

Traffic and Meteorological Impacts on Near-Road Air Quality: Summary of Methods and Trends from the Raleigh Near-Road Study

Richard Baldauf

U.S. Environmental Protection Agency, Office of Research and Development, National Risk Management Research Laboratory, Research Triangle Park, NC, and Office of Air and Radiation, Office of Transportation and Air Quality, National Vehicle and Fuel Emissions Laboratory, Ann Arbor, MI

Eben Thoma, Michael Hays, Richard Shores, John Kinsey, Brian Gullett, and Sue Kimbrough

U.S. Environmental Protection Agency, Office of Research and Development, National Risk Management Research Laboratory, Research Triangle Park, NC

Vlad Isakov

National Oceanic and Atmospheric Administration, Atmospheric Sciences Modeling Division, Research Triangle Park, NC

Thomas Long and Richard Snow

ARCADIS Inc., Research Triangle Park, NC

Andrey Khlystov

Department of Civil and Environmental Engineering, Pratt School of Engineering, Duke University, Durham, NC

Jason Weinstein, Fu-Lin Chen, Robert Seila, and David Olson

U.S. Environmental Protection Agency, Office of Research and Development, National Exposure Research Laboratory, Research Triangle Park, NC

Ian Gilmour and Seung-Hyun Cho

U.S. Environmental Protection Agency, Office of Research and Development, National Health and Environmental Effects Research Laboratory, Research Triangle Park, NC

Nealson Watkins and Patricia Rowley

U.S. Environmental Protection Agency, Office of Air and Radiation, Research Triangle Park, NC

John Bang

North Carolina Central University, Department of Environmental Sciences, Durham, NC

IMPLICATIONS

Increasing evidence of adverse health effects for populations spending large amounts of time near major roadways warrants investigation into the relationship of traffic activity and meteorology on the air quality to which these populations are exposed. Understanding these relationships will lead to better methods of protecting public health through improved voluntary, regulatory, and planning actions.

ABSTRACT

A growing number of epidemiological studies conducted worldwide suggest an increase in the occurrence of adverse health effects in populations living, working, or going to school near major roadways. A study was designed to assess traffic emissions impacts on air quality and particle toxicity near a heavily traveled highway. In an attempt to describe the complex mixture of pollutants and atmospheric transport mechanisms affecting pollutant dispersion in this near-highway environment, several real-time and time-integrated sampling devices measured

air quality concentrations at multiple distances and heights from the road. Pollutants analyzed included U.S. Environmental Protection Agency (EPA)-regulated gases, particulate matter (coarse, fine, and ultrafine), and air toxics. Pollutant measurements were synchronized with real-time traffic and meteorological monitoring devices to provide continuous and integrated assessments of the variation of near-road air pollutant concentrations and particle toxicity with changing traffic and environmental conditions, as well as distance from the road. Measurement results demonstrated the temporal and spatial impact of traffic emissions on near-road air quality. The distribution of mobile source emitted gas and particulate pollutants under all wind and traffic conditions indicated a higher proportion of elevated concentrations near the road, suggesting elevated exposures for populations spending significant amounts of time in this microenvironment. Diurnal variations in pollutant concentrations also demonstrated the impact of traffic activity and meteorology on near-road air quality. Time-resolved measurements of multiple pollutants demonstrated that traffic emissions produced a complex mixture of criteria and air toxic pollutants in this microenvironment. These results provide a foundation for future assessments of these data to identify the relationship of traffic activity and meteorology on air quality concentrations and population exposures.

INTRODUCTION

In recent years, several epidemiological studies have reported associations between a population's proximity to high-traffic-volume roadways and adverse health effects, which include asthma and other respiratory symptoms,^{1–10} birth and developmental effects,^{11–15} premature mortality,^{16–20} cardiovascular effects,^{21–23} and cancer.^{24–26} These studies typically compare the occurrence of adverse health effects in populations that live, work, or go to school near heavily traveled roadways.

Motor vehicles influence the temporal and spatial patterns of regulated gases, particulate matter (PM), and air toxic pollutant concentrations. Emissions from motor vehicle operations near major roads have led to elevated concentrations of certain air pollutants, including carbon monoxide (CO); nitric oxides (NO_x); nitrogen dioxide (NO₂); coarse (PM_{10–2.5}), fine (PM_{2.5}), and ultrafine (PM_{0.1}) PM; black carbon (BC); and benzene near large roadways when compared with overall urban background levels.^{27–33} Several recent studies have focused on PM measurements, identifying elevated ultrafine particle number concentrations in close proximity to roadways.^{28,34–38} In general, these studies focused on specific pollutants or class of pollutants, with limited information on traffic activity during the measurements.

This project provided data to characterize the influence of traffic-generated emissions on the temporal and spatial variability in pollutant concentrations in the near-road environment. The primary objectives were to identify appropriate monitoring techniques to measure the complex mixture of traffic-related pollutants in the near-road environment, determine how traffic and environmental conditions affect near-road air quality, and evaluate existing emissions and dispersion models for near-road applications. This paper presents a description of the methods used in the

study, as well as a summary of results illustrating the relationship of meteorology, traffic, and air quality concentrations near the road. Other publications will present additional results on specific monitoring techniques evaluating near-road air pollutant concentrations, detailed associations between traffic conditions and pollutant concentrations near the road, effects of roadside structures, and comparison of monitored and modeled data. Because of the large scope of this project, a presentation of all results from this study is not feasible in one paper.

METHODS

The project study design focused on highly time-resolved characterization of traffic activity, meteorology, and air quality at varying distances from the road. Selected air quality parameters were chosen to represent the complex mixture of pollutants emitted by motor vehicles. In addition to real-time air quality monitoring, select time-integrated measurements allowed for detailed chemical speciation and the evaluation of particle toxicity.

Field Site

A site in Raleigh, NC provided the opportunity to assess several factors influencing air quality near major roads. Figure 1 shows the project location, adjacent to U.S. Interstate 440 (I-440). I-440 is a limited-access highway supporting approximately 125,000 vehicles/day. An open field at-grade with the highway extends for approximately 120 m to the north of I-440, with the only structures present between the field and I-440 travel lanes being a guardrail and shrubbery, approximately 1 m in height and width. A two-story building sits to the north of the field. This building extends for approximately 80 m away from the highway and houses an adult educational facility. The building's parking lot lies to the west of the sampling sites, with less than 100 passenger cars per day estimated to use this lot during the study. An access road supporting less than 200 vehicles per day runs parallel to the highway approximately 10 m from the edge of the I-440 travel lanes. A truck rental business operates at the end of this access road; thus, a large portion of the

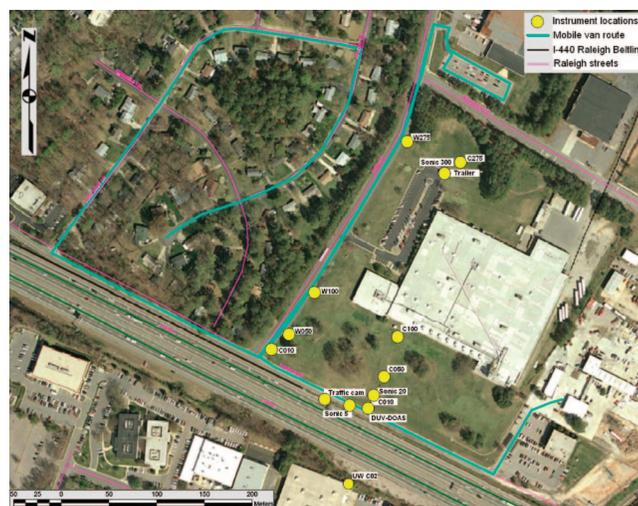


Figure 1. Map of the study location including the relative placement of the monitoring instrumentation (shown as yellow circles). The light blue line represents the route driven by the mobile monitoring vehicle.

vehicles on the access road during the study consisted of heavy-duty trucks. A noise barrier exists approximately 5 m from the edge of the I-440 travel lanes, beginning approximately 40 m west of the center of the open field. This barrier extends over 1 km west along I-440. South of the highway, an approximately 5-m elevation drop occurs at a 45° angle. Two-story office buildings are located at the bottom of the hill; thus, the rooftops of these buildings are essentially at-grade with the road. With the exception of the highway, no other major air pollution sources were identified within several kilometers of the study site.

On the basis of historical meteorological monitoring data collected at Raleigh-Durham International Airport indicating predominant winds from the south/southwest for this region, downwind monitoring sites were established to the north of I-440, with an upwind site located to the south of the highway. The monitoring network consisted of six primary monitoring sites to assess near-road air quality with no obstructions to airflow present: one upwind and five downwind of I-440. The downwind sites were located along a transect perpendicular to I-440 approximately 5, 20, 50, 100, and 300 m to the north of the edge of the nearest travel lane. The 5-m downwind site provided measurements between I-440 and the access road, whereas the remaining sites provided data downwind of both I-440 and the access road. Thus, the influence of vehicles on the access road could be assessed. Intensive monitoring occurred at the 20- and 300-m sites, with the other sites providing supplemental data to evaluate the potential shape of concentration gradients away from the road. A secondary transect was also established behind the noise barrier approximately 20, 50, 100, and 300 m to the north of the edge of the nearest travel lane of I-440. These sites provided supplemental data to make comparisons with the unobstructed transect measurements. Figure 1 shows the approximate locations of these monitoring sites. Data collection occurred during July and August 2006.

The following sections summarize the monitoring equipment and methods implemented for the study. Table 1 lists the parameters measured and instruments used in the study, as well as the location of the measurements.

Traffic Activity

Traffic surveillance cameras mounted on a 12-m utility pole located approximately 5 m from the edge of I-440 provided video data of traffic activity on I-440 and the access road. TigerEye software (DTS Inc.) remotely processed vehicle frequency, speed, and class (motorcycles, light-duty cars, light-duty trucks, and heavy-duty trucks) as a function of time during daylight hours of the study. Computer hard drives on-site stored all traffic video information to allow for visual confirmation of the software outputs.

Meteorology

Meteorological data measurements included wind speed, wind direction, temperature, and humidity. For wind speed and direction parameters, measurement methods included cup anemometer stations (HOBO Weather Station, Onset Corp.) and sonic anemometers (Model 81000 Ultrasonic Anemometer, R.M. Young Co.) at several locations. Sonic anemometers were located at downwind sites at 5 (Sonic-5), 20 (Sonic-20), and 100 (Sonic-100) m

whereas the sites at 20 (Met-20) and 300 (Met-300) m contained the cup anemometer stations. 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. The wind sensors at the 100- and 300-m sites provided data on the consistency of winds from the road, as well as the potential influence of the building on airflow around these sites.

