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UNIVERSITY OF CALIFORNIA,  
IRVINE

Regional Scale Dispersion Modeling and Analysis of Directly Emitted Fine Particulate Matter  
from Mobile Source Pollutants Using AERMOD

DISSERTATION

Submitted in partial satisfaction of the requirements  
for the degree of

DOCTOR OF PHILOSOPHY

in Civil Engineering

by

Seth Daniel Contreras

Dissertation Committee:  
Professor Michael G. McNally, Chair  
Professor Stephen G. Ritchie  
Assistant Professor John D. Houston

2015



## **DEDICATION**

To my mom; for showing me the path of a true human being.

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# CURRICULUM VITAE

## EDUCATION

- PhD **University of California, Irvine**  
Civil & Environmental Engineering: emphasis in Transportation, 2015
- MS **University of California, Berkeley**  
Civil & Environmental Engineering: emphasis in Transportation, 2009
- BS **California State Polytechnic Pomona**  
Civil Engineering, 2008
- AA **Cerritos College**, Norwalk, CA  
Natural Sciences, 2005

## RESEARCH EXPERIENCE

- University of California, Irvine** (9/2010 – 3/2015)  
Ph.D. program, Institute of Transportation Studies  
*Thesis*: Regional scale dispersion modeling and analysis of directly emitted fine particulate matter from mobile source pollutants using AERMOD.
- Establish a methodology for quantifying fine particulate matter (PM<sub>2.5</sub>) concentration gradients due to mobile source pollutants and to estimate population exposure at a regional scale. We propose a novel air dispersion modeling framework using AERMOD with data from a regional travel demand model that can produce a high resolution concentration surface for a large metropolitan area. We will demonstrate the feasibility of our methodology and how integrating the dispersion modeling framework into the travel demand modeling process routinely performed when developing regional transportation plans can lead to more environmentally and financially sustainable transportation plans.
- Natural Resources Defense Council**, Santa Monica, CA (6/2011 – 9/2011)  
*Graduate Science Intern*, Transportation & Air Quality division
- Examined air quality issues near roadways in Southern California.
  - Reviewed current U.S./California air quality regulations and policy initiatives.
  - Estimated spatial concentration levels of PM<sub>2.5</sub> near roadways in Los Angeles County, CA and analyzed variability in population exposure using ArcGIS and AERMOD.
- Transportation Sustainability Research Center**, Richmond, CA (8/08 – 6/09)  
*Graduate Researcher*, Transportation & Energy Systems division
- Policy and research analysis of AB32 on methods for reducing GHG emissions in CA.
  - Assisted in data collection and analysis on *Car-Sharing* in the San Francisco bay area.
- California State Polytechnic Pomona** (1/2006 – 6/2008)  
*Project Manager*, Senior Project Design
- Coordinated the research and design of a large scale roundabout-interchange conversion.
  - Directed a team of five colleagues in establishing performance measures to evaluate the design alternatives, including simulation, delay, safety, & economic & environmental impacts.
- California State University of Long Beach** (9/2001 – 6/2003)  
*Student Researcher*, C.O.R.E.T Program
- Studied teen alcoholism by creating and analyzing a survey of 200 high school subjects.

## TEACHING EXPERIENCE

**University of California, Irvine** (9/2012 – 6/2014)  
*Graduate Teaching Assistant, Department of Civil and Environmental Engineering*

- Teaching assistant for an undergraduate civil engineering senior design practicum consisting of 128 students.
- Created a web-based arena for weekly homework assignments and discussion.

**University of California, Irvine** (3/2012 – 6/2012)  
*Graduate Teaching Assistant, Department of Civil and Environmental Engineering*

- Assisted in the lab portion of an upper-division undergraduate civil engineering course in transportation planning, which involved the application of Transcad.
- Graded weekly homework assignments with a class size of 51 undergraduate students.

## OTHER WORK EXPERIENCE

**Los Angeles County Metropolitan Transportation Authority** (2/14 - 7/14)  
*Transportation Operations Intern, Department of Wayside Traction & Power*

- Provided assistance with maintaining all traction power substation facilities.
- Prepared detailed maps inventorying & locating all traction power assets via ArcGIS.

**Port of Long Beach, CA** (5/2012 – 02/2014)  
*Transportation Planning Intern, Department of Transportation Planning*

- Evaluated and prepared traffic and rail impact analysis studies for port facilities.
- Reviewed and updated planning documents in accordance with CEQA guidelines.
- Project Manager for the Port's annual traffic count program

**City of Santa Ana, CA** (5/2007 – 6/2008)  
*Transportation Intern, Traffic Engineering Department*

- Answered questions from the general public concerning traffic-related issues.
- Prepared and modified traffic control plans using *Microstation*.
- Analyzed speed studies and pedestrian/vehicular counts and warrants.  
Created a Two-Way STOP warrant according to *CAMUTCD* standards.
- Presented at neighborhood meetings and addressed service requests from the public.

**City of Cerritos, CA** (12/2006 – 5/2007)  
*Public Works Intern, Department of Public Works*

- Investigated complaints in public right-of-ways and assisted work crews in conducting field surveys.
- Commanded the corporate yard radio communication system.

**Los Angeles Music Center** (9/2005 – 9/2011)  
*Dancer/Narrator, Pacifico Dance Company*

- Participant of the *Los Angeles Music Center on Tour*, performing Mexican folkloric dance at school assemblies in the greater Los Angeles area.
- Led in the narration of several assemblies, educating the youth on the art & culture of Mexico.

**Y.M.C.A, Lakewood, CA** (9/2000 – 9/2004)  
*Hockey Referee, Roller Hockey League*

- Encouraged sportsmanship and team play amongst young adults.  
Was promoted to Head-Referee within first year of employment.

- PRESENTATIONS** **Contreras, S.**, Gould, G. (January 15, 2013). *Regional Scale Dispersion Modeling and Analysis of Directly Emitted Fine Particulate Matter from Highway Vehicles Using AERMOD*. Presented at the Transportation Research Board 92<sup>nd</sup> annual meeting, Washington, D.C.
- Contreras, S.** (January 13, 2012). *Spatial Concentration Estimates of PM<sub>2.5</sub> Near Roadways in Southern CA using AERMOD*. Presented at the Institute of Transportation Studies, U.C. Irvine, CA.
- Contreras, S.** (May, 2011). *Roundabout: An Alternative Method of Intersection Control*. Presented at the Institute of Transportation Studies, U.C. Irvine, CA.
- Contreras, S.** (April, 2009). *The Effectiveness of Congestion Pricing: An International Experience*. Presented at the University of California at Berkeley.
- Contreras, S.** (May, 2008). *Intersection Improvements: Comparison of Roundabout-Conversion to Alternative Methods*. Presented at California State Polytechnic Pomona Senior Project Design.

**AFFILIATIONS** Transportation Research Board  
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# **ABSTRACT OF THE DISSERTATION**

Regional Scale Dispersion Modeling and Analysis of Directly Emitted Fine Particulate Matter from Mobile Source Pollutants Using AERMOD

By

Seth Daniel Contreras

Doctor of Philosophy in Civil Engineering

University of California, Irvine, 2015

Professor Michael G. McNally, Chair

A large and growing body of literature associates proximity to major roadways with increased risk of many negative health outcomes and suggests that exposure to fine particulate matter (PM<sub>2.5</sub>) may be a substantial factor. Directly emitted and non-reactive mobile source air pollutants such as directly emitted fine particulate matter can form large spatial concentration gradients along major roadways, in addition to causing significantly large temporal and seasonal variation in air pollutant concentrations within urban areas. Current modeling and regulatory approaches for minimizing exposure have limited spatial resolution and do not fully exploit the available data.

The objective is to establish a methodology for quantifying fine particulate matter concentration gradients due to mobile source pollutants and to estimate the resulting population exposure at a regional scale. A novel air dispersion modeling framework is proposed using the Environmental Protection Agency's regulatory model AERMOD with data from a regional travel demand model that can produce a high resolution concentration surface for a considerably large metropolitan area; in our case, Los Angeles County, California.

We find that PM<sub>2.5</sub> concentrations are highest and most widespread during the morning and evening commutes, particularly during the winter months. This is likely caused by a combination of stable atmospheric conditions during the early morning and after sunset in the evening and higher traffic volumes during the morning and evening commutes. During the midday hours concentrations are at their lowest even though traffic volumes are still much higher than during the evening. This is likely the result of heating during the day time which leads to unstable atmospheric conditions that cause more vertical mixing and lateral dispersion, reducing ground level PM<sub>2.5</sub> concentrations by transport and dilution. With respect to roadway centerlines, PM<sub>2.5</sub> concentrations drop off quickly, reaching relatively low concentrations between 150m to 200m from the center line of high volume roads. However, during stable atmospheric conditions (e.g., nighttime & winter season) concentrations remain elevated at distances up to 1,000m from roadway centerlines.

We will demonstrate the feasibility of our methodology and how integrating the dispersion modeling framework into the travel demand modeling process routinely performed when developing and analyzing regional transportation improvement initiatives can lead to more environmentally and financially sustainable transportation plans. Regional strategies that minimize exposure, rather than inventories, could be established, environmental justice concerns are easily identified, and projects likely to cause local pollution “hotspots” can be proactively screened out, saving time and money for the transportation agency.

## **CHAPTER 1      INTRODUCTION**

Directly emitted mobile source air pollutants often reach high concentrations along major roadways but the concentration of these pollutants decays rapidly with distance from the roadway edge (1). This causes large spatial variations in the concentration of many mobile source air pollutants within urban areas, presenting a challenge for determining local concentrations and exposure levels. The ability to accurately model near roadway air pollutant concentrations across urban areas is an important step for developing more sustainable regional transportation plans that increase mobility while minimizing exposure to dangerous air pollutants. Living near high volume roads has been linked with many negative health outcomes, including heart disease, respiratory illness, and cancer (2-8). Recent studies link these negative health outcomes, at least partially, with exposure to mobile source particulate matter (9-13).

The objective of this dissertation is to present a spatially detailed framework for modeling directly emitted fine particulate matter from automotive emissions at the regional scale. This study will focus primarily on fine particulate matter because of the link with negative health outcomes, previous literature raising concerns about elevated concentrations near major roadways, and the Environmental Protection Agency's (EPA) consideration of new rules requiring additional particulate matter air quality monitors near roadways. The analysis framework presented herein could also be used for modeling other important mobile source emissions such as nitrogen dioxide, ultra-fine particulate matter, and other hazardous air toxics.



Directly emitted fine particulate matter is defined as particulate matter less than 2.5  $\mu\text{m}$  in diameter ( $\text{PM}_{2.5}$ ) and is directly emitted from vehicles in the exhaust stream, from tire and road wear, and as break dust. Other vehicle exhaust components also combine and change over time in the atmosphere to form secondary  $\text{PM}_{2.5}$ . Secondary  $\text{PM}_{2.5}$  is a regional pollutant while directly emitted  $\text{PM}_{2.5}$  is a more localized phenomena as explained above.

The EPA regulates  $\text{PM}_{2.5}$  under the Clean Air Act which establishes National Ambient Air Quality Standards (NAAQS) defining the maximum allowable concentration of  $\text{PM}_{2.5}$  in the outside air. Transportation planners and agencies in regions where  $\text{PM}_{2.5}$  concentrations regularly exceed the NAAQS (i.e., nonattainment areas) must ensure that transportation plans and projects will not cause additional violations of the NAAQS or prolong the timeframe established to meet the NAAQS. In these regions two types of modeling are regularly used to determine continued compliance: regional emission inventories and “hotspot” analysis. However, these methods alone are not well suited to ensure that all areas, or even most, are (or will) be in compliance with the  $\text{PM}_{2.5}$  NAAQS.

Regional emission inventories are used to determine the likelihood of a region’s long range transportation plan causing additional or prolonged violations of the NAAQS. The emission inventory is an accounting of the total mass of  $\text{PM}_{2.5}$  emitted per year across the region and is compared with a regional emission budget approved by the EPA. If the inventory falls within the budget then the plan is generally considered to be “conforming” (see Table 1.1). That is, the plan fits with the region’s overall air quality improvement plan which considers all sources of  $\text{PM}_{2.5}$

pollution. This framework works well for regional air pollutants such as smog, carbon dioxide, and secondary PM<sub>2.5</sub>; however, it is unable to identify if regional transportation plans will continue to produce localized PM<sub>2.5</sub> violations, where those violations may occur, and what strategies could minimize the violations (see Figure 1.1).

County		Tons/Day								
		ROG Summer	ROG Annual	NO <sub>x</sub> Summer	NO <sub>x</sub> Annual	NO <sub>x</sub> Winter	CO Winter	PM10 Annual	PM2.5 Annual	SO <sub>x</sub> Annual
Los Angeles /a/	Existing	96	94	199	203	218	902	14	9	1
	Plan	42	41	70	71	75	299	12	8	1
	Difference	(54)	(54)	(129)	(132)	(143)	(603)	(1)	(1)	0
Imperial	Existing	5	4	14	13	14	34	1	1	0
	Plan	4	3	9	9	9	24	1	1	0
	Difference	(1)	(1)	(4)	(4)	(5)	(10)	0	0	0
Orange	Existing	31	30	52	53	58	280	4	3	0
	Plan	14	14	19	19	20	96	4	3	0
	Difference	(16)	(16)	(34)	(34)	(38)	(184)	0	0	0
Riverside /b/	Existing	26	23	76	76	80	227	5	4	0
	Plan	15	13	35	35	36	114	5	3	1
	Difference	(11)	(10)	(41)	(41)	(44)	(113)	0	0	0
San Bernardino /c/	Existing	28	25	81	81	85	251	5	4	0
	Plan	15	13	37	37	38	114	5	3	0
	Difference	(13)	(12)	(44)	(44)	(47)	(137)	0	0	0
Ventura	Existing	10	10	16	16	18	83	1	1	0
	Plan	4	4	5	6	6	27	1	1	0
	Difference	(5)	(5)	(10)	(11)	(12)	(56)	0	0	0

/a/ Los Angeles County excludes Antelope Valley  
 /b/ Riverside County includes portions of the SCAB, MDAB and Coachella Valley  
 /c/ San Bernardino County includes the SCAB and MDAB portions  
 SOURCE: SCAG Transportation Modeling, 2011.

SCAG 2012 RTP, DPEIR: Air Quality

**Table 1.1 Criteria Pollutant Mass Emissions by County – Existing (2012) vs. Plan (2035)**



**Figure 1.1 SCAQMD Regional Air Quality Index of the South Coast Air Basin**

Given the limitation of emission inventories, the EPA also requires PM<sub>2.5</sub> “hotspot” analyses for transportation projects in nonattainment areas that have the potential to increase PM<sub>2.5</sub> emission rates (14). The hotspot analysis generates a spatially detailed map of PM<sub>2.5</sub> concentrations around the proposed transportation project and its alternatives using an air dispersion model (e.g. AERMOD or CALINE). The hotspot analysis adds the incremental PM<sub>2.5</sub> concentrations from the project to estimates of the existing PM<sub>2.5</sub> concentration in the area measured at nearby air quality monitors and then determines if any areas will have PM<sub>2.5</sub> concentrations that exceed the NAAQS. The hotspot analysis occurs after a specific transportation project has been proposed

for construction and during the preparation of required environmental review documents (e.g., environmental impact statement). During the environmental review several alternatives are compared including a no-build alternative and several others which typically represent alternative alignments or various levels of additional capacity. If the hotspot analysis indicates that the build alternatives will cause violations of the NAAQS the project may be abandoned or various mitigations strategies may be implemented.

One example of this application is provided in Figure 1.2 where a regional “hot-spot” analysis was performed by the California Air Resources Board to estimate mobile source PM<sub>2.5</sub> concentration gradients at a regional scale using SCAG’s 2012 RTP. One major drawback of this application however was the limited number of regional roadways modeled in the analysis. At least one major freeway corridor was selected for each of the six counties that form the SCAG region, and of those freeways selected the segment within each corridor that exhibited the highest daily traffic volume according to the regional travel demand model were quantitatively modeled using the EPA’s Transportation Conformity Guidance for Quantitative Hot-Spot Analyses in PM<sub>2.5</sub> and PM<sub>10</sub> Nonattainment and Maintenance Areas guidelines. The segments identified as containing the highest daily traffic volumes that were to be modeled in the hot-spot analysis included:

- **I-405** – in Seal Beach, east of the I-605 interchange (Orange County)
- **I-710** – in Compton, north of the intersection with SR-91 (Los Angeles County)
- **I-8** – in El Centro (Imperial County)
- **SR-60** – in Ontario, west of the I-15 interchange (San Bernardino County)



While the current hotspot analysis framework provides a good check on air quality concerns before construction begins, it has some weaknesses which limit its effectiveness at improving regional air quality. The current hotspot analysis framework is only required for transportation improvement projects, and therefore does not consider that there may be regions along existing infrastructure that cause local violations of the NAAQS. Similarly, the current framework does not consider how changes in traffic volume along individual roadways due to population or employment growth and spillover effects from regional transportation projects may cause local violations of the NAAQS. Furthermore, because the hotspot analysis takes place during a project's implementation phase the range of alternatives available for reducing the concentration of PM<sub>2.5</sub> are constrained. For example, during the typical environmental review for a project proposing to add capacity to a highway segment with the goal of reducing congestion the alternatives are typically no-build and various levels of additional capacity. However, at the regional planning phase a much larger set of alternatives are available for consideration such as expanding regional transit service, encouraging land use decisions that reduce travel demand, adopting more stringent emission control standards, and adopting financial incentives to reduce travel demand such as a vehicle miles traveled tax, pay as you go insurance, congestion charging, or higher fuel taxes.

## 1.1 PROBLEM STATEMENT

The primary objectives of this dissertation are the following:

1. Quantify PM<sub>2.5</sub> concentration gradients from mobile source pollutants at a regional scale;
2. Estimate population exposure to the PM<sub>2.5</sub> concentration levels calculated in part 1 using data from the US Census Bureau;
3. Demonstrate the feasibility and practicality of our approach by integrating the proposed methodology into the regional transportation planning process; &
4. Provide a tool for planners and policy makers to assess Environmental Justice (EJ) issues.

We will demonstrate the feasibility of such large scale dispersion modeling by considering an extremely large area, which in our case is Los Angeles County, California. The results of our proposed framework will also demonstrate the insight obtained from modeling a large metropolitan region with regards to spatial and temporal concentration patterns, population exposure levels, and environmental justice considerations. These methods will also be useful for refining epidemiology studies and in siting new air quality monitoring stations where they are likely to capture the highest levels of population exposure. By integrating our proposed methodology into the regional transportation planning process routinely performed by metropolitan planning organizations, projects likely to cause local pollution “hotspots” can be proactively screened out, saving time and money for the transportation agency. This large scale modeling requires some compromise and innovation however in order to enable feasible computation times given the limitations and complexities of current dispersion models.

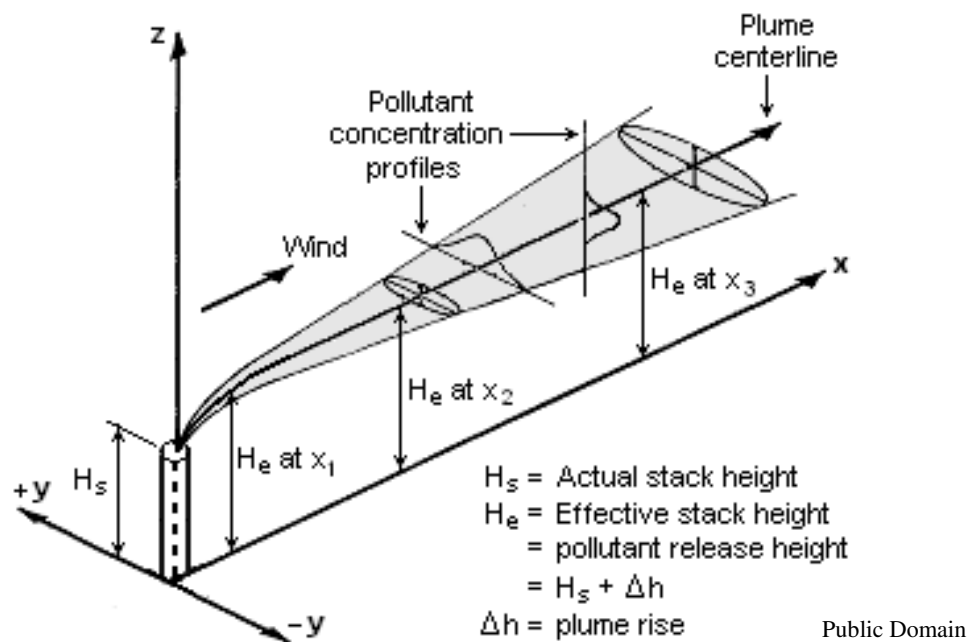
## **CHAPTER 2      AIR DISPERSION MODELING BACKGROUND**

Air dispersion modeling uses mathematical equations to describe the atmosphere, dispersion, chemical, and physical processes within a plume. In hydrodynamics, a plume is a column of one fluid or gas moving through another. In the case of air dispersion modeling, a plume represents the movement of pollutants in the air (i.e. air pollution). The purpose of air dispersion modeling is to calculate concentrations of air pollutants emitted by a variety of sources, including industrial plants and vehicular traffic, at different receptor locations (see Figure 2.1). This method replaces the generic proximity buffer approach, or fixed-distance, which assumes that air pollution disperses equally in all directions from a source.

Air dispersion modeling takes into account the physical properties of the pollutants, such as density, characteristics of sources, including emission rates, velocity, and temperature, meteorological conditions, such as temperature, wind speed and direction, topographical features, and the effects of the surrounding built environment. In doing so, air dispersion modeling can provide a more accurate assessment of air pollutant exposure. Pollutant concentrations that are of importance for measuring include: PM, NO<sub>x</sub>, SO<sub>x</sub>, CO, and various other gases and particles.



