidemiologic studies typically use ambient monitoring data collected for regulatory purposes or study-specific monitors for short duration (e.g., 2 week time periods) for selected research studies. These studies assume that concentrations at a single monitor, or average concentrations over a few monitors, are representative of the complex spatial and temporal patterns of air quality within a study area. However, there is increasing evidence that the monitoring network is not capturing the sharp gradients in exposure due to locally high concentrations (e.g., near major roadways, factories, ports). For many of the HAPs, ambient monitoring data are often nonexistent or very sparse. . In order to reduce uncertainty that may be introduced via exposure misclassification and/or prediction error, these epidemiologic studies (especially time-series studies) require an accurate assessment of the complex temporal and spatial variations in ambient concentrations. Improving characterization of air pollution exposures involves novel approaches to estimating ambient concentrations, a better understanding of the personal-ambient relationships, and personal exposure modeling.

2. Air Quality Modeling Approach for Estimating Exposures

U.S. EPA in collaboration with University of Michigan is developing and evaluating several types or tiers of exposure metrics for traffic-related and regional pollutants that differ in their modeling approaches for addressing the spatial and temporal heterogeneity of pollutant concentrations (Vette et. al., 2013). We hypothesize that using more refined exposure estimates will provide greater power to detect associations with health outcomes, particularly for traffic-related pollutants that can vary considerably over short distances and time scales. We use air quality modeling to estimate exposures to traffic-generated pollutants in support of the Near-road Exposures to Urban air pollutant Study (NEXUS) study assessing the impact of near-roadway pollution on children's exposures and resulting respiratory effects. Three traffic exposure groups were identified in order to test for differences between the low diesel (LD), high diesel (HD) and low traffic (LT) areas (Fig. 1). Children in the LD and HD groups live within 150 meters of a major roadway while those in the LT group live greater than 300 meters for a major roadway.

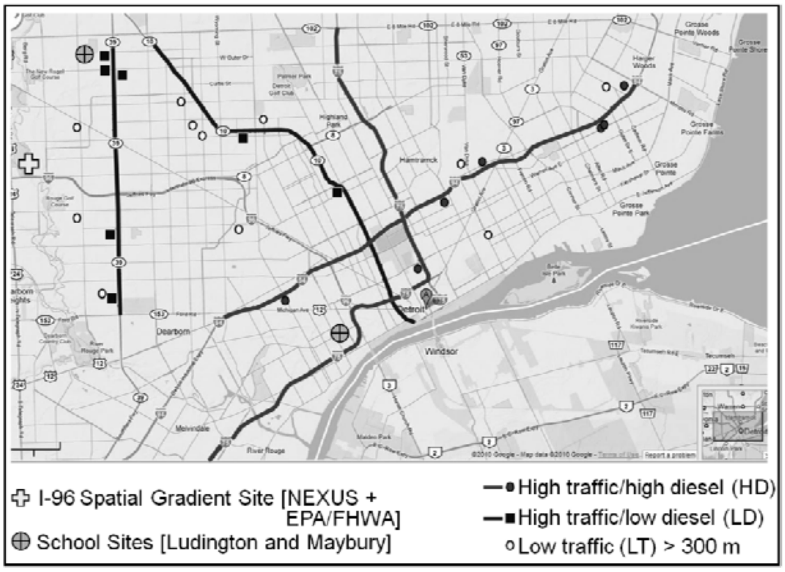

Figure 1. Modeling domain for the NEXUS study.

In this study, we use a combination of local-scale dispersion models, region-scale models and observations to provide spatially-resolved pollutant concentrations for the epidemiologic analysis. Temporally and spatially-resolved pollutant concentrations, associated with local variations of emissions and meteorology, were estimated using a combination of AERMOD (Cimorelli et. al., 2005) and RLINE (Snyder et. al., 2013) dispersion models. RLINE is a research-level, line-source dispersion model being developed by EPA's Office of Research and Development as a part of the ongoing effort to develop tools for a comprehensive evaluation of air quality impacts in the near-road environment. This model is being used in conjunction with traffic activity and primary mobile source emission estimates to model hourly exposure from roadway emissions for study participants' home and school locations. AERMOD is used to estimate additional exposures from stationery sources. For the background estimates, we used a space/time ordinary kriging (STOK) method that combines air quality system (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 the background concentrations. An example of modelled $PM_{2.5}$ and NO_x concentrations as a function of distance from a roadway is shown in Figure 2.