Air Quality

Air quality monitors measured pollutant concentrations at multiple distances from the road, as shown in Figure 1 and Table 1. Measurements of regulated gases, PM, 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. In addition to the air quality measurements described below, a series of sulfur hexafluoride (SF₆) releases provided information on the transport and dispersion of air masses off the roadway. Detailed descriptions of the SF₆ analyses and results will be presented in later publications. The following sections provide descriptions of the air quality monitoring conducted for each of the air pollutant categories evaluated.

Regulated Gases. Real-time gas analyzers, meeting U.S. Environmental Protection Agency (EPA) federal reference method (FRM) or equivalent method (FEM) criteria, measured CO, CO₂, NO_x, and total hydrocarbon (THC) pollutant concentrations at 20 and 300 m from the road. These analyzers collected measurements at 20-sec averaging periods for all hours of the day at a height approximately 2 m above ground. Two CO₂ FRM samplers also measured concentrations at 4 and 8 m above ground at the 20-m site. Multipoint calibration, zero, and span check procedures provided an assessment of the measurement accuracy for each analyzer. These analyzers provided near real-time analyses of regulated pollutant concentrations related to traffic activity, as well as a determination of the change in concentration with increased distance from the road.

Additional monitoring techniques also measured concentrations of regulated gases. Optical remote sensing (ORS) devices measured CO, CO₂, nitric oxide (NO), SF₆, formaldehyde (HCHO) and integrated THC concentrations along multiple paths near the highway. Ground-based ORS instruments utilized infrared (IR), visible, and/or ultraviolet (UV) light beams projected over open paths to spatially measure averaged gaseous pollutant concentrations in the intersected air column using optical absorption spectroscopy. An open-path Fourier transform IR (OP-FTIR) spectrometer and a deep UV differential optical absorption spectrometer (DUV-DOAS) operated in pairs at both the 5- and 20-m sites. The optical paths of the OP-FTIR/DUV-DOAS pairs at these sites were located in close proximity to each other and parallel to I-440. The OP-FTIRs were monostatic in configuration and measured CO, CO₂, SF₆, and THC with 30-sec time resolution.^{39,40} The bistatic DUV-DOASs measured NO and an integrated THC deep UV band with 5-sec time resolution.^{41,42} The optical paths for 5- and 20-m sites were 149 m in length and approximately 2 m above the ground to approximate breathing level height. A positional-scanning monostatic

Table 1. List of parameters measured, including instrumentation and location of the sampling.

Parameter Measured	Sampling Method	Instrument/Media	Sampling Frequency (average time)	Location (distance from road)						
				5 m	20 m	50 m	100 m	300 m	Upwind	
CO	FRM	API Model 300 (San Diego, CA)	Continuous (20 sec)		X					
		TECO Model 48 (Franklin, MA)	Continuous (20 sec)					X		
	ORS OP-FTIR	IMACC Inc. (Round Rock, TX)	Continuous (30 sec)	X	X					
	ORS OP-FTIR	AIL Systems Inc. (Deer Park, NY)	Continuous (1 min)		X ^a					
CO ₂	Portable	TSI Q-Trak Mo. 8554 (Shoreview, MN)	Continuous (20 sec)		X	X	X	X	X	
		Siemens ULTRAMAT (New York, NY)	Continuous (20 sec)		X (2 m)			X	X	
		Horiba Model VA (Ann Arbor, MI)	Continuous (1 sec)		X (4 m)					
	FRM	Horiba Model VA (Ann Arbor, MI)	Continuous (1 sec)		X (8 m)					
		ORS OP-FTIR	IMACC Inc., (Round Rock, TX)	Continuous (30 sec)	X	X				
		ORS OP-FTIR	AIL Systems Inc. (Deer Park, NY)	Continuous (1 min)		X ^a				
NO _x	Portable	TSI Q-Trak Mo. 8554 (Shoreview, MN)	Continuous (20 sec)		X	X	X	X	X	
		API Model 200 ^o (San Diego, CA)	Continuous (20 sec)		X					
	FRM	TECO Model 42S (Franklin, MA)	Continuous (20 sec)					X		
NO	ORS DUV-DOAS	Cerex Environmental (Atlanta, GA)	Continuous (5 sec)	X	X					
THCs	FRM	Horiba FIA 220 (Ann Arbor, MI, USA)	Continuous (20 sec)		X			X		
		IMACC Inc., (Round Rock, TX)	Continuous (30 sec)	X	X					
	ORS OP-FTIR	AIL Systems Inc. (Deer Park, NY)	Continuous (1 min)		X ^a					
Benzene	TO-15	Summa canister	Integrated (1 and 12 hr)		X	X	X	X	X	
		Jet-REMPI-TOFMS	Continuous (1 sec)		X					
Toluene	TO-15	Summa canister	Integrated (1 and 12 hr)		X	X	X	X		
		Jet-REMPI-TOFMS ^c	Continuous (1 sec)		X					
		OPSIS AB (Furulund, Sweden)	Continuous (5 sec)		X					
Formaldehyde	ORS UV-DOAS	Summa canister	Integrated (1 and 12 hr)		X	X	X	X	X	
Acrolein	TO-15	Jet-REMPI-TOFMS	Continuous (1 sec)		X	X	X	X	X	
Polyaromatic hydrocarbons					X	X	X	X	X	
PM _{10-2.5}	FRM Gravimetric	R&P Partisol Plus 2025 (Albany, NY)	Integrated (24 hr)		X			X	X	
	Portable Gravimetric	AirMetrics Minivol (Eugene, OR)	Integrated (24 hr)	X	X	X	X	X	X	
PM _{2.5}	FEM TEOM	R&P Series 1400 ^o (Albany, NY)	Continuous (1 min)		X (4 m)					
	FEM TEOM	R&P Series 1400 ^o (Albany, NY, USA)	Continuous (1 min)		X (8 m)					
	Portable	TSI Sidepak (Shoreview, MN)	Continuous (20 sec)		X	X	X	X	X	
	FRM Gravimetric	R&P Partisol Plus 2025 (Albany, NY)	Integrated (24 hr)		X			X	X	
	Portable	AirMetrics Minivol (Eugene, OR, USA)	Integrated (24 hr)	X	X	X	X	X	X	
	Portable	TSI P-Trak 8525 (Shoreview, MN)	Continuous (20 sec)		X	X	X	X	X	
Particle number	EEPS/SMPS	TSI Model 3090 EEPS TSI Model 3936 SMPS (Shoreview, MN)	Continuous (1-sec EEPS) (2-min SMPS)		X (4 m)					
Particle number and size distribution	APS/SMPS	TSI Model 3321 APS TSI Model 3934 SMPS (Shoreview, MN)	Continuous (2-min APS) (2-min SMPS)		X (8 m)					
PM carbon content	Dekati LPI	Dekati Ltd. (Tampere, Finland)	Integrated (24 hr)		X			X	X	
		Magee Scientific AE3 (Berkeley, CA)	Continuous (1 min)		X					
	Aethalometer	Magee Scientific AE4 (Berkeley, CA)	Continuous (1 min)					X		
		EC/OC (NIOSH5040)	Pre-fired 47-mm quartz filter (with quartz filter back-up)	Integrated (24 hr)	X	X ^b				
PM (organics)	High-volume	Tisch Environmental (Cleves, OH)	Integrated (24 hr)		X					
PM (toxicity)	High-volume	R&P ChemVol (Albany, NY)	Integrated (24 hr)		X			X		
SF ₆ tracer gas	GC-PID	Lagus Autotrac (Escondido, CA)	Continuous (1 min)							
		IMACC Inc., Round Rock, TX)	Continuous (30 sec)	X	X					
	ORS OP-FTIR	AIL Systems Inc. (Deer Park, NY)	Continuous (1 min)		X ^a					
		Summa canister	Integrated (1 hr)		X	X	X	X		
Traffic	Video	DTS Inc TigerEye (Albuquerque, NM)	Continuous (20 sec)	X						
Meteorology	Sonic anemometer	R.M. Young Co. 81000 (Traverse City, MI)	Continuous (4 per sec)	X	X		X	X		
	Cup and vane	Onset Corp. HOBO (Pocasset, MA)	Continuous (20 sec)		X					

Notes: ^aIncludes one path parallel to the highway and one path perpendicular between the 20- and 100-m sites; ^bSamples collected at 4 and 8 m above ground level; ^cTOFMS = time-of-flight mass spectrometry.

OP-FTIR also positioned at the 20-m site acquired data sequentially along four separate paths. Two paths were located parallel to the other ORS units at the 20-m site, but measured concentrations at elevated positions of 7 and 15 m above the ground to estimate the vertical dimensions of the traffic emission plume. Two elevated

optical paths were also configured perpendicular to I-440 beginning at the 20-m site and terminating at the 100-m site for path lengths of 83 and 85 m, respectively. A sample acquisition time of 5 sec resulted in a total cycle time for all four paths of approximately 1 min. Also near the 20-m downwind site, a DUV-DOAS measured HCHO

at a 1-min time resolution over a 228-m path length using the method described by Platt.⁴³ A monastic OP-FTIR measured CO, CO₂, SF₆, and THC pollutant concentrations at the 20-m site behind the noise barrier. The instrument's terminating retroreflector was located at the base of the noise barrier 129 m to the west.

Implementation of the ORS methods provided information on the flux of pollutants from the roadway and an estimate of the change in concentration with distance. In addition, the parallel paths on both sides of the access road (5- and 20-m sites, respectively) allowed an evaluation of the impact of vehicles on the access road to the air quality measurements downwind of this road. The unit located behind the noise barrier also allowed for an assessment of the potential impact of this barrier on air quality concentrations directly behind the structure.

Portable, less expensive, industrial hygiene monitors located at all of the primary and secondary monitoring sites collected CO, CO₂, temperature, and humidity data. Each monitor provided 20-sec average concentration measurements for 24 hr each day during the study. As shown in Table 1, these monitors were collocated with CO and CO₂ FRM analyzers at the 20- and 300-m sites. In addition, two portable samplers collected collocated measurements at the 50-m site. Study personnel rotated these monitors among the sites every three days. Operation of these monitors provided an assessment of potentially less expensive alternatives to measuring near-road air quality, as well as the ability to measure multiple locations without external power to assess concentration gradients away from the roadway.

