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HYBRID AIR QUALITY MODELING APPROACH FOR USE IN THE NEAR-ROAD EXPOSURES TO URBAN AIR POLLUTANT STUDY (NEXUS)

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Abstract: The Near-road EXposures to Urban air pollutant Study (NEXUS) investigated whether children with asthma living in close proximity to major roadways in Detroit, MI, (particularly near roadways with high diesel traffic) have greater health impacts associated with exposure to air pollutants than those living farther away. A major challenge in such health and exposure studies is the lack of information regarding pollutant exposure characterization. Air quality modeling can provide spatially and temporally varying exposure estimates for examining relationships between traffic-related air pollutants and adverse health outcomes. This paper presents a hybrid air quality modeling approach and its application in NEXUS in order to provide spatial and temporally varying exposure estimates and identification of the mobile source contribution to the total pollutant exposure. Model-based exposure metrics, associated with local variations of emissions and meteorology, were estimated using a combination of the AERMOD and R-LINE 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. The regional background contribution was estimated using a combination of the Community Multiscale Air Quality (CMAQ) model and the Space/Time Ordinary Kriging (STOK) model. To capture the near-road pollutant gradients, refined "mini-grids" of model receptors were placed around participant homes. Mini-grids gave anonymity to 50 or 100 m, a distance sufficient to protect participants' identity. Exposure metrics were calculated from mini-grids to produce an estimate at each home location (n=160). Exposure metrics for CO, NO_x, $PM_{2.5}$ and its components (EC and OC) were predicted for the following time periods: daily: 24 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 the health study domain (Fall 2010 – Spring 2012) were used in the epidemiologic analyses. Preliminary results of the epidemiologic analyses using model-based exposure estimates indicate a potential to help discern relationships between air quality and health outcomes. This modeling approach can be used for improving exposure assessments in future air pollution health studies.

Key words: *Dispersion Modeling, Air pollution, Exposure, Traffic.*

INTRODUCTION

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 adequate exposure characterization. This is especially important for epidemiologic studies focusing on exposures to traffic emissions. Numerous air quality monitoring studies conducted near major roadways have measured elevated concentrations, compared with overall urban background levels, of a number of motor-vehicle-emitted air pollutants. These steep gradients of pollutant concentrations near roadways also vary in time due to changes in meteorology and traffic activity. Therefore, both spatially- and temporally-resolved air quality concentrations are needed to provide adequate input to epidemiologic analyses. In this study, we use a hybrid air quality modeling approach and its application in the Near-road EXposures to Urban air pollutant Study (NEXUS) in order to provide spatial and temporally varying exposure estimates and identification of the mobile source contribution to the total pollutant exposure.

AIR QUALITY MODELING APPROACH FOR ESTIMATING EXPOSURE METRICS

The NEXUS study is investigating whether children with asthma living in close proximity to major roadways in Detroit, MI experience greater health impacts associated with air pollutants than those living farther away, particularly near roadways with high levels of diesel traffic (Vette et al. 2013). We use a combination of local-scale dispersion models, region-scale models and observations to provide spatially-resolved pollutant concentrations for the epidemiologic analysis. There are two major groups of air quality models relevant for use in supporting epidemiology studies: grid-based regional photochemical models and plume dispersion models. Grid-based models, such as the Community Multiscale Air Quality (CMAQ) model, provide concentrations for large areas at high time resolution but cannot provide resolved features smaller than a grid cell, usually a few tens of kilometers across. Plume dispersion models, such as AERMOD (Cimorelli et. al., 2005), can provide these resolved concentrations gradients such as those occurring close to roadways at distances from 10s to 100s of meters (Cook et. al., 2008). To account for the limitations of these types of models, a hybrid approach is often used where concentrations from a grid-based chemical transport model and a local-scale dispersion model are added to provide contributions from photochemical interactions, long-range (regional) transport, and details attributable to local-scale dispersion (Crooks et. al., 2013; Sarnat et. al., 2013; Lobdell et. al., 2011, Isakov et. al., 2009). In this study, temporally and spatially-resolved pollutant concentrations, associated with local variations of emissions and meteorology, were estimated using a combination of AERMOD and R-LINE (Snyder et. al., 2013) dispersion models. R-LINE 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 further 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 exposures to traffic emissions for the participants of the NEXUS study. Exposures to air pollution from stationary sources such stacks from manufacturing facilities were modelled using AERMOD. The background contribution was estimated using a combination of the Community Multiscale Air Quality (CMAQ) model and ambient measurements processes by the Space/Time Ordinary Kriging (STOK) method. The modeling provided hourly pollutant concentrations for CO, NO_x, total $PM_{2.5}$ mass, and its components elemental carbon (EC) and organic carbon (OC), and benzene. Hourly concentrations were processed to calculate daily and annual average exposure metrics for each study participants' home and school location for use in the epidemiologic analyses.

