Atmospheric Environment 98 (2014) 581–590

Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Modeling particle number concentrations along Interstate 10 in El Paso, Texas

Hector A. Olvera [a, b, c, *], Omar Jimenez [d], Elias Provencio-Vasquez [b, c]

[a] *Center for Environmental Resource Management, University of Texas at El Paso, 500 W. University Ave., El Paso, TX 79968, USA*
[b] *School of Nursing, University of Texas at El Paso, 500 W. University Ave., EL Paso, TX 79968, USA*
[c] *Hispanic Health Disparities Research Center, University of Texas at El Paso, 500 W. University Ave., EL Paso, TX 79968, USA*
[d] *Department of Civil Engineering, University of Texas at El Paso, 500 W. University Ave., El Paso, TX 79968, USA*

HIGHLIGHTS

- Annual particle number concentrations around a highway were estimated.
- Atmospheric dispersion and land use regression models were used.
- The emission factor and the background adjustment had an impact on accuracy.
- The two models captured the impact of traffic near and away from the highway.
- The modeling technique would be feasible in regions where traffic data is available.

ARTICLE INFO

Article history:
Received 7 October 2013
Received in revised form
8 September 2014
Accepted 10 September 2014
Available online 16 September 2014

Keywords:
Dispersion model
Land use regression
Ultrafine
US–Mexico border

ABSTRACT

Annual average daily particle number concentrations around a highway were estimated with an atmospheric dispersion model and a land use regression model. The dispersion model was used to estimate particle concentrations along Interstate 10 at 98 locations within El Paso, Texas. This model employed annual averaged wind speed and annual average daily traffic counts as inputs. A land use regression model with vehicle kilometers traveled as the predictor variable was used to estimate local background concentrations away from the highway to adjust the near-highway concentration estimates. Estimated particle number concentrations ranged between 9.8×10^3 particles/cc and 1.3×10^5 particles/cc, and averaged 2.5×10^4 particles/cc (SE 421.0). Estimates were compared against values measured at seven sites located along I10 throughout the region. The average fractional error was 6% and ranged between −1% and −13% across sites. The largest bias of −13% was observed at a semi-rural site where traffic was lowest. The average bias amongst urban sites was 5%. The accuracy of the estimates depended primarily on the emission factor and the adjustment to local background conditions. An emission factor of 1.63×10^{14} particles/veh-km was based on a value proposed in the literature and adjusted with local measurements. The integration of the two modeling techniques ensured that the particle number concentrations estimates captured the impact of traffic along both the highway and arterial roadways. The performance and economical aspects of the two modeling techniques used in this study shows that producing particle concentration surfaces along major roadways would be feasible in urban regions where traffic and meteorological data are readily available.

1. Introduction

Recently, determining the role of ultrafine particles (UFP) in the causation of adverse health effects has received increased interest (Oberdörster et al., 2005; Weichenthal, 2012). A reason of concern is that compared to larger size fractions, UFP (<100 nm) has higher deposition efficiencies in the respiratory tract of healthy humans and even higher in children and other susceptible groups (Chalupa et al., 2004; Daigle et al., 2003; Löndahl et al., 2007; Olvera et al., 2012b; Stewart et al., 2010). Despite considerable research, the long-term effects due to exposure, as well as the mechanisms of action and causal components of UFP remains elusive. An important reason for this gap is the lack of spatially resolved exposure

---

[*] Corresponding author. Center for Environmental Resource Management, University of Texas at El Paso, 500 W University Ave., El Paso, TX 79968, USA.
E-mail addresses: holvera@utep.edu, holvera.utep@gmail.com (H.A. Olvera).

http://dx.doi.org/10.1016/j.atmosenv.2014.09.030
1352-2310/

data within urban regions. In these regions, motor vehicles are the main source of ultrafine particles (Morawska et al., 2008). Consequently, near highways particle number concentrations (PNC) can reach up to 30 times the local background levels (Morawska et al., 2008; Zhang and Wexler, 2004). Downwind from highways, PNC decays exponentially and reaches local background levels at distances beyond 300 m (Morawska et al., 2008). At larger scales and away from highways, PNC continues to vary primarily as a function of arterial traffic (Hoek et al., 2011). Exposure assessment for epidemiological studies requires modeling tools that can accurately account for PNC variation across these two scales. Several modeling techniques have been used to estimate PNC within urban environments, both at near-road and regional scales (Hoek et al., 2011; Jamriska and Morawska, 2001; Kumar et al., 2011; Patton et al., 2014; Perkins et al., 2013; Zhang et al., 2005; Zhu and Hinds, 2005; Zwack et al., 2011). In particular, dispersion modeling has been effectively used to reproduce PNC gradients near highways (Zhu and Hinds, 2005). Whereas at regional scales, PNC has been estimated with land use regression models with traffic as a primary predictor (Hoek et al., 2011; Rivera et al., 2012).