Air Toxics. In addition to the measurement of THC, individual air toxic compounds were monitored. Air toxic monitoring included near-real-time measurements and integrated samples. As described in the previous section, ORS devices measured HCHO and THCs. In addition to the ORS devices, a Jet resonance-enhanced multiphoton ionization with time-of-flight mass spectrometer (Jet-REMPI) measured near real-time concentrations of select air toxics at the primary 20-m downwind site. Oudejans et al.⁴⁴ provide details on the laser system and other instrument components and methods that were used in this study. Study personnel conducted a mass calibration of the Jet-REMPI daily using internal gas standards. The instrument reported 1-sec time-resolved concentrations of benzene, toluene, and select polycyclic aromatic hydrocarbons (including naphthalene). Implementation of the Jet-REMPI in this study provided one of the first real-time measurements of mobile-source-related air toxics in a near-road environment. In addition, collocation of this device with other air toxic monitoring equipment provided an opportunity to compare multiple monitoring techniques for near-road measurements.

Although the real-time measurements provided information on air toxic concentrations within 20 m of the highway, these samplers could only provide limited information on concentration gradients. To supplement the continuous measurements, Summa canisters collected integrated air samples at each of the upwind and downwind primary monitoring sites. Samples were collected over three different time intervals: 1-hr average samples during the morning rush hour (7:00 to 8:00 a.m.), 1-hr average samples during the evening rush hour (4:30 to 5:30 p.m.), and 12-hr

average daytime samples (6:00 a.m. to 6:00 p.m.) collected at the 20- and 300-m sites only). All canisters were cleaned before use in the field. Daily laboratory and field blanks provided information on potential contamination of the canister samples.

PM. PM sampling provided continuous and integrated measurements for particle physical and chemical components. The size ranges analyzed included PM_{10-2.5} (aerodynamic diameter between 10 and 2.5 μm), PM_{2.5} (aerodynamic diameter less than 2.5 μm), and PM_{0.1} (aerodynamic diameter less than 0.1 μm) mode particles. Continuous measurements provided information on the relationship of vehicle activity and environmental conditions with near-road PM concentrations and characteristics. For PM components that could not be measured continuously, integrated samples provided information on the relative abundance of these components.

A suite of monitoring equipment located at the primary downwind site 20 m from the road collected continuous and integrated PM samples to determine the concentration and characteristics of aerosols present in the near-road environment. This site contained monitoring devices to determine the following parameters: mass, number, size distribution, carbon content (BC and elemental carbon [EC]/organic carbon [OC]), organic composition, and elemental composition. The majority of the samplers were located at breathing level height (~2 m above ground). In addition, select monitors also collected PM samples at heights of 4 and 8 m above ground for PM_{2.5} mass, particle size distribution, particle number, CO₂, and EC/OC at this site as noted in Table 1.

PM mass measurements included continuous FEM samplers, portable continuous industrial hygiene samplers, integrated FRM monitors, portable air quality samplers, and multistage impactors. Continuous PM_{2.5} measurements were collected at the 4- and 8-m heights using a FEM tapered element oscillating microbalance (TEOM).⁴⁵ The TEOMs operated continuously for 24 hr per day and reported concentrations at an averaging period of 30-sec. These samplers provided measurements to associate traffic activity with PM concentrations, as well as the flux of particles off the roadway. Portable industrial hygiene PM_{2.5} samplers (Sidepaks) also measured continuously for 24-hr/day at an averaging period of 20 sec. In addition to being collocated with other PM instrumentation at the 20-m site, these samplers were located at all of the other sites in the monitoring network, including collocated samplers at the 100-m site. Study personnel rotated these samplers every 3 days. These samplers were installed to evaluate cost-effective techniques that do not require external power to identify PM_{2.5} concentration gradients.

FRM samplers collected PM_{2.5} filters at the upwind, 20-, and 300-m primary sites for gravimetric analysis to determine PM mass concentrations. These samplers collected a 23-hr average daily sample, with 1-hr filter changes beginning at 1:30 p.m. each day. A very sharp-cut cyclone inlet (VSCC; URG Corp.) was used for these samplers. The sample flow rate was 16.7 L/min through a single 47-mm filter. The flow rate was monitored and regulated by the sampler's integrated microprocessor, software, air temperature and pressure sensors, and mass flow controller. These

samplers provided reference concentrations for comparison with the other continuous and integrated monitoring techniques.

In addition to the FRMs, portable filter-based air quality samplers (Minivols) collected PM_{10} and $PM_{2.5}$ size-segregated samples at a flow rate of 5 L/min.⁴⁶ PM_{10} and $PM_{2.5}$ samplers were placed at the primary upwind and downwind monitoring sites. In addition, a collocated set of samplers was placed at the 100-m site. These samplers were rotated among the monitoring sites on a daily basis. Like the continuous portable monitors, these samplers provided cost-effective data at locations not requiring external power to assess potential $PM_{2.5}$ concentration gradients.

Multistage low-pressure impactors (LPIs) collected PM mass in 13 size fractions ranging from under $0.02 \mu m$ to greater than $10 \mu m$ in aerodynamic diameter at the upwind, 20-, and 300-m sites. In addition to mass distributions in the multiple size ranges, these samples provided particles for elemental analysis by inductively coupled plasma-mass spectrometry. The LPI located at the 20-m site collected a daily 24-hr sample at a flow rate of 30 L/min. The two LPIs located at the upwind and 300-m sites collected a 7-day sample at 10 L/min to ensure sufficient mass on each stage for the gravimetric and elemental analyses.

To assess changes in particles with changing traffic conditions, the size distributions of the PM present in the near-road environment, based on measurements at the 20-m site, were collected in near real-time using a scanning mobility particle sizer (SMPS) in conjunction with a condensation particle counter (CPC) and differential mobility analyzer (DMA) at 4 and 8 m above ground. In addition to the SMPS, an Engine Exhaust Particle Sizer (EEPS) and an aerodynamic particle sizer (APS) measured particle size distributions and number counts at the 4- and 8-m heights, as indicated in Table 1. These size-segregated samples allow for the determination of the amount and composition of particles in multiple size fractions to aid in the evaluation of the relative impact from tailpipe emissions, brake and tire wear, and re-entrained road dust.

Portable industrial hygiene monitors (P-Trak) continuously measured total particle number counts at all of the monitoring sites. This sampler operated 12 hr per day (5:30 a.m. to 5:30 p.m.) and collected 20-sec average particle number data. These samplers required the addition of alcohol to the monitors' wick after 6 hr of sampling. Alcohol changes occurred at 8:30 a.m. and 2:30 p.m. daily. Study personnel rotated these monitors every third day of sampling. Because the presence of large numbers of ultrafine particles in the near-road environment has been cited as a potential health concern, these samplers were evaluated as a cost-effective alternative to assess this parameter.

Because motor vehicles emit significant amounts of carbon particles, aethalometers measured continuous BC concentrations at the 20- and 300-m sites. These samplers operated continuously throughout the day, with daily flow calibration checks. Data were reported in 2-min averaging periods to evaluate associations with traffic activity. In addition to BC, motor vehicles emit a complex

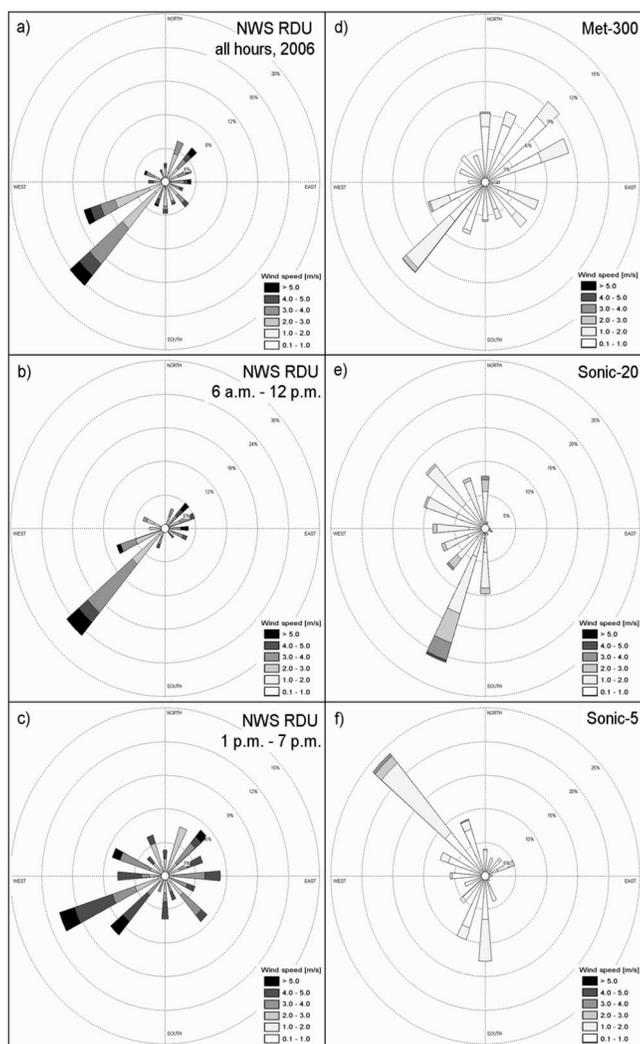


Figure 2. Wind roses: (a) NWS dsRDU airport all hours; (b) NWS RDU airport morning hours; (c) NWS RDU airport afternoon hours; (d) Met-300 station July/August 2006; (e) Sonic-20 station July/August 2006; and (f) Sonic-5 station July/August 2006.

mixture of elemental and organic compounds. One set of pre-fired 47-mm quartz fiber filters with a quartz filter backup collected a sample each day at the 20-m site at the 4- and 8-m heights, respectively, for EC and OC analysis using the National Institute for Occupational Safety and Health 5040 method.⁴⁷ A set of laboratory and field blank filters were also analyzed daily. In addition to EC/OC measurements, high volume sampling at the 20- and 300-m sites measured particulate and semi-volatile OC compounds. The high-volume sampler (Tisch Environmental) collected at a flow rate of 230 L/min for analysis of speciated organic $PM_{2.5}$ using a TE-1000 polyurethane foam (PUF) high-volume air sampler. Samples were collected daily (24-hr sampling interval) with baked quartz filters (102-mm diameter, Pall Life Sciences, TISSU-QUARTZ 2500QAT-UP). Approximately 15% of samples were collected as field blanks.

