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Field evaluation of vegetation and noise barriers for mitigation of near-freeway air pollution under variable wind conditions

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ABSTRACT

Traffic-related air pollutants are a significant public health concern, particularly near freeways. Previous studies have suggested either soundwall or vegetation barriers might reduce the near-freeway air pollution. This study aims to investigate the effectiveness of a combination of both soundwall and vegetation barrier for reducing ultrafine particles (UFPs, diameter ≤ 100 nm) and $PM_{2.5}$ (diameter ≤ 2.5 μm) concentrations. Concurrent data collection was carried out at both upwind and downwind fixed locations approximately 10–15 m away from the edge of two major freeways in California. This study observed that the reduction of UFP and $PM_{2.5}$ was generally greater with the combination barrier than with either soundwall or vegetation alone. Since there were no non-barrier sites at the study locations, the reductions reported here are all in relative terms. The soundwall barrier was more effective for reducing $PM_{2.5}$ (25–53%) than UFPs (0–5%), and was most effective (51–53% for $PM_{2.5}$) when the wind speed ranged between 1 and 2 m/s. Under the same range of wind speed, the vegetation barrier had little effect (0–5%) on reducing $PM_{2.5}$; but was effective at reducing UFP (up to 50%). For both types of roadside barrier, decreasing wind speed resulted in greater net reduction of UFPs (i.e., total number particle concentrations; inversely proportional). This trend was observed, however, only within specific particle size ranges (i.e., diameter < 20 nm for the soundwall barrier and 12–60 nm for the vegetation barrier). Out of these size ranges, the reduction of UFP concentration was proportional to increasing wind speed. Overall findings of this study support positive effects of soundwall and vegetation barriers for near-freeway air pollution mitigation.

1. Introduction

Motor vehicle emissions contribute to ambient fine particulate matter ($PM_{2.5}$, diameter ≤ 2.5 μm) and ultrafine particles (UFPs, diameter < 0.1 μm). UFP concentrations are usually much higher within a few hundred meters of a major freeway than in urban background (Kim et al., 2002; Kittelson et al., 2004; Morawska et al., 2008; Zhu et al., 2002a, 2002b). The elevated level of near-freeway air pollution has been linked to various adverse health effects, including birth defects, pulmonary disorders, and cardiovascular diseases (Beelen et al., 2008; Gehring et al., 2010; Hoek et al., 2002; Wellenius et al., 2012; Wilhelm and Ritz, 2003).

In an effort to mitigate these adverse health outcomes, an increasing number of recent studies have explored the potential use of a noise barrier (i.e., a soundwall barrier) to reduce air pollution in near-freeway communities. In a field study using tracer gas, a soundwall barrier was found to reduce the downwind SF_6 concentrations by 20–50% (Finn et al., 2010). A similar level of reduction (i.e., ~20%) was reported in a wind tunnel study (Heist et al., 2009). The structure of a soundwall barrier modifies the wind-driven airflow field in the vicinity behind the barrier structure, thereby carrying over a plume of vehicle-emitted air pollutants from the ground level to the height of the barrier or above (Bowker et al., 2007; Ning et al., 2010). Consequently, the soundwall barrier helps create additional dispersion to decrease the level of the particulate air pollutants by 15–80% near roadways relative to an open area (Amini et al., 2016; Baldauf et al., 2008; Venkatram et al., 2016).

In addition to the soundwall barrier, vegetation barriers were also studied for the potential benefit of reducing air pollution levels near roadways. The foliage of a vegetation barrier has a large surface area that can promote the dry deposition of particulate pollutants; in addition, the structure of the vegetation barrier can also help increase the

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vertical mixing and dispersion of air pollutants (Beckett et al., 2000; Bussotti et al., 1995; Fuller et al., 2009; Heath et al., 1999; Heichel and Hankin, 1976; Munch, 1993; Raupach et al., 2001). Previous modeling and measurement studies have demonstrated that a vegetation barrier can provide an additional reduction of UFPs when it is installed in addition to a near-road soundwall barrier (Baldauf et al., 2008; Bowker et al., 2007). A combination barrier consisting of soundwall and vegetation can lead to a greater reduction of UFPs than a soundwall barrier alone (Baldauf et al., 2008; Tong et al., 2016).

There is a large variability in the previous findings about the effectiveness of road-side vegetation barriers on reducing air pollution. The characteristics of vegetation (i.e., height, thickness, porosity, and species) can also influence the effectiveness of vegetation barrier in reducing the concentrations of air pollutants near roadways (Baldauf, 2017; Baldauf et al., 2008). For example, a previous study found that vegetation barriers had relatively little effect on reducing UFPs; however, a follow-up study at the same site observed a reduction of 38–64% for UFP number concentrations when the wind speed was equal to or above 0.5 m/s (Hagler et al., 2012; Lin et al., 2016). Other than wind speed, the particle size is another factor that may contribute to the variable findings in the literature. A recent study reported a negligible reduction of fine and coarse particles (0.5–10 μm in diameter) downwind of a vegetation barrier, whereas an overall reduction of black carbon (typically, ≤ 1 μm in diameter) was ~12% and the reduction increased up to 22% at higher wind speed (Brantley et al., 2014). Thus, previous findings were inconsistent potentially due to the high variability associated with wind speed and particle size in addition to differences in vegetation characteristics.