The goal of this study was to estimate PNC along the section of Interstate 10 (I10) that crosses El Paso, Texas using both dispersion and LUR modeling. Specifically, an atmospheric dispersion model was used to estimate PNC gradients at 98 locations along I10, while an LUR model with arterial traffic as a predictor was used to estimate local background concentrations away from the highway to adjust the near-highway PNC gradients. The atmospheric dispersion model used in this study was explicitly proposed for exposure assessment purposes and shown to effectively estimate PNC near Interstate 405 in Los Angeles, CA (Zhu and Hinds, 2005). The atmospheric dispersion model was selected based on its economy, simplicity, and most importantly its good performance. More sophisticated modeling alternatives such as CFD or urban scale atmospheric models (e.g., CMAQ) were considered impractical, as the implementation of such models requires superior expertise, intensive computational capacity, and considerably more input data and preprocessing (e.g., urban morphology, traffic modeling, meteorological modeling, emission modeling, etc).

The atmospheric dispersion model was evaluated by comparing PNC estimates against measurements performed during a single day, at one location, and under suitable conditions (e.g., consistent sea breeze blowing perpendicular from highway towards measurement sites) (Zhu and Hinds, 2005). This study takes the implementation of the proposed model one step further by employing it to predict annually averaged daily PNC across multiple sites within a city. Since the dispersion model does not account for background levels, PNC estimates need to be adjusted accordingly. Across urban regions and away from highways, traffic intensity has been shown to be a valid predictor of PNC using land use regression models (Hoek et al., 2011; Rivera et al., 2012). In this study, background levels were estimated with a land use regression model with vehicle kilometers traveled (VKT) as the predictor variable. To the best of our knowledge, this manuscript presents the first attempt to employ this modeling approach to estimate PNC along a highway and averaged across extended periods of time. In this regard, the results, challenges, and shortcomings presented in this manuscript will be particularly useful to those seeking to employ modeling techniques for chronic exposure assessment purposes of ultrafine particles near highways. In general, this manuscript adds to a body of research that aims at improving our capacity to produce more accurate estimates of the spatial distribution of PNC at regional scales, which will help advance our understanding of the health impacts of ultrafine particles.

2. Methods

2.1. Study site

El Paso, Texas is a port of entry between the U.S. and Mexico with six crossing stations located along its border with Ciudad Juarez, Chihuahua. The transport of goods from the prominent assembly industry in northern Mexico into the U.S. results in elevated traffic of heavy duty diesel vehicles on the three major highways that cross the region; 1) I10 (east to west), 2) state highway 54 (north to south), and 3) loop highway 375 surrounding the region (Fig. 1). Of all three, I10 has the highest traffic volumes of both private and commercial vehicles. The area around the intersection of I10 and highway 54 has been identified as a $PM_{2.5}$ hot-spot induced by vehicle emissions (Olvera et al., 2012a). Within the county, I10 crosses through rural, residential, commercial, and industrial land-uses. Also, several schools, daycare facilities, senior citizen residential communities, and hospitals are located within 1000 m of to the highway.

2.2. Dispersion model

As discussed by Zhang and Wexler (2004) vehicle exhaust undergoes two distinct dilution stages after emitted. During the first stage, dilution is dominated by traffic-generated turbulence and dilution ratios reach 1000:1 within 1–3 s. This stage is referred to as “tailpipe-to-road”. During the second stage, dilution is mainly dependent on atmospheric turbulence and the dilution ratios reach 10:1 in about 3–10 min. This stage is referred as the “road-to-ambient”. Zhu and Hinds (2005) derived a simple dispersion model from the atmospheric diffusion equation based on the dominance of atmospheric dispersion in the “road-to-ambient” stage. A detailed description of the dispersion model and its derivation is available in Zhu and Hinds (2005). In short, the dispersion model incorporates a source strength variable that represents the unit length flux through the plane on the downwind side of the freeway and thus requires emission factors estimated at the road level (Zhang et al., 2005). As discussed by (Zhang et al., 2005) particle number emission factors estimated from road side measurements typically employ a control volume approach that masks the “tailpipe-to-road” effects and produces values at the road level as required by the atmospheric dispersion model. The atmospheric dispersion model does not account for several physical processes (e.g., enhanced Brownian coagulation due to van der Waals forces, evaporation, condensation) believed to be essential when predicting particle size distributions as a function of distance from traffic (Jacobson, 2004; Zhang and Wexler, 2004). However, for the prediction of PNC as function of distance from traffic the consideration of only atmospheric dispersion produced good results (Zhu and Hinds, 2005). The dispersion model had the following form:

$$C(x,z) = \frac{q_1}{ux\sqrt{2\gamma\pi}}\left\{\exp\left(-\frac{(z-h)^2}{2\gamma x^2}\right) + \exp\left(-\frac{(z+h)^2}{2\gamma x^2}\right)\right\} \tag{1}$$

where q_1 (particle m^{-1} s^{-1}) is the source term and is related to the emission factor EF (particle vehicle^{-1} m^{-1}) and traffic volume V (vehicle s^{-1}) by

$$q_1 = \mathrm{EF} \times V \tag{2}$$

and u is the average wind velocity, x is the downwind distance from the road, z is the measurement height, h is the height of emission, and γ is a turbulence parameter defined as $0.16\ (w^*/u)^2$ when