Additional high-volume samplers (ChemVol Impactor) collected large mass samples of $PM_{10-2.5}$, $PM_{2.5}$, and $PM_{0.1}$ to assess the toxicity of particles in the different size fractions. This sampler was located at the 20- and 300-m

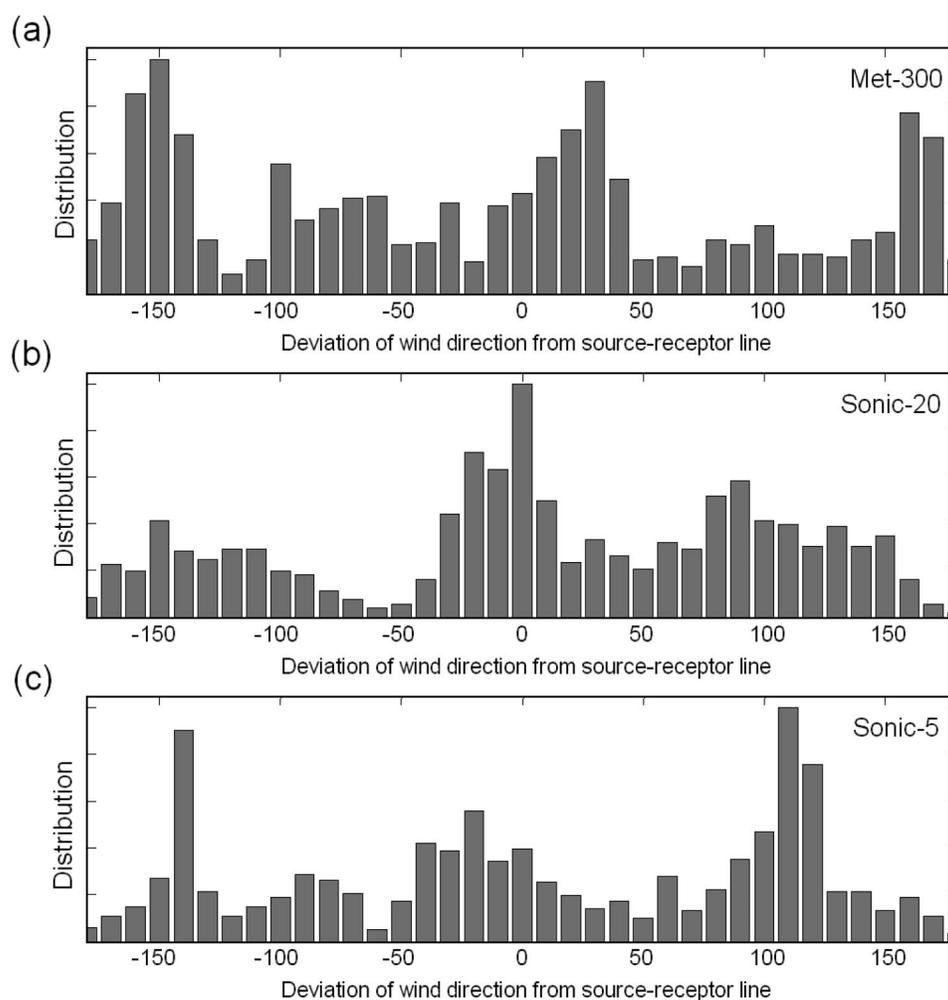


Figure 3. Distributions of wind directions at multiple stations: (a) Met-300, (b) Sonic-20, and (c) Sonic-5.

sites to evaluate potential differences in toxicity at increasing distance from the road. Samples collected for toxicity testing used PUF substrate (McMaster-Carr) for the $PM_{10-2.5}$ and $PM_{2.5}$ stages and polypropylene fiber filter (Grade 5300 medium, Monadnock Non-Wovens LLC) for $PM_{0.1}$ collection. The sampler collected at 900 L/min, so a handheld anemometer was used to ensure that this high-volume sampler did not affect airflow around the other sampling devices. Once the PM samples were extracted in methanol and the PM suspensions dried, concentrated, and diluted, mice were intratracheally instilled with samples from each size fraction. Lung lavage fluid was analyzed for signs of inflammation. Results of this work will be reported separately.

In addition to the fixed site monitoring, the Duke University mobile laboratory provided PM size distribution data at varying locations throughout the study area. A minivan equipped with a global positioning system (GPS) and PM measurement devices recorded the location and pollutant concentrations while driving over a predefined route in the vicinity of the fixed sites. Inlet air entered through a 3-m long, 0.5-in. outer diameter stainless steel pipe, with the inlet located at a 2-m height, above and in front of the driver's side of the cabin. The clocks of the instruments and the GPS were synchronized before each sampling period. The data were adjusted for

the delay time required for air to reach the instruments through the sampling line. Khylstov et al.^{48,49} provide more detail on the mobile monitoring system used in the study.

The data from the on-board instruments were combined with the location data from the GPS to produce a concentration map of the study area. The resolution of the GPS limits the spatial resolution of the measurements to approximately 7 m. For the study, two identical DMA-CPC (TSI 3071 DMA and TSI 3010 CPC) combinations provided number concentrations for 20 and 75-nm size particles. One DMA was set to a constant voltage, selecting a nearly monodisperse aerosol of 20 nm in diameter. The other DMA was set to select 75-nm particles at 10 measurements/sec (10 Hz). The particle counts were converted to the number concentration using the charging efficiency for the particles at that size. To obtain information on other particle sizes and to assess how the variability at one size compares to the variability at other sizes, a limited set of runs were made over the same route, during which one instrument sampled 20-nm particles at 10 Hz, whereas the other collected in the SMPS mode,⁵⁰ measuring the size distribution in the range of 12–300 nm with an averaging period of 20 sec.

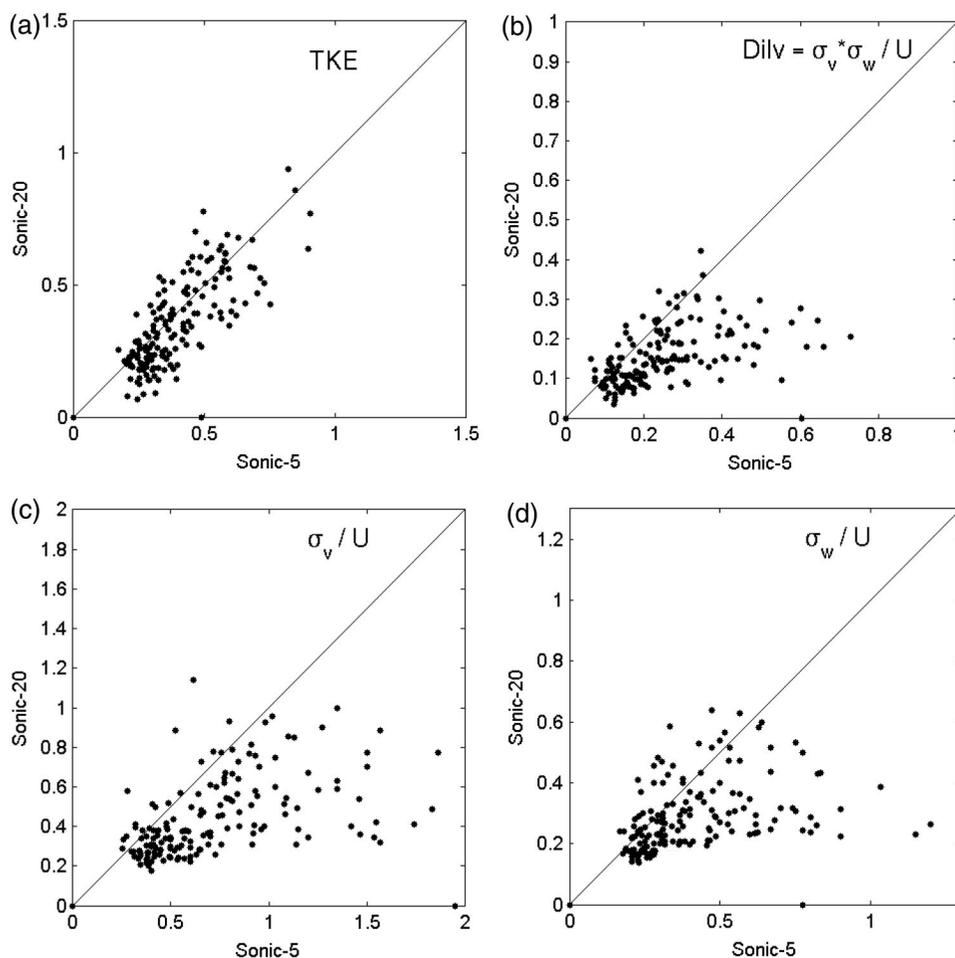


Figure 4. Comparison of (a) turbulent kinetic energy, (b) dilution velocity, (c) horizontal turbulent intensity, and (d) vertical turbulent intensities at 5- and 20-m distances from the road.

RESULTS AND DISCUSSION

The results described in this paper focus on general trends and associations between the parameters measured. The complexity of the interaction among traffic activity, environmental conditions, and air pollutant concentrations precludes a detailed assessment of all study results and analyses in this paper. Future papers will describe these complex interactions, as well as the evaluation of assessment tools to characterize these conditions.

Meteorology

Historical meteorological monitoring data collected at Raleigh-Durham (RDU) International Airport's National Weather Service (NWS) station, located approximately 13 km from the site, indicated predominant wind directions from the south and southwest for the study area (Figure 2a). The southwesterly winds typically occur during the morning hours (Figure 2b), whereas winds are more variable in the afternoon (Figure 2c).

Figure 2, d-f, shows the distribution of winds from several of the field site instruments during the study period. These figures demonstrate the local-scale variability in wind direction. Wind roses for the 300-m (Figure 2d) and 20-m (Figure 2e) sites indicate similar patterns to the RDU NWS historical data. However, measurements from the 5-m site suggest that local-scale effects, such as

vehicle-induced turbulence from the road, likely alter wind patterns adjacent to the road.

Figure 3 shows distributions of deviations of wind direction from the source-receptor line normal from the road (206°) for the following instruments: Met-300, Sonic-20, and Sonic-5. Met-300, and Sonic-20. These showed similarities in the distributions of wind direction deviations. The distributions reveal a peak within a 90° sector of normal. The distributions also show other peaks at $\pm 10^\circ$ and even at $\pm 180^\circ$. Similarly, distributions of wind direction deviations from the other two instruments, more closely located to the road, show maximum at $\pm 100^\circ$.

