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A spatial-temporal regression model to predict daily outdoor residential PAH concentrations in an epidemiologic study in Fresno, CA

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ABSTRACT

Background: Polycyclic aromatic hydrocarbons (PAHs) are generated as a byproduct of combustion, and are associated with respiratory symptoms and increased risk of asthma attacks.
Objectives: To assign daily, outdoor exposures to participants in the Fresno Asthmatic Children's Environment Study (FACES) using land use regression models for the sum of 4-, 5- and 6-ring PAHs (PAH456).
Methods: PAH data were collected daily at the EPA Supersite in Fresno, CA from 10/2000 through 2/2007. From 2/2002 to 2/2003, intensive air pollution sampling was conducted at 83 homes of participants in the FACES study. These measurement data were combined with meteorological data, source data, and other spatial variables to form a land use regression model to assign daily exposure at all FACES homes for all years of the study (2001–2008).
Results: The model for daily, outdoor residential PAH456 concentrations accounted for 80% of the between-home variability and 18% of the within-home variability. Both temporal and spatial variables were significant in the model. Traffic characteristics and home heating fuel were the main spatial explanatory variables.
Conclusions: Because spatial and temporal distributions of PAHs vary on an intra-urban scale, the location of the child's home within the urban setting plays an important role in the level of exposure that each child has to PAHs.

1. Introduction

The majority of health effect research focused on daily exposure to ambient pollutants has used a single central monitor to assign exposure to participants (Peel et al., 2005; Penttinen et al., 2001), relying on the assumption that temporal variability overshadows spatial variability such that exposure misclassification is negligible. When incorrect, this assumption could lead to exposure misclassification of spatially heterogeneous pollutants and result in significant differences in the correlation to the health outcome (Sarnat et al., 2010; Wilson et al., 2005, 2007). The degree of heterogeneity of a pollutant's spatial distribution can be tested by examining the absolute concentrations, correlation coefficients, and the coefficient of divergence between measured data at different sites (Wilson et al., 2005). Using these techniques, researchers have found many air toxics, including PAHs, with enough heterogeneity that using a single monitor would cause some degree of exposure misclassification (Lehndorff and Schwark, 2004; Levy et al., 2001). If the distribution of PAHs is heterogeneous within the study area and some spatially resolved measurement data are available, modeling the spatial distribution may be preferable to using a central monitor value directly (Ito et al., 2004). However, in a moderate to large urban area for a cohort epidemiology study collecting personal PAH samples or even a large number of cross-sectional samples is not feasible. The intent of this paper is to model the daily individual exposures to outdoor residential PAHs, over 8 years of follow-up, through land use regression (LUR) modeling.

PAHs are a class of compounds characterized by fused aromatic rings that form when organic matter undergoes incomplete combustion. PAHs generally exist in complex mixtures of combustion products

Abbreviations: DEP, Diesel exhaust particles; EPA, United States Environmental Protection Agency; FACES, Fresno Asthmatic Children's Environment Study; FL, Fuel loading factor for agricultural burning; HI, Home intensive; IARC, International Agency for Research on Cancer; LUR, Land use regression; PAH, Polycyclic aromatic hydrocarbons; PAH456, Sum of the PAHs with 4-, 5-, or 6-rings; SJVUAPCD, San Joaquin Valley Unified Air Pollution Control District.

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such as diesel exhaust, soot, and wood and tobacco smoke. They exist in ambient air as gases (gas-phase) and adsorbed to particulate matter (particle-phase or particle-bound). PAHs are produced by both diesel and gasoline fuel combustion (Cadle et al., 1999; Marr et al., 1999; Riddle et al., 2007; Rogge et al., 1993), as well as biomass burning (Jenkins et al., 1996; Schauer and Cass, 2000). However, PAHs are not merely another proxy for traffic exhaust, they are well-known as carcinogens (International Agency for Research on Cancer, 1989) and toxic air contaminants (Office of Environmental Health Hazard Assessment, 2001). PAHs have most recently been implicated in short-term respiratory health outcomes (Delfino, 2002; Diaz-Sanchez et al., 1994) and immunological functioning related to mechanisms involved with asthma and atopy (Finkelman et al., 2004; Nadeau et al., 2010; Perera et al., 2009). Despite this increasing interest in health effects related to exposure to ambient concentrations of PAHs, to our knowledge, no data exist on daily intra-urban spatial distributions or individual exposure estimates in the context of an epidemiologic cohort study.

LUR models are spatial regression models that relate location-specific data on pollutant concentrations to location-specific source and environment data using regression (Briggs et al., 1997). Unlike interpolation methods, such as kriging, LUR models are able to exploit measurement data to build a smooth pollutant surface even when there are significant local sources and intra-urban variability (Jerrett et al., 2005). The majority of LUR models and spatial models for air pollution exposures related to health effects has focused on modeling annual average exposure to NO_2, CO, or particulate matter (Hoek et al., 2008). While PAHs share some emission sources with these pollutants, the spatial distributions of these three pollutants are not identical (Fischer et al., 2000; Levy et al., 2001; Sarnat et al., 2010).

