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Modeling the impacts of traffic emissions on air toxics concentrations near roadways

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ABSTRACT

The dispersion formulation incorporated in the U.S. Environmental Protection Agency's AERMOD regulatory dispersion model is used to estimate the contribution of traffic-generated emissions of select VOCs – benzene, 1,3-butadiene, toluene – to ambient air concentrations at downwind receptors ranging from 10-m to 100-m from the edge of a major highway in Raleigh, North Carolina. The contributions are computed using the following steps: 1) Evaluate dispersion model estimates with 10-min averaged NO data measured at 7 m and 17 m from the edge of the road during a field study conducted in August, 2006; this step determines the uncertainty in model estimates. 2) Use dispersion model estimates and their uncertainties, determined in step 1, to construct pseudo-observations. 3) Fit pseudo-observations to actual observations of VOC concentrations measured during five periods of the field study. This provides estimates of the contributions of traffic emissions to the VOC concentrations at the receptors located from 10 m to 100 m from the road. In addition, it provides estimates of emission factors and background concentrations of the VOCs, which are supported by independent estimates from motor vehicle emissions models and regional air quality measurements. The results presented in the paper demonstrate the suitability of the formulation in AERMOD for estimating concentrations associated with mobile source emissions near roadways. This paper also presents an evaluation of the key emissions and dispersion modeling inputs necessary for conducting assessments of local-scale impacts from traffic emissions.

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1. Introduction

Emissions from motor vehicles greatly influence the temporal and spatial patterns of air pollutant concentrations within urban areas. Air quality monitoring studies conducted near major roadways reveal elevated concentrations of motor vehicle emitted pollutants compared to overall urban background levels. Health studies have also indicated that populations near roads have an increased risk for a number of adverse effects (e.g. Samet, 2007). These results from air quality and health effects studies motivated a comprehensive field study to characterize the influence of traffic-generated emissions on the temporal and spatial variability of air pollutant concentrations in the near-road environment (Baldauf et al., 2008).

This paper presents the development and application of a method to estimate the contributions of traffic-related emissions to air pollutant concentrations within 100-m of the road. It is based on using a dispersion model to interpret air quality measurements made close to the road. The model used in this study is that incorporated in AERMOD (Cimorelli et al., 2005), which reflects current understanding of dispersion and micrometeorology, and has replaced the Industrial Source Complex (ISC) model as the guideline dispersion model for regulatory applications. The first step of the analysis is the evaluation of the performance of the AERMOD algorithm using path averaged NO concentrations measured during the field study. This step quantifies the uncertainty in model estimates. These uncertainty estimates are then combined with model estimates to simulate observations of air quality using nominal emission factors predicted by U.S. Environmental Protection Agency's MOBILE6 (U.S. EPA, 2003). The simulated observations are then fitted to actual measurements to yield

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estimates of background concentrations and the contribution of traffic emissions to the measured pollutant concentrations. This process also results in corrections to the emission factors to better reflect emissions during actual driving conditions. We next describe the field study that collected the measurements used in the method.

2. Field measurements

The field study, conducted during July and August, 2006, adjacent to U.S. Interstate 440 (I-440), in Raleigh, North Carolina, obtained time-resolved measurements of traffic activity, meteorology, and air quality at varying distances from the road (Baldauf et al., 2008). Selected air quality parameters, including criteria and air toxic pollutants, represented the complex mixture of pollutants emitted by motor vehicles.

Fig. 1 presents the project location adjacent to I-440, which is a limited-access highway supporting approximately 125,000 vehicles per day. An open, grassy field, at-grade with the highway, extends for approximately 120 m to the north of I-440, with only a guardrail and shrubbery approximately 1 m in height and width between the field and I-440 travel lanes. Baldauf et al. (2008) provides additional information on the study site and measurements collected during the project.

Traffic surveillance cameras provided video data of traffic activity on I-440 and a nearby access road. TigreEye™ software (DTS Inc., Albuquerque, NM, USA) remotely calculated vehicle frequency, speed, and class (motorcycles, light-duty cars, light-duty trucks, and heavy-duty truck) as a function of time during daylight hours of the study.

Onsite wind measurements were collected at downwind sites at 5, 20, and 100 m using sonic anemometers (Model 81000 Ultrasonic Anemometer, R.M. Young Company, Traverse City, MI, USA). At the 20-m site, two sonic anemometers measured wind speed and direction at heights of 4 and 8 m above ground. Comparison of the data at the 5 and 20-m sites provided information on the horizontal and vertical extent of the turbulent mixing zone from the highway.

Air quality monitors measured pollutant concentrations at multiple distances from the road. Measurements of regulated gases, particulate matter, and air toxics provided information on the concentration of these pollutants during changing traffic and environmental conditions. An on-site master clock provided time synchronized measurements for all of the monitoring equipment.

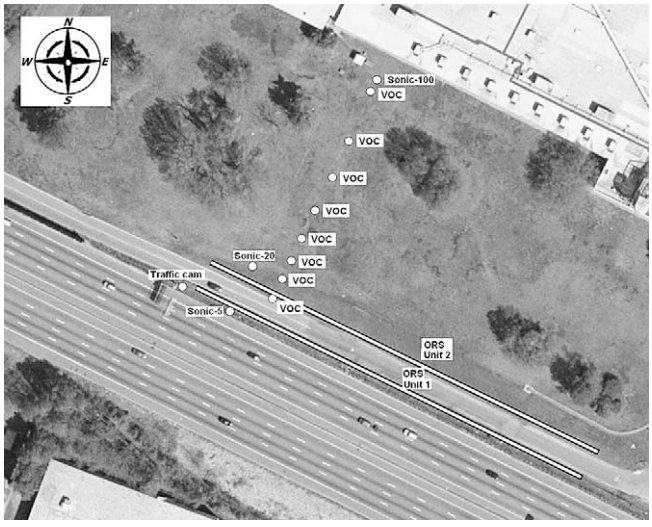

Fig. 1. Map of study location.

Optical remote sensing (ORS) devices measured NO concentrations along a number of paths near the highway as shown in Fig. 1. Ground-based ORS instruments utilized infrared, visible and/or ultraviolet light beams projected over open paths to measure spatially averaged gaseous pollutant concentrations in the intersected air column using optical absorption spectroscopy as described in Thoma et al. (2008). ORS instruments were set up parallel to the road at distances of approximately 7-m and 17-m from the nearest travel lane. The open-path horizontal sampling distance was 149-m and the optical paths were 2-m above the ground.

Canister measurements of volatile organic compounds (VOCs) provided concentrations for multiple air toxic pollutants. There were five intensive sampling periods to supplement the measurements described in Baldauf et al. (2008): two in the afternoon of August 3 and one on the mornings of August 7, 8, and 10. On each sample period a set of ten, 6-l summa canisters were suspended ~1.5-m above the surface from metal stakes and located 13, 19, 25, 31, 43, 58, 74, and 92-m normal to the road as shown in Fig. 1. Three canisters were sampled at the 13-m point and one canister at the other locations. When the canister valve was opened ambient air flowed through a filter and critical orifice (Entech Instruments, Inc., Simi Valley, CA) into the evacuated canister to a pressure of approximately one-half atmosphere (atm) over a 35-min period. Sample pumps, which can be sources of contamination, were not used. Canisters were pressurized to approximately 1.3 atm with zero-grade air before analysis. Prior to sampling the canisters were cleaned in the laboratory by filling and evacuating humidified zero-grade air three times in an oven at 120 °C.

VOCs were determined by capillary gas chromatographic (GC) and flame ionization detection (FID). C-2 to C-14 compounds were separated on a 60-m, 0.32 internal diameter (i.d.) fused silica column coated with 1-μm DB-1 (J&W Scientific, Folsom, CA) non-polar liquid phase. The GC oven and column were cooled by liquid nitrogen and subsequently programmed from −50 °C, held for 2-min, to 280 °C for 1.75-min at 8 °C per min. We used a Dewar containing liquid argon at −185.9 °C to cryogenically concentrate 450 ml of air in a stainless steel, U-shaped, one-eighth inch outer diameter (o.d.) tube containing glass beads. The trap containing condensed VOCs was immersed in a Dewar of near boiling water to volatilize and inject the VOCs on to the GC column. Further details on this method are provided in Seila et al. (1989). A propane-in-air standard reference material (National Institutes of Science and Technology) was employed to determine the FID per carbon calibration factor.

3. Modeling dispersion of pollutants near a highway

To facilitate the application of AERMOD in estimating concentrations near the road, we constructed a stand-alone model that incorporated only the surface dispersion algorithms in AERMOD. For this application, the road is treated as an area source that is 1600 m long and 32 m wide to simulate a 6-lane highway with median and shoulders. The vertical dispersion parameter σ_z during daytime conditions (Venkatram, 1992) of the study is given by

$$\sigma_z = \sqrt{\frac{2}{\pi}}\frac{u_*}{U}x\left(1+\alpha\left(\frac{x}{|L|}\right)^2\right)^{1/2}, \quad (1)$$

where u_* is the surface friction velocity, U is the mean wind speed at a reference height, z_r, x is the downwind distance, L is the Monin-Obukhov length, and $\alpha = 0.006$ is an empirical constant. The vertical mixing induced by traffic is accounted through specifying an initial mixing of 2-m, added to the vertical dispersion parameter