Significant pollutant concentrations may be observed even when the wind direction occurs outside of the 90° sector normal from the road. Venkatram et al.⁵¹ referred to disorganized transport by complex flows next to a source as upwind meandering. To understand the relative impact of meandering, turbulent intensities and wind speed are examined. The distributions of vertical and horizontal turbulent intensities (σ_v/U and σ_w/U , respectively) are shown in Figure 4 as a function of hour of day for all days of observations. The diurnal behavior of vertical and horizontal turbulent intensities was similar to that of the wind speed, with the lower values occurring during the

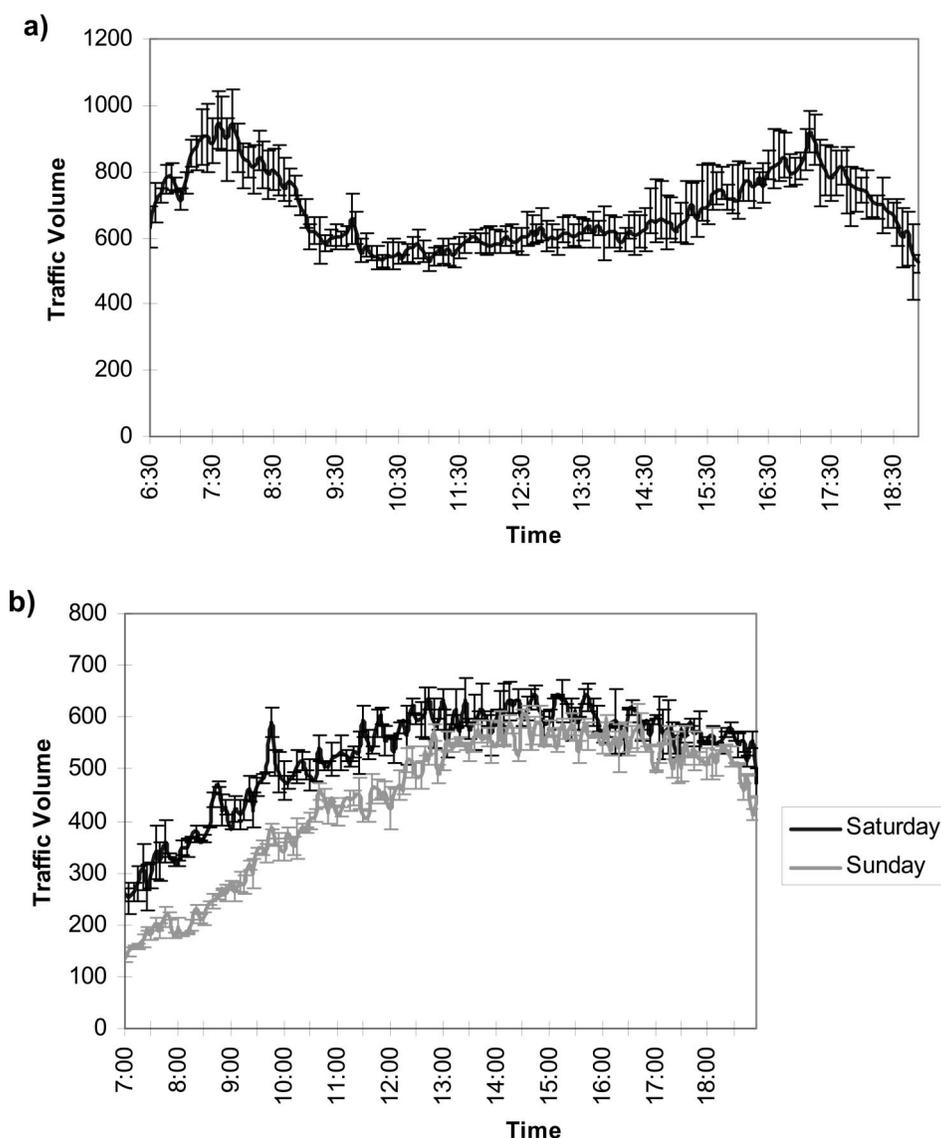


Figure 5. Average and range of 5-min traffic volumes for (a) weekdays and (b) weekends.

morning and the higher values occurring during the afternoon.

The horizontal turbulent intensities, σ_v/U , varied from 0.1 to 1 during the course of the day, with large values, exceeding 1.5, occurring between 12:00 and 5:00 p.m. The majority of the vertical turbulent intensities, σ_w/U , were between 0.2 and 0.6. The meteorological observations indicated that turbulence near the road was significant; therefore, both direct transport by the mean wind and turbulent diffusion likely impacted pollutant concentrations and dispersion near the road. Generally, weekend days during the study had few time periods with winds from the south.

Traffic Characterization

Traffic activity data indicated that motor vehicle volumes on the highway during the study reflected typical urban traffic patterns. As shown in Figure 5, elevated traffic volumes occurred during morning and evening rush hour time periods during weekdays. Traffic activity generally

decreased on weekend days, especially during the morning hours, with Sunday mornings experiencing slightly lower traffic volumes than Saturday mornings. The percentage of heavy-duty trucks operating on the road also varied between weekdays (average truck percentage of 5%) and weekends (average truck percentage of 2%), with these percentages generally remaining constant during daylight hours.

Daily visual counts of 15-min averaging periods during morning rush hour, afternoon, and evening rush hour conditions on select study days provided an assessment of the precision and accuracy of the software output. A comparison of software and visual traffic counts resulted in a correlation coefficient (r^2) value of 0.97 for total traffic count ($C_a = 1.27C_s$ where C_a is the actual vehicle count and C_s is the count from the software program; $n = 13$). A comparison of vehicle classes resulted in a correlation of 0.97 ($C_a = 1.31C_s$) for light-duty passenger cars, trucks, and motorcycles and 0.60 ($C_a = 0.92C_s$) for heavy-duty trucks. Although the software counts provided a good

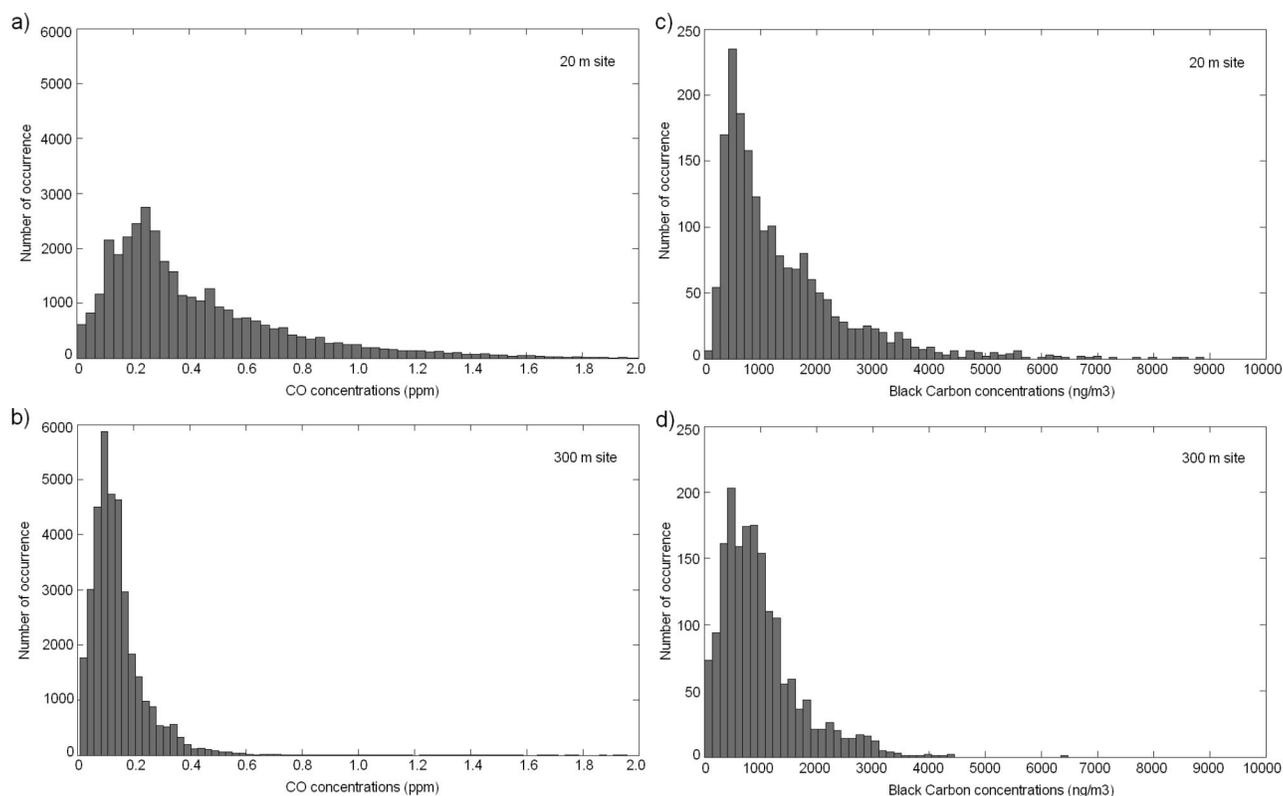


Figure 6. Distribution of (a and b) CO and (c and d) BC concentrations measured at (a and c) 20 m and (b and d) 300 m from the road during the study period.

indication of the trend in the total traffic counts, the software undercounted the actual number of vehicles on the road. Further analysis of the video revealed that this discrepancy likely resulted from the angle of the camera display. During several instances, a large truck in a lane closer to the video camera obstructed the view of passenger cars in more distant lanes. In addition, if two or more passenger cars appeared next to each other in the video, whether in adjacent or the same travel lanes, the software program often misclassified these vehicles as one truck. These factors led to an overcount of heavy-duty trucks and an undercount of light-duty vehicles. Because light-duty vehicles dominated the number of vehicles in the fleet at this location, these factors led to a general underestimate of the total traffic volume. In addition, the precision and accuracy of the vehicle counts and fleet characterization generally decreased as the distance from the camera to the travel lane increased. Future studies will place the camera as close to the center of the highway as possible to limit this effect. For this initial assessment of the software, the accuracy and precision of the speed component of the software was not assessed. Traffic volumes shown in these results were corrected by the total count regression equations.