2. Methods

2.1. Study background and population

The combination of Fresno's geographic location and meteorology contributes to very poor air quality in both the summer and the winter (Blanchard et al., 1999). Because of the Southern Sierra Nevada in the West, the Tehachapi Mountains on the south, and the Coastal Range Mountains in the East, the San Joaquin air basin (in which Fresno is located) does not have an outlet for air pollution. Additionally, during the winter months, inversion layers from lowered mixing heights cause stagnation in the valley air. Main sources of PAHs in Fresno are the freeways, major arterials, agricultural burns, residential fireplace and woodburning stove use, and heating (Schauer and Cass, 2000). Fresno has three major freeways, but US Route 99 on the western edge of the city, is heavily used by truck traffic through the region whereas centrally-located State Route 41 is primarily local, light-duty vehicles (Margolis et al., 2009).

The Fresno Asthmatic Children's Environment Study (FACES) focused on quantifying the relationship between air pollution and the natural history of asthma symptoms and lung function growth in 315 young children, ages 6–11 years at entry, with asthma who reside in Fresno, California. Further details on the design of the study and cohort characteristics have been published elsewhere (Mann et al., 2010; Margolis et al., 2009; Nadeau et al., 2010). The participants in FACES were contacted every 3 months to collect health data and confirm residential address. From 2/2002 through 2/2003, a substudy of 83 homes of FACES participants, the home intensive (HI) substudy, was conducted to collect more detailed pollution and activity data from participants (Fig. 1). These participants were selected based on residential location in relation to anticipated traffic exposure (low or high) and smoking status of parents (non-smoking).

2.2. Field sampling

Two field sampling methods were used to characterize airborne concentrations of ambient PAHs for modeling daily exposures. First, a real-time monitor of particle-bound PAHs, the PAS2000 (EcoChem Analytics, League City, TX) collected data from October 2000 through September 2008 at the EPA Supersite in Fresno (Fig. 1). The PAS2000 uses a photoelectric aerosol sensor to measure the levels of particle-bound ambient PAH with three rings or greater.

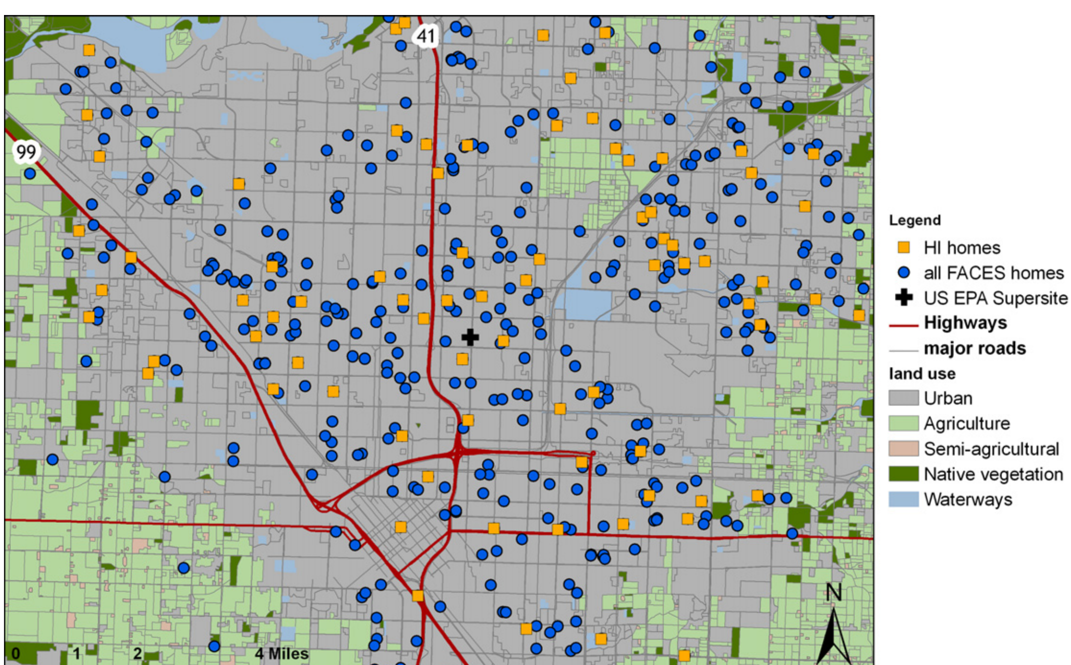

Fig. 1. Locations of FACES participants (blue circles and orange squares), HI sub-study participants (orange squares), and the US EPA Supersite.