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On-road black carbon instrument intercomparison and aerosol characteristics by driving environment

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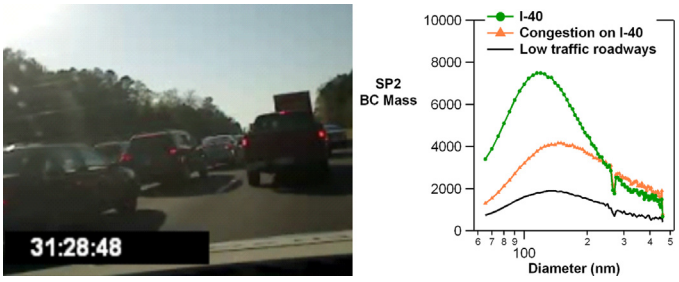
HIGHLIGHTS

- BC instruments correlated well at high time resolution.
- Fresh emissions had a much smaller BC peak diameter than aged particles.
- BC emissions during stop-and-go traffic were lower than normal highway driving.

GRAPHICAL ABSTRACT



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ABSTRACT

Large spatial variations of black carbon (BC) concentrations in the on-road and near-road environments necessitate measurements with high spatial resolution to assess exposure accurately. A series of measurements was made comparing the performance of several different BC instruments (Single Particle Soot Photometer, Photo-Acoustic Soot Spectrometer, and Aethalometer) for high time resolution mobile measurements, capable of mapping spatial gradients. All instruments were highly correlated at high time resolution (r^2 = 0.80–0.89 at a 2-s resolution), however the slope ranged from 0.52 to 1.03, with the Single Particle Soot Photometer (SP2) consistently reporting the lowest BC concentrations. BC and ultrafine particle (UFP) concentrations were two-fold higher on the highway compared to surrounding roads with lower traffic counts. The BC size distribution had a mass median diameter of approximately 120 nm, which was smaller and less coated than aged urban BC. Mean UFP and BC concentrations were 2 and 1.4 times greater, respectively, during free flowing traffic on the highway compared with times when there was stop-and-go congestion, providing evidence that transit time is not a good predictor of BC or UFP exposure.

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1. Introduction

The transportation sector is currently the dominant source of black carbon (BC) emissions in the United States, contributing 52% to the total mass emissions (Lamarque et al., 2010). In urban areas, where the majority of BC emissions occur, 67% of BC concentrations are estimated to be attributable to diesel vehicles and 20% to gasoline vehicles (Lambe et al., 2009). As a marker for combustion-generated pollutants, BC has been associated with adverse health effects in epidemiology studies (Janssen et al., 2012, 2011). Additionally, BC is considered a short-term climate forcer that may have an important impact on climate change, as it is an efficient absorber of solar radiation (Ramanathan and Carmichael, 2008). With potential impacts on clouds and snow and ice-covered areas, BC is

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Abbreviations

AE-42	Aethalometer
BC	black carbon
EEPS	engine exhaust particle sizer
MAC	mass specific absorption coefficient
LII	laser induced incandescence
ONA	optimized noise averaging
PASS-3	3 wavelength photoacoustic soot spectrometer
RMS	root mean square
SP2	single particle soot spectrometer
UFP	ultrafine particle

estimated to contribute +1.1 (with upper and lower bounds of +0.17 to +2.1) W m^{-2} of warming (Bond et al., 2013).

Nearly 30% of the inhaled dose of BC can be attributed to time spent during commuting (Dons et al., 2012). However, travel time is not a good predictor of dose, probably due to the highly variable traffic patterns and thus variable spatial distribution (Dons et al., 2012). For example, increased particle exposure has been associated with increased traffic count (Kaur et al., 2007), and increased in-cabin particle concentrations were associated with increased number of stops and decreased vehicle speed (Alm et al., 1999). Due to the large spatial variability of pollutants in the near-road environment and these impacts on personal exposures and thus health effects, high spatial resolution measurements of ambient particles on mobile measurement platforms have become more common. Measurements have been made of the spatial distribution of BC and particle concentration on roadways (Westerdahl et al., 2005), downwind of roadways (Hagler et al., 2010), and downwind of roadways with various barriers (Hagler et al., 2012). On-road mobile measurements have been used to determine the impacts of different conditions (e.g., road type, vehicle type, vehicle conditions) on ultrafine particle (UFP) emissions (Fruin et al., 2008; Wehner et al., 2009). However, similar measurements of BC emissions have been limited by instruments with slow time response or only a few conditions investigated (Park et al., 2011; Zavala et al., 2009).