Air Quality Measurements

Results from the air quality measurements demonstrated the general relationship between meteorology, traffic emissions, and pollutant concentrations near the road. For a general assessment of the spatial and temporal impacts from traffic emissions, CO and BC were used to represent primary gas and particulate tailpipe emissions

from motor vehicles. Figure 6, a and b, presents the distribution of 20-sec average weekday CO and BC concentrations, respectively, measured 20 and 300 m from the road during the study. The data include all wind directions and hours of the day during the study for each respective pollutant. As seen in the figure, the frequency of elevated CO and BC concentration measurements increased at the 20-m site compared with the 300-m site. At the 20-m site, the maximum CO measurement was 3.92 ppm and the median measurement was 0.25 ppm. The maximum and median CO concentrations at the 300-m site were 2.97 and 0.12 ppm, respectively. The maximum and median BC measurement at the 20-m site were 13,420 and 1014 ng/m³, respectively, with maximum and median BC concentrations at the 300-m site of 6479 and 824 ng/m³, respectively.

Figure 6 suggests that more pronounced long-term differences occurred for CO than BC concentrations between the two sites. The fairly low volume of heavy-duty trucks on I-440 during the study may explain these results. Although all motor vehicles emit BC, heavy-duty diesel trucks do tend to emit more on a per vehicle basis. Lower fleet-averaged emission rates due to the lower volume of heavy-duty trucks may have resulted in a smaller difference in BC concentrations as compared with CO concentrations.

The temporal variability of CO and BC concentrations also reflected the influence of traffic emissions and meteorological conditions on near-road air quality. Figure 7 shows a time-series comparison of CO and BC concentrations with wind direction data for a specific day (August 7, 2006). Figure 7 shows elevated CO and BC concentrations during

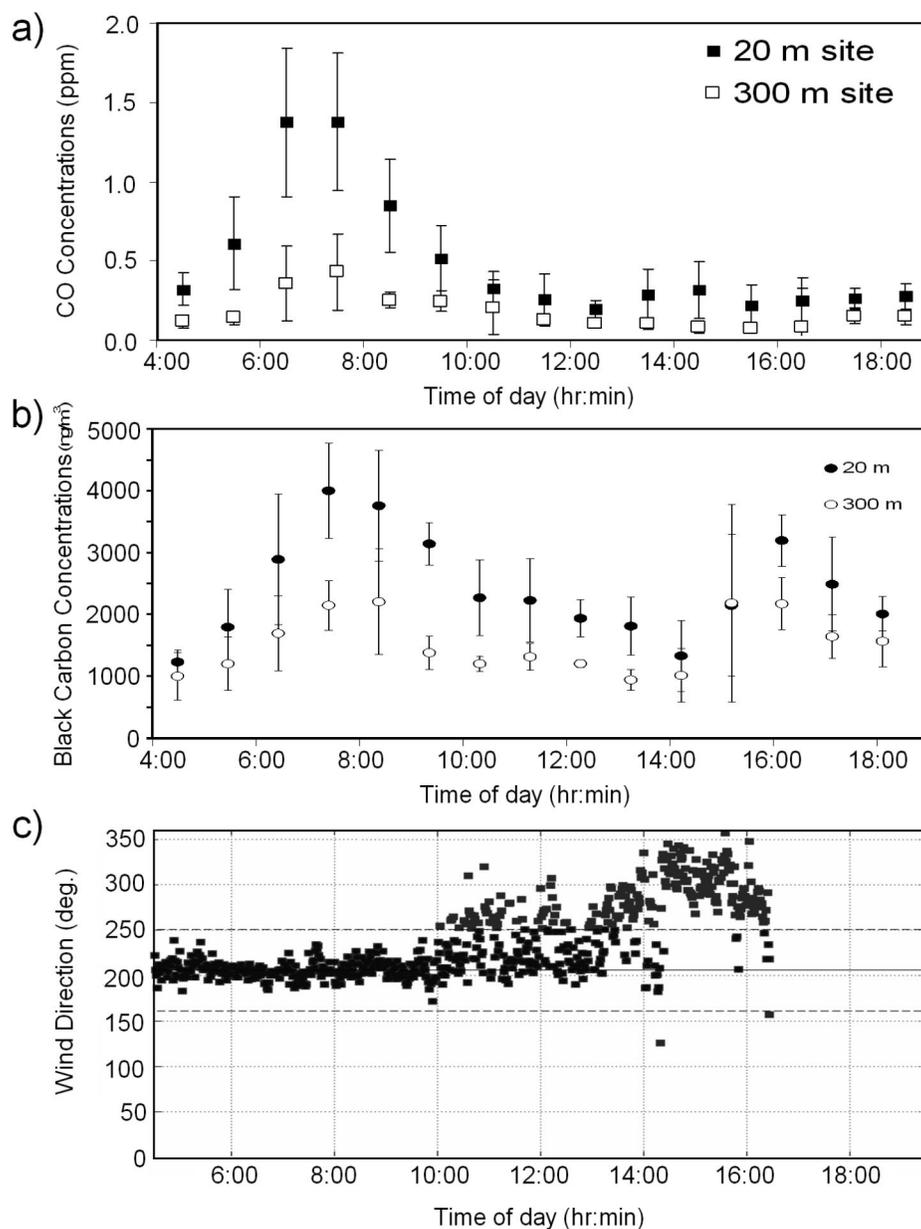


Figure 7. Comparison of (a) CO and (b) BC hourly average pollutant concentrations and measurement standard deviations by distance from the road on August 7, 2006. Panel c shows the 1-min average wind speed and direction profiles for this day on the basis of measurements from Sonic-20.

time periods with elevated traffic activity as well as winds from the road (during morning rush hour). When the wind direction reversed away from the road, concentrations generally decreased (during afternoon rush hour).

Figure 7 also shows the concentration differences between the 20- and 300-m sites. Significant differences occurred during morning rush hours with winds from the road; however, the figure also indicates that higher pollutant concentrations still occurred near the road during the afternoon rush hour even when the winds were not from the road. These elevated concentrations may have resulted from elevated background concentrations, but the increased concentrations at the 20-m site suggest that local traffic activity may also be impacting pollutant concentrations near the road because of the meandering effect previously described.

Figure 8 highlights the complex mixture of pollutants present in the near-road microenvironment. This figure contains time-resolved (30-sec moving average) plots for a specific sampling day (August 3, 2006) for NO, CO, ammonia, benzene, and naphthalene measured with some of the advanced instrumentation described in this paper. Figure 8a shows that morning rush hour winds were from the road (denoted by the line at 206°, which is perpendicular to the road), whereas afternoons varied. The combinations of traffic activity and wind patterns resulted in similarly elevated concentrations of multiple pollutants during this day. The figure shows a general temporal agreement among these inert and reactive compounds, with maximum concentrations occurring during peak traffic activity and winds from the road during the morning rush hour. These time-resolved measurements also

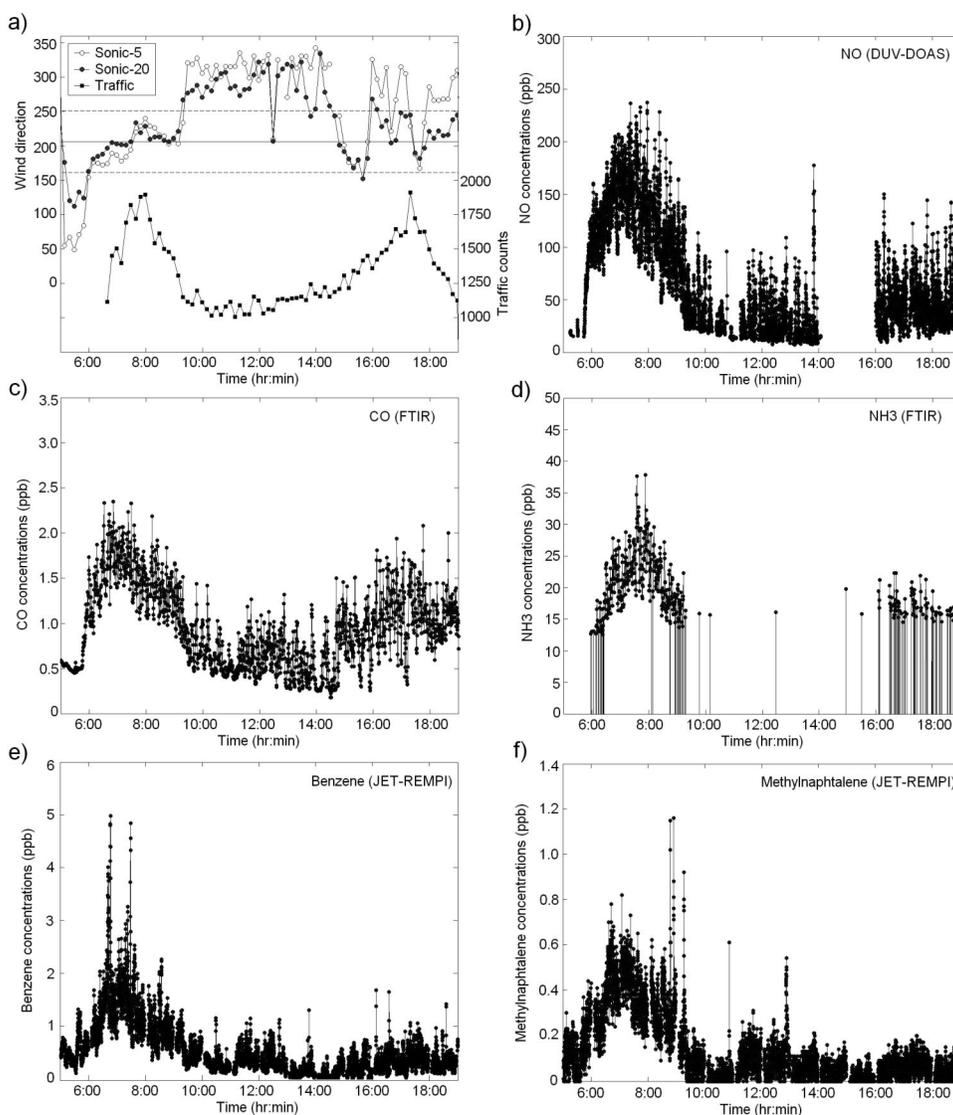


Figure 8. Comparison of measurements from DUV-DOAs, FTIR, and Jet-REMPI for August 3, 2006 for (a) wind direction, (b) NO, (c) CO, (d) NH₃, (e) benzene, and (f) methylnaphthalene.

indicated a high degree of temporal variability in near-road gaseous pollutant concentrations. Additional information on time-resolved measurements from this study, in addition to the time-dependent effects of wind parameters and traffic activity on near-road concentrations will be provided in future publications.