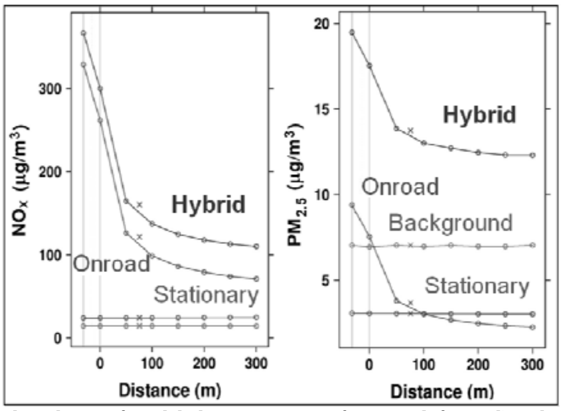

Figure 2. Near road gradients of modeled concentrations for NO_X (left panel) and $PM_{2.5}$ (right panel).

Figure 2 represents average hourly pollutant concentration gradients for one major roadway in Detroit, MI. These panels show the homogeneity in the background pollutant levels. For this particular location, the stationary source pollutant levels also seem homogeneous as a function of distance from the roadway suggesting there is no large nearby source of these pollutants. Thus in this case, the pollutant gradients are completely due to the dispersion of primary emissions from traffic on this roadway. The interesting thing to note is that NOx concentrations from traffic remain above background levels even 300m from the roadway, however $PM_{2.5}$ concentrations are slightly elevated above background levels from primary traffic emissions within ~50m from the roadway then fall below background levels. This behavior shows the mostly regional behavior of PM2.5, but source specific behavior of NOx in the absence of a large nearby stationary source. This reemphasizes the need to have highly resolved emissions and modeling to adequately resolve concentration differences in the near-road environment that impact personal exposures.

3. Model-Based Exposure Metrics for Use in the Epidemiologic Study NEXUS

The modeling provided hourly pollutant concentrations for CO, NO_x, $PM_{2.5}$ and its components (EC and OC) at each study participant location. From the hourly concentration, exposure metrics were calculated for the following time periods: daily: 24hr period; a.m. off-peak: 1-6; a.m. peak: 7-8; mid-day: 9-14; p.m. peak: 15-17; and p.m. off-peak: 18-24. These daily exposure metrics capturing spatial and temporal variability across health study domain (Fall 2010 – Spring 2012) were used in the epidemiologic analyses. Preliminary results (not shown here) using simple proximity-based exposure metrics in epidemiologic models with health outcomes were mixed (i.e. expected effect but not statistically significant), so may not be adequate for this study. However, advanced model-based exposure metrics may help to discern the relationships between air quality and health outcomes. Table 1 below compares the Asthma Control Test (ACT) scores using two different exposure metrics as inputs – primary $PM_{2.5}$ from mobile sources and urban background $PM_{2.5}$. ACT scores have a maximum of 25 (good asthma control); scores below 19 suggest poor asthma control.

Table 1. Asthma Control Test (ACT) scores using GEE models.

Modeled Exposure Metric	ACT Score	Standard Error	p value
Primary $PM_{2.5}$ (from mobile sources)	**-0.51**	**0.26**	**0.05**
Urban Background $PM_{2.5}$	0.22	0.22	0.30

The results indicate that for primary traffic-related $PM_{2.5}$, each 1 $\mu g/m^3$ increase in $PM_{2.5}$ concentration is associated with a 0.5 decrease in ACT which obtained statistical significance. Thus, 3-5 $\mu g/m^3$ level of primary $PM_{2.5}$ concentrations typically observed near roads would lead to a 1.5 - 2.5 change in ACT score which is very significant. The elevated $PM_{2.5}$ levels near roadways are dependent on the dispersion conditions, traffic volume, and fleet mix (diesel percentage). From the results presented in Table 1, a positive association begins to emerge between roadways with large traffic volumes (especially those with large diesel percentages) and a decrease in ACT scores, suggesting worsening asthmatic symptoms.

Disclaimer: This paper has been subjected to Agency review and approved for publication. Approval does not signify that the contents reflect the views of the Agency nor does mention of trade names or commercial products constitute endorsement or recommendation for use. The authors would like to acknowledge contributions by Toby Lewis, Tom Robins, Graciela Mentz of University of Michigan.

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Questions and Answers

Questioneer Name: Pius Lee

Q: As high diesel emision is tracked well by $PM_{2.5}$. That seemed to be the primary species triggering asthma attack. Also is one of your listing of possible species of air pollutants contributing to ACT score: e.g. one slide showed $PM_{2.5}$, EC, NO_x … Are these ranked in their contribution to ACT score?

A: We showed only preliminary results from the epidemiologic analysis using exposure metrics for primary $PM_{2.5}$ as an input. The analysis is still ongoing and we expect to have the risk coefficients for other pollutants when the epidemiologic study is completed so we would be able to compare relative risks coefficients for diesel PM and other pollutants such as CO and NO_x.