RESULTS AND DISCUSSION

The hybrid modeling provided hourly concentration at each NEXUS location in three selected traffic exposure groups. The 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). From the hourly concentration, exposure metrics were calculated for the following time periods: 24-hour (daily); 1-6 (a.m. offpeak); 7-8 (a.m. peak); 9-14 (mid-day); 15-17 (p.m. peak); and 18-24 (p.m. off-peak). These hours correspond to the reported local-time (i.e. hour 1 represents from 12:01 a.m. – 1:00 a.m.). These are calculated with a 70% completeness criterion for the hourly meteorology in each time period. These daily exposure metrics for CO, NO_x, $PM_{2.5}$ and its components (EC and OC), capturing spatial and temporal variability across the health study domain (Fall 2010 – Spring 2012) were used in the epidemiologic analyses. Model results were evaluated using ambient monitoring data in Detroit from the routine observational network (AQS) and from the intensive monitoring campaign which was part of the NEXUS study. The modeled concentrations generally follow the time series of observed data, however there are some over-predictions at certain hours. Comparison of diurnal patterns of modeled and observed concentrations showed that the model was able to reproduce the morning and afternoon peaks. Overall, the model was able to capture the magnitude and time patterns of near road pollutant concentrations, critical for the exposure and health studies.

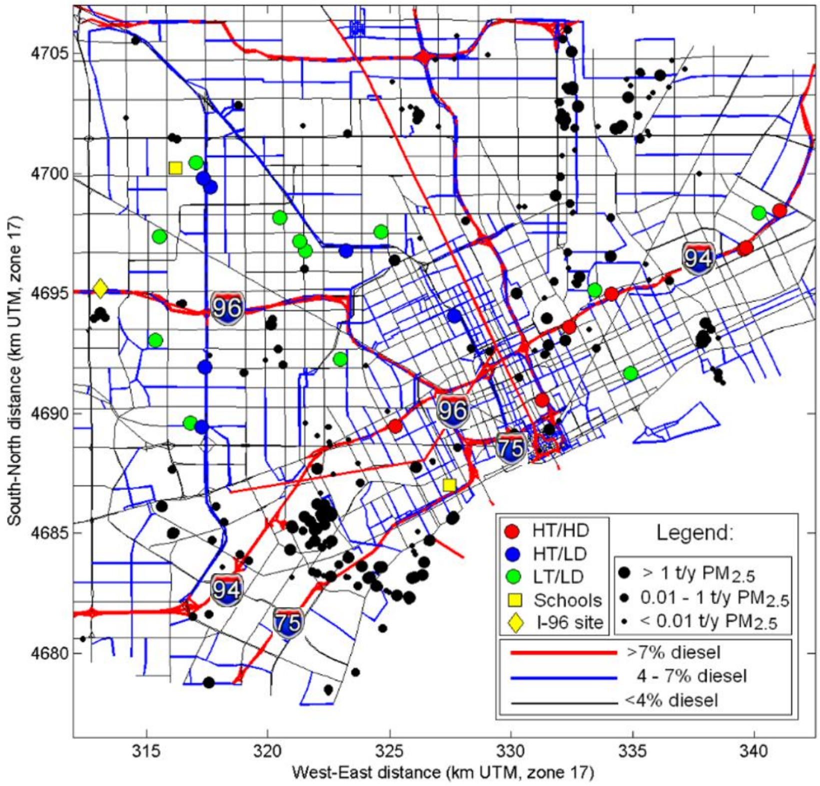

Figure 1. Modeling domain for the NEXUS study. Major highways are shown as red and blue lines (for > 7% diesel and 4-7% diesel fraction) and other roads – as black lines. Model receptors are shown in red, blue and green circles for the HD, LD and LT traffic exposure group, respectively. Stationary sources are shown as black dots (symbol size indicates the magnitude of $PM_{2.5}$ annual emissions).

CONCLUSIONS

Here we presented an application of a hybrid modeling approach to estimate traffic-related exposures in support of an urban scale exposure and epidemiology study. The modeling approach involved the development and use of a detailed emissions inventory and dispersion model to estimate ambient air pollution concentrations. The emissions inventory was based on a detailed geometry of the road network, traffic volumes, temporal allocation factors, fleet mix, and pollutant specific emission factors. These road-link emissions were used as inputs to R-LINE, the newly developed dispersion model specifically designed for near-road applications. Thus, the model-based exposure metrics provided the temporal and spatial resolution needed for the epidemiologic study. The hybrid modeling approach also provided an opportunity to compare relative contributions of various sources: stationary sources, roadways, urban background, and total. The hybrid modeling approach used in NEXUS provide 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. Such additional information on strong spatial and temporal variation of pollutant concentrations and the relative contribution of various source categories to the total concentration could benefit future traffic-related health assessments. The hybrid modeling approach used in NEXUS could be also used for estimating exposures in other epidemiological studies where adequate measurements of traffic- or other source-related air pollutants are not feasible.

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