Although the fixed site monitoring provided information on the temporal and spatial variation of pollutant concentrations in one dimension away from the highway, the mobile monitoring van provided two-dimensional spatial variability in pollutant concentrations. Figure 9 shows the route driven by the van (Figure 9a) with corresponding concentration measurements of a single particle size (aerodynamic diameter of 20 nm; Figure 9b) with winds directionally from the road. The locations of maximum concentration occurred when the van was driven on the access road with no noise barrier present between the road and I-440. Particle concentrations decreased during this portion of the route driven behind the noise barrier. This figure also shows a decrease in particle concentrations as the van drove away from the highway. The

results from the monitoring van demonstrated the spatial variability of particle concentrations with distance from the road, as well as the potential influence of roadside structures on ambient pollutant concentrations. A quantitative assessment of the decrease in pollutant concentrations behind the noise barrier will be examined in future publications.

SUMMARY

This paper summarized a field study in Raleigh, NC, that integrated multiple measurement techniques to assess the spatial and temporal variability of a complex mixture of pollutants present in a near-road microenvironment. This study integrated several novel monitoring techniques to provide new insights on the impact of motor vehicle emissions on near-road air quality and adverse health effects, including the following items.

- Real-time traffic and meteorological monitoring to assess the relationship of these factors on near-road air quality and impacts.

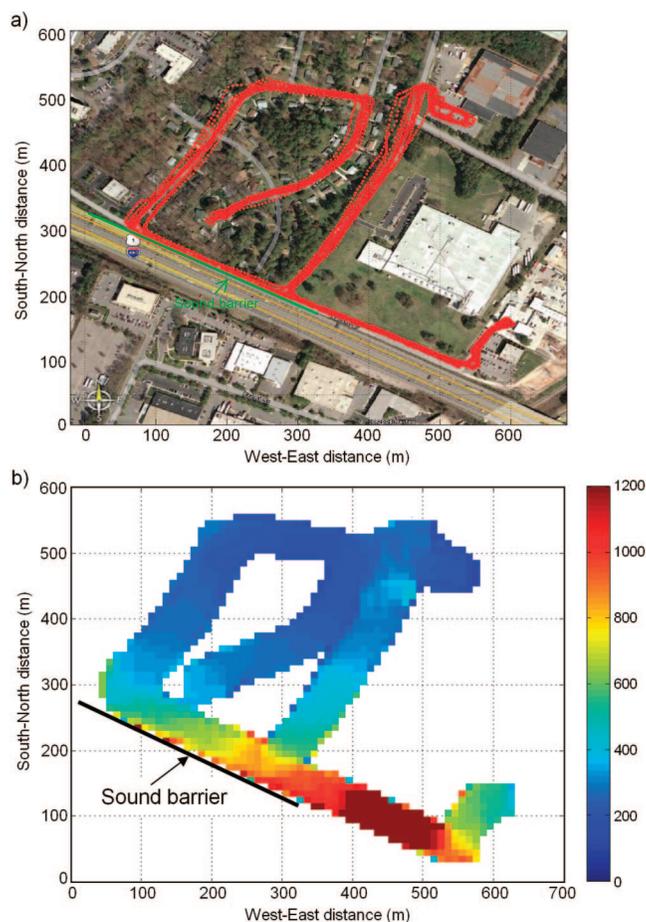


Figure 9. (a) Map of the route driven by the mobile monitoring van with (b) corresponding 20-nm size particle number concentrations as a function of distance. The approximate location of the sound barrier is shown.

- Multipollutant and highly time-resolved measurements to evaluate the complex mixture and variability of pollutants present near roads.
- Multilocation measurements, including mobile sampling, to identify the spatial zone of influence of motor vehicle-emitted pollutants.
- Presence of roadside barriers and open terrain along the same stretch of limited-access highway to analyze the effect these structures have on air transport and pollutant concentrations.

Results presented in this paper demonstrated the general air quality impacts of traffic emissions on the nearby highway and the relationship of these impacts to meteorological conditions. The data indicated that overall concentrations of known mobile source emitted gaseous (CO) and particulate (BC) pollutants were elevated near the road, and the concentrations of these pollutants generally increased with increasing traffic activity. The data also revealed a complex mixture of pollutants present near the road that followed this same general diurnal pattern, suggesting that populations spending significant amounts of time near a large roadway are subject to elevated concentrations of multiple air contaminants. In addition, elevated concentrations near the road did not occur only when winds were coming from the road, suggesting that pollutant meandering may contribute to the elevated exposures experienced near a

road. Mobile monitoring results suggested that the presence of roadside structures, such as noise barriers, do affect air pollutant concentrations in the vicinity of the structure. Data from this study suggest a significant decrease in pollutant concentrations immediately behind the barrier with winds from the roadway.

ACKNOWLEDGMENTS

This work reflects the collaboration of many individuals working with the EPA near-road program. In particular, the authors thank Doug McKinney, Dave Kryak, and Bill Russo of EPA's Office of Research and Development for their assistance in identifying, organizing, and implementing the near-road research program. The authors also thank the North Carolina Lions Club for the Blind for access to portions of the field site used in this study.

Disclaimer: This article has been reviewed by EPA's Office of Research and Development and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the agency nor does mention of trade names or commercial products constitute endorsement or recommendation for use. The research presented here was performed under the Memorandum of Understanding between EPA and the U.S. Department of Commerce's National Oceanic and Atmospheric Administration (NOAA) and under agreement number DW13921548. This work constitutes a contribution to the NOAA Air Quality Program. Although it has been reviewed by EPA and NOAA and approved for publication, it does not necessarily reflect their policies or views. The U.S. Government right to retain a nonexclusive royalty-free license in and to any copyright is acknowledged.

REFERENCES

1. Brunekreef, B.; Janssen, N.A.H.; de Hartog, J.; Harssema, H.; Knape, M.; van Vliet, P. Air Pollution from Truck Traffic and Lung Function in Children Living near Motorways; *Epidemiol.* **1997**, *8*, 298-303.
2. English, P.; Neutra, R.; Scaif, R.; Sullivan, M.; Waller, L.; Zhu, L. Examining Associations between Childhood Asthma and Traffic Flow Using a Geographic Information System; *Environ. Health Perspect.* **1999**, *107*, 761-767.
3. Brauer, M.; Hoek, G.; Van Vliet, P.; Meliefste, K.; Fishcer, P.H.; Wijga, A.; Koopman, L.P.; Neijens, H.J.; Gerritsen, J.; Kerkhof, M.; Heinrich, J.; Bellander, T.; Brunekreef, B. Air Pollution from Traffic and the Development of Respiratory Infections and Asthmatic and Allergic Symptoms in Children; *Am. J. Respir. Crit. Care Med.* **2002**, *166*, 1092-1098.
4. Delfino, R.J. Epidemiologic Evidence for Asthma and Exposure to Air Toxics: Linkages between Occupational, Indoor, and Community Air Pollution Research; *Environ. Health Perspect.* **2002**, *110*(Suppl 4), 573-589.
5. Kim, J.J.; Smorodinsky, S.; Ostro, B.; Lipsett, M.; Singer, B.C.; Hodgson, A.T. Traffic-Related Air Pollution and Respiratory Health: the East Bay Children's Respiratory Health Study; *Epidemiol.* **2002**, *13*, S100.
6. Garshick, E.; Laden, F.; Hart, J.E.; Caron, A. Residence near a Major Road and Respiratory Symptoms in U.S. Veterans; *Epidemiol.* **2003**, *14*, 728-736.
7. Janssen, N.A.H.; van Vliet, P.H.N.; Aarts, F.; Harssema, H.; Brunekreef, B. Assessment of Exposure to Traffic Related Air Pollution of Children Attending Schools near Motorways; *Atmos. Environ.* **2002**, *35*, 3875-3884.
8. Gauderman, W.J.; Avol, E.; Lurmann, F.; Kuenzli, N.; Gilliland, F.; Peters, J.; McConnell, R. Childhood Asthma and Exposure to Traffic and Nitrogen Dioxide; *Epidemiol.* **2005**, *16*, 737-743.
9. Heinrich, J.; Topp, R.; Gehring, U.; Thefeld, W. Traffic at Residential Address, Respiratory Health, and Atopy in Adults: the National German Health Survey 1998; *Environ. Res.* **2005**, *98*, 240-249.
10. McConnell, R.; Berhane, K.; Yao, L.; Jerrett, M.; Lurmann, F.; Gilliland, F.; Kuenzli, N.; Gauderman, J.; Avol, E.; Thomas, D.; Peters, J. Traffic, Susceptibility, and Childhood Asthma; *Environ. Health Perspect.* **2006**, *114*, 766-772.
11. Ritz, B.; Yu, F. The Effect of Ambient Carbon Monoxide on Low Birth Weight among Children Born in Southern California between 1989 and 1993; *Environ. Health Perspect.* **1999**, *107*, 17-25.