The objectives of this study are (1) to determine the effects of a combination barrier of both soundwall and vegetation on reducing particle concentrations near freeways, in comparison with the effects of either one alone; and (2) to better understand the effectiveness with respect to wind speeds and particle sizes. We carried out a series of field sampling campaigns with concurrent measurements at 3–4 locations close (10–15 m) to the road-side barriers along two major freeways in California. As part of a larger study, the current work focuses on discussing the UFP and $PM_{2.5}$ concentration data collected with a vegetation-soundwall combination barrier in comparison with the datasets obtained either with a vegetation barrier or with a soundwall barrier alone.

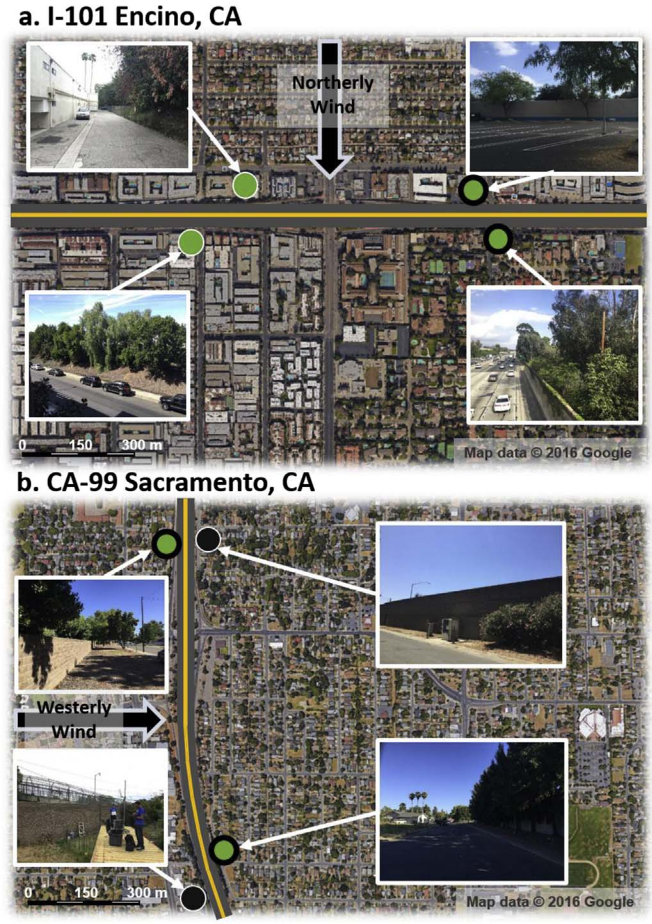

Fig. 1. Aerial images of the study sites near (a) I-101 freeway in Encino and (b) CA-99 freeway in Sacramento. Black and green dots indicate the presence of soundwall and vegetation barriers, respectively. Green dots with black outline indicate the sampling locations with vegetation-soundwall combination barriers. The arrows show the wind directions desirable for the field studies in Encino (0 ± 45°) and in Sacramento (270 ± 45°). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

2. Methodology

2.1. Study sites

Field sampling campaigns were conducted at two study sites near major freeways in Encino and Sacramento, California. The first sampling campaign was carried out near the I-101 in Encino from March 23, 2016, to April 8, 2016. Fig. 1a is an aerial image of the study site in Encino. The area near the I-101 in Encino had a vegetation barrier along the freeway with and without a soundwall barrier. The elevation of the I-101 freeway was either depressed by approximately 1 m or nearly even relative to the ground level beside the freeway at the sampling location. The distribution of vegetation (i.e., planted trees) was relatively uniform. While the height of the vegetation ranged from 6 to 22 m, the height of the soundwall was consistent at ~4 m along the I-101 freeway at this study site. Stationary data collection was conducted at ~15 m away from the edge of the freeway (i.e., 40–45 m from the center line of the freeway).

The second study site was selected near the CA-99 in Sacramento (See Fig. 1b). Data were collected at this sampling site from June 17, 2016, to July 1, 2016. This study site had soundwall barriers of a consistent height (5 m) along the CA-99 freeway with and without a vegetation barrier. The height of vegetation was also relatively consistent (i.e., 16–17 m). Like the I-101 study site in Encino, the elevation of the CA-99 freeway was slightly depressed or even (−1 m–0 m) relative to the ground level. All sampling instruments were located about 10–15 m away from the edge of the CA-99 freeway (i.e., 40–45 m from the center line of the freeway).

In Fig. 1, stationary sampling locations are marked with four circular marks. Different schemes of the circles represent different combinations of soundwall and vegetation for each sampling location. For example, green dots in Fig. 1a are stationary sampling locations next to a vegetation barrier along the I-101 freeway in Encino. Black dot is a stationary sampling location next to a soundwall barrier. Green dots with black outlines represent the sampling locations with both soundwall and vegetation barriers (i.e., combination barrier). Table 1 summarizes detailed information about the two study sites near the I-101 in Encino and the CA-99 in Sacramento. There was no major source of air pollution in the vicinity of the study areas upwind and downwind of the freeways, except for the freeway traffic emissions.