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The effects of vegetation barriers on near-road ultrafine particle number and carbon monoxide concentrations

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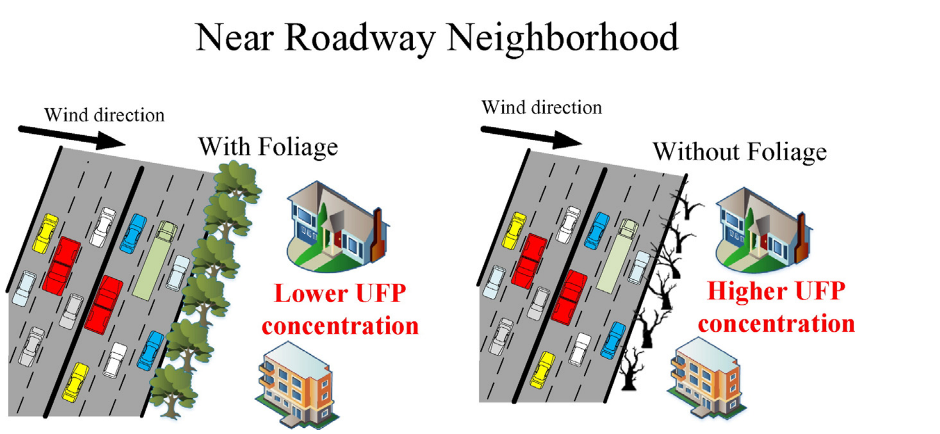
HIGHLIGHTS

- Both mobile and stationary measurements were conducted and agreed within 20%.
- Vegetation barriers with full foliage can reduce UFP and CO concentrations.
- Vegetation barriers without full foliage cannot reduce UFP concentrations.

GRAPHICAL ABSTRACT



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ABSTRACT

Numerous studies have shown that people living in near-roadway communities (within 100 m of the road) are exposed to high ultrafine particle (UFP) number concentrations, which may be associated with adverse health effects. Vegetation barriers have been shown to affect pollutant transport via particle deposition to leaves and altering the dispersion of emission plumes, which in turn would modify the exposure of near-roadway communities to traffic-related UFPs. In this study, both stationary (equipped with a Scanning Mobility Particle Sizer, SMPS) and mobile (equipped with Fast Mobility Particle Sizer, FMPS) measurements were conducted to investigate the effects of vegetation barriers on downwind UFP (particle diameters ranging from 14 to 102 nm) concentrations at two sites in North Carolina, USA. One site had mainly deciduous vegetation while the other was primarily coniferous; both sites have a nearby open field without the vegetation barriers along the same stretch of limited access road, which served as a reference. During downwind conditions (traffic emissions transported towards the vegetation barrier) and when the wind speed was above or equal to 0.5 m/s, field measurements indicated that vegetation barriers with full foliage reduced UFP and CO concentrations by 37.7–63.6% and 23.6–56.1%, respectively. When the test was repeated at the same sites during winter periods when deciduous foliage was reduced, the deciduous barrier during winter showed no significant change in UFP concentration before and after the barrier.

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Results from the stationary (using SMPS) and mobile (using FMPS) measurements for UFP total number concentrations generally agreed to within 20%.

1. Introduction

Exposure to ultrafine particles (UFP; aerodynamic diameter ≤ 100 nm) has been associated with adverse health effects. Cardiovascular and respiratory diseases have been linked to UFP exposure (Delfino et al., 2005; Oberdorster et al., 2005; Peters et al., 1997). UFPs have small particle size and low mass but large number concentrations and high surface area. UFP contributions to $PM_{2.5}$ mass are <5% in cities such as Saitma, Japan, and Pittsburgh, PA, USA (Cabada et al., 2004; Kawanaka et al., 2006). Despite its low contribution to PM mass, UFP can contribute up to 92% of the total numbers of particles in urban areas (Salma et al., 2011; Tuch et al., 1997).

A recent study indicated people living in near-roadway environments (generally within 100–300 m of a high-traffic roadway) experienced higher (up to a factor of two) UFP exposure compared to ambient background levels (He, 2010; He and Dhaniyala, 2012; Westerdahl et al., 2005; Yazdi et al., 2015). The main source of UFP in near-roadway communities is from vehicle emissions. Gasoline and diesel engines emit particles with count median diameter size ranging from 40 to 60 nm (Ristovski et al., 1998) and 20–130 nm (Morawska et al., 1998a; Morawska et al., 1998b), respectively. Exposure to traffic-derived UFP has also been associated with a significant increase in excess mortality (Breitner et al., 2011; Kumar et al., 2011). People living near roadways have been shown to experience increased risks for asthma and respiratory disease as well (Delfino, 2002; Li et al., 2010; McConnell et al., 2006).

