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Particle number emission factors for an urban highway tunnel

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HIGHLIGHTS

- Temporal differences in particle number emission factor (EF_{PN}) were measured.
- EF_{PN} was ∼2-fold higher in winter and spring compared to summer and fall.
- EF_{PN} was ∼2-fold higher in the morning compared to the afternoon/evening.

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ABSTRACT

Exposure to traffic-related air pollution has been linked to increased risks of cardiopulmonary disease, asthma, and reduced lung function. Ultrafine particles (UFP; aerodynamic diameter < 100 nm), one component of traffic exhaust, may contribute to these risks. This paper describes the development of UFP emission factors, an important input parameter for dispersion models used for exposure assessment. Measurements of particle number concentration (PNC), a proxy for UFP, were performed in the Central Artery Tunnel on Interstate-93 in Boston (MA, USA). The tunnel system consists of two, unidirectional bores, which each carry $\sim 9 \times 10^4$ vehicles per day (diesel vehicles comprise 2–5% of the fleet in the southbound tunnel and 1–3% in the northbound tunnel). A tunnel was chosen for study because it provided an enclosed environment where the effects of lateral and vertical dispersion by ambient air and photochemical reactions would be minimized. Data were collected using a mobile platform equipped with rapid-response instruments for measuring PNC (4–3000 nm) as well as NO_x. Because Boston is located in a temperate region (latitude 42° N), we were interested in studying seasonal and diurnal differences in emission factors. To characterize seasonal differences, mobile monitoring was performed on 36 days spaced at 7–14 day intervals over one year (Sept. 2010–Sept. 2011); to characterize diurnal differences intensive mobile monitoring ($n = 90$ total trips through the tunnels) was performed over the course of two consecutive days in January 2012. All data collected during congested traffic conditions (∼7% of total data set) were removed from the analysis. The median PNC inside the two tunnels for all trips during the 12-month campaign was 3–4-fold higher than on I-93 immediately outside the tunnel and 7–10-fold higher than on I-93 4 km from the tunnel. The median particle number emission factors (EF_{PN}) (±median absolute deviation) for the southbound and northbound tunnels were 5.1×10^{14} (2.3×10^{14}) and 1.4×10^{14} (4.2×10^{13}) particles vehicle^{-1} km^{-1}, respectively. EF_{PN} values were ∼2-fold higher in winter and spring (average ambient temperature at the time of monitoring = 6.9 °C) compared to summer and fall (12.9 °C), and ∼2-fold higher in the morning (−7.9 °C) compared to the afternoon/evening (−0.9 °C) on two consecutive winter days. Our results suggest that seasonal and diurnal variations in particulate emissions from highway vehicles may be important to consider in developing EF_{PN} values.

1. Introduction

Concern that traffic-generated ultrafine particles (UFP; aerodynamic diameter < 100 nm) may be a risk factor for cardiovascular and respiratory diseases has motivated research to better quantify UFP exposures near busy roadways, where high levels of UFP are typically observed (Brugge et al., 2007; Delfino et al., 2005; Sioutas et al., 2005). Studies have shown that once emitted by vehicles,

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primary UFP rapidly mix with surrounding air leading to sharp decreases in concentration with distance from roadways (Durant et al., 2010; Karner et al., 2010; Molnar et al., 2002; Pirjola et al., 2006; Zhu et al., 2004). In addition, depending on ambient temperature and the presence of chemical precursors, UFP can undergo reactions (condensation, evaporation, photochemical oxidation) that can cause the number concentration, size distribution and chemical composition to change over relatively short time scales (minutes) and distances (tens of meters) (Morawska et al., 2008; Zhang and Wexler, 2004). In previous work to estimate traffic-generated air pollutant levels near roadways, dispersion models such as CALINE3, CALINE4 and AERMOD have been used. An advantage of dispersion models is that they provide a framework for evaluating the effects of meteorology (wind speed and direction, mixing height) and reactions on air pollutants downwind of sources. Pollutants commonly modeled with line-source dispersion models include carbon monoxide, nitrogen oxides (NO_X), sulfur dioxide, and volatile organic compounds (Benson, 1992; Jerrett et al., 2005; Venkatram et al., 2009; Wilton et al., 2010). In contrast, relatively little work has been done to model dispersion of UFP near roadways in part because UFP emission factors from motor vehicles have not been well characterized.