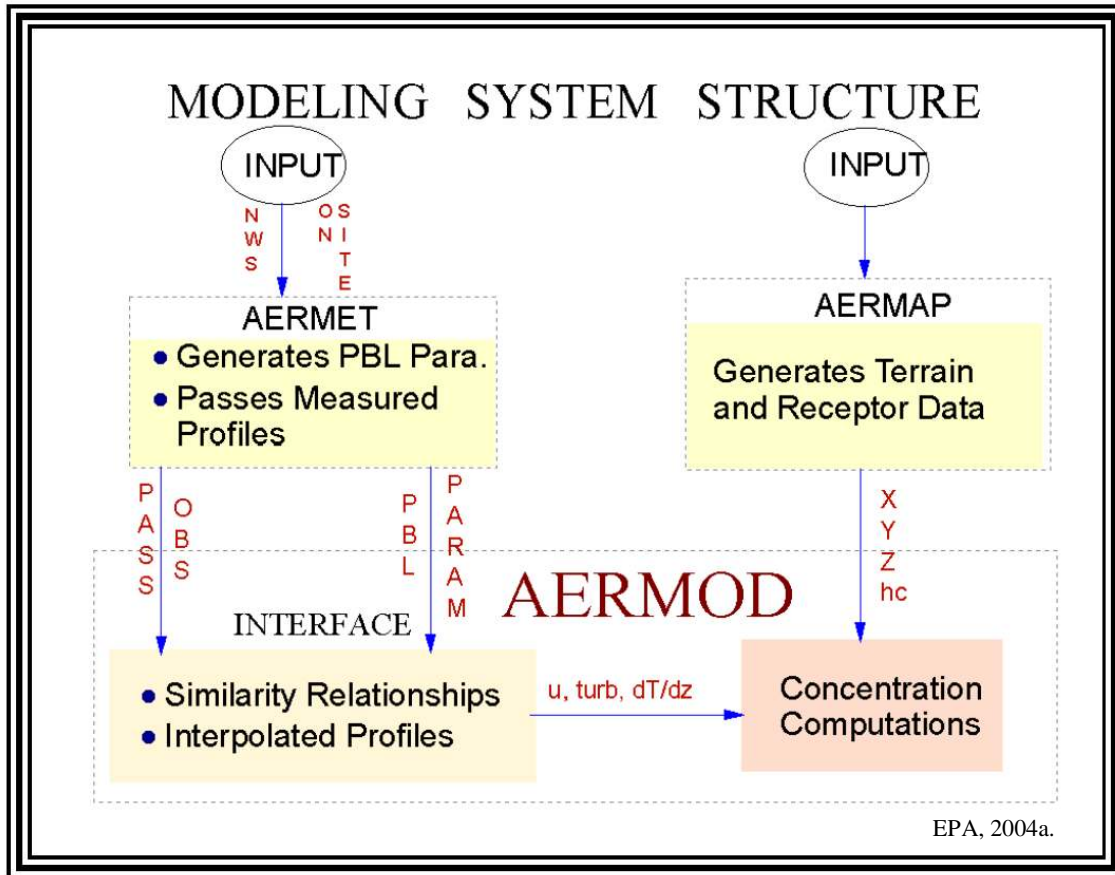
Pollutant concentrations are calculated using mathematical equations comprised of two types of variables: Emission and Meteorological/Topographical variables. The mathematical equations describe the relevant physical processes between the variables, which is derived from the mass principle conservation. In the case of air dispersion modeling near roadways, several models have been developed to determine the temporal and spatial concentration gradients due to vehicular exhaust emissions (VEEs). These models are referred to as Line Source Emission Models (or LSEMs), in that they model the VEEs on roadways as line sources. Such LSEMs can include, among others, AERMOD, CALINE4, CAL3QHC, CALPUFF, ISC3, and HIWAY. Further description of each model, including limitations and case studies, will be provided in the ensuing sections. Table 2.1 provides a summary of the line source emission dispersion models presented therein.



**Figure 2.1 Visualization of a Buoyant Gaussian Air Pollutant Dispersion Plume**

## 2.1 AERMOD

AERMOD, the American Meteorological Society & Environmental Protection Agency Regulatory Model Improvement Committee Dispersion Model, is a steady-state *Gaussian* (*i.e.* normal distribution) plume dispersion model based on the planetary boundary layer (PBL), including the stable boundary layer (SBL), and the convective boundary layer (CBL), and is defined by horizontal and vertical meteorological variables, including turbulence structure, and scaling concepts (for simple & complex terrain). Pollutants modeled in AERMOD include gases and particles in 1-4h, 6h, 8h, 12h, or 24 hour averages. Monthly averages, and averages for the entire data period, (1 year for example) may also be modeled. AERMOD has the capability of modeling roadways as pollutant line sources by area or volume. AERMOD is the EPA preferred, or recommended, dispersion model as of 2005 (replacing ISC3). Figure 2.2 describes the modeling system structure of AERMOD, including its pre-processors and major inputs.



**Figure 2.2 Modeling System Structure of AERMOD**

### **ADVANTAGES**

- Models multiple sources of different types: Point, Area & Volume (such as industrial, mining, landfill, & road sources);
- Model typically used for large urban areas (i.e. regional);
- Both horizontal AND vertical variations in the PBL are incorporated into the model's predictions;
- Models complex terrain (both urban and/or rural) and considers the influence of buildings and other structures; &

- Provides detailed resolution of the spatial variations in hourly-average concentrations of airborne pollutants because of the improved spatial emission allocations.

## LIMITATIONS

- *Gaussian* dispersion models do not account for chemical reactions, or physical dynamics (condensation, coagulation, etc.);
- Since *steady-state* is assumed, (that is, particle dispersion process achieves steady-state instantaneously) the Gaussian plume model does not account for the time required for the pollutant to travel to the receptor (i.e. aerosol dynamics, which would account for interaction between the plumes);
- *Gaussian* models are not designed to model dispersion at sites close to the source (within 100 m);
- *Gaussian* models are not designed to model dispersion under low wind conditions, or in street canyons;
- Simplified treatment of turbulence and meteorology. Therefore, best suited to calculating hourly pollutant concentrations;
- *Gaussian* model not able to calculate recirculation effects caused by multiple buildings or at intersections;
- Relatively intensive data needs (such as meteorological data);
- Inputs and parameters of AERMOD require some degree of generalization and averaging of data;

*(continued on next page)*

- Buffer analysis (both fixed distance & plume) is essentially a binary model (either exposed or unexposed) due to the simplification of a discrete boundary (rather than continuous);
- Receptor Grid size limited to < 50 km;
- Models line sources *indirectly* (i.e. series of volume or area sources); &
- Assumes dispersion of air pollution plumes to be continuous (i.e. no puffs).

### **CASE STUDIES AND MODEL PERFORMANCE**

- i. **Chen, H., et al. (15):** AERMOD under-predicted PM<sub>2.5</sub> (estimated versus observed) at an intersection in Sacramento;
  
- ii. **Kesarker, A.P., et al (16):** AERMOD generally underestimates the concentrations of PM<sub>10</sub> (24 hourly averaged) over Pune, India. Used different meteorological inputs however (WRF, as opposed to AERMET). Assumed flat terrain (no AERMAP). Multiple sources and sinks used;
  
- iii. **Zhang, Q., et al. (17):** AERMOD simulated data of SO<sub>2</sub> and NO<sub>x</sub> concentrations agreed reasonably with observed data over Hangzhou, China. Simulated data of PM<sub>10</sub> concentrations (annual averages) were much lower than observed data (secondary PM<sub>10</sub> data were not included in the model);

- iv. **Zhang, K., et al. (18):** AERMOD produced “satisfactory” PM (or Black Carbon) predictions near roadways in South Bronx, NY. Modeled roadways as multiple segments of area sources. Used MOBILE6.2 for emission factors;
  
- v. **Cook, R., et al. (19):** Emission inventory includes emissions for individual road links (using GIS & output from TDM, such as traffic activity on any given link). Link-based methodology applied to New Haven, CT. A hybrid air quality model was used (CMAQ and AERMOD). AERMOD used to capture running emissions associated with road links (which were modeled as area sources), & CMAQ used to capture other types of vehicle emissions (such as diurnal & hot soak emissions). Developed Consolidated Community Emissions Processing Tool (CONCEPT), a tool to obtain emission rates at the link level. Modeled two pollutants: Benzene and CO (Hourly averages / spatial & temporal variations). They compared modeled predictions with observed measurements and found that “generally” the modeled results agreed with the observed values (within a factor of two); &
  
- vi. **Maantay, J.A., et al. (20):** Loosely integrated AERMOD with ArcGIS to simulate air dispersion from stationary sources in the Bronx, NY for five pollutants: PM<sub>10</sub>, PM<sub>2.5</sub>, NO<sub>x</sub>, CO, and SO<sub>2</sub>. Plume buffers of pollutant concentrations around the sources were calculated (as opposed to fixed-distance proximity). Application of the plume buffers confirmed that the higher asthma hospitalization rates were associated with the higher potential exposure to local air pollution. Empirical verification of the model results was not conducted (i.e. observed concentrations from monitoring

stations). Authors argued that it was not useful to validate the AERMOD output against the data (from monitoring stations) due to the limited number, altitudinal location, & biased spatial distribution of these monitors.

## 2.2 CALINE

CALINE, the California Line Source Dispersion Model, is a steady-state, line source, *Gaussian* plume dispersion model used to predict air pollutant concentrations near roadways. CALINE models pollution concentrations from vehicular traffic as an infinite line source divided into a series of elements (or multiple VOLUME sources), and then summed. The model was first published in 1972 by Beaton, J.L., et al. The model has been updated over time with various software versions. For example, CALINE3 (1979) replaced the virtual point approximation with an equivalent finite line source representation and added a multiple link option. CALINE4 (1984) is the most recent version of the CALINE model series developed by CALTRANS. Pollutants modeled in CALINE4 include: CO, NO<sub>2</sub>, and TSP (in 1h, 24h, and worst case). One of the main differences between CALINE4 and AERMOD is the vertical distribution within the CBL of the AERMOD model is *Bi-Gaussian* (i.e. concentration calculated as weighted average of two Gaussian distributions). Inputs to CALINE4 include: Vehicle-related data (such as volumes and emission factors), meteorological data, link geometry, and receptor coordinates.

## **ADAVANTAGES**

- Designed to model concentrations near roadways (could be a limitation also);
- Can model air quality at intersections;
- Incorporates flexible input/output options, as well as wind variability (includes an option to model air quality near intersections); &
- User-friendly & does not require extensive computer power (or time).

## **LIMITATIONS**

- Limited to urban dispersion modeling over short distances (100-500m);
- Not recommended for low wind speeds;
- Local scale modeling (not for regional);
- Models line sources only;
- Only measures three pollutant types (CO, NO<sub>2</sub>, & TSP);
- Tendency to predict higher concentrations for parallel wind case;
- Assumes horizontally homogeneous wind flow;
- Not designed to model complex terrain; &
- Not able to treat explicitly the various turbulent mixing processes near roadways (such as vehicle-induced & road-induced turbulence)



## CASE STUDIES AND MODEL PERFORMANCE

- i. **Chen, H., et al. (15):** CALINE4 performed “moderately” well in predicting near-road  $PM_{2.5}$  concentrations at an intersection in Sacramento, CA. For a roadway in London, CALINE4 resulted in over-predictions of near-road  $PM_{2.5}$  concentrations when incremental concentrations due to on-road emissions were low, while under-predictions occurred when incremental concentrations were high. The authors point out the street canyon and receptor locations likely contributed to the relatively poor performance of the models at the London site;
  
- ii. **Batterman et al. (21):** Authors utilized both statistical (time-series) and simulation models (CALINE4) to estimate vehicle contributions to pollutant levels near roadways. A one year study period (2004) monitoring CO and  $PM_{2.5}$  concentrations near a major highway in Detroit, Michigan was analyzed. CALINE4 performed “reasonably well” in estimating CO concentrations near the highway, but it significantly underestimated  $PM_{2.5}$  concentrations. The authors point out that the  $PM_{2.5}$  emission factor estimates (using MOBILE6.2) were 4 to 5 times lower than the observed measurements, a likely result of underestimating  $PM_{2.5}$  concentrations; &
  
- iii. **Gramotnev et al. (22):** Used a modified version of CALINE4 to estimate motor vehicle emission factors of fine and ultrafine particles near a busy road in the Brisbane area of Australia. They found that the CALINE4 model results matched well with the observed rate of dispersion with distance from the road.

## 2.3 CAL3QHC

CAL3QHC is an air quality model specifically designed for intersection analysis. Similar to the previously mentioned dispersion models, CAL3QHC is a *Gaussian* plume, steady-state model. It was originally intended to predict CO concentrations (and PM) at intersections. The model is considered an enhanced version of CALINE3 (i.e. CALINE3 is included in the model formulation), with an additional algorithm that estimates the lengths of vehicular queues at signalized intersections, in order to account for the contribution of idling vehicles. The dispersion process of CAL3QHC is the same as that in CALINE4, however, CAL3QHC uses atmosphere stabilities to estimate the horizontal dispersion parameter ( $\sigma_y$ ) and the vertical dispersion parameter ( $\sigma_z$ ) is not modified by the vehicle-induced heat algorithm. The model requires the same inputs as the CALINE3 model, as well as several other additional parameters, such as idling emission rates and intersection signal timing.

**ADVANTAGES** (see CALINE advantages)

**LIMITATIONS** (see CALINE limitations)

### CASE STUDIES AND MODEL PERFORMANCE

- i. **Moseholm et. Al (23):** CAL3QHC model yielded unsatisfying results in forecasting CO concentration near an intersection. However, conditions included low wind speeds, and tall buildings nearby;

- ii. **Zhou, H., & Sperling, D. (24):** Author's found that mixed traffic (bikes & vehicles) and near-road high-rise buildings caused CAL3Qhc predictions of CO concentrations to be poor;
  
- iii. **Abdul-Wahab, S.A. (25):** CAL3QHC performed generally well in predicting CO concentrations near an intersection in Muscat, Oman. Conditions included open areas with moderate traffic volumes;
  
- iv. **Kho et al. (26):** CAL3QHC predicted results correlated well with the measured data in predicting CO concentrations at two major trafficked suburban intersections in Malaysia (10-year study period); &
  
- v. **Gokhale, S., and Raokhade, N. (27):** CAL3QHC predicted PM<sub>2.5</sub> and PM<sub>10</sub> concentrations did not match well with the measured concentrations at an urban traffic intersection in Ganeshguri during the winter period. Author's note, PM dispersion from non-traffic sources may have been a main contributor to the mismatch.

## 2.4 CALPUFF

CALPUFF, or the California Puff Model (developed by CALTRANS), is a multilayer, non-steady state, *Lagrangian Gaussian* puff dispersion model which can simulate the effects of time- and space-varying meteorological conditions on pollutant transport, transformation, and removal. The “*Puff*” portion of the model refers to the non-continuous characteristics of the air dispersion plume, which tends to be a more accurate representation of ambient air properties. The model provides four different source types: point, line, volume, and area source using an integrated puff formulation incorporating the effects of plume rise, partial penetration, buoyant/momentum plume rise, and stack/building effects.

### ADVANTAGES

- Model simulates the dispersion AND transformation (chemical) processes of emitted material;
- Models line sources directly;
- Models complex terrain and long range effects (including overwater transport, coastal interaction effects, and wet and dry removal); &
- Contains algorithms for near-source effects (i.e. building downwash).

### LIMITATIONS

- Primarily used to calculate hourly concentrations;
- Model does not include any modeling of particle dynamics;
- Does not calculate particle size distribution;

- Used to model on a regional scale (not local); &
- Not recommended for calculation of timescales shorter than 1 hour, or where dispersion is heavily influenced by turbulence, such as in an urban environment.

## **CASE STUDIES AND MODEL PERFORMANCE**

- i. **Elbir, T. (28):** CALPUFF used to predict dispersion of SO<sub>2</sub> emissions from industrial & domestic heating sources in Izmir, Turkey (80x100km modeling domain) in 2000. The overall model performance (when compared to measurements from 4 monitoring stations) was found good with an accuracy of about 68%; &
  
- ii. **Cohen et al. (29):** Used CALPUFF dispersion model to assign emissions to individual road links in Portland, Oregon. Pollutant concentrations of benzene, 1,3-butadiene, and diesel PM were estimated with the model. The model indicated a zone of influence around a roadway as between 200 and 400 meters.

## 2.5 ISC3

The ISC3 model, or Industrial Source Complex model (version 3), is a steady-state, *Gaussian* plume model used to assess pollutant concentrations from a variety of sources associated with an industrial complex. It models point, area, line, and volume sources. ISC3 was replaced by AERMOD in 2005 by the EPA and is considered the preferred air dispersion model.

### **ADVANTAGES**

- Major advantage of ISC3 over AERMOD is its relative simplicity of use, and robust predictions;
- Models concentrations for averaging times of 1 hour up to a year; &
- Requires minimum input of meteorological data.

### **LIMITATIONS**

- Mainly used for simple terrain and industrial-like sources; &
- Model does not accommodate improved knowledge of the structure of the atmospheric boundary layer and resulting estimations of turbulent dispersion processes (i.e. contains 1960's technology).

## **CASE STUDIES AND MODEL PERFORMANCE**

- i. **US EPA (30):** Assessed the model results of AERMOD and ISC3 for comparison/evaluation purposes. Conducted several studies in a variety of types of environments (including 4 short-term and 6 long-term) and sources (mostly stationary). The results showed an overall predicted-to-observed ratio for short-term averages of 0.97 for AERMOD, and 0.94 for ISC3; &
  
- ii. **Hanna et al. (31):** Model evaluation of AERMOD compared to ISC3. Performed 5 sets of field observations of different scenarios (flat versus elevated terrain/ urban versus rural) and different source types (mostly stationary point sources). Results showed ISC3 typically over-predicts, has a scatter of a factor 3. AERMOD (which under-predicted by 40% and had a scatter of a factor of 2) was found to perform better than ISC3.

## 2.6 HIWAY

HIWAY was developed by the EPA in 1975 (current version is HIWAY4), and is based on the *Gaussian* equation (steady-state). The model is used for estimating the concentrations of nonreactive pollutants from highway traffic (modeled as a series of finite line sources).

### ADVANTAGES

- Designed specifically for modeling highway traffic sources (line)

### LIMITATIONS

- Not recommended for modeling over short distances, complex terrain, near tall structures, or low winds;
- Mainly applicable to modeling CO concentrations only;
- Overestimates for cases of parallel wind;
- Designed for local scale modeling (not regional); &
- Not designed to model intersections.

### CASE STUDIES AND MODEL PERFORMANCE

- Chock, D.P. (32):** HIWAY model overestimates pollutant concentrations adjacent to the highway; &
- Noll et al. (33):** HIWAY model overestimates CO concentrations for parallel wind cases, and underestimates for crosswind cases<sup>34</sup>



## 2.7 STATISTICAL MODELS

Statistical models calculate pollutant concentrations by statistical methods from meteorological and traffic data after an appropriate statistical relationship has been obtained empirically from measured observations (e.g. regression or time-series analysis). There are typically two statistical approaches: Spatial or Land Use regression models, and Non-Spatial models

### LIMITATIONS

- Requirements of long historical data and lack of physical interpretation;
- Cannot provide information about how pollutant levels would respond to emission controls; &
- Site specific & underperform when modeled with nonlinear data.

### CASE STUDIES AND MODEL PERFORMANCE

- i. **Levy et al. (34):** Used linear mixed effects regression models to predict concentrations of PM<sub>2.5</sub>, polycyclic aromatic hydrocarbons (PAHs) and ultrafine particles with traffic counts, wind direction, and distance to road (accounting for autocorrelation). The results showed large diesel vehicle counts were significantly associated with roadside PAHs, but little relation with PM<sub>2.5</sub>;

- ii. **Aldrin and Haff (35):** Used generalized additive models (GAM) to link PM size fractions, NO and NO<sub>2</sub> concentrations to traffic counts, temperature, wind speed/direction, precipitation, relative humidity and snow cover (non-linear relation). A reasonably “good fit” was obtained, with the most important predictor variables being traffic counts and wind speed/direction; &
  
- iii. **Ross et al. (36):** Developed a regression model to predict PM<sub>2.5</sub> concentrations in the New York City region using data on nearby traffic, emissions, population, and land use (no meteorological variables included). The results showed that traffic within a buffer of 300-500m explained the greatest proportion of variance (37-44%).

**Table 2.1 Summary Table of Line Source Emission Dispersion Models**

<b>Model</b>	<b>Model<sup>a</sup> Type</b>	<b>Scale<sup>b</sup></b>	<b>Grid Size</b>	<b>Resolution</b>	<b>Source<sup>c</sup> Types</b>	<b>Pollutants<sup>d</sup></b>	<b>Output Frequency</b>	<b>Atm.<sup>e</sup> Stability</b>	<b>Turbulence<sup>f</sup></b>
<b>AERMOD</b>	<b>Bi Gaussian Steady State GP</b>	<b>L, R</b>	<b>&lt; 50 km</b>	<b>H: no limits V: no limits</b>	<b>P, A, V (L treated as series of V)</b>	<b>G, P</b>	<b>1h, 24h, 1yr</b>	<b>BL</b>	<b>AMB</b>
CALINE4	Steady State GP	L	H: 100- 500m	1m	L	CO, NO <sub>2</sub> , TSP	1h, 8h, worst case	P	VIT, AMB
<b>CAL3QHC</b>	<b>Steady State GP</b>	<b>L (Intersection)</b>			<b>L</b>	<b>CO, PM</b>			<b>AMB</b>
CALPUFF	Multi-layer Non-steady state GPuff	R	<200km	H: no limits V: no limits	P, L, A, V	G, P	> 1h	BL	AMB
<b>ISC3</b>	<b>Steady State GP</b>				<b>P, L, A, V</b>		<b>1h up to 1yr</b>		
HIWAY2	Steady State GP	L	10-100m but up to 10km dep. scale factor	1m	L	Non- reactive gases	1h	P	VIT, AMB

<sup>a</sup>Model Types: GP = Gaussian Plume, GPuff = Gaussian Puff

<sup>b</sup>Scale: L = Local, R = Regional

<sup>c</sup>Source Types: L = Line, P = Point, A = Area, V = Volume

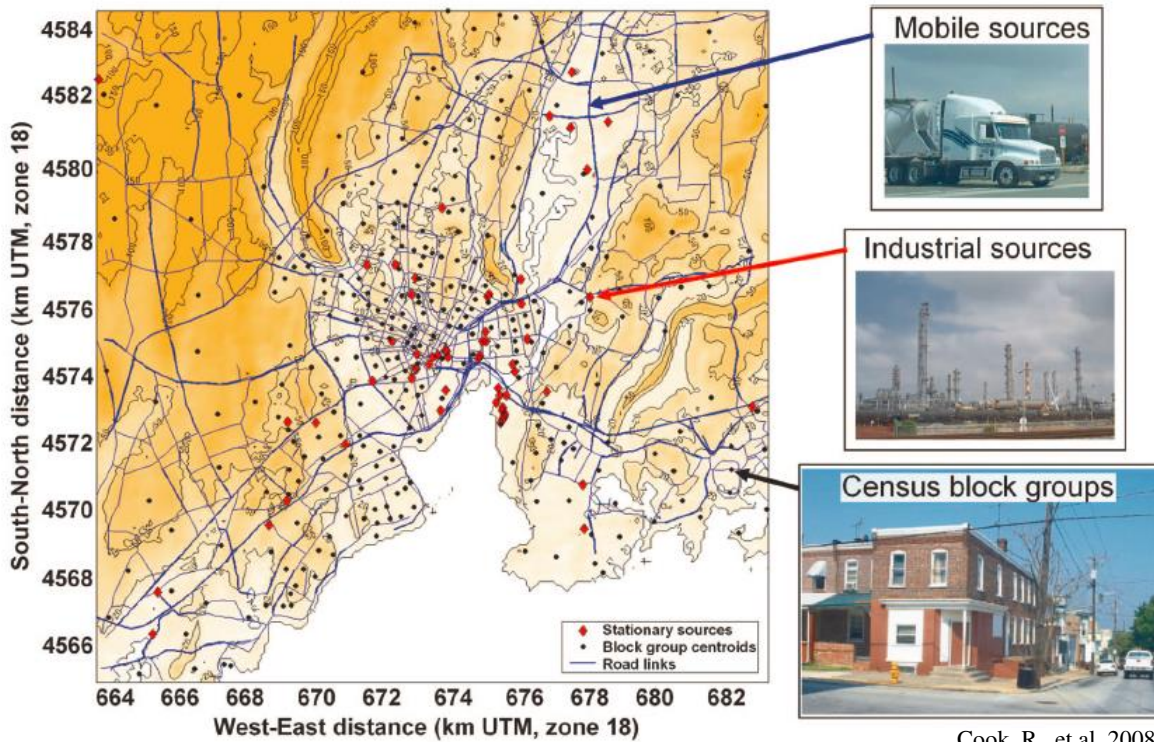
<sup>d</sup>Pollutants: G = Gases, P = Particles

<sup>e</sup>Atmospheric Stability: P = Pasquill, BL = Boundary Layer Scaling

<sup>f</sup>Turbulence: VIT = Vehicle Induced Turbulence, AMB = Turbulence of Ambient Air

## CHAPTER 3      LITERATURE REVIEW

Previous studies that have modeled mobile source pollutants at a regional scale have used either dispersion models or land-use regression (LUR) models. Greco et al. (37) estimated PM<sub>2.5</sub> intake fractions from highway vehicles in the Boston metro area (165.9 km<sup>2</sup> with 23,398 road segments) by applying the air dispersion model CAL3QHCR. The intake fraction measures how much of each road segment's emissions are inhaled by the population in an area defined by the authors, in this case 6 radial buffers around each segment with a maximum extent of 5km from the roadway. The authors analyzed how meteorology, population patterns, and the layout of the road network affect intake fractions using a constant emission rate for all roadway segments. That is, the model does not consider how variations in vehicle activity and fleets affect exposure; however, their analysis does highlight that even with this simplification there is significant variability in exposure to directly emitted PM<sub>2.5</sub> within urban areas. Cook, R., et al. (19) modeled PM<sub>2.5</sub> emissions from multiple sources, including mobile sources, in New Haven, CT using the AERMOD dispersion model. Their method for modeling highway sources considered differences in vehicle activity and fleets across road segments by incorporating information from the regional transportation agency's travel demand model. The authors generated a region-wide receptor grid by placing receptors at the centroid of each U.S. Census block group (See Figure 3.1). Their modeling found significant spatial variation in PM<sub>2.5</sub> concentrations among census block groups within New Haven, with mobile sources being a major source of the variation.

