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Determinants of the spatial distributions of elemental carbon and particulate matter in eight Southern Californian communities

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HIGHLIGHTS

- Fine spatial scale EC and PM were measured in Southern Californian communities.
- Combined multi-community prediction models were generally robust for EC.
- There was substantial heterogeneity in effects of near-roadway traffic metrics on EC.
- This heterogeneity varied by regional pollution and distance to shoreline.
- Model R^2 of a novel 0.2 μm EC fraction was not larger than for $EC_{2.5}$.

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ABSTRACT

Emerging evidence indicates that near-roadway pollution (NRP) in ambient air has adverse health effects. However, specific components of the NRP mixture responsible for these effects have not been established. A major limitation for health studies is the lack of exposure models that estimate NRP components observed in epidemiological studies over fine spatial scale of tens to hundreds of meters. In this study, exposure models were developed for fine-scale variation in biologically relevant elemental carbon (EC). Measurements of particulate matter (PM) and EC less than 2.5 μm in aerodynamic diameter ($EC_{2.5}$) and of PM and EC of nanoscale size less than 0.2 μm were made at up to 29 locations in each of eight Southern California Children's Health Study communities. Regression-based prediction models were developed using a guided forward selection process to identify traffic variables and other pollutant sources, community physical characteristics and land use as predictors of PM and EC variation in each community. A combined eight-community model including only CALINE4 near-roadway dispersion-estimated vehicular emissions accounting for distance, distance-weighted traffic volume, and meteorology, explained 51% of the $EC_{0.2}$ variability. Community-specific models identified additional predictors in some communities; however, in most communities the correlation between predicted concentrations from the eight-community model and observed concentrations stratified by community was similar to those for the community-specific models. $EC_{2.5}$ could be predicted as well as $EC_{0.2}$. $EC_{2.5}$ estimated from CALINE4 and population density explained 53% of the within-community variation. Exposure prediction was further improved after accounting for between-community heterogeneity of CALINE4 effects associated with average distance to Pacific Ocean shoreline (to 61% for $EC_{0.2}$) and for regional NO_x pollution (to 57% for $EC_{2.5}$). PM fine spatial scale variation was poorly predicted in both size fractions. In conclusion, models of exposure that include traffic measures such as CALINE4 can provide useful estimates for $EC_{0.2}$ and $EC_{2.5}$ on a spatial scale appropriate for health studies of NRP in selected Southern California communities.

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1. Introduction

Emerging evidence suggests that near-roadway air pollution is associated with chronic respiratory, cardiovascular, and neurological diseases (Guxens and Sunyer, 2012; HEI, 2010). Considerable uncertainty exists as to the components of the near-roadway pollutant mixture responsible for chronic health effects. Oxides of nitrogen have been commonly measured to develop near-roadway prediction models because of the close association between NO_x and vehicular emissions and the existence of inexpensive passive NO_x monitors (HEI, 2010). Although acute effects of NO_2 have been observed at ambient concentrations, toxicological studies have identified components of ambient particulate matter as more likely to be responsible for the chronic effects of near-roadway exposures. Recent epidemiological studies have reported health associations with estimated exposure to particulate elemental carbon (EC), employing models based on traffic metrics and other land use (Brauer et al., 2007; Morgenstern et al., 2007; Ryan et al., 2007). Particles with EC may also contain transition metals and organic compounds that cause oxidative stress and inflammation known to be involved in the pathogenesis of asthma and other respiratory diseases (Ghio et al., 2012; Riedl and Diaz-Sanchez, 2005). EC, especially smaller particles, carries these toxicologically relevant particle components deep into the lung. However, there have been few exposure models estimating components of particulate matter on a fine spatial scale of tens to a few hundred meters that is relevant for epidemiological studies examining near roadway effects.

In Southern California, EC is a useful marker for vehicular combustion products, especially from diesel powered vehicles, which are the primary EC source (Schauer, 2003). Smaller contributions to ambient EC are made by wood smoke (little used in our study communities), ship emissions, railways, and off-road vehicles (EPA, 2012). For this study, we measured and modeled Southern California EC concentrations in the fine respirable fraction less than 2.5 μm in aerodynamic diameter ($EC_{2.5}$) and in a nanoscale size fraction less than 0.2 μm ($EC_{0.2}$) that we anticipated might better reflect the near-roadway gradient in ultrafine particles in communities participating in the Children's Health Study (CHS), a large prospective study of cardio-respiratory health (McConnell et al., 2010). The study is notable for the fine spatial scale at which these measurements were made in order to assess small-scale intra-community variation. Information on traffic, land use and other community features were used to develop models of within-community exposure, based on measurements made at informatively selected locations in each study community. We also measured and modeled intra-community variation in particulate matter (PM) mass in the 2.5 and 0.2 μm size fractions ($PM_{2.5}$ and $PM_{0.2}$). Additionally, we assessed both within- and between-community variation of these pollutants.

2. Methods

2.1. Study locations and air sampling

Air pollution samplers for size-resolved PM mass and components were deployed from November 2008 until December 2009 in up to 29 informatively selected locations within each of eight Southern California communities (see Fig. 1) in which CHS participants are currently being studied. Sample locations were selected from among participants' homes based on high or low impacts of freeway, non-freeway, and other non-traffic sources. All samplers were deployed at the same time in each community for two consecutive two-week periods during warm and cool times of year, for a total of four two-week sampling periods per community. Size-resolved PM less than 0.2 ($PM_{0.2}$) and 0.2–2.5 μm in aerodynamic diameter ($PM_{0.2-2.5}$) were collected on modified Harvard cascade impactors (Lee et al., 2006). $PM_{2.5}$ was estimated by summing the $PM_{0.2-2.5}$ and $PM_{0.2}$ stage data. EC was collected from different sampling lines and measured using a thermal–optical transmittance method. Additional information on the selection of sampling locations and on air monitoring is available in the Online Supplement and in a previous report (Fruin et al., 2014).

2.2. Predictors of EC and PM mass

Potential predictors of EC included distance (and inverse distance) to roadways and other sources, traffic density in distance buffers around sampling locations, dispersion modeled traffic pollutant exposure, length of road and amount of green space in buffers around sampling locations, population density and elevation. Predictors were linked to GPS measurements made at the sampling locations using GIS software (ArcGIS). Details are provided in the Online Supplement.

Annual average daily traffic (AADT) volumes on roadways and truck percentage were obtained from the California Department of Transportation (Caltrans) milepost data for freeways and numbered state highways for 2009 (CALTRANS, 2010) and Dynamap Traffic Count (Version 10.2) datasets produced by TeleAtlas (Boston, Massachusetts) for other roads. Roadway classification was based on the Functional Class Code (FCC) as found in the Dynamap dataset. Density plots were generated within the GIS using a linear decay function that approximated the decrease in ambient

Fig. 1. Map of communities.