The presence of noise barriers and vegetation along the roadway can alter the dispersion of UFP and other emitted pollutants such as carbon monoxide (CO). Reductions of CO and UFP up to 15% and 50%, respectively, have been reported in near roadway communities with noise barriers along the roadway (Baldauf et al., 2008a; Baldauf et al., 2008b; Bowker et al., 2007; Hagler et al., 2011).

Both stationary and mobile monitoring are popular methods for characterizing UFP concentrations in near roadway communities. Stationary measurements usually require several sets of the same instruments placed at different locations at the measurement site (Kimbrough et al., 2011; Vette et al., 2013). The main advantage of stationary measurements is that temporal variability can be well characterized at a fixed site. However, the disadvantages of stationary measurements include the following: (1) lack of fine spatial resolution; (2) more costly since stationary sites often require several sets of the same instruments; (3) require ongoing good agreement among the instruments. In contrast, mobile measurements require only one set of instruments and can assess the spatial variability of pollutants in a relatively short amount of time, although this method cannot simultaneously measure at multiple locations with a single vehicle (Yli-Tuomi et al., 2005). For example, mobile measurement in the Netherlands showed exponential decrease of particle number and mass concentration as a function of distance from the road (Weijers et al., 2004). Mobile measurement in Wilmington, DE, USA, also demonstrated that the spatial variability of hexavalent and trivalent chromium in ambient aerosols can be determined (Khlystov and Ma, 2006). Another mobile measurement study in Durham, NC, USA, indicated that UFP and CO levels within 15–150 m from the highway were significantly higher than the urban background (Hagler et al., 2010). However, only a few studies have compared the two methods. (Hagler et al., 2012) investigated the effect of roadside vegetation on near-road UFP under different wind conditions. The daily wind speed and direction readings were averaged over the two-hour measurement period, resulting in many days when the wind direction was categorized as "variable" (i.e., wind direction standard deviation $\sigma_\theta > 50°$). During this study on coniferous trees, 7 of 16 days were labeled "variable", and no sampling days were categorized as "downwind" of the roadway where the anticipated effect of trees was the highest. With stationary sampling, the continuous nature of the sampling allows the isolation of trends for subsets of the sampling sessions when the wind direction is "downwind" of the roadway and when the wind speed is above or equal to 0.5 m/s. The focus on downwind conditions also isolates trends where the highest traffic-related pollution exposure is anticipated. In addition, comparing downwind periods with and without deciduous foliage allows the investigation of the effect of foliage on UFP concentration.

In this study, we used the results from the Chapel Hill and Mebane, NC field studies (Hagler et al., 2012) to compare mobile and stationary measurements in evaluating the effects of vegetation barriers on near-

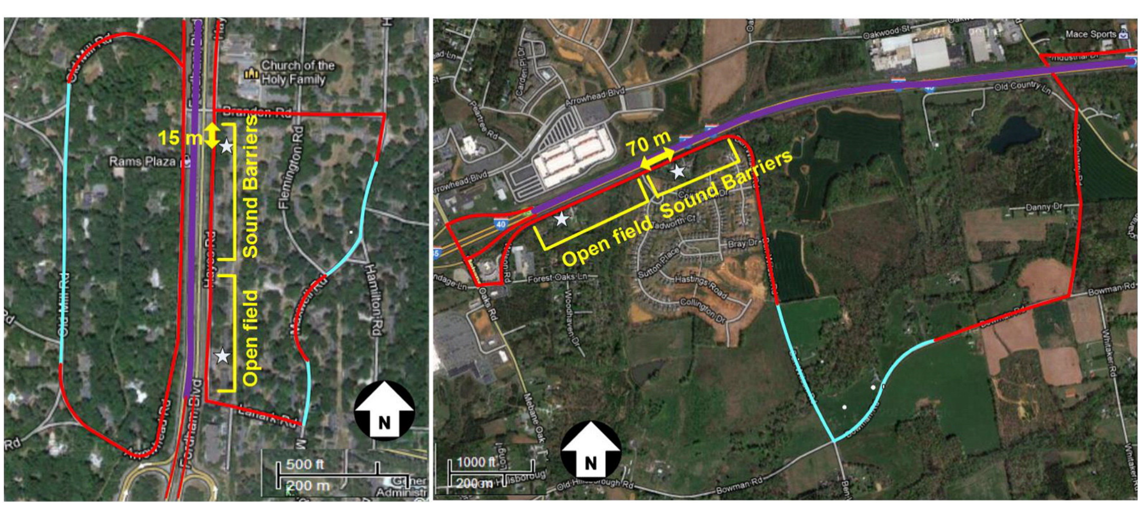

Fig. 1. Aerial photographs of the two near-roadway communities of Chapel Hill (left panel) and Mebane (right panel). The stationary sites are located at the star sign while the route for the mobile measurements is colored as: purple for on-highway, red for on-roads covering the near-road environments, and blue for the sections representing background concentrations. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)