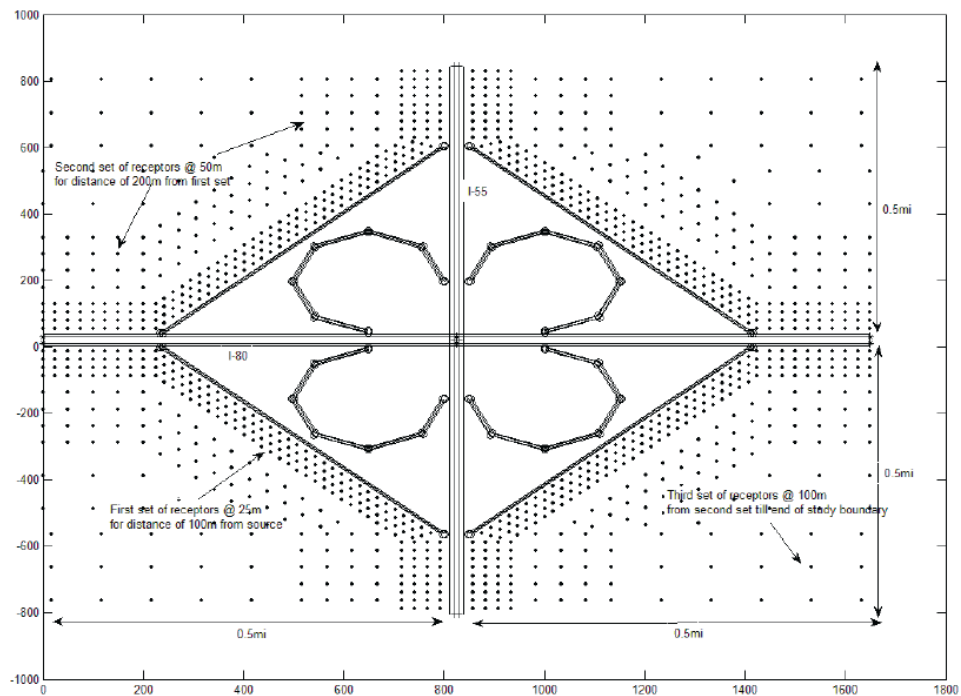


Cook, R., et al. 2008

**Figure 3.1 Cook, R., et al. 2008 New Haven, CT Modeling Domain and Receptor Grid**

Lin, J., et al. (38) proposed a detailed methodology for project-level PM<sub>2.5</sub> conformity guidance by using the dispersion model AERMOD coupled with the emission factor model MOVES and applying the analysis to a clover-leaf interchange in Illinois. MOVES is a new-generation emission factor regulatory model developed by the EPA. Emission rates for each link segment were calculated using traffic count volumes provided by the Illinois department of transportation. Figure 3.2 shows the receptor grid and respective spacing for the defined modeling domain. The first line of receptors was placed at 50 feet (17m) from the roadway edge to account for right-of-way distance. A total of 36 sources and 1,168 receptors were used for this case study. The highest PM<sub>2.5</sub> concentration observed from the model was 0.45 µg/m<sup>3</sup> (excluding background concentration). As expected, these concentrations were observed at locations where traffic

volumes were the highest, and in the direction of prevailing winds. The authors note that the  $PM_{2.5}$  concentration estimates modeled in the study were not validated with roadside measurements. Also, the authors recommend that future work should look into the sensitivity and accuracy of AERMOD and determine a balance between number of sources modeled and computational speed.



**Figure 3.2 Lin, J., et al. I-80 & I-55 Freeway Interchange Model Domain & Receptor Grid**

While dispersion models offer a detailed bottom-up approach for generating spatially detailed estimates of regional air pollutant concentrations, LUR models offer an alternative top-down approach. Jerrett et al. (39) model ambient concentrations of nitrogen dioxide ( $NO_2$ ) in Toronto, Canada, using a LUR model to assess spatial variation within the urban area. The LUR model is developed by regressing a wide range of land-use, population, transportation, and other spatially

distributed variables on measured NO<sub>2</sub> concentrations at 95 monitoring locations. They produce a model with a relatively good fit ( $R^2 = 0.69$ ) where variables related to highway traffic levels and proximity are significant predictors. The model is used to generate a predictive NO<sub>2</sub> concentration surface that aligns well with monitoring data and indicates elevated concentrations along major roadways in the downtown area. Novotny et al. (40) show how LUR models can be created for much larger regions, in their case the United States. The authors follow a similar approach to Jerrett et al. (39), but combine satellite based NO<sub>2</sub> data with on the ground monitoring data (EPA NAAQ monitors) to develop a LUR model. Their model also shows a good fit to the observed data ( $R^2 = 0.77$ ) and that major roadways are a significant factor in predicting spatial patterns of NO<sub>2</sub> concentration.

Both dispersion models and LUR models appear well suited for modeling the spatial patterns of PM<sub>2.5</sub> concentrations within large urban areas. Each method also has several limitations. One limitation of currently published studies that use dispersion modeling for large urban areas is that they are limited in spatial resolution. For example, Cook et al. (19) consider a dense array of sources (individual road segments as well as various stationary point sources) but limit the receptor network to the centroid of census block groups while Greco et al. (37) place 8 receptors in each of their radial buffers. Receptor networks are typically constrained to limit computation times that can easily extend for weeks or even years when modeling a large area. The main drawback of LUR models are large data requirements which also involve collecting new monitoring data. The results of a particular LUR model may be partially transferable to other regions, but differences in vehicle fleets, fuels, weather, and non-transportation sources will require adjustments and additional calibration.

In this dissertation we will apply the air dispersion model AERMOD to create a spatially detailed surface of PM<sub>2.5</sub> concentration from vehicle traffic. Our choice is largely driven by data availability since we have vehicle traffic and fleet data for all major roads in the six-county SCAG region, which includes Los Angeles County, while there are only a few existing PM<sub>2.5</sub> monitors that could be used to create a LUR. Since we use traffic data derived from the region's travel demand model, the air quality modeling framework we develop can also be tightly integrated with the regional travel demand modeling process. Lastly, air dispersion models can produce more spatially detailed concentration estimates depending on the quality of input data and complexity of the dispersion model algorithms since they are not limited by the spatial scale of the explanatory variables used in LUR models.

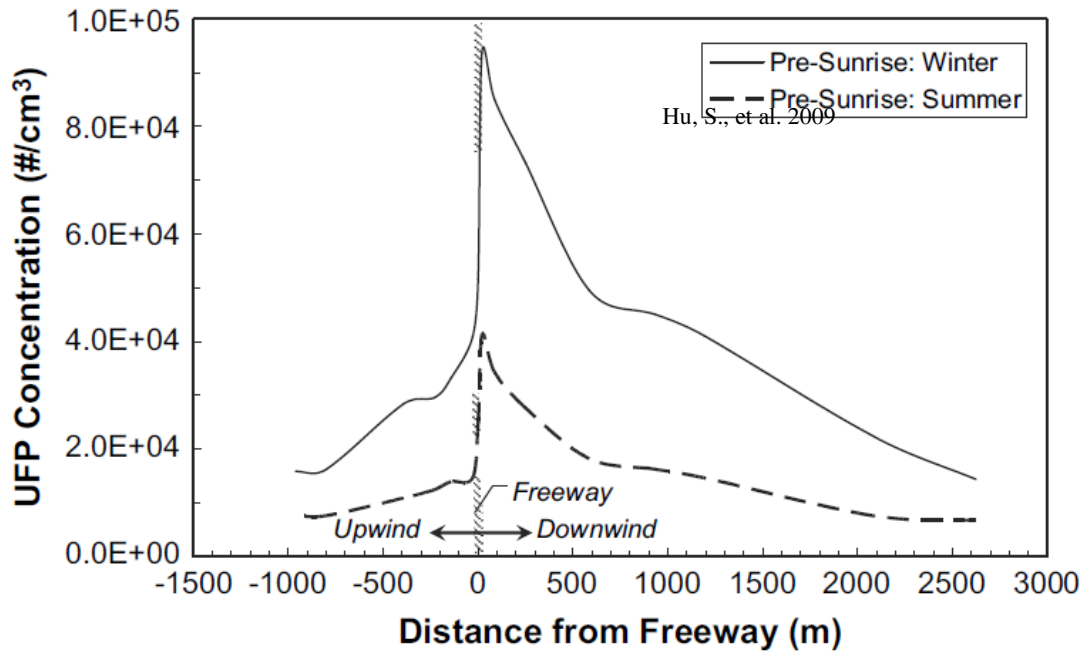
As previously discussed, several dispersion models have been developed that are capable of modeling mobile source vehicle exhaust emissions as line sources including: AERMOD, CALINE4, CAL3QHC, CALPUFF, ISC3, and HIWAY (41-45). Each of these models use different methods to estimate mobile source emission rates, pollutant dispersion, and in some cases chemical and physical processes within the plume. For example, AERMOD, which is EPA's preferred or recommended model for PM<sub>2.5</sub> hotspot analysis (46), is based on a steady-state Gaussian solution to the atmospheric dispersion equation and determines nonreactive air pollutant concentration levels at user defined receptor locations (47). Previous studies have found that AERMOD produces reliable estimates of particulate matter concentration along roadways (18). Other studies have found that CALINE also performs well (21), while Chen et al. (15) find that CALINE4 and CAL3QHC out-perform AERMOD in their analysis of an intersection in Sacramento, CA. For a complete review of these models see Nagendra (41).



While questions remain over which model is most accurate, we choose AERMOD for several reasons. AERMOD is EPA's preferred or recommended model for estimating near roadway  $PM_{2.5}$  concentrations, concentrations can be modeled long distances from each source, dense user defined receptor networks are easily created, and the simple model interface makes it easy to script and automate the modeling process in a GIS environment.

### 3.1 EMPIRICAL STUDIES

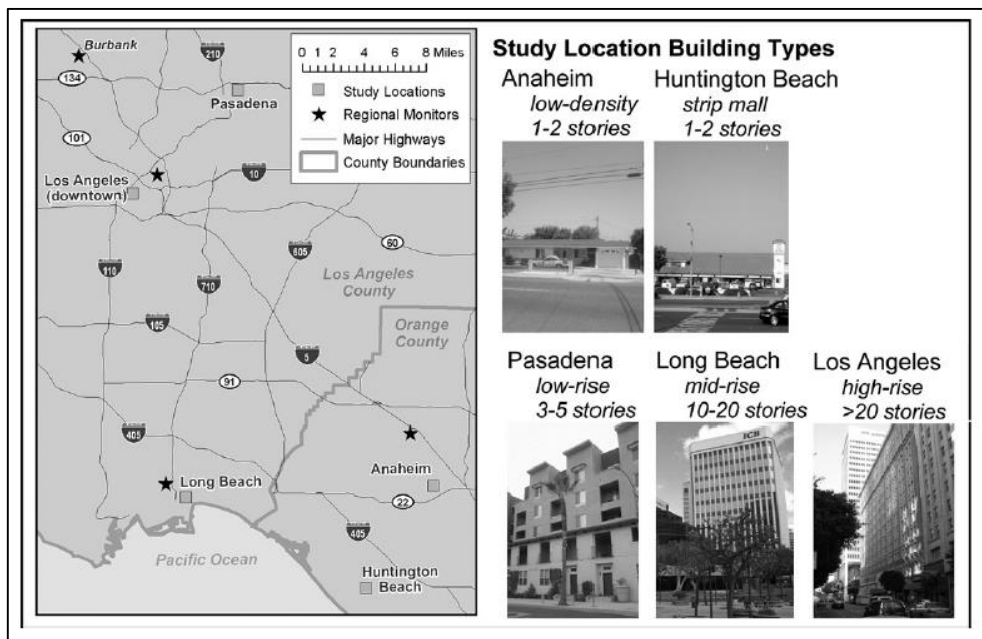
Although the consensus as to the accuracy and reliability of dispersion modeling still remains unclear, several studies have embarked on estimating near-road PM<sub>2.5</sub> concentration levels from an empirical approach. Hu, S., et al. (48) in 2008 conducted field measurements of various mobile source pollutants up to 3.6KM from a freeway in Southern California. Using an electric vehicle mobile platform equipped with fast-response instruments, the authors were able to measure real-time concentration levels of ultra-fine particles, NO, and particle-bound polycyclic aromatic hydrocarbons. The purpose of the study was to measure the impact of pre-sunrise conditions on air pollutant concentrations downwind of a freeway in both winter and summer periods. Based on field measurements, the authors found that pollutant concentration levels remained elevated up to 1,200 meters downwind from the freeway (600 meters upwind) and did not reach background levels until almost 2,600 meters during pre-sunrise conditions (see Figure 3.3). In contrast, concentration levels measured after sunrise reached background levels at approximately 300 meters from the freeway, which is typically found in most studies. The authors found strong correlation between measured concentration levels and traffic counts on the freeway, and associated the higher observed concentration levels downwind of the freeway during pre-sunrise conditions to nocturnal surface temperature inversion, low wind speeds, and high relative humidity.



**Figure 3.3 Ultrafine PM Concentration Gradients versus Distance from Freeway**

Boarnet, M.G., Houston, D., et al. (49) in 2008 measured fine particulate concentrations on sidewalks in five Southern California cities. The authors aimed to measure the impact of varying degrees of urban developments and land use patterns on fine particulate concentration levels on sidewalks and near busy intersections. Using “DustTrak Aerosol Monitors” the authors took stationary and mobile measurements of fine particulate concentration on sidewalks in five Southern California cities (see Figure 3.4). The average concentration levels ranged from 20 to 70  $\mu\text{g}/\text{m}^3$  across the entire study area, suggesting that near-roadway concentration levels vary significantly across the built urban environment. The authors applied a regression model and confirmed that traffic levels and the surrounding built environment characteristics contributed significantly to these varying concentration levels, after accounting for meteorological factors,

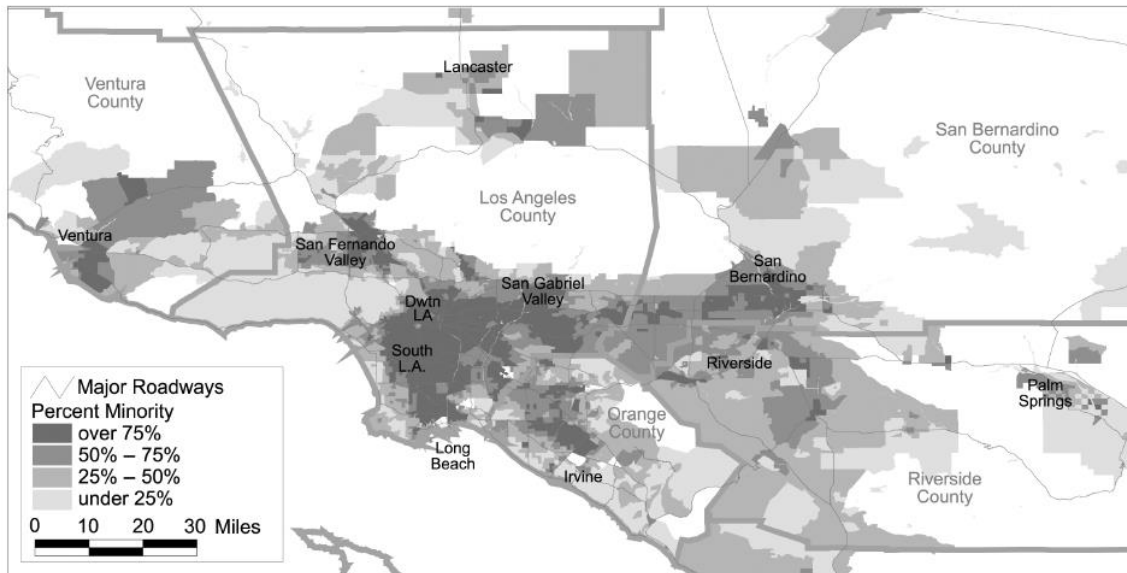
time of day, and location in the region. However, it is later argued by the authors that these variables explained a small amount of the total variation in the observed fine particulate concentrations and that future work should analyze the impacts of the surrounding built environment, along with localized traffic levels, on near-roadway fine particulate concentration levels after accounting for meteorological variables.



**Figure 3.4 Boarnet, M.G., Houston, D., et al. So. CA Study Locations & Building Types**

### **3.2 ENVIRONMENTAL JUSTICE**

Estimating population exposure to mobile source pollutants presents an opportunity to identify potential environmental justice concerns, as well as provide urban planners with the appropriate tools necessary for epidemiology studies. Individuals living near or adjacent to high volume roadways are exposed to high concentration levels of mobile source pollutants, and a growing body of literature continues to show that prolonged exposure to these pollutants, and in particular PM<sub>2.5</sub>, can lead to severe health risks. Such implications will require cautious urban planning and policy strategies in order to mitigate the potential for serious health risks. One study in 2004 by Houston, D., et al. (50) proposed analyzing potential disparities of urban traffic densities on disadvantaged neighborhoods in Southern California by using 2000 census data. When combined with major roadway traffic count measures from the Highway Performance and Monitoring System (PEMs) maintained by Caltrans, the authors found that minority and high-poverty neighborhoods are exposed to twice the level of traffic density compared to the rest of the Southern California region (see Figure 3.5). By utilizing road density as a proxy to pollutant exposure, the authors make the argument that exposure to high traffic volumes may be associated with higher risks of vehicle-related pollutant exposure.

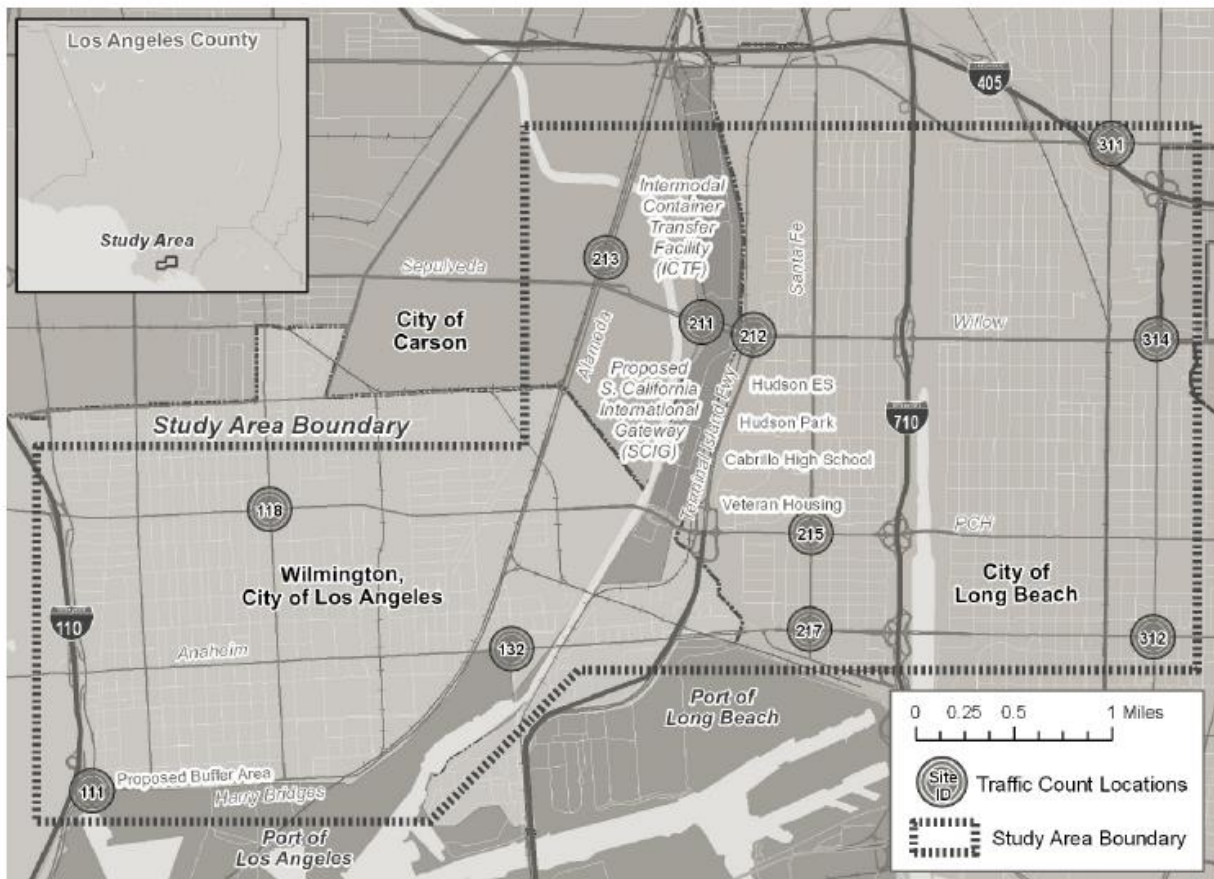


Houston, D., et al. 2004

**Figure 3.5 Minority Neighborhoods in Southern California, 2000 Census**

Houston, D. expanded on his 2004 study by analyzing the impacts of increased port-related diesel truck traffic in communities adjacent to the Ports of Los Angeles and Long Beach, or the San Pedro Bay Ports (51). Container volumes at the San Pedro Bay Ports have nearly tripled in the past 15 years resulting in the increase of drayage traffic activities. These activities include inter- and intra-terminal trips, trips to and from intermodal facilities, local amenities, and regional goods movement corridors, such as the I-710 freeway. Due to the limited availability of on-road heavy duty diesel truck volume data on local streets, the authors recorded video measurements of surface traffic at 11 key intersections and segments in the vicinity of the Ports (see Figure 3.6). The authors found that truck volumes often reached 400-600 heavy duty diesel trucks per hour at locations directly upwind of sensitive land uses, such as schools, parks, and residences, raising serious public health concerns for the inhabitants residing in these