In this paper we describe our effort to study vehicle exhaust emissions in an urban highway tunnel to estimate particle number emission factors for a mixed vehicle fleet under real-world driving conditions. In fully enclosed tunnels where dispersion and photochemical oxidation of exhaust constituents are reduced relative to ambient air, primary emissions from vehicles can be quantified for different driving conditions. Because pollutant levels tend to increase with distance in unidirectional tunnels, measurements of particle gradients within tunnels coupled with traffic data can be used to estimate emission factors. Emission factors based on actual driving conditions inside tunnels provide a valuable complement to emission factors generated using more standardized approaches (e.g., dynamometer tests), which do not capture the full range of engine types and loads observed for a mixed vehicle fleet operating under real-world conditions (Jamriska and Morawska, 2001).

Our objectives were to characterize UFP levels and emission factors under typical driving conditions in an urban highway tunnel. We studied the Thomas P. O'Neill Jr. Tunnel ("Central Artery Tunnel"), the underground portion of Interstate-93 (I-93) in Boston (Massachusetts, USA; Fig. 1). Air quality data was collected using a mobile monitoring platform. Mobile monitoring is particularly useful for characterizing urban roadways where variations in traffic

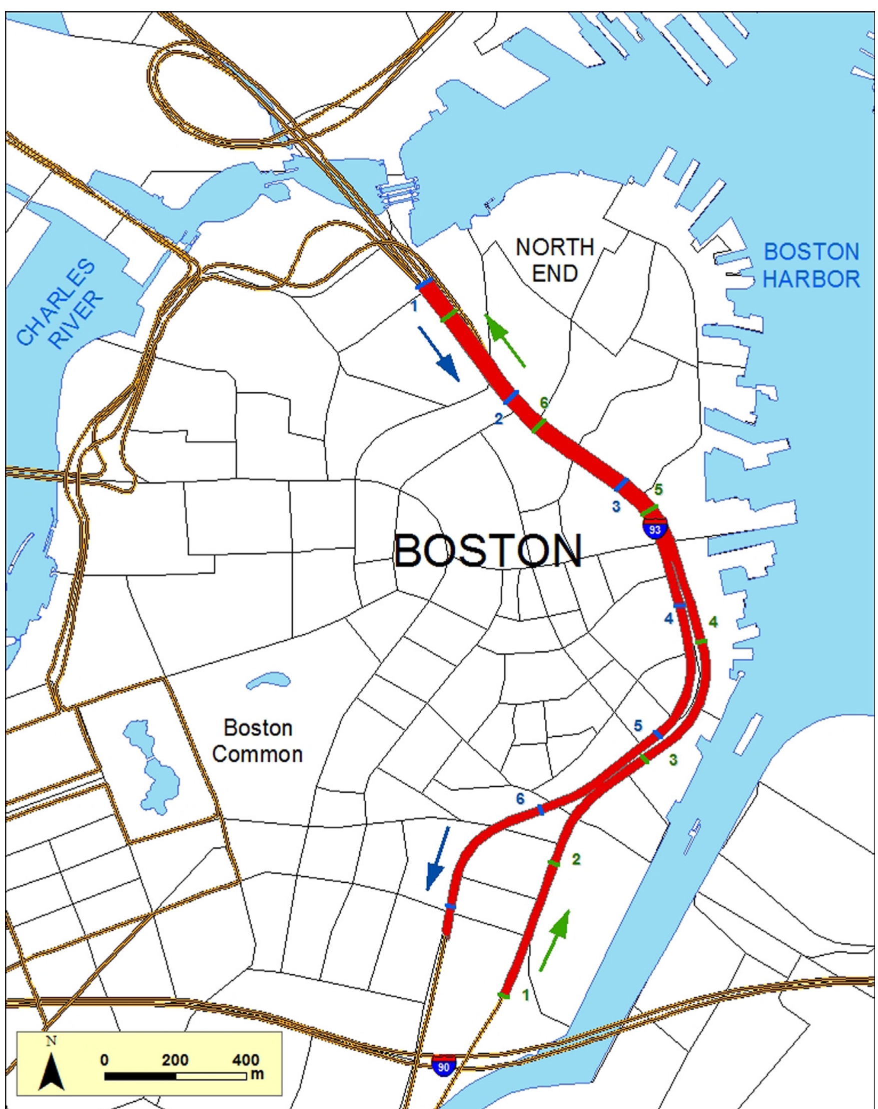

Fig. 1. Central Artery Tunnel in Boston (MA, USA). Arrows indicate traffic direction; numbers and tick marks show the locations of data bins in Fig. 2.