Sampling in the on-road environment poses several challenges for BC measuring instruments. Instruments need to be capable of rapid sampling (<10 s), portable, accurate over several orders of magnitude in concentration, and have the ability to withstand a sampling environment subject to vibration and noise. Previous comparisons of BC measurements have been carried out at stationary ambient monitoring sites (Chow et al., 2009; Kondo et al., 2011) and did not assess all the factors that impact mobile measurements. Liggio et al. (2012) recently carried out an on-road BC comparison, but this study was limited to two laser induced incandescence (LII) instruments, and there was no assessment of how the instruments responded at high time resolution. At present, there has not been a full assessment of multiple BC measurement methods in the on-road environment.

The objective of this study was to assess the ability of several high time resolution instruments to capture on-road BC concentrations. An additional objective was to use these measurements to characterize aerosol characteristics: particle size distribution, BC concentration, and optical properties in a variety of different driving environments. Measurements were made onboard an electric vehicle operated in a variety of traffic environments and vehicle operating conditions including morning and afternoon rush hour, stop-and-go congestion, a heavily traveled intersection, and lightly traveled secondary roads.

2. Methods

2.1. Mobile measurement platform

Measurements of BC mass concentration, aerosol absorption, and size distribution were made on-road in and around Research Triangle Park, NC, in April of 2010. Instruments were securely installed onboard a converted all electric PT Cruiser (Hybrid Technologies) outfitted with a GPS (Hemisphere GPS Inc.) and a windshield-mounted video camera as described by Hagler et al. (2010). Ambient air was sampled through a forward facing isokinetic inlet (at 15.6 m s^{-1}) located on the rear passenger window. The sample was split between the instruments using a flow splitter and transmitted to each particle measuring instrument through conductive silicone tubing.

The vehicle was driven on a route including a major highway, Interstate 40 (I-40), as well as several nearby arterial roads to capture different road types (Fig. 1). These varying roadways and driving conditions were chosen to represent an array of driving patterns: a background section with low traffic counts, a heavily

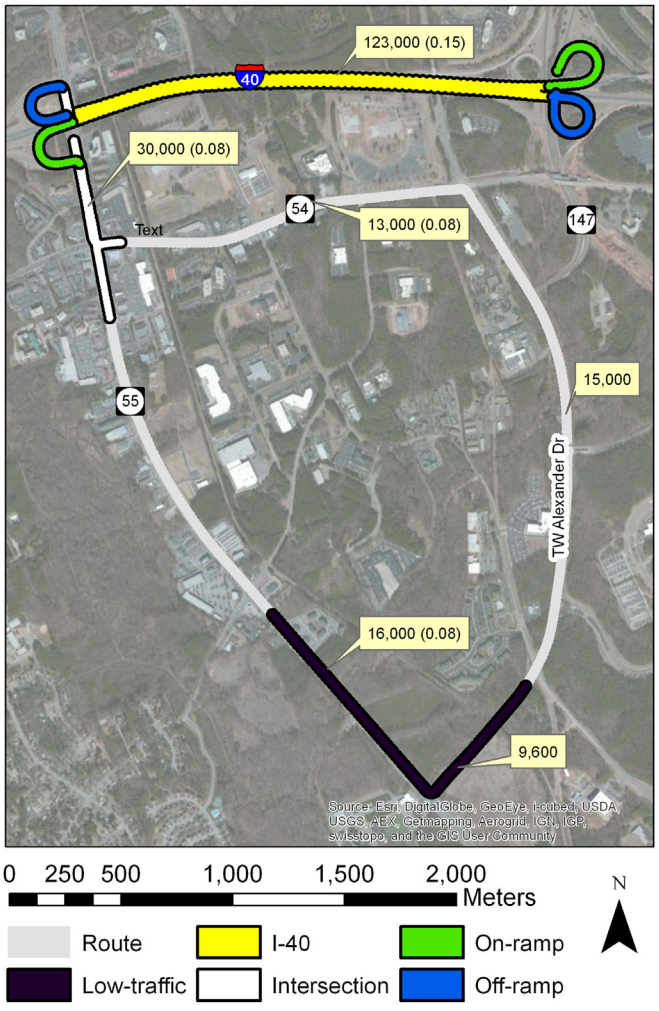

Fig. 1. Route that the electric vehicle followed during sampling. The different colors denote locations representing different road types and driving modes. Roads are labeled with the 2010 traffic volumes and truck fraction in parentheses.