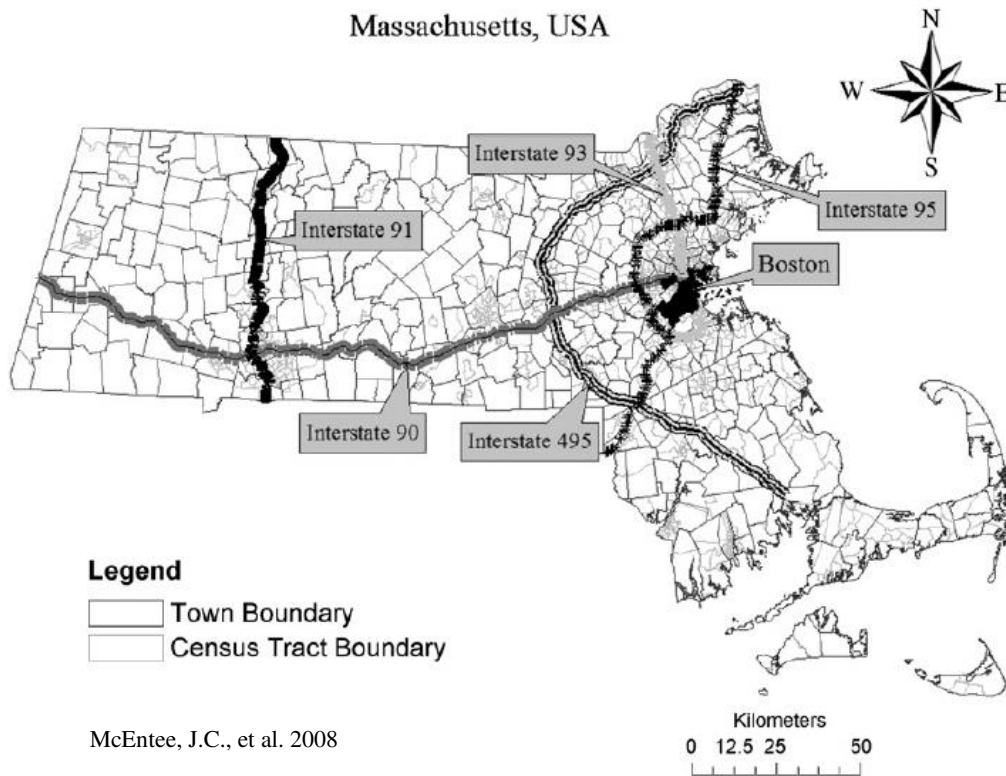
communities. The authors also discuss the implications of increased diesel truck traffic from an environmental justice standpoint given the low-income, high-minority status of the impacted communities, proposing policy and emission control strategies to mitigate local air pollution impacts. Although truck traffic volume was utilized in this study as a proxy for exposure to mobile source pollutants, the authors provide reasonable insights into the potential impacts of increased diesel truck traffic on neighboring communities as a result of annual container growth at ports.



Houston, D., et al. 2008

**Figure 3.6 Diesel Truck Count Intersections in Wilmington and Long Beach, CA**

In an attempt to further justify the positive correlation between near-roadway pollutant exposure and increased health risks, McEntee, J.C., et al. (52) analyzed measurements of diesel particulate matter concentrations on major highways in Massachusetts, USA (see Figure 3.7 below) and the associated lung cancer and asthma incidences reported along the corridors. After a Hot Spot analysis was performed it was statistically revealed that a significantly higher number of asthma cases were reported in areas of elevated particulate matter concentrations when compared to areas of lower particulate matter concentrations.



**Figure 3.7 Massachusetts, USA Corridor Study Area of Diesel Particulate Matter**



Brugge, D., et al. (53) provide a comprehensive literature review of the multiple studies examining epidemiologic evidence of cardiac and pulmonary health risks associated with exposure to mobile source pollutants. The studies reviewed by the authors assessed the evidence of reported health risks as a result of exposure to mobile source pollutants by way of proximity to highways, actual pollutant concentration exposure, or both. Based on the findings of the reviewed studies, the authors conclude that children who reside in close proximity to major highways are at a higher risk of developing asthma and reduced lung function. The studies also collectively indicate that exposure to elevated levels of particulate matter concentrations is strongly associated with cardiac disease and pulmonary mortality. Although it is yet to be proven the exact nature and magnitude of the risks associated with exposure to mobile source pollutants, the evidence presented in the reviewed studies suggest a substantial link between near-roadway exposures and adverse health outcomes. Table 3.1 provides a summary analysis of the studies reviewed by Brugge, D., et al.

**Table 3.1 Summary of Reviewed Epidemiologic Studies of Near-Highway Health Effects by Brugge, D., et al.**

Citation	Location	Highway traffic intensity <sup>a</sup>	Pollutants measured <sup>b</sup>	Distance from highway	Health Outcomes	Statistical association <sup>e</sup>
Schwartz et al. 2005 (22)	Boston	NA	PM <sub>2.5</sub> , BC, CO	NA	Heart rate variability	Decreases in measures of heart rate variability
Adar et al. 2007 (23)	St. Louis, Missouri	NA	PM <sub>2.5</sub> , BC, UFP	On highway in busses	Heart rate variability	Decreases in measures of heart rate variability
Hoek et al. 2002 (24)	Netherlands	NA	BC, NO <sub>2</sub>	Continuous <sup>d</sup>	Cardio-pulmonary mortality, lung cancer	1.41 OR for living near road
Tonne et al. 2007 (41)	Worcester, Mass.	NA	PM <sub>2.5</sub>	Continuous <sup>d</sup>	Acute myocardial infarction (AMI)	5% increase in odds of AMI
Venn et al. 2001 (49)	Nottingham, UK	NA	NA	Continuous <sup>d</sup>	Wheezing in children	1.08 OR for living w/ in 150 m of road
Nicolai et al. 2003 (58)	Munich, Germany	>30,000 veh/d	Soot, benzene, NO <sub>2</sub>	Traffic counts within 50 m of house	Asthma, respiratory symptoms, allergy	1.79 OR for asthma and high traffic volume
Gauderman et al. 2005 (65)	Southern California	NA	NO <sub>2</sub>	Continuous <sup>d</sup>	Asthma, respiratory symptoms	Increased asthma closer to freeways
McConnell et al. 2006 (57)	Southern California	NA	NA	Continuous <sup>d</sup>	Asthma	Large risk for children living w/in 75 m of road
Ryan, et al. 2007 (59)	Cincinnati, Ohio	> 1,000 trucks/d	PM <sub>2.5</sub>	400 m	Wheezing in children	NA
Kim et al. 2004 (60)	San Francisco	90,000 – 210,000 veh/d	PM, BC, NO <sub>x</sub>	School sites	Childhood asthma	1.07 OR for high levels of NO <sub>x</sub>
Wjst et al. 1993 (68)	Munich, Germany	7,000–125,000 veh/d	NO <sub>x</sub> , CO	School sites	Asthma, bronchitis	Several statistical associations found
Bruneekreef et al. 1997 (69)	Netherlands	80,000 – 152,000 veh/d	PM <sub>10</sub> , NO <sub>2</sub>	Continuous <sup>d</sup>	Lung function	Decreased FEV with proximity to high truck traffic
Janssen et al. 2003 (74)	Netherlands	30,000–155,000 veh/d	PM <sub>2.5</sub> , NO <sub>2</sub> , benzene	< 400 m <sup>c</sup>	Lung function, respiratory symptoms	No association with lung function
Peters et al. 1999 (82)	Southern California	NA	PM <sub>10</sub> , NO <sub>2</sub>	NA	Asthma, bronchitis, cough, wheeze	1.54 OR of wheeze for boys with exposure to NO <sub>2</sub>
Brauer et al. 2007 (67)	Netherlands	Highways and streets	PM <sub>2.5</sub> , NO <sub>2</sub> , soot	Modeled exposure	Asthma, allergy, bronchitis, respiratory symptoms	Strongest association was with food allergies
Visser et al. 2004 (91)	Amsterdam	> 10,000 veh/d	NA	NA	Cancer	Multiple associations
Vineis et al. 2006 (87)	10 European countries	NA	PM <sub>10</sub> , NO <sub>2</sub> , SO <sub>2</sub>	NA	Cancer	1.46 OR near heavy traffic, 1.30 OR for high exposure to NO <sub>2</sub>
Gauderman et al. 2007 (73)	Southern California	NA	PM <sub>10</sub> , NO <sub>2</sub>	Continuous <sup>d</sup>	Lung Function	Decreased FEV for those living near freeway

<sup>a</sup>As defined in article cited (veh/d = vehicles per day; veh/h = vehicles per hour).

<sup>b</sup>UFP = ultrafine particles; FP = fine particles; PM<sub>2.5</sub> = particles with aerodynamic diameter ≤ 2.5 μm; PM<sub>10</sub> = particles with aerodynamic diameter ≤ 10 μm; BC = black carbon; PPAH = particle-bound polycyclic aromatic hydrocarbons; VOCs = volatile organic compounds

<sup>c</sup>Pollutant measurements were made along a transect away from the highway

<sup>d</sup>Proximity of each participant to a major road was calculated using GIS software

<sup>e</sup>Statistical association between proximity to highway or exposure to traffic-generated pollutants and measured health outcomes

NA = not applicable; measurements were not made.

## CHAPTER 4      METHODOLOGY

A limitation in using AERMOD for modeling emissions from a large transportation network with tens of thousands of sources and millions of receptors is model run time. For example, it would take several months to produce the results described in this dissertation by running AERMOD for the entire Los Angeles County region in a single process on a standard desktop computer. Our solution is a novel rastering (or analytical) approach that breaks down the problem into smaller units that can be processed in parallel on multiple processors. This approach significantly speeds up the computation by using more computer processing power and by limiting the number of source-receptor pairs that are modeled.

### 4.1      Traffic Data

Given the nature of the proposed methodology for estimating mobile source PM<sub>2.5</sub> concentration gradients near roadways at a regional scale, careful consideration must be taken into account when selecting the roadway traffic data that is to be analyzed. There currently exists a wide range of databases for retrieving traffic volume data in the state of California. They include:

- **Caltrans Performance Measurement System (PeMS)**

Provides real-time traffic data (speed, volume, & density) from over 25,000 individual detectors spanning the freeway system across all major metropolitan areas of the State of California. The system also provides other pertinent information including, among others, incidents, lane closures, toll tags, and vehicle classification. The database also provides over ten years of archived data for historical analysis; (<http://pems.dot.ca.gov/>)

- **California Weigh-in-Motion data (WIM)**

Also operated by Caltrans, this system provides 24-hour traffic information on freeway segments throughout the State of California, including speed, classification, axle spacing, axle weights, and gross weights. The data collected by WIM is essential for numerous studies, including pavement, capacity, accident rate, and truck activity studies. Currently there exists approximately 106 WIM collection sites in operation across California. It is anticipated that the system will expand its operation in the coming years;

(<http://www.dot.ca.gov/hq/traffops/trucks/datawim/>)

- **Highway Performance Monitoring System (HPMS)**

The HPMS is an information database of the highway system at a national level and is maintained by the United States Department of Transportation (Division of Federal Highways). The HPMS is a collaborative effort between states and MPOs in order to provide federally classified performance characteristics and physical conditions of all public roadways for rural and urban areas. The system provides information on roadway geometrics, total lane mileage, traffic operations, pavement condition, and future Annual Average Daily Traffic (AADT) estimates. The primary purpose of the HPMS is to provide support for a data driven decision-making process within FHWA, DOT, and

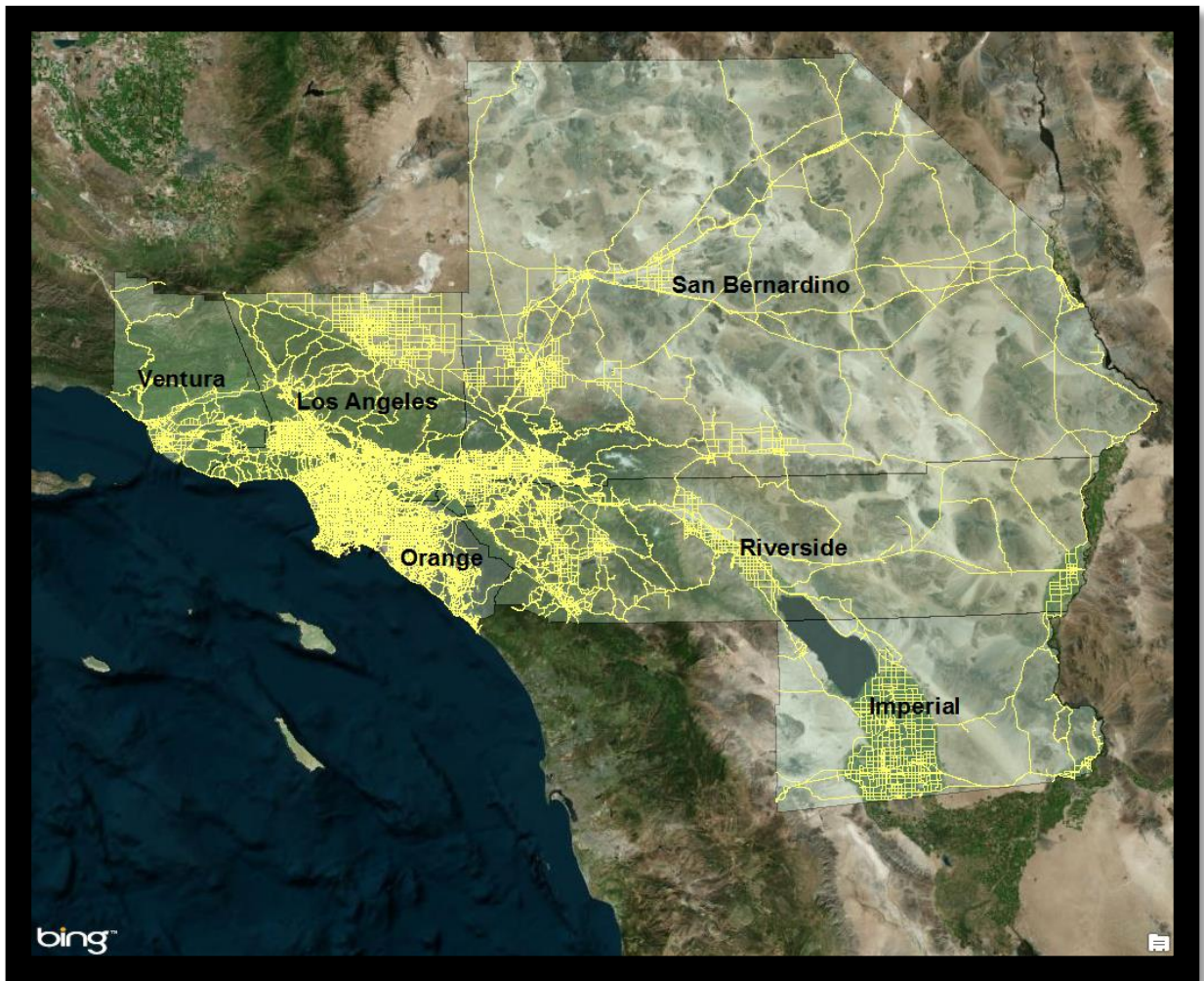
Congress; (<http://www.fhwa.dot.gov/policyinformation/hpms.cfm>)

- **California Air Resources Board Vehicle Activity Database (CALVAD)**

The California Air Resources Board Vehicle Activity Database, or CALVAD, is a data fusion application combining all three traffic information databases described above (PeMS, WIM, & HPMS). The system is maintained in partnership between Caltrans and the Institute of Transportation Studies at UC Irvine and the Transportation Electronics Lab at Cal Poly San Luis Obispo. The objective of CALVAD is to integrate disparate data sources in order to develop a comprehensive view of VMT and speed estimates for different vehicle classes in the state of California. The purpose of the program is to provide policy analysts and decision makers with the best available data in order to provide assistance during planning, development, and investment stages. The project is currently in its developing stages; (<http://www.ctmlabs.net/projects/calvad>)

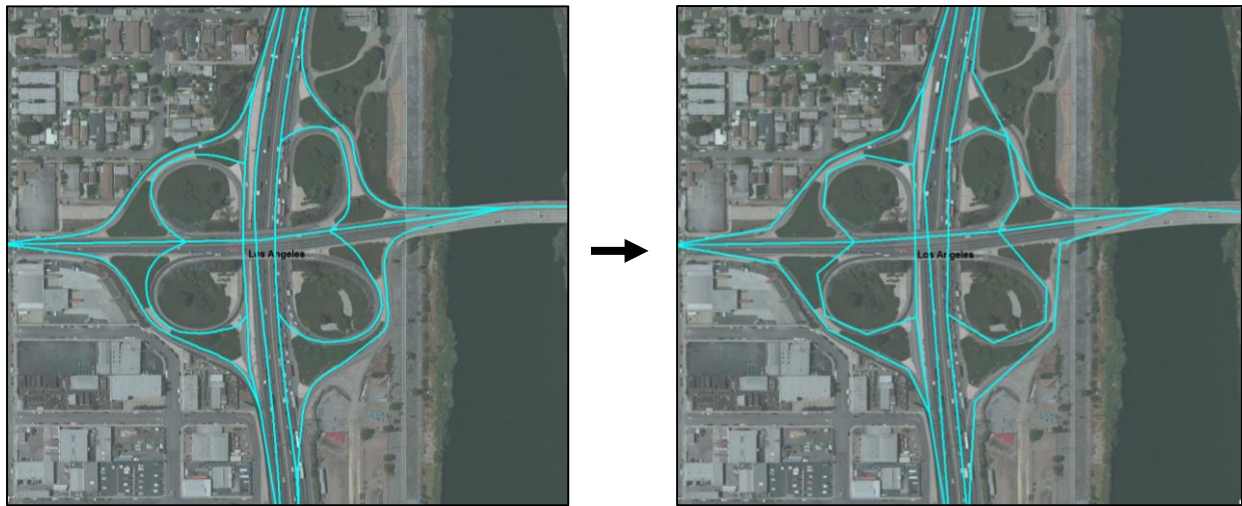
While there exists multiple data sources for retrieving traffic volume and speed data for our modeling domain, the data selected for the purposes of our analysis was obtained from the Southern California Association of Government's (SCAG) regional travel demand model as implemented for their 2012 Regional Transportation Plan (54). The traffic data provides modeled trip counts over each link for two vehicle classes (light/medium duty and heavy duty) and five time periods (morning commute, mid-day, evening commute, evening, and night time) for the entire six-county region, including Los Angeles. SCAG is the largest metropolitan planning organization in the nation with over 18 million residents and more than 190 cities. The regional travel demand model analyzes three scenarios, including 2008 as the baseline and calibrated year, and a future horizon year of 2035 (both baseline and RTP).

Although the previously described databases (PeMS, WIM, and HPMS) have the potential to provide better estimates of real-time traffic and speed measurements, and hence improving our estimates of PM<sub>2.5</sub> concentration gradients near roadways, their coverage of regional roadway networks are primarily limited to highway facilities. Regional travel demand models on the other hand traditionally model link trip counts and speeds for not only highway facilities, but also for arterial and at times even collector streets. For example, SCAG's regional travel demand model includes a roadway network of approximately 100,000 links. Utilizing output from an MPO's regional travel demand model does however present several limitations of its own. Although regional travel demand models are calibrated and modeled trip counts validated by way of screen-lines, validation of average speeds over each link has yet to be implemented into the modeling process. Moreover, regional travel demand models fail to capture congestion effects, including idle time at signalized intersections, which can be critical when estimating roadway emissions. Such limitations however could potentially present conservative estimates when calculating our final PM<sub>2.5</sub> concentration gradients. Be that as it may, given the objective of the proposed regional dispersion modeling framework that is to be integrated into the MPO's regional transportation planning process, the ability to assess population exposure to PM<sub>2.5</sub> can universally be achieved by utilizing output from a regional travel demand model. Moreover, in order to estimate current and projected PM<sub>2.5</sub> concentration exposure levels, regional travel demand models are the only source available that provides forecasted traffic volumes and speed estimates at a regional scale. Furthermore, the onset of negative health outcomes due to exposure to vehicle-related emissions generally arise as a result of prolonged exposure, as opposed to real-time, instantaneous exposure. In other words, regional travel demand models provide relatively reasonable estimates of average weekday trips over an entire year period.



**Figure 4.1 SCAG's 2012 RTP County Travel Demand Model Network**

Several simplifying assumptions and modifications were applied to the regional roadway network in order to model the sources in AERMOD as area sources. For example, to calculate the area of each link, which is required for subsequent modeling, we transformed curvy road segments into a series of shorter straight lines with a maximum 10m offset from the actual centerline using the generalization tool in ArcGIS version 10.0 (See Figure 4.2).



**Figure 4.2 Before and After Generalization of Curved Roadway Segments in ArcGIS 10.0**

## **4.2 Emissions Modeling**

There exists a variety of emission factor models for mobile source pollutants, including the Environmental Protection Agency’s Motor Vehicle Emission Simulator (MOVES) and the California Air Resources Board’s Emission Factor Model (EMFAC2011). Both models estimate emissions for mobile sources covering a broad range of pollutants, including  $PM_{2.5}$ . Given the modeling domain selected for our proposed methodology, we chose to use CARB’s EMFAC2011 (55) emission factor model due to its built-in characteristics of the South Coast Air Basin. For example, motor vehicle fleet age, type, and population in EMFAC2011 is based on 2009 California Department of Motor Vehicles data. Furthermore, all travel activity, including vehicle miles traveled, number of trips, and vehicle class distribution, are provided by regional Metropolitan Planning Organizations, including SCAG.



EMFAC2011 was modeled for the appropriate calendar year scenario (2008) in order to estimate vehicle emission rates of PM<sub>2.5</sub> in grams per mile for each link, *i*, and time period, *j* (see Appendix Exhibit A). We combined the emission factors for each heavy duty truck category (i.e., Light-, Medium-, & Heavy-Duty Truck) into a single heavy duty vehicle emission factor,  $EF_{hd,i,j}$ . The remaining vehicle categories were combined into a single emission factor representing light and medium duty vehicles,  $EF_{lm,i,j}$ . Following equation 1 below, the emission factors were then combined with the traffic data and road network of SCAG's regional travel demand model to estimate the rate of emission generated by each link,  $ER_{i,j}$ , in g/s-m<sup>2</sup>.

$$ER_{i,j} = \frac{(EF_{lm,i,j} \cdot N_{lm,i,j} + EF_{hd,i,j} \cdot N_{hd,i,j}) \cdot L_j}{A_j \cdot T_i} \quad (1)$$

Where;

$EF$  = PM<sub>2.5</sub> emission rates from EMFAC2011 for each vehicle class ( $lm$ = light and medium duty,  $hd$  = heavy duty) and time period, *i* (*i* = AM, MD, PM, EVE, & NT), and link, *j* (total ~ 190,000), in g/m.