12. Ritz, B.; Yu, F.; Chapa, G.; Fruin, S. Effect of Air Pollution on Preterm Birth among Children Born in Southern California between 1989 and 1993; *Epidemiol.* **2000**, *11*, 502-511.
13. Gehring, U.; Cyrus, J.; Sedlmeir, G.; Brunedreef, B.; Belander, T.; Fischer, T.; Bauer, C.P.; Reinhardt, D.; Wichmann, H.E.; Heinrich, J. Traffic-Related Air Pollution and Respiratory Health during the First Two Years of Life; *Eur. Respir. J.* **2002**, *19*, 690-698.
14. Wilhelm, M.; Ritz, B. Residential Proximity to Traffic and Adverse Birth Outcomes in Los Angeles County, California, 1994-1996; *Environ. Health Perspect.* **2003**, *111*, 207-216.
15. Mannes, T.; Jalaludin, B.; Morgan, G.; Lincoln, D.; Sheppard, V.; Corbett, S. Impact of Ambient Air Pollution on Birth Weight in Sydney, Australia; *Occup. Environ. Med.* **2005**, *62*, 524-530.
16. Laden, F.; Neas, L.M.; Dockery, D.W.; Schwartz, J. Association of Fine Particulate Matter from Different Sources with Daily Mortality in Six U.S. Cities; *Environ. Health Perspect.* **2000**, *108*, 941-947.
17. Hoek, G.; Brunekreef, B.; Goldbohm, S.; Fischer, P.; van den Brandt, P.A. Association between Mortality and Indicators of Traffic-Related Air Pollution in the Netherlands: a Cohort Study; *Lancet* **2002**, *360*, 1203-1209.
18. Finkelstein, M.M. Mortality and Indicators of Traffic-Related Air Pollution; *Lancet* **2003**, *361*, p 430 (author reply).
19. Finkelstein, M.M.; Jerrett, M.; Sears, M.R. Traffic Air Pollution and Mortality Rate Advancement Periods; *Am. J. Epidemiol.* **2004**, *160*, 173-177.
20. Jerrett, M.; Burnett, R.; Pope, C.A., 3rd; Krewski, D.; Newbold K.B.; Thurston, G.; Shi, Y.; Finkelstein, N.; Calle, E.E.; Thun, M.J. Spatial Analysis of Air Pollution and Mortality in Los Angeles; *Epidemiol.* **2005**, *16*, 727-736.
21. Peters, A.; von Klot, S.; Heier, M.; Trentinaglia, I.; Hormann, A.; Wichmann, E.; Lowel, H. Exposure to Traffic and the Onset of Myocardial Infarction; *New Engl. J. Med.* **2004**, *351*, 1721-1730.
22. Riediker, M.; Cascio, W.E.; Griggs, T.R.; Herbst, M.C.; Bromber, P.A.; Neas, L.; Williams, R.; Devlin, R.B. Particulate Matter Exposure in Cars Is Associated with Cardiovascular Effects in Healthy, Young Men; *Am. J. Respir. Crit. Care Med.* **2004**, *169*, 934-940.
23. Schwartz, J.; Litonjua, L.; Suh, H.; Verrier, M.; Zanobetti, A.; Syring, M.; Nearing, B.; Verrier, R.; Stone, P.; MacCallum, G.; Speizer, F.E.; Gold, D.R. Traffic Related Pollution and Heart Rate Variability in a Panel of Elderly Subjects; *Thorax* **2005**, *60*, 455-461.
24. Knox, E.G.; Gilman, E.A. Hazard Proximities of Childhood Cancers in Great Britain from 1953-1980; *J. Epidemiol. Commun. Health* **1997**, *51*, 151-159.
25. Harrison, R.M.; Leung, P.L.; Somerville, L. Analysis of Incidence of Childhood Cancer in the West Midlands of the United Kingdom in Relation to Proximity of Main Roads and Petrol Stations; *Occup. Environ. Med.* **1999**, *56*, 774-780.
26. Pearson, R.L.; Wachtel, H.; Ebi, L. Distance-Weighted Traffic Density in Proximity to a Home Is a Risk Factor for Leukemia and Other Childhood Cancers; *J. Air & Waste Manage. Assoc.* **2000**, *50*, 175-180.
27. Harrison, R.M.; Tilling, R.; Callen Romero, M.S.; Harrad, S.; Jarvis, K. A Study of Trace Metals and Polycyclic Aromatic Hydrocarbons in the Roadside Environment; *Atmos. Environ.* **2003**, *37*, 2391-2402.
28. Reponen, T.; Grinshpun, S.A.; Trakumas, S.; Martuzevicius, D.; Wang, Z.-M.; LeMasters, G.; Lockey, J.E.; Biswas, P. Concentration Gradient Patterns of Aerosol Particles near Interstate Highways in the Greater Cincinnati Airshed; *J. Environ. Monit.* **2003**, *5*, 557-562.
29. Sapkota, A.; Buckley, T.J. The Mobile Source Effect on Curbside 1,3-Butadiene, Benzene, and Particle-Bound Polycyclic Aromatic Hydrocarbons Assessed at a Tollbooth; *J. Air & Waste Manage. Assoc.* **2003**, *53*, 740-748.
30. Kim, J.J.; Smorodinsky, S.; Lipsett, M.; Singer, B.C.; Hogsdon, A.T.; Ostro, B. Traffic-Related Air Pollution near Busy Roads: the East Bay Children's Respiratory Health Study; *Am. J. Respir. Crit. Care Med.* **2004**, *170*, 520-526.
31. Giugliano, M.; Lonati, G.; Butelli, P.; Romeo, L.; Tardivo, R.; Grosso, M. Fine Particulate (PM_{2.5}-PM₁) at Urban Sites with Different Traffic Exposure; *Atmos. Environ.* **2005**, *39*, 2421-2431.
32. Weisel, C.P.; Zhang, J.; Turpin, B.J.; Morandi, M.T.; Colome, S.; Stock, T.H.; Spector, D.M. *Relationships of Indoor, Outdoor, and Personal Air (RIOPA), Part I Collection Methods and Descriptive Analyses Assessment of the Contribution to Personal Exposures of Air Toxics from Mobile Sources*; Final Report to Health Effects Institute; Research Report 130/NUATRC Report 7; 2005.
33. Pirjola, L.; Paasonen, P.; Pfeiffer, D.; Hussein, T.; Hameri, K.; Koskentalo, T.; Virtanen, A.; Ronkko, T.; Keskinen, J.; Pakkanen, T.A.; Hillamo, R.E. Dispersion of Particles and Trace Gases nearby a City Highway: Mobile Laboratory Measurements in Finland; *Atmos. Environ.* **2006**, *40*, 867-879.
34. Hitchins, J.; Morawska, L.; Wolff, R.; Gilbert, D. Concentrations of Submicrometre Particles from Vehicle Emissions near a Major Road; *Atmos. Environ.* **2000**, *34*, 51-59.
35. Zhu, Y.; Hinds, W.C.; Kim, S.; Shen, S.; Sioutas, C. Study of Ultrafine Particles near a Major Highway with Heavy-Duty Diesel Traffic; *Atmos. Environ.* **2002**, *36*, 4323-4335.
36. Zhu, Y.; Hinds, W.C.; Kim, S.; Sioutas, C. Concentration and Size Distribution of Ultrafine Particles near a Major Highway; *J. Air & Waste Manage. Assoc.* **2002**, *52*, 1032-1042.
37. Kittelson, D.B.; Watts, W.F.; Johnson, J.P. Nanoparticle Emissions on Minnesota Highways; *Atmos. Environ.* **2004**, *38*, 9-19.
38. Zhang, K.M.; Wexler, A.S.; Zhu, Y.F.; Hinds, W.C.; Sioutas, C. Evolution of Particle Number Distribution near Roadways. Part II: the 'Road-to-Ambient' Process; *Atmos. Environ.* **2004**, *38*, 6655-6665.
39. Russwurm, G.M. Compendium Method T0-16 Long-Path Fourier Transform Infrared Monitoring of Atmospheric Gases; EPA/625/R-96/010b; U.S. Environmental Protection Agency: Center for Environmental Research Information, Office of Research and Development: Cincinnati, OH, 1999.
40. *Standard Guide for Open-Path Fourier Transform Infrared (OP/FT-IR) Monitoring of Gases and Vapors in Air. 2002 ASTM Standard Designation E 1865-97*; American Society for Testing and Materials: West Conshohocken, PA, 2002.
41. Thoma, E.D.; Thompson, E.L.; Shores, R.C.; Harris, D.B. Measurement of Low Level Air Toxics with Modified UV DOAS. In *Proceedings of the 99th Annual Conference of the Air & Waste Management Association*; A&WMA: Pittsburgh, PA, 2006; Paper AO-1b-270.
42. Thoma, E.D.; Shores, R.; Isakov, V.; Baldauf, R.W. Characterization of Near-Road Pollutant Gradients Using Path-Integrated Optical Remote Sensing; *J. Air & Waste Manage. Assoc.* **2008**, *58*, 879-890.
43. Platt, U. In *Air Monitoring by Spectroscopic Techniques*; Sigrist, M, Ed.; Wiley: New York, 1994; pp 27-84.
44. Oudejans, L.; Touati, A.; Gullett, B. Real-Time, On-Line Characterization of Diesel Generator Air Toxic Emissions by Resonance Enhanced Multi-Photon Ionization Time of Flight Mass Spectrometry; *Anal. Chem.* **2004**, *76*, 2517-2524.
45. Kinsey, J.S.; Linna, K.J.; Squier, W.C.; Muleski, G.E.; Cowherd, C., Jr. Characterization of Fugitive PM_{2.5} Emissions from Construction Mud/Dirt Carryout; *J. Air & Waste Manage. Assoc.* **2004**, *54*, 1394-1404.
46. Baldauf, R.W.; Lane, D.D.; Marotz, G.A.; Wiener, R.W. Performance Evaluation of the Portable MiniVol Particulate Matter Sampler; *Atmos. Environ.* **2001**, *35*, 6087-6091.
47. Birch, M.E.; Cary, R.A. Elemental Carbon-Based Method for Monitoring Occupational Exposures to Particulate Diesel Exhaust; *Aerosol Sci. Technol.* **1996**, *25*, 221-241.
48. Khlystov, A.; Stanier, C.; Pandis, S.N. An Algorithm for Combining Electrical Mobility and Aerodynamic Size Distributions Data when Measuring Ambient Aerosol; *Aerosol Sci. Technol.* **2004**, *38*, 229-238.
49. Khlystov, A.; Ma, Y. An On-Line Instrument for Mobile Measurements of the Spatial Variability of Hexavalent and Trivalent Chromium in Urban Air; *Atmos. Environ.* **2006**, *40*, 8088-8093.
50. Wang, S.C.; Flagan, R.C. Scanning Electrical Mobility Spectrometer; *Aerosol Sci. Technol.* **1990**, *13*, 230-240.
51. Venkatram, A.; Isakov, V.; Yuan, J.; Pankratz, D. Modeling Dispersion at Distances of Meters from Urban Sources; *Atmos. Environ.* **2004**, *38*, 4633-4641.

About the Authors

This project represented a broad collaboration among EPA and academic researchers to identify key measurement techniques useful in describing the complex relationships of traffic, meteorology, and air quality near a large roadway. Researchers from EPA's Office of Research and Development represented the National Risk Management Research Laboratory, the National Exposure Research Laboratory, and the National Health Effects and Environmental Research Laboratory in Research Triangle Park, NC. Several scientists from EPA's Office of Air and Radiation also participated in the study. In addition to EPA researchers, Vlad Isakov is a scientist with the National Oceanographic and Atmospheric Administration, Atmospheric Sciences Modeling Division working in partnership with the EPA in Research Triangle Park, NC. Andrey Khlystov is an assistant professor at Duke University's Pratt School of Engineering in the Department of Civil and Environmental Engineering located in Durham, NC. John Bang is also an assistant professor in North Carolina Central University's Department of Environmental Sciences located in Durham, NC. Please address correspondence to: Rich Baldauf, EPA, 109 TW Alexander Drive, E343-02, Research Triangle Park, NC 27711; phone: +1-919-541-4386; fax: +1-919-541-0359; e-mail: baldauf.richard@epa.gov.