$N$  = Number of vehicle trips for each vehicle class ( $lm$  = light and medium duty,  $hd$  = heavy duty) for each time period, *i*, and link, *j*.

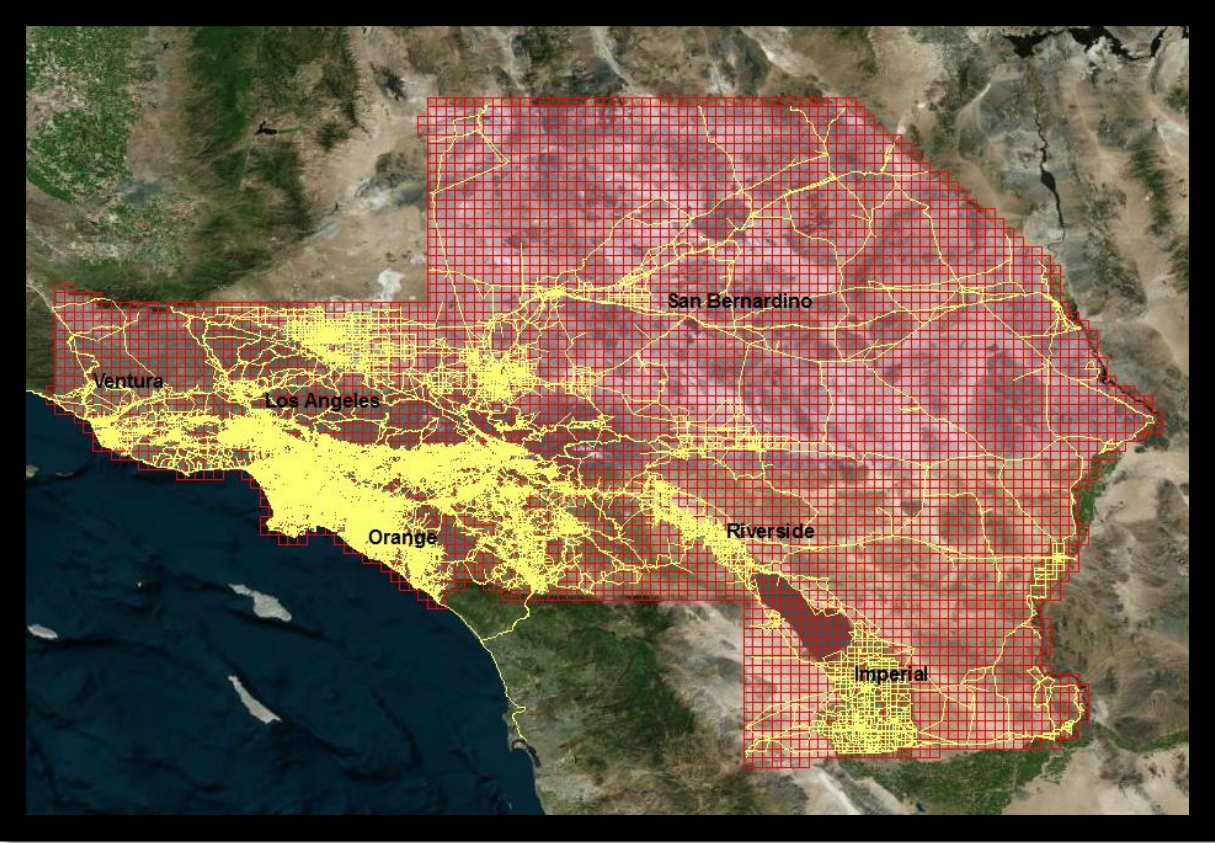
$L$  = length of each link, *j*, in meters

$A$  = area of each link, *j*, in m<sup>2</sup>

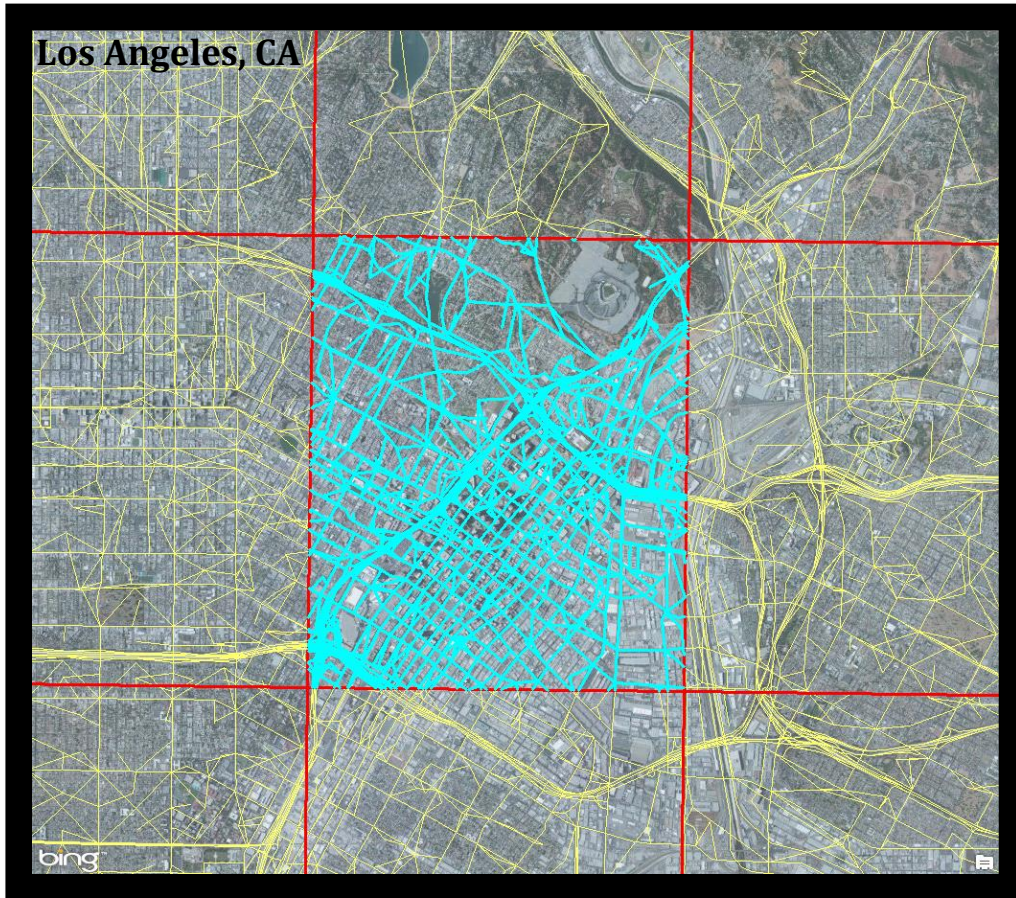
$T$  = length of each time period, *i*, in seconds.

### **4.3 Air Dispersion Modeling**

A limitation in using AERMOD for modeling emissions from a regional transportation network is model run time. For example, it would take several years to produce the results described in this dissertation by running AERMOD for all six counties of the SCAG region in a single process on a standard desktop computer. Our solution is a novel rastering approach that breaks the problem into smaller units that can be processed in parallel on multiple processors. This is achieved by intersecting the SCAG regional roadway network with a grid of 5KM by 5KM square cells (See Figure 4.3). Each cell, and its corresponding roadways, is then modeled in AERMOD independently, and in parallel, with adjacent cells (See Figure 4.4). This approach speeds up the computation by using more computer processing power and limiting the number of source-receptor pairs that are modeled. Future work should look into the trade-offs between the area of the grid cells and model run time. For example, minimizing the area of a square cell will reduce the number of source-receptor pairs modeled in AERMOD, but in turn will increase the number of total cells modeled across the entire study region.



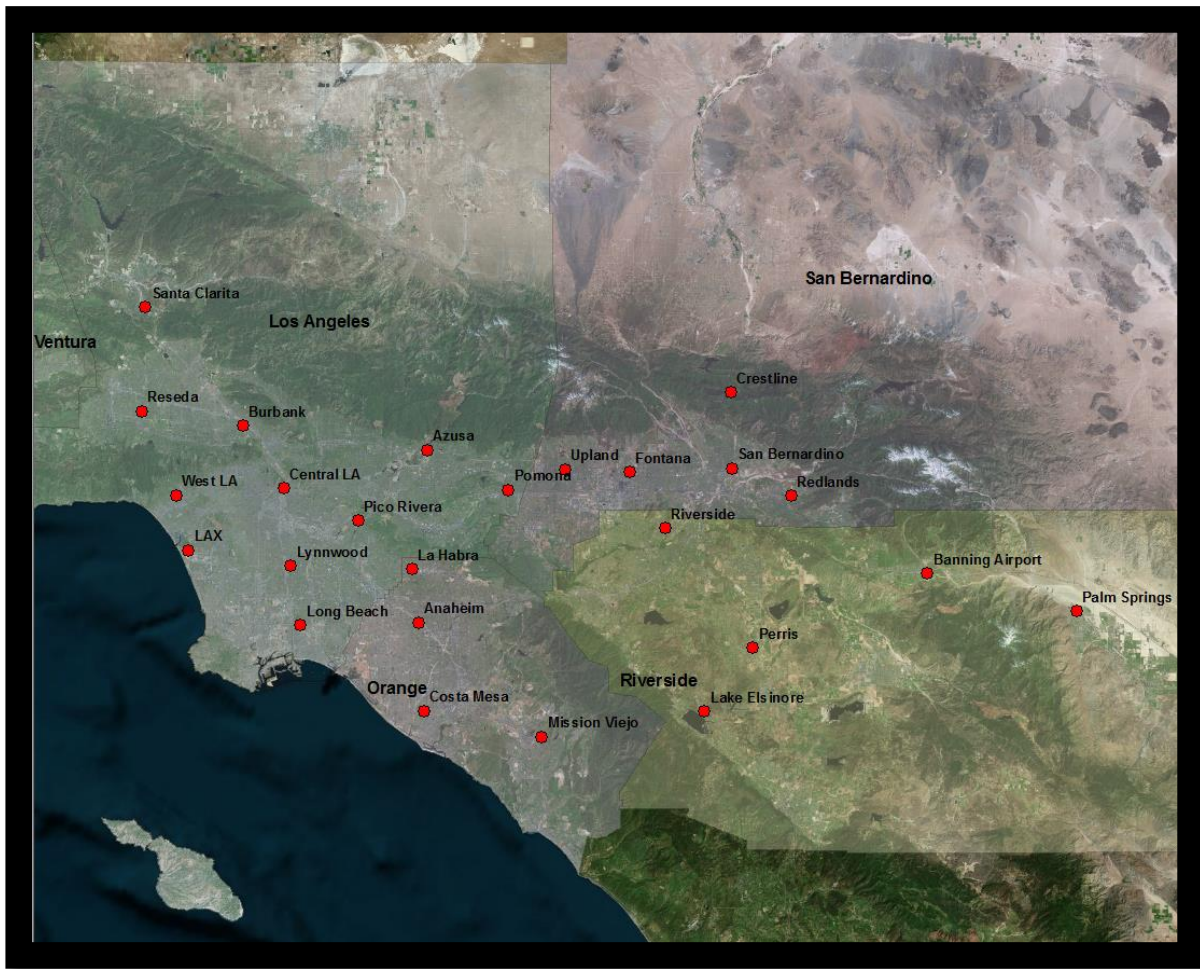
**Figure 4.3 Grid of 25 Square Kilometer Cells Intersecting the SCAG Region**



**Figure 4.4 Selected Links within a 25<sup>2</sup> Kilometer Cell to be modeled in AERMOD**

From this point forward we followed EPA’s mobile source PM<sub>2.5</sub> “hot-spot” conformity guidance (14). We used AERMET to process meteorological data provided by the South Coast Air Quality Management District (SCAQMD). The SCAQMD operates 26 air monitoring and weather recording stations throughout the south coast air basin (See Figure 4.5). Each 5km grid was assigned meteorological data from the nearest station. Each station reports hourly surface and upper air data from January 1<sup>st</sup>, 2005 to December 31<sup>st</sup>, 2009. The EPA guidance recommends running AERMOD with a 3 year record of meteorological data for regulatory purposes (i.e., to

find the worst case pollution day). However, we are primarily interested in estimating the average pollution concentration. Therefore, to limit computation time we only modeled the 1<sup>st</sup> and 15<sup>th</sup> day of each month over a 3 year data record period (2007-2009) for two seasons; winter and summer periods as defined in AERMOD. We then averaged the daily estimates for all 5 time periods corresponding to our traffic data to calculate annual average PM<sub>2.5</sub> concentration gradients. We also accounted for varying terrain heights by including 1-degree digital elevation model (DEM) topographical data from the U.S. Geological Survey.



**Figure 4.5 South Coast Air Quality Management District Air Monitoring and Weather Recording Stations (Total = 26)**

## 4.4 AERMOD Inputs

The primary inputs for the air dispersion model AERMOD include the following:

### CO – control pathway

- Model Options: U.S. EPA regulatory default with *urban* option
- Population needed for each grid (use 2010 Census)

### SO – source pathway

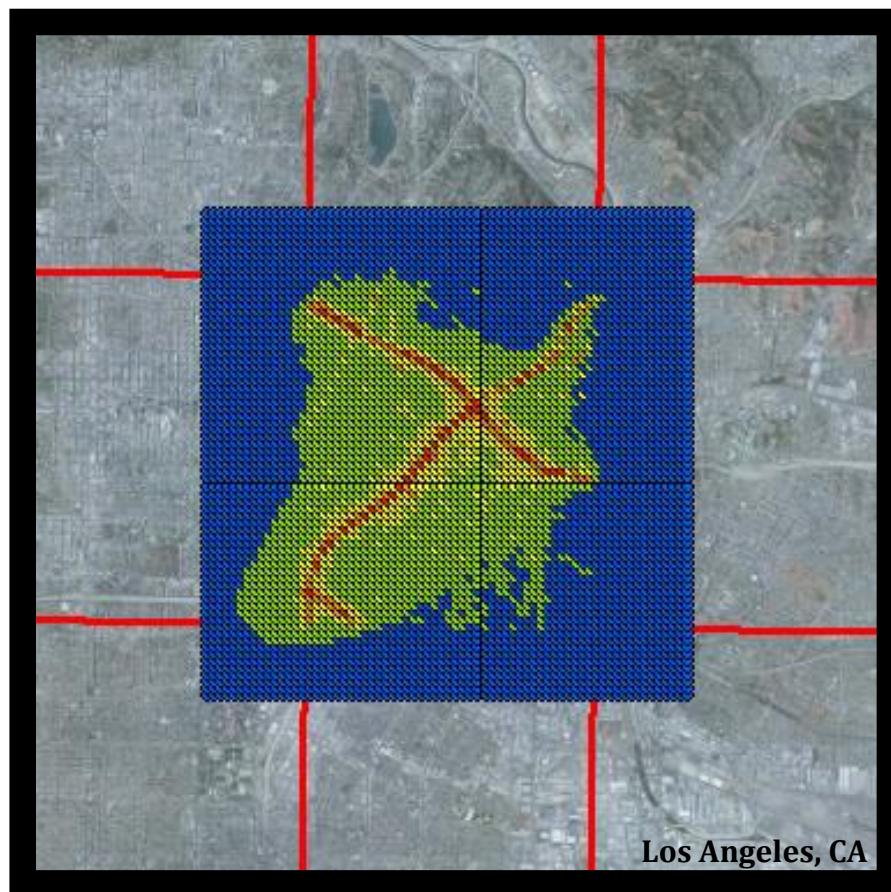
- Links modeled as **AREA** sources
- Release height above ground = 1.3m (auto), 3.4m (truck)
- Initial vertical dimension of plume ( $\sigma_{zo}$ ) = 1.2m (auto), 3.2m (truck)
- Lateral dimension ( $X_{init}$ ):
  - Calculated using number of lanes information from SCAG network
- Emission rate ( $g/sm^2$ ) determined by equation (1):

### RE – receptor pathway

- Preprocessor **AERMAP**: Terrain data from USGS (1-degree DEM) [www.webgis.com](http://www.webgis.com)
- 7km x 7km grid of receptors (5km x 5 km grid of sources)
- Receptor spacing = 100m
- 4,900 receptors/grid (includes 1km buffer)

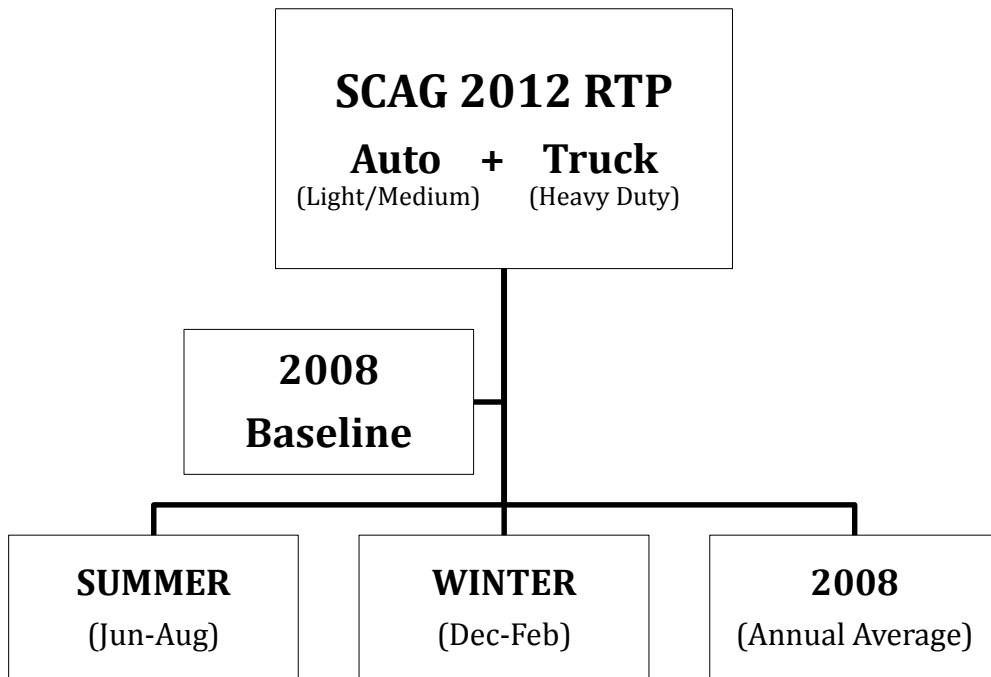
## ME – meteorology pathway

- Surface & Upper Air meteorological data for input to AERMOD provided by SCAQMD  
<http://www.aqmd.gov/smog/metdata/aermod.html>
- Includes 26 stations
- 5-year data record (2005-2009)



**Figure 4.6 Sample of PM<sub>2.5</sub> Concentration Receptor Results ( $\mu\text{g}/\text{m}^3$ ) within a 25 Square Kilometer Cell Modeled in central Los Angeles, CA using AERMOD (Blue = 0.025280-0.166390, Green = 0.166391-0.380820, Yellow = 0.380821-0.729310, Orange = 0.729311-1.445360, Red = 1.445361-3.965610)**

Figure 4.6 provides a sample output of a 25 square kilometer receptor cell in central Los Angeles, CA using base year 2008 traffic volume. As expected, PM<sub>2.5</sub> concentration levels remain relatively high along major corridors, and reduce in concentration as the distance from the roadway centerline increases. The values of the concentration levels produced above by AERMOD have significant implications (with a maximum concentration level reaching approximately 4.0 µg/m<sup>3</sup>) given that the maximum allowable concentration exposure level to PM<sub>2.5</sub>, as set forth by the National Ambient Air Quality Standards, is 12 µg/m<sup>3</sup> (annual average). A total of 4,900 receptors were modeled for this cell; 2,500 of which were cell-specific, and 2,400 were receptors corresponding to adjacent cells in order to capture edge effects.



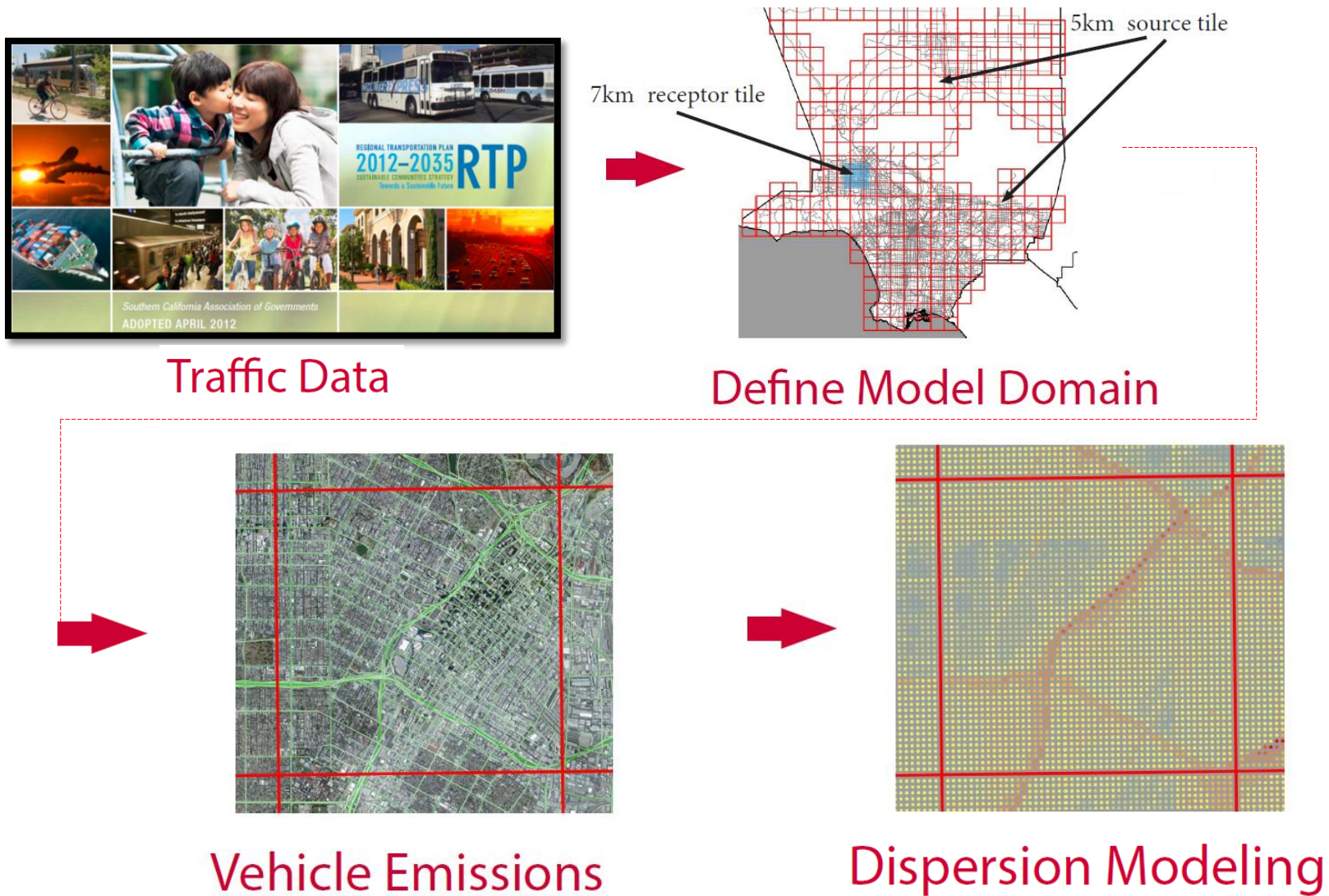
**Figure 4.7 AERMOD PM<sub>2.5</sub> Concentration Modeling Scenarios**



Figure 4.7 provides an outline of the alternative scenarios that will be modeled in AERMOD after applying the aforementioned methodology to the selected case study; which in our case will be Los Angeles County, CA. The vehicle fleet will consist of automobile (light and medium duty vehicles) and truck (heavy duty vehicles) as defined by SCAG's 2012 RTP. PM<sub>2.5</sub> concentration levels will then be estimated for a total of three time periods in AERMOD: Summer, Winter, and total annual average for the base year 2008 (where link volumes have been calibrated). Figure 4.8 provides a flowchart diagram of the newly proposed regional dispersion modeling framework presented in this paper.

Figure 4.8

**NEW REGIONAL DISPERSION MODELING FRAMEWORK**

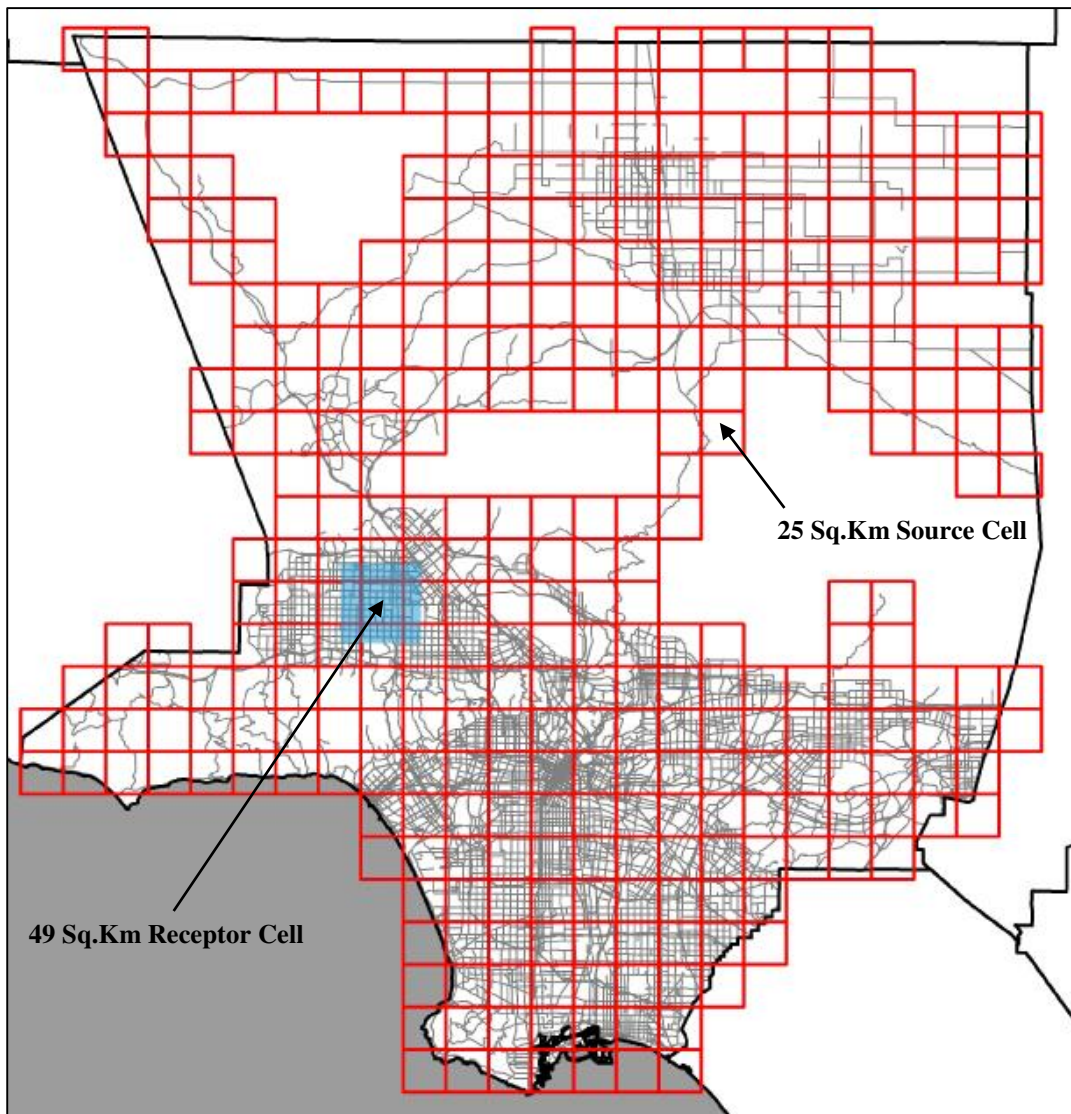


## 4.5 Study Location: Los Angeles County, California

The modeling domain selected to demonstrate the feasibility of our proposed methodology is Los Angeles County, California, the most populous county in the United States with a population of approximately 9.8 million residents in 2012 according to the U.S. Census Bureau. The county has a total area of 4,752 square miles (12,308 km<sup>2</sup>) and over 25,000 miles (40,200 km) of major roadways represented by 49,501 links in the region's travel demand model. This proportion of links accounts for more than 50% of the entire roadway link network represented in SCAG's regional travel demand model. It is also worth noting that one of the primary objectives of the proposed methodology is to estimate population exposure to PM<sub>2.5</sub>, leading to the removal of rural and low-volume roadways from the analysis. Suffice to say, the selected study area may actually account for more than 60-70% of the SCAG roadway network being analyzed. Lastly, in a recent publication by the American Lung Association, the city of Los Angeles, CA, was ranked atop the list of having the poorest air quality across the entire United States (56).

We begin by intersecting the Los Angeles County road network with a 5km x 5km cell grid using ArcGIS version 10.0 (see Figure 4.9). Each square in the grid defines the links (or sources) included in an individual model run. For each 25 square km cell we then create a 7km x 7km grid of receptors with 100m spacing centered on the cell. The receptor grid creates a 1,000m buffer around each source grid in order to capture edge effects. We choose a 1,000m buffer based on previous research that indicates PM<sub>2.5</sub> emissions generally reach background levels within this distance (1). After the sources defined by each grid are modeled in separate processes the results are pooled together to form a single receptor grid that contains point estimates of PM<sub>2.5</sub>

concentrations covering all of Los Angeles County (e.g., see Figure 5.1 in the results section). We automated the processes of creating the required AERMOD input files (see Appendix Exhibit B) and post processing the output for each 5km grid within ArcGIS version 10.0 using VBA scripting language. For each 5km grid, our methodology follows the EPA quantitative hotspot guidance using the area source method to represent roadways (14).

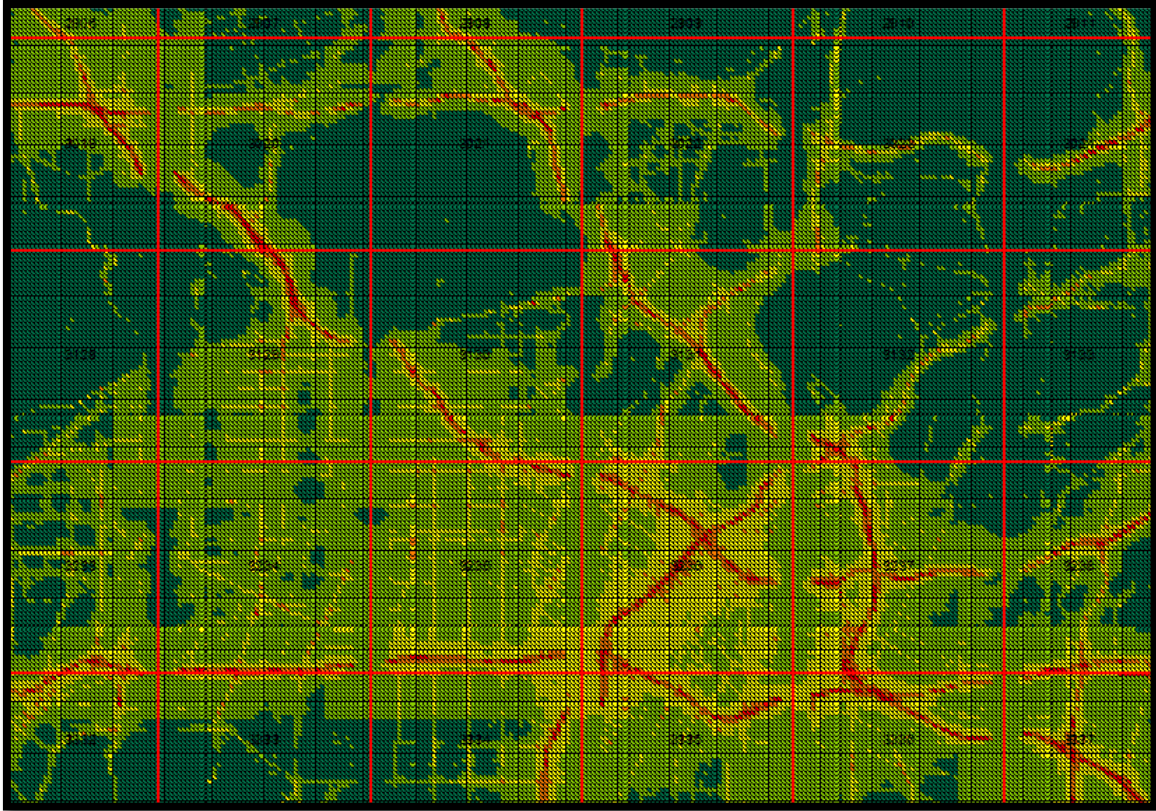


**Figure 4.9 Raster of Los Angeles County Road Network (Gray Lines); 5km x 5km Cell Grid Defining Links (or Sources) Included in each Model Run (Red Grid), and Example of a 7km by 7km Receptor Network Centered on a Source Grid (Blue Shading)**

## CHAPTER 5 RESULTS

The dispersion modeling results described below were produced on standard desktop computers running the Microsoft Windows 7 operating system with Intel Corei7 and Core2Duo processors. Using 16 computer processing units (each processor has 2 to 4 units) we were able to produce the displayed results within 72 hours. Results could be obtained more quickly using commercial computer servers, advanced computer workstations, or cloud computing services where more processing units are available.

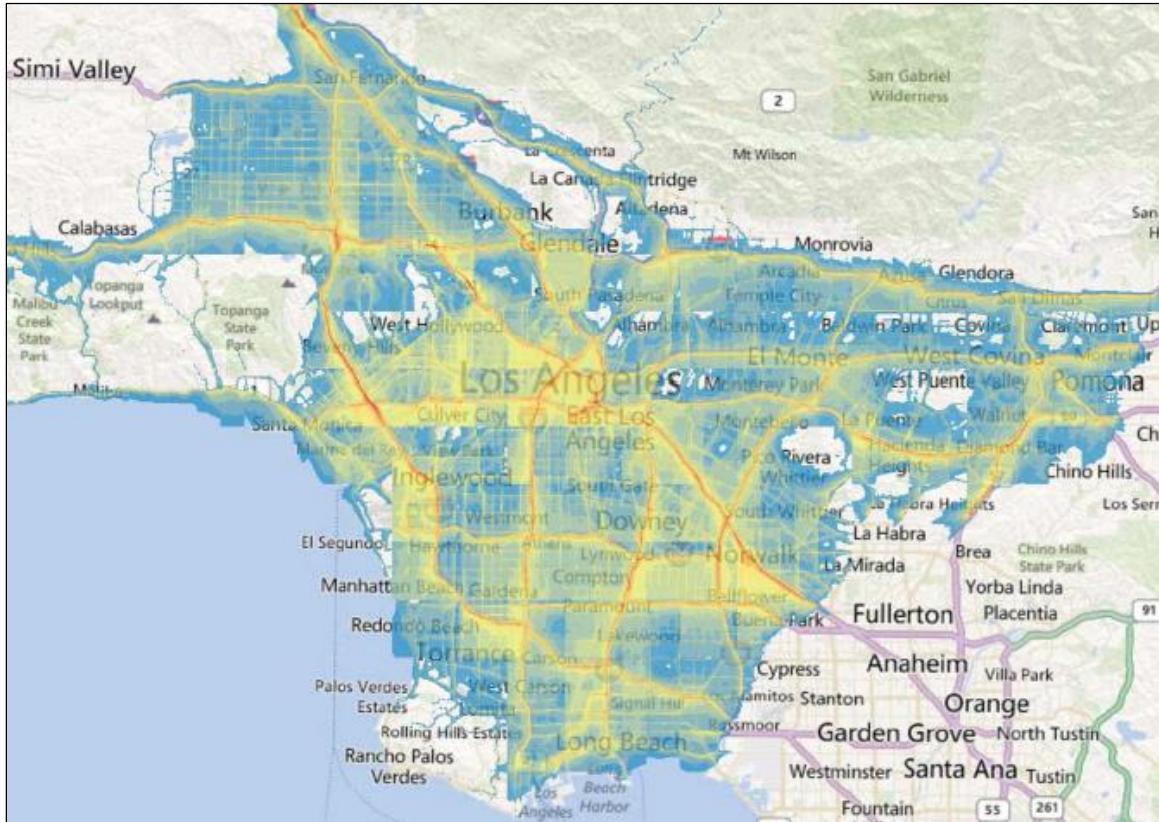
The modeling results by annual average and season are shown in Figures 5.1, 5.2, and 5.3 respectively. The maps show large spatial and seasonal variations in PM<sub>2.5</sub> concentration within Los Angeles County and PM<sub>2.5</sub> concentrations are highest and most widespread during the winter months. This is likely caused by a combination of stable atmospheric conditions during the early morning and after sunset in the evening (in the winter the evening commute occurs after sunset) and higher traffic volumes during the morning and evening commutes. During the midday hours concentrations are at their lowest even though traffic volumes are still much higher than during the evening. This is likely the result of heating during the day time which leads to unstable atmospheric conditions that cause more vertical mixing and lateral dispersion, reducing ground level PM<sub>2.5</sub> concentrations by transport and dilution. Elevated concentrations of PM<sub>2.5</sub> are also generally confined to a narrow corridor along major roadways. However, in areas with many adjacent high volume roads, PM<sub>2.5</sub> concentrations can be elevated over larger areas. For example, in downtown Los Angeles the 24hr annual average concentration of directly emitted PM<sub>2.5</sub> from vehicle traffic does not fall below 1.5 µg/m<sup>3</sup> in an approximately 9 mi<sup>2</sup> area.



PM2.5 Concentration ( $\mu\text{g}/\text{m}^3$ )

- ◆ 0.000100 - 0.117980
- ◆ 0.117981 - 0.288820
- ◆ 0.288821 - 0.628090
- ◆ 0.628091 - 1.269550
- ◆ 1.269551 - 4.319810

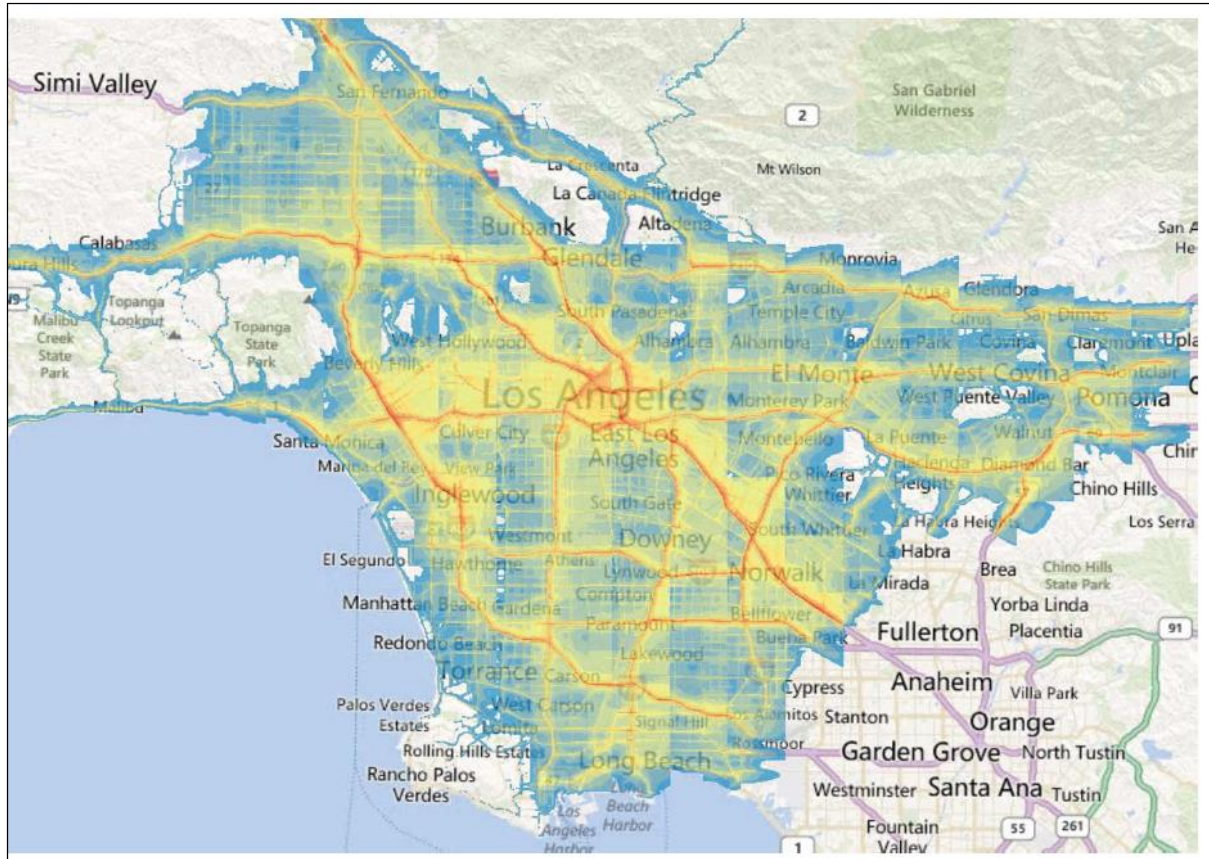
**Figure 5.1 Annual Average PM2.5 Concentration Gradient Map for Central Los Angeles, CA in Year 2008 with Baseline Modeled Trips**



PM2.5 Concentration ( $\mu\text{g}/\text{m}^3$ )

- ◆ 0.000100 - 0.117980
- ◆ 0.117981 - 0.288820
- ◆ 0.288821 - 0.628090
- ◆ 0.628091 - 1.269550
- ◆ 1.269551 - 5.70403

**Figure 5.2 Average PM2.5 Concentration Gradient Map for Los Angeles County during Summer Season with 2008 Baseline Traffic Volumes**



PM2.5 Concentration ( $\mu\text{g}/\text{m}^3$ )

- ◆ 0.000100 - 0.117980
- ◆ 0.117981 - 0.288820
- ◆ 0.288821 - 0.628090
- ◆ 0.628091 - 1.269550
- ◆ 1.269551 - 5.70403

**Figure 5.3 Average PM2.5 Concentration Gradient Map for Los Angeles County during Winter Season with 2008 Baseline Traffic Volumes**



24-hour PM <sub>2.5</sub> Concentration	Air Quality Index Levels
0.0 µg/m <sup>3</sup> to 12.0 µg/m <sup>3</sup>	Good (Green)
12.1 µg/m <sup>3</sup> to 35.4 µg/m <sup>3</sup>	Moderate (Yellow)
35.5 µg/m <sup>3</sup> to 55.4 µg/m <sup>3</sup>	Unhealthy for Sensitive Groups (Orange)
55.5 µg/m <sup>3</sup> to 150.4 µg/m <sup>3</sup>	Unhealthy (Red)
150.5 µg/m <sup>3</sup> to 250.4 µg/m <sup>3</sup>	Very Unhealthy (Purple)
greater than or equal to 250.5 µg/m <sup>3</sup>	Hazardous (Maroon)

**TABLE 5.1 Environmental Protection Agency 24-hour PM<sub>2.5</sub> Concentration Air Quality Index**

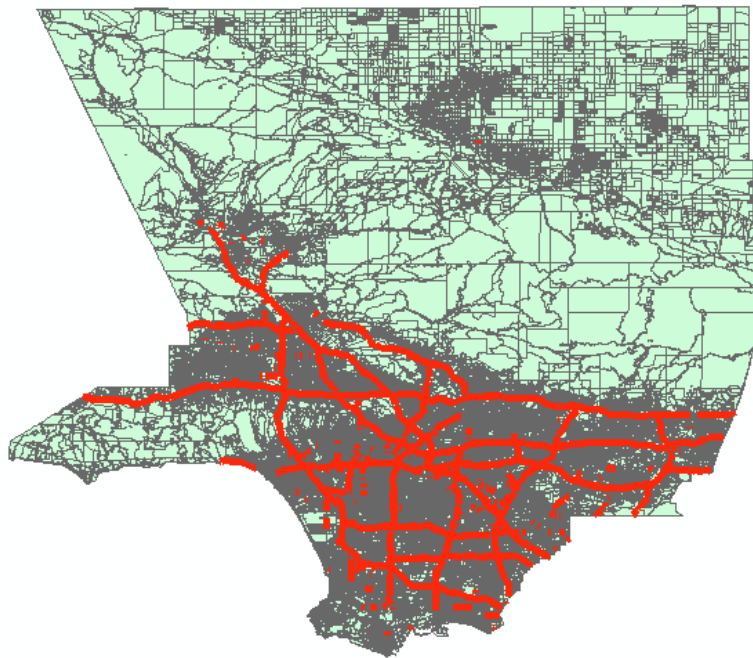
Table 5.1 above provides the ranges of PM<sub>2.5</sub> concentration levels (24-hour) with respect to the state of air quality as set forth by the Environmental Protection Agency (see corresponding Figure 1.1). The values of PM<sub>2.5</sub> provided in the table indicate the level of exposure one may be subjected to over a 24-hour period in order to achieve a certain level of air quality (Good-Hazardous). These values should provide an indication as to the amount of fine particulate matter that one individual can safely be exposed to without suffering permanent health defects. The ensuing sections will analyze further the results of the produced PM<sub>2.5</sub> concentration maps by comparing the air quality standards set forth in Table 5.1 with direct population exposure and distance from roadway centerlines.

## 5.1 PM<sub>2.5</sub> Concentration Gradients Relative to Roadway Centerline

One key factor that may be calculated using the resulting PM<sub>2.5</sub> concentration maps created above is to estimate the rate at which fine particulate matter concentration decreases with respect to the roadway centerline. This is first achieved by creating cross sectional PM<sub>2.5</sub> concentration gradients for all roads in Los Angeles County with greater than 50,000 AADT since this class of roads corresponds to roads that have been subjects in previous monitoring studies (Figure 5.4). The gradients were constructed by creating a series of ring buffers at 50 meter intervals around the transportation network and then intersecting those buffers with our PM<sub>2.5</sub> concentration surfaces (e.g., Figure 5.3). The resulting curves in Figure 5.5 indicates that PM<sub>2.5</sub> concentrations drop off quickly, reaching relatively low concentrations between 300m to 400m from the center line of high volumes roads. However, during stable atmospheric conditions (e.g., nighttime & winter season) concentrations remain elevated at distances up to 1,000m from roadway centerlines. These results correspond to previous findings from monitoring studies, including Hu, S., et al. (48) who found that concentrations of ultrafine particles (UFP), which are smaller in diameter in comparison to PM<sub>2.5</sub>, remained relatively high up to distances 2.6-3.6km downwind of a freeway in Southern California (for a comprehensive set of comparisons that include PM<sub>2.5</sub> monitoring studies see Karner et al. (1), and in particular their supplemental information).

Some caution should be exercised interpreting the curves in Figure 5.5. The buffers were drawn around both sides of roadway links, therefore gradients from the “upwind” and “downwind” side of the freeway were averaged together. The gradient experienced on just the downwind side of the roadway where winds are perpendicular would be more gradual and extend further. However,

in Los Angeles, wind directions change direction throughout the day and vary by season. Additionally, most roads do not align perfectly perpendicular to the prevailing wind direction. The curves therefore represent a reasonable estimate of average concentration gradients, but not the gradient that can be expected on a particular day or at a particular location. The magnitude of the gradients will vary by traffic volume, but the general shape and extent of the curves should be similar regardless.



**Figure 5.4 Los Angeles County Road Segments (red) with > 50,000 AADT**

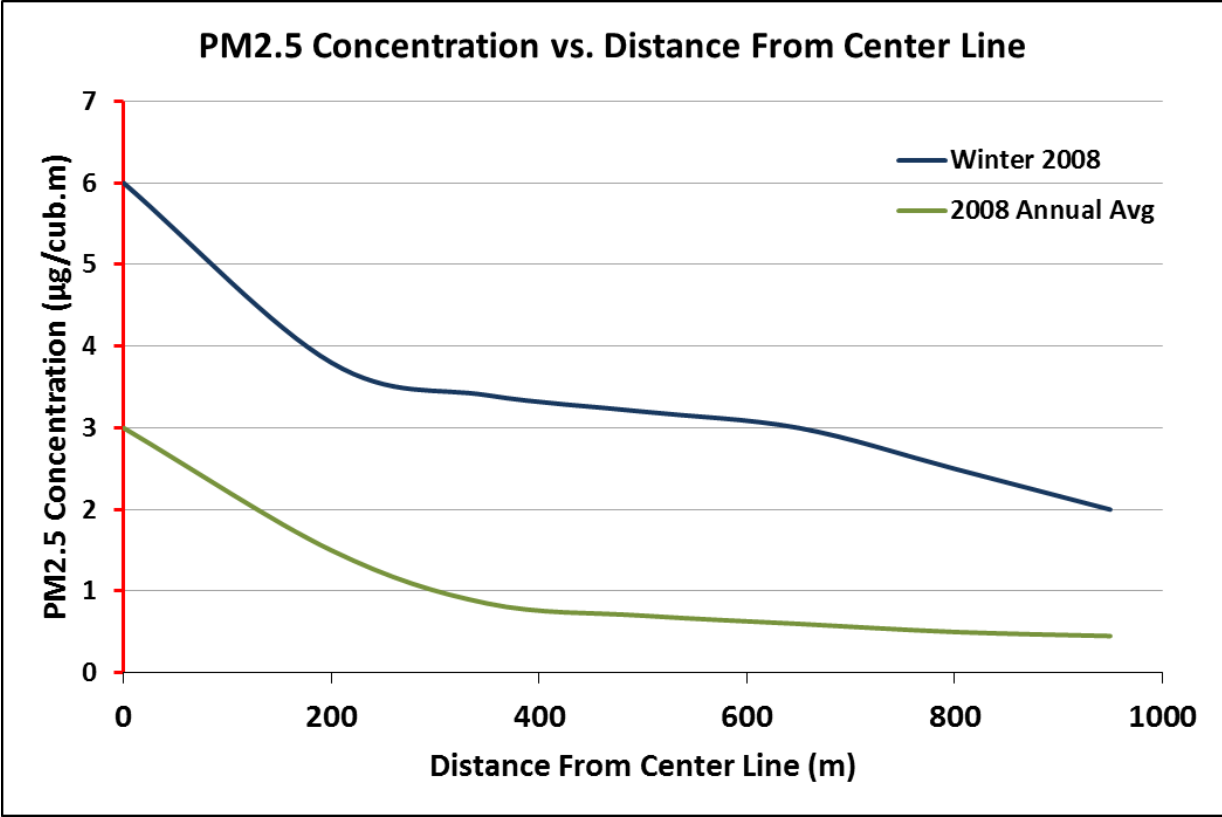
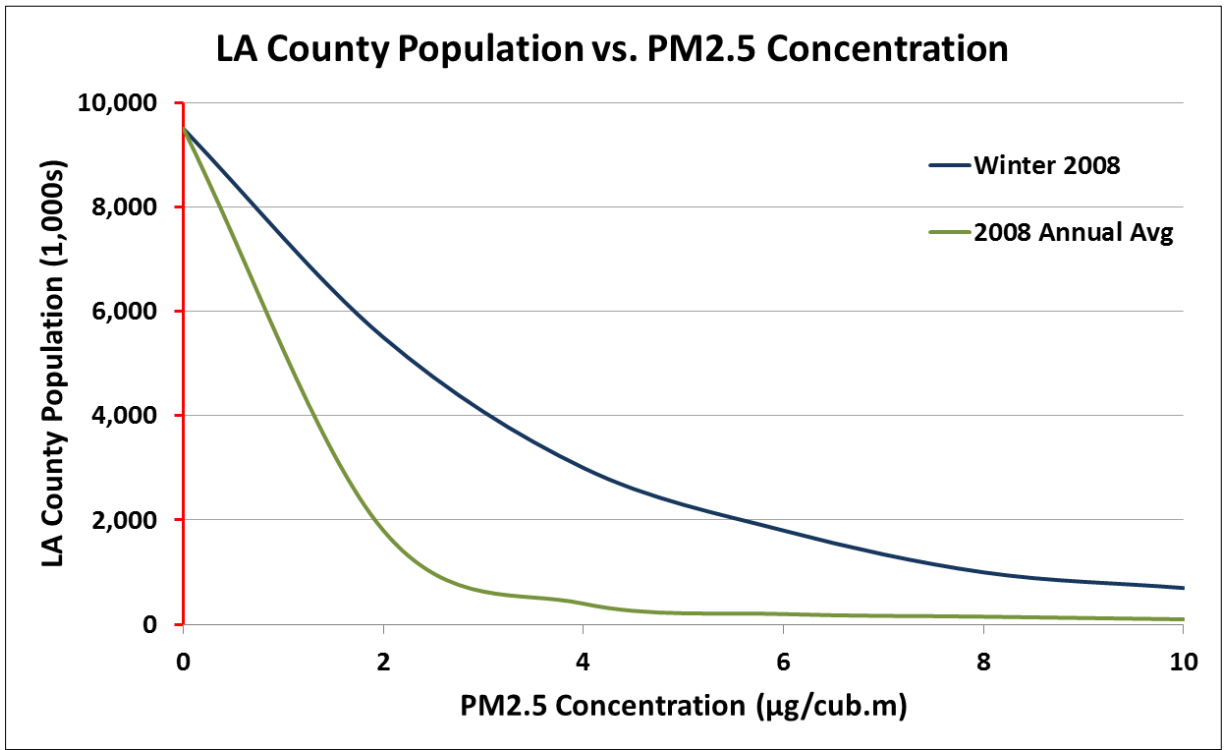


Figure 5.5 Average PM2.5 Concentration Gradients from Roadway Centerlines in Los Angeles County, CA (for road segments with > 50,000 AADT)

## 5.2 Population Exposure Analysis

To estimate population exposure and explore environmental justice issues we overlaid year 2010 U.S. Census block level population and tract level demographic and median household income data with our dispersion modeling results. However, the dispersion results provide point estimates every 100 meters. To accurately combine the Census data and PM<sub>2.5</sub> concentration data we first create a continuous surface from the PM<sub>2.5</sub> point estimates using a regularized spline interpolation method with a 20 meter output resolution. We then compute the average PM<sub>2.5</sub> concentration in each census tract and block group by intersecting their boundaries with the PM<sub>2.5</sub> surface. The average tract and block group PM<sub>2.5</sub> concentrations are then linked to a database containing the census tract and block group level data. These computations are each completed in ArcGIS version 10.0. Using GIS we intersected each concentration surface with a shape file delineating year 2010 U.S. Census tract and block group level data located in the county of Los Angeles, CA. We then calculated the average PM<sub>2.5</sub> concentration in each census block and linked these data to a database of year 2010 census block population estimates in order to estimate average exposure. The results are shown in Figure 5.6 and Table 5.2. As expected, exposure is highest during the winter season. During such conditions, more than 2 million people live in census blocks where highway vehicles account for more than 5 µg/m<sup>3</sup> of PM<sub>2.5</sub>. This is a significant level of PM<sub>2.5</sub> considering that the NAAQS standards are 12 µg/m<sup>3</sup> (annual average) and 35 µg/m<sup>3</sup> (24hr average) and that directly emitted PM<sub>2.5</sub> is only one of many sources of PM<sub>2.5</sub> emissions in an urban area. For example, CARB estimates that only 17% of PM<sub>2.5</sub> emissions by mass in Los Angeles County are from on-road mobile sources (55).



**Figure 5.6 Los Angeles County Population Exposure to Fine Particulate Matter by Year and Season**

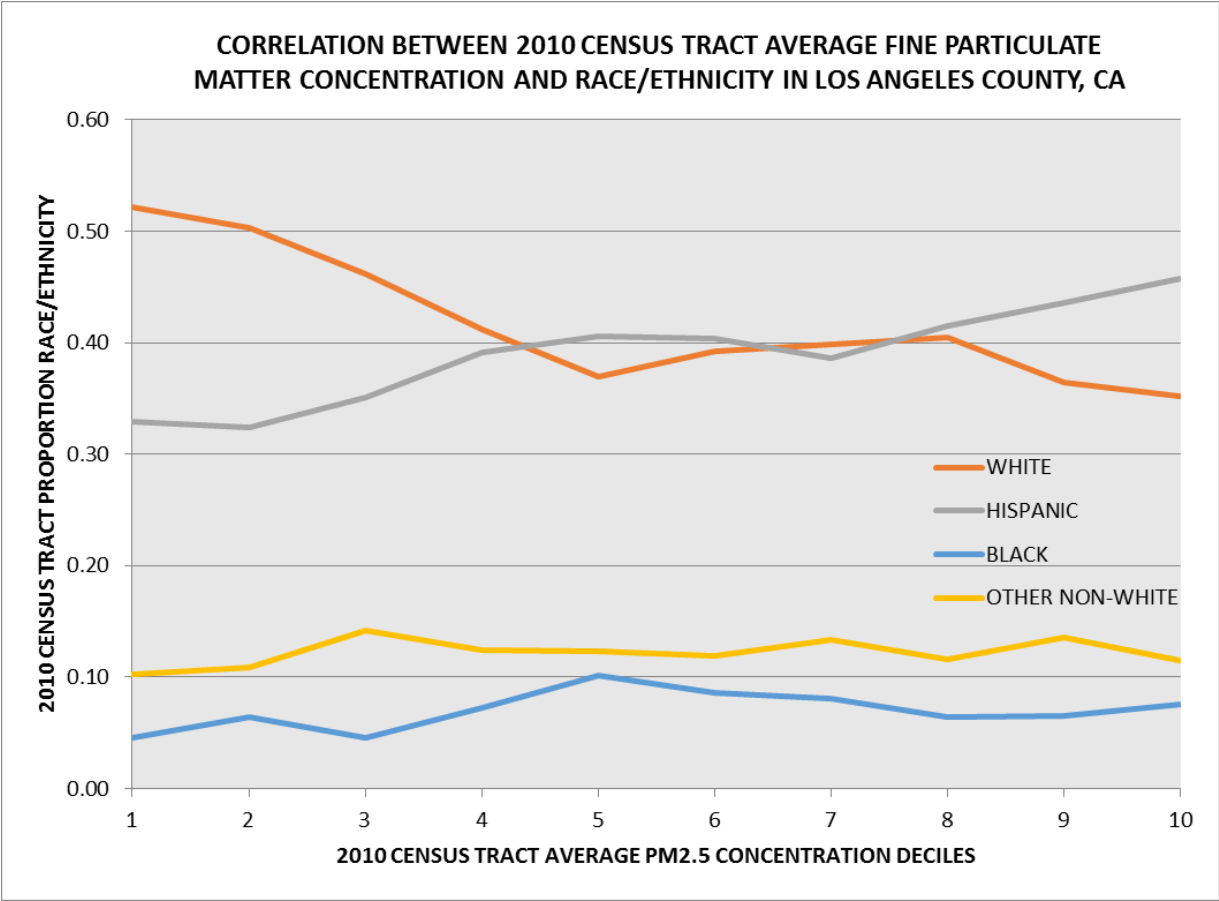
<b>PM2.5 (<math>\mu\text{g}/\text{m}^3</math>)</b>	<b>POPULATION (2008)</b>	<b>POPULATION (SUMMER)</b>	<b>POPULATION (WINTER)</b>
0 - 1.1	4,010,993	6,063,040	2,674,305
1.11 - 1.2	2,971,903	2,021,610	2,929,330
1.21 - 1.3	1,107,355	544,291	1,676,307
1.31 - 1.4	474,217	234,296	784,534
1.41 - 1.6	346,548	169,791	656,694
1.61 - 2.8	119,734	86,033	217,437
2.81 - 3.2	123,573	100,707	147,593
3.21 - 4.6	72,960	39,792	97,703
4.61 - 5.0	27,934	10,126	47,459
5.0 >	19,353	4,884	43,208
<b>TOTAL</b>	<b>9,274,570</b>	<b>9,274,570</b>	<b>9,274,570</b>

**Table 5.2 Census Block Population Statistics Grouped by Fine Particulate Matter Ranges**

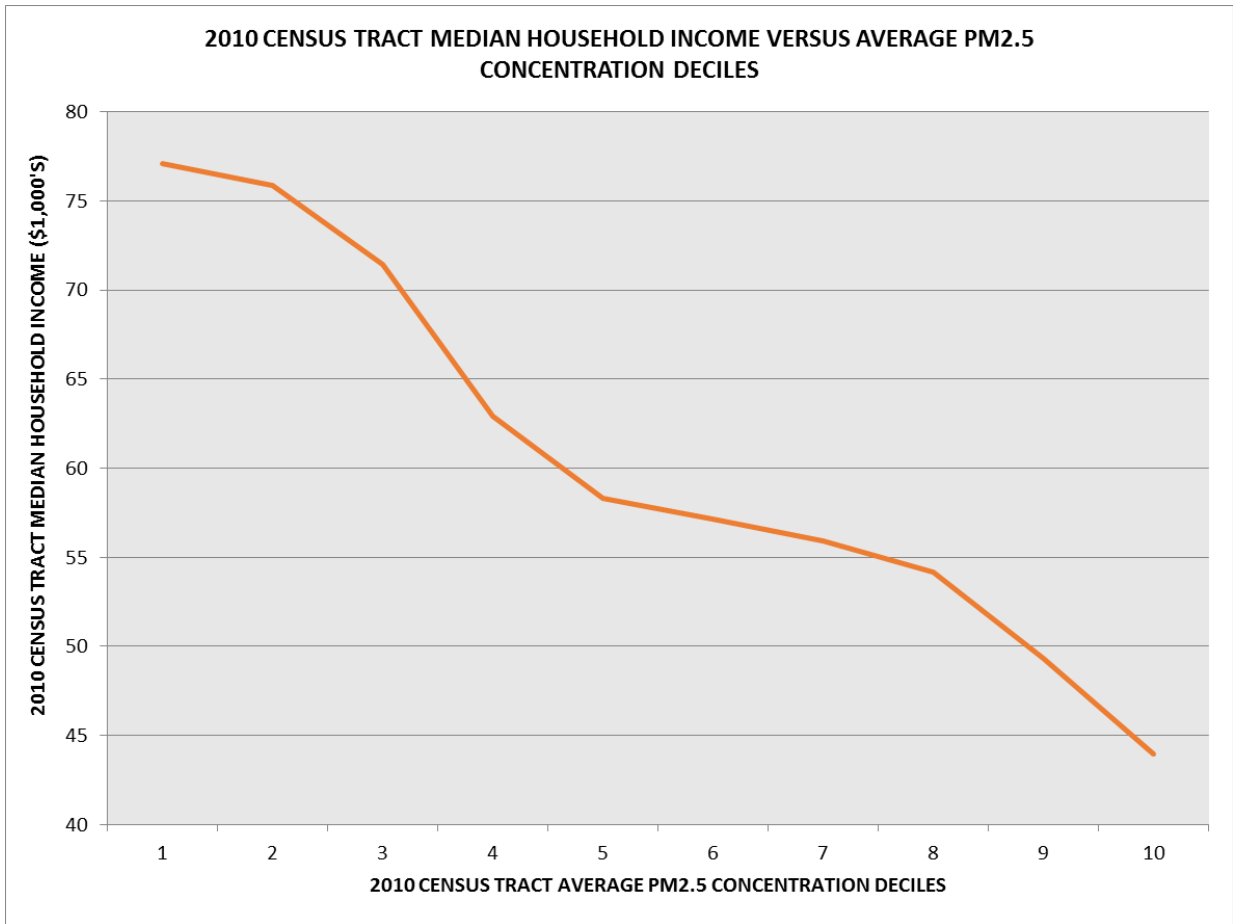
### 5.3 Environmental Justice Analysis

We also consider environmental justice concerns by looking at how tract level race (or ethnicity) and median household incomes vary by average tract level PM<sub>2.5</sub> concentrations. Previous studies have shown that low income and minority residents are disproportionately located in areas near high volume roads or where mobile source air pollutant emissions are higher (50-51, 57). These studies have often relied on analytical methods that use proximity to roadways or emission inventories as proxies for direct exposure to mobile source emissions. Nonetheless, our results (Figure 5.7) generally confirm what these previous studies have found. The plots in Figures 5.7 show the proportion of race/ethnicity and median household income by average census tract level PM<sub>2.5</sub> concentration deciles (see Table 5.3 for summary statistics defining the deciles). The census tracts with the highest PM<sub>2.5</sub> concentrations on average have the highest proportion of Hispanic/Latino residents. The range is also very large with the lowest 10% of census tracts by PM<sub>2.5</sub> concentrations being 52% white while the highest 10% of census blocks by PM<sub>2.5</sub> concentration are just 35% white. Looking at different minority groups reveals that most of this trend is driven by disparities in the Latino and Hispanic population, though disparities are evident in most minority populations. Similar results are found between median household income and PM<sub>2.5</sub> concentrations. The population living in the lowest decile has an average median household income of \$77,080 while the average median household income for the population living in the highest decile is only \$43,985 (see Figure 5.8).





**Figure 5.7 Correlation between Census Tract Average Fine Particulate Matter Concentration and Race in Los Angeles County, CA**



**Figure 5.8 Correlation between Census Tract Average Fine Particulate Matter Concentration and Median Household Income in Los Angeles County, CA**

Decile	2008 PM2.5 concentration ( $\mu\text{g}/\text{m}^3$ )		Population				Median Household Income
	Mean	Range	White	Latino	Black	Other Non- White	
1	0.04	0.0-0.012	589,180	371,944	51,565	116,100	\$77,080
2	0.25	0.121-0.4	632,854	407,532	80,644	137,098	\$75,897
3	0.50	0.41-0.61	592,725	450,781	58,276	182,246	\$71,467
4	0.72	0.62-0.80	523,655	497,358	92,156	157,574	\$62,948
5	0.90	0.81-1.00	482,252	530,334	132,609	161,380	\$58,323
6	1.109	1.11-1.12	499,681	514,793	109,187	151,589	\$57,140
7	2.134	1.121-2.15	485,418	470,374	98,425	162,561	\$55,906
8	3.173	2.151-3.19	494,973	507,999	78,549	141,728	\$54,186
9	4.231	3.191-4.28	428,651	513,365	76,554	159,256	\$49,341
10	5.389	4.28-5.89	410,026	532,688	88,321	134,171	\$43,985

**Table 5.3 Census Tract Summary Statistics Grouped by Fine Particulate Matter Concentration Deciles**

## 5.4 Model Validation

In order to more accurately determine the particle matter concentration levels experienced near roadways, instrument measuring devices are available from industry that can quantify real-time PM<sub>2.5</sub> concentration levels to a certain degree of confidence, or accuracy. Such an approach, if applied to our framework, would require many hours of field work and the acquisition of instrument devices in order to produce concentration level readings at the scale discussed in this paper. Future work may look into validating the results produced therein by comparing the results produced in this paper (e.g., using AERMOD) versus actual field readings, yet doing so at a regional scale would require a vast amount of resources with today's current technology. However, another possible option for determining the accuracy and validity of our results is to compare the concentration gradients with readings from the SCAQMD air quality monitoring stations located throughout the basin (see Figure 4.5). The results determined using AERMOD should fall below the station readings since the air quality monitors capture all emission sources. When selecting this approach, one can also determine the contribution of roadway emissions to total regional emissions by means of deduction. In other words, these air quality monitoring stations will include all background noise (in addition to mobile source pollutants). One possible outcome of our study would enable an agency to confirm (or disprove) the contribution of roadway emissions to regional emissions since the percentage contribution is still debatable amongst industry, researchers, and policy advocates.

## 5.5 Transportation Planning Process Integration

As part of objective three of this dissertation it is our desired attempt to show how the proposed methodological framework for estimating  $PM_{2.5}$  at a regional scale can be integrated into the transportation planning process of any MPO in order to assess immediate environmental impacts of proposed long range transportation plans. The transportation planning process is best described by Manheim, M. (71), which involves two major components for analysis: The transport system (or network), T, and the activity system (or users), A, and each are measured based on the performance of the network and the demand of the users. Manheim had the foresight to treat the transportation system as a multidisciplinary science, drawing on the fields of engineering, planning, economics, environmental, operations research, logistics, and political science (among others).

The transport (T) and activity (A) systems are equilibrated by way of the traditional 4-step method: trip generation, trip distribution, mode choice, (time of day) and traffic assignment. After the first iteration of flows and levels of service are produced, they are then relayed back to the beginning of the process as new inputs by way of feedback and repeated until convergence is achieved. It is at this stage in the process (after convergence is met) that our proposed methodology can be introduced and implemented into Manheim's transportation planning process flow-chart to instantaneously determine which areas in the network exhibit hot spots that exceed the maximum allowable  $PM_{2.5}$  concentration levels as set forth by the EPA's National Ambient Air Quality Standards.

The integration of our proposed methodology into the transportation planning process is now made possible given its feasible computation speed of applying an air dispersion model to an entire region. If after convergence is achieved and there indeed exists a significant amount of hot spot locations that exceed these standards, especially in areas where there is a high likelihood of direct population exposure (using the methods presented in sections 5.2 and 5.3) or near sensitive land uses (such as hospitals or schools), then the transportation agency can revisit their long range transportation and evaluate alternatives (at a regional scale) in order to minimize exposure to projected hot spot locations. Such integration into the transportation planning process can lead to more environmentally and financially sustainable transportation plans. Regional strategies that minimize exposure, rather than inventories, could be established, environmental justice concerns are easily identified, and projects likely to cause local pollution “hotspots” can be proactively screened out, saving time and money for the transportation agency.

## CHAPTER 6 CONCLUSIONS

Recall, the previously discussed objectives of this dissertation included the following:

1. Quantify PM<sub>2.5</sub> concentration gradients from mobile source pollutants at a regional scale;
2. Estimate population exposure to the PM<sub>2.5</sub> concentration levels calculated in part 1 using data from the US Census Bureau;
3. Demonstrate the feasibility and practicality of our approach by integrating the proposed methodology into the regional transportation planning process; &
4. Provide a tool for planners and policy makers to assess Environmental Justice (EJ) issues.

We demonstrated in Chapter four how objective one can be achieved by adopting a raster technique that overlays a grid on top of a county-wide transportation network which then allows an agency to apply EPA's hot spot analysis guidelines at a regional scale and in a feasible amount of time. In section 5.2 it was shown that direct population exposure to PM<sub>2.5</sub> can be reasonably estimated by overlaying (and intersecting) the concentration gradient maps produced in Chapter five on top of US Census block level data in ArcGIS, thereby achieving objective two. Objective three was discussed in section 5.5 on how our proposed framework can be integrated into an MPO's regional transportation planning process in a practical and feasible (computationally speaking) manner. We also showed in section 5.3 how our methodology can be utilized as a tool for urban planners to assess the potential for Environmental Justice (EJ) issues, satisfying the final objective of our dissertation.

Though efforts are being made to apply air dispersion models to large scale transport networks at a sub-regional scale, such as Cook, R., et al.'s 2008 study in New Haven, CT with a city-wide, block-level, modeling domain, or Wu, J., et al.'s (72) parcel-level application of CALINE in the surrounding San Pedro Bay Ports communities, the major contribution and improvement we are making to today's state of the practice with our proposed methodology is that it will allow MPO's (or air quality management districts) to conduct a PM<sub>2.5</sub> hot spot analysis, but at a regional scale and in a feasible amount of time (maintaining the spatial resolution with our 100m receptor spacing cell grid). As an added feature of our framework, environmental justice issues and population exposure can be investigated (based on several simplifying assumptions and reasonable modifications to the analysis).

As evidence by the recent passage of the EPA's revisions to the air quality standards for fine particulate matter, which raises the annual health National Ambient Air Quality Standard (NAAQS) for fine particulates from 15.0 to 12.0 micrograms per cubic meter ( $\mu\text{g}/\text{m}^3$ ), the public health issues associated with exposure to high levels of fine particulates are beginning to receive much needed attention from a national regulatory level. This research demonstrates that high resolution air dispersion modeling can be performed for large transportation networks with a few simplifying assumptions and the application of a novel rastering approach. We also demonstrated unique insights that are gained from modeling such a large area. For example, we are able to estimate population exposure and find strong spatial and seasonal trends affecting population exposure. We are also able to complete a detailed analysis of exposure by race/ethnicity and income.



The general consensus on how vehicle emission concentrations decay with respect to distance from the roadway edge, and in particular  $PM_{2.5}$ , is still a debatable and controversial topic amongst scientists and policy makers and the research continues to show enough inconsistency that prevents our field from reaching a unanimous verdict. Section 5.1 provided an additional feature to our proposed framework by estimating modeled  $PM_{2.5}$  concentrations with respect to roadway centerlines at a regional scale (by intersecting roadways of 50,000 ADT or greater with ring buffers in ArcGIS and calculating the average  $PM_{2.5}$  concentration in each respective buffer). Even with this crude approach to evaluating concentration levels as one moves away from the roadway edge, it was shown that our modeled results reasonably compare with empirical studies that took  $PM_{2.5}$  readings with increasing distance from the roadway's edge. Karner, et al. (1) summarized 41 monitoring studies dating back to 1978 and found that almost all pollutants (including  $PM_{2.5}$ ) decay to background concentrations between 160-570m from the edge of the road (when normalizing pollutant concentrations to the roadway edge and excluding background level concentrations), which corresponds to our  $PM_{2.5}$  concentration curves in Figure 5.5. However, the authors also found that no trend existed between  $PM_{2.5}$  and distance from the roadway edge when normalizing pollutant concentrations to background levels, which include background level  $PM_{2.5}$  measurements. The authors suggest that one possible explanation for these differences between the normalization methods arose due to the "likely bias inherent in background normalization, since some reported background values tend to under-predict actual background." Future work of our methodology will add background level concentration readings, which will have a significant impact on the curves produced in Chapter 5, and thereby confirm (or disprove) the results presented by Karner, et al., but for now, our modeling results show relative agreement amongst other monitoring studies.

In relation to environmental justice, previous studies have consistently shown that low income and minority residents are disproportionately located in areas near high volume roads or where mobile source air pollutant emissions (PM<sub>2.5</sub> especially) are higher. However, these studies have often relied on analytical methods that use proximity to roadways (50), traffic volumes (51, 57) or emission inventories (37) as proxies for direct exposure to mobile source emissions. The environmental justice methodology presented in sections 5.2 & 5.3 of this paper provide a solution to these limitations by allowing for the estimation of direct PM<sub>2.5</sub> exposure and at a regional scale. In general, our results show consistency with these studies in regards to higher exposure levels amongst low income and minority residents in the LA County region.

Another unique feature of our proposed methodology is the ability to capture population exposure estimates at the census block level, yet still retain the modeling domain of a large region and dense roadway network. Previous EJ studies that found significant correlations between low income and minority groups and higher exposure to mobile source pollutants (and/or traffic volumes) often performed the population exposure analysis at the census block-level (or tract level), yet with a transport network no larger than a city-wide, sub-regional scale (19, 37, 72). However, McEntee, J.C., et al. (52) made an attempt to estimate exposure at a larger scale by analyzing measurements of diesel particulate matter concentrations on major highways in Massachusetts, and the associated lung cancer and asthma incidences reported along the corridors. Nonetheless, their study was limited to 5 major freeway corridors, excluding a significant portion of the state's highway and arterial transport network. Our methodology would avoid such limitations by modeling a large regional, dense network and capture the associated impacts at the parcel level.

The framework for modeling PM<sub>2.5</sub> (or other non-reactive pollutants) described above has many practical applications that can help improve regional and local air quality, protecting public health and ensuring environmental justice. The modeling framework can be fully integrated into the routine travel demand modeling process conducted by every regional transportation planning agency. The resulting maps produced in Chapter 5 provide unique insights into PM<sub>2.5</sub> modeling, including the significant role atmospheric conditions and changes in season play in PM<sub>2.5</sub> concentration levels and gradients after controlling for traffic variables. The spatially detailed PM<sub>2.5</sub> concentration surfaces can also provide information about how different planning scenarios affect population exposure, providing valuable and instantaneous information to the regional planning agency and allowing for the exclusion of transportation projects from regional transportation plans that will cause localized PM<sub>2.5</sub> hotspots or environmental justice concerns. This proactive approach could save considerable time and money during the implementation phase of individual projects in addition to understanding how changing regional population and employment patterns affect pollutant concentrations and exposure. For example, how do smart growth policies, such as SCAG's Sustainable Communities Strategies (SCS) that encourage density, affect exposure?

The detailed PM<sub>2.5</sub> surfaces can also be used to support future research. The concentration and population data can be used as inputs to a health risk model, such as the HARP model available from the California Air Resources Board, to quantify how different transportation plans may affect health outcomes or how health risks vary across socio-economic groups. The data may also be used in place of traffic pollution proxy variables and the highly aggregate National Air Toxics Assessment data commonly used in epidemiology studies.

## CHAPTER 7      FUTURE WORK

Our future work will involve a number of refined steps, including revisiting the modeling process to find the optimal tradeoff between computational speed and resolution. Additional investigation to validate the performance and output of AERMOD (and perhaps other air dispersion models) for modeling transportation networks is also needed given the small number of current studies, many with inconclusive findings. Below is a list of recommended tasks that should be considered for the next stages:

1. Run the model to determine PM<sub>2.5</sub> concentration estimates for horizon year 2035;
2. Perform statistical and sensitivity analysis on the changes in PM<sub>2.5</sub> concentration levels & exposure (2008 vs 2035);
3. Determine optimal locations for new air quality monitoring stations;
4. Demonstrate practicality of the model by proactively screening out non-conforming/non-attainment achieving transportation improvement projects;
5. Future integration of proposed framework with activity-based travel demand models;
6. When possible, include regional travel demand model average link speed calibration;
7. Extend the cell buffer beyond 1,000KM;
8. Model truck and autos separately, as well as AM & PM peak-periods;
9. Include all other emission background sources in AERMOD, including rail, airplane, ships, ports, and industrial and commercial sources (i.e. power plants); &
10. Estimate PM<sub>2.5</sub> concentration exposure with respect to age groups.

# **APPENDIX**

## **EXHIBIT A**

EMFAC2011 Output Summary Sheet

Title : **LA County 2008**

Version : Emfac2011-LDV V2.50.58.094 Sp: Trip Assign Santa Clara County

Run Date : 2013/11/14 11:41:48

Scen Year: 2008 -- All model years in the range 1965 to 2008 selected

Season : Annual

Area : Los Angeles

Year: 2008 -- Model Years 1965 to 2008 Inclusive -- ANNUAL

Emfac2011-LDV Emission Factors: V2.50.58.094 Sp: Trip Assign Santa Clara County

County Average                      Los Angeles                      County Average

Table 1: Running Exhaust Emissions (grams/mile; grams/idle-hour)

Pollutant Name: PM2.5                      Temperature: 70F Relative Humidity: 50%

Speed							
MPH	LDA	LDT	MDT	HDT	UBUS	MCY	ALL
0	0.000	0.000	0.054	0.000	0.000	0.000	0.011
5	0.021	0.022	0.021	0.045	0.666	0.003	0.023
10	0.014	0.015	0.015	0.030	0.483	0.002	0.016
15	0.010	0.010	0.011	0.021	0.363	0.002	0.011
20	0.007	0.008	0.008	0.015	0.282	0.002	0.009
25	0.006	0.006	0.007	0.012	0.227	0.002	0.007
30	0.005	0.005	0.006	0.011	0.190	0.002	0.006
35	0.004	0.004	0.005	0.009	0.164	0.001	0.005
40	0.004	0.004	0.004	0.009	0.147	0.002	0.004
45	0.003	0.004	0.004	0.009	0.136	0.002	0.004
50	0.003	0.004	0.004	0.009	0.130	0.002	0.004
55	0.003	0.004	0.004	0.010	0.130	0.002	0.004
60	0.004	0.004	0.004	0.011	0.133	0.003	0.004
65	0.004	0.005	0.004	0.013	0.142	0.004	0.005

Title : **LA County 2008 Summer**

Version : Emfac2011-LDV V2.50.58.094 Sp: Trip Assign Santa Clara County

Run Date : 2013/11/08 11:41:48

Scen Year: 2008 -- All model years in the range 1965 to 2008 selected

Season : Summer

Area : Los Angeles

Year: 2008 -- Model Years 1965 to 2008 Inclusive -- SUMMER

Emfac2011-LDV Emission Factors: V2.50.58.094 Sp: Trip Assign Santa Clara County

County Average                      Los Angeles                      County Average

Table 1: Running Exhaust Emissions (grams/mile; grams/idle-hour)

Pollutant Name: PM2.5                      Temperature: 70F Relative Humidity: 50%

Speed							
MPH	LDA	LDT	MDT	HDT	UBUS	MCY	ALL
0	0.000	0.000	0.054	0.000	0.000	0.000	0.011
5	0.021	0.022	0.021	0.045	0.666	0.003	0.023
10	0.014	0.015	0.015	0.030	0.483	0.002	0.016
15	0.010	0.010	0.011	0.021	0.363	0.002	0.011
20	0.007	0.008	0.008	0.015	0.282	0.002	0.009
25	0.006	0.006	0.007	0.012	0.227	0.002	0.007
30	0.005	0.005	0.006	0.011	0.190	0.002	0.006
35	0.004	0.004	0.005	0.009	0.164	0.001	0.005
40	0.004	0.004	0.004	0.009	0.147	0.002	0.004
45	0.003	0.004	0.004	0.009	0.136	0.002	0.004
50	0.003	0.004	0.004	0.009	0.130	0.002	0.004
55	0.003	0.004	0.004	0.010	0.130	0.002	0.004
60	0.004	0.004	0.004	0.011	0.133	0.003	0.004
65	0.004	0.005	0.004	0.013	0.142	0.004	0.005



Title : **LA County 2008 Winter**

Version : Emfac2011-LDV V2.50.58.094 Sp: Trip Assign Santa Clara County

Run Date : 2013/11/08 11:41:48

Scen Year: 2008 -- All model years in the range 1965 to 2008 selected

Season : Winter

Area : Los Angeles

Year: 2008 -- Model Years 1965 to 2008 Inclusive -- WINTER

Emfac2011-LDV Emission Factors: V2.50.58.094 Sp: Trip Assign Santa Clara County

County Average                      Los Angeles                      County Average

Table 1: Running Exhaust Emissions (grams/mile; grams/idle-hour)

Pollutant Name: PM2.5                      Temperature: 60F Relative Humidity: 50%

Speed							
MPH	LDA	LDT	MDT	HDT	UBUS	MCY	ALL
0	0.000	0.000	0.054	0.000	0.000	0.000	0.011
5	0.021	0.022	0.021	0.045	0.666	0.003	0.023
10	0.014	0.015	0.015	0.030	0.483	0.002	0.016
15	0.010	0.010	0.011	0.021	0.363	0.002	0.011
20	0.007	0.008	0.008	0.015	0.282	0.002	0.009
25	0.006	0.006	0.007	0.012	0.227	0.002	0.007
30	0.005	0.005	0.006	0.011	0.190	0.002	0.006
35	0.004	0.004	0.005	0.009	0.164	0.001	0.005
40	0.004	0.004	0.004	0.009	0.147	0.002	0.004
45	0.003	0.004	0.004	0.009	0.136	0.002	0.004
50	0.003	0.004	0.004	0.009	0.130	0.002	0.004
55	0.003	0.004	0.004	0.010	0.130	0.002	0.004
60	0.004	0.004	0.004	0.011	0.133	0.003	0.004
65	0.004	0.005	0.004	0.013	0.142	0.004	0.005

## **EXHIBIT B**

Sample AERMOD Run File

**2008 AERMOD INPUTS:**

CO STARTING

CO TITLEONE 2791 2008BL

\*\* Model DEFAULT options are used, and pollutant Concentrations are determined

CO MODELOPT DFAULT CONC

\*\* Pop Defined Urban Name

CO URBANOPT 4500 2791

CO AVERTIME PERIOD

CO POLLUTID FINEPM25

CO ERRORFIL ERROR.ERR

CO RUNORNOT RUN

CO FINISHED

\*\*\*\*\*

SO STARTING

\*\* Location File

SO INCLUDED 2791\_SO.SOU

\*\* Parameters File

SO INCLUDED 2008\_PARAMETERS.DAT

\*\* Variable Emission Rates by Hour of Day

SO INCLUDED EMISFACT.EMF

\*\* Urban Name & Sources modeled with urban effects

SO URBANSRC 2791 0-190312

\*\* Mandatory - Groups sources together in a single run

\*\* GrpID Source Range

SO SRCGROUP 2791 0-190312

SO FINISHED

\*\*\*\*\*

RE STARTING

\*\* RE ELEVUNIT METERS

RE INCLUDED 2791\_RE.REC

RE FINISHED

\*\*\*\*\*

ME STARTING

ME SURFFILE laxh6.SFC

ME PROFFILE laxh6.PFL

\*\* ID YEAR Location

ME SURFDATA 9999 2006 LAX

ME UAIRDATA 3190 2006 LAX

\*\* Base elevation of weather tower

ME PROFBASE 42 METERS

\*\* AERMOD will READ this data range only

\*\* Note: Check for Leap Year

ME STARTEND 08 01 01 08 12 31

\*\* AERMOD will PROCESS this day range only

ME DAYRANGE 1/2 1/15 2/1 2/15 3/1 3/15 4/1 4/15 5/1 5/15 6/1 6/15 7/1 7/15 8/1 8/15 9/1 9/15 10/1  
10/15 11/1 11/15 12/1 12/15

ME FINISHED

\*\*\*\*\*

OU STARTING

\*\* This file will provide the 24-hour average concentration at each receptor, for each day analyzed (36 days)

\*\* OU POSTFILE 24 3236 PLOT PLT\_TOTAL\_08BL\_24.PLT

\*\* This file will provide the overall average concentration for each receptor (total time period is 36 days x 24 hours/day)

OU PLOTFILE PERIOD 2791 2791\_2008.PLT

OU FINISHED

\*\*\*\*\*

**SUMMER AERMOD INPUTS:**

\*\* AERMOD Version 11103

CO STARTING

CO TITLEONE 2791 SUMMER2008BL

\*\* Model DEFAULT options are used & pollutant concentrations are determined  
CO MODELOPT DFAULT CONC

\*\* Pop Defined Urban Name  
CO URBANOPT 4500 2791

CO AVERTIME PERIOD

CO POLLUTID FINEPM25

CO ERRORFIL ERROR.ERR

CO RUNORNOT RUN

CO FINISHED

\*\*\*\*\*

SO STARTING

\*\* Location File  
SO INCLUDED 2791\_SO.SOU

\*\* Parameters File  
SO INCLUDED 2008\_PARAMETERS.DAT

\*\* Variable Emission Rates by Hour of Day  
SO INCLUDED EMISFACT.EMF

\*\* Urban Name & Sources modeled with urban effects  
SO URBANSRC 2791 0-190312

\*\* Mandatory - Groups sources together in a single run

\*\* GrpID Source Range  
SO SRCGROUP 2791 0-190312

SO FINISHED

\*\*\*\*\*

RE STARTING

\*\* RE ELEVUNIT METERS

RE INCLUDED 2791\_RE.REC

RE FINISHED

\*\*\*\*\*

ME STARTING

ME SURFFILE laxh6.SFC

ME PROFFILE laxh6.PFL

\*\* ID YEAR Location

ME SURFDATA 9999 2006 LAX

ME UAIRDATA 3190 2006 LAX

\*\* Base elevation of weather tower

ME PROFBASE 42 METERS

\*\* AERMOD will READ this data range only

\*\* Note: Check for Leap Year

ME STARTEND 07 01 01 09 12 31

\*\* AERMOD will PROCESS this day range only

\*\* Jun July August

ME DAYRANGE 6/1 6/15 7/1 7/15 8/1 8/15

ME FINISHED

\*\*\*\*\*

OU STARTING

\*\* This file will provide the 24-hour average concentration at each receptor, for each day analyzed (36 days)

\*\* OU POSTFILE 24 3236 PLOT PLT\_TOTAL\_08BL\_24.PLT

\*\* This file will provide the overall average concentration for each receptor (total time period is 36 days x 24 hours/day)

OU PLOTFILE PERIOD 2791 2791\_SUMMER2008.PLT

OU FINISHED

\*\*\*\*\*

**WINTER AERMOD INPUTS:**

\*\* AERMOD Version 11103

CO STARTING

CO TITLEONE 2791 WINTER2008BL

\*\* Model DEFAULT options are used & pollutant concentrations are determined  
CO MODELOPT DFAULT CONC

\*\* Pop Defined Urban Name  
CO URBANOPT 4500 2791

CO AVERTIME PERIOD

CO POLLUTID FINEPM25

CO ERRORFIL ERROR.ERR

CO RUNORNOT RUN

CO FINISHED

\*\*\*\*\*

SO STARTING

\*\* Location File  
SO INCLUDED 2791\_SO.SOU

\*\* Parameters File  
SO INCLUDED 2008\_PARAMETERS.DAT

\*\* Variable Emission Rates by Hour of Day  
SO INCLUDED EMISFACT.EMF

\*\* Urban Name & Sources modeled with urban effects  
SO URBANSRC 2791 0-190312

\*\* Mandatory - Groups sources together in a single run

\*\* GrpID Source Range  
SO SRCGROUP 2791 0-190312

SO FINISHED

\*\*\*\*\*

RE STARTING

\*\* RE ELEVUNIT METERS

RE INCLUDED 2791\_RE.REC

RE FINISHED

\*\*\*\*\*

ME STARTING

ME SURFFILE laxh6.SFC

ME PROFFILE laxh6.PFL

\*\* ID YEAR Location

ME SURFDATA 9999 2006 LAX

ME UAIRDATA 3190 2006 LAX

\*\* Base elevation of weather tower

ME PROFBASE 42 METERS

\*\* AERMOD will READ this data range only

\*\* Note: Check for Leap Year

ME STARTEND 07 01 01 09 12 31

\*\* AERMOD will PROCESS this day range only

\*\* Dec Jan Feb

ME DAYRANGE 12/1 12/15 1/1 1/15 2/1 2/15

ME FINISHED

\*\*\*\*\*

OU STARTING

\*\* This file will provide the 24-hour average concentration at each receptor, for each day analyzed (36 days)

\*\* OU POSTFILE 24 3236 PLOT PLT\_TOTAL\_08BL\_24.PLT

\*\* This file will provide the overall average concentration for each receptor (total time period is 36 days x 24 hours/day)

OU PLOTFILE PERIOD 2791 2791\_WINTER2008.PLT

OU FINISHED

\*\*\*\*\*



**AM PEAK PERIOD AERMOD INPUTS:**

\*\* AERMOD Version 11103

CO STARTING

CO TITLEONE 2791 AM2008BL

\*\* Model DEFAULT options are used & pollutant concentrations are determined  
CO MODELOPT DFAULT CONC

\*\* Pop Defined Urban Name  
CO URBANOPT 4500 2791

CO AVERTIME PERIOD

CO POLLUTID FINEPM25

CO ERRORFIL ERROR.ERR

CO RUNORNOT RUN

CO FINISHED

\*\*\*\*\*

SO STARTING

\*\* Location File  
SO INCLUDED 2791\_AM\_SO.SOU

\*\* Parameters File  
SO INCLUDED AM2008\_PARAMETERS.DAT

\*\* Variable Emission Rates by Hour of Day  
SO INCLUDED EMISFACT.EMF

\*\* Urban Name & Sources modeled with urban effects  
SO URBANSRC 2791 0-190312

\*\* Mandatory - Groups sources together in a single run

\*\* GrpID Source Range  
SO SRCGROUP 2791 0-190312

SO FINISHED

\*\*\*\*\*

RE STARTING

\*\* RE ELEVUNIT METERS

RE INCLUDED 2791\_RE.REC

RE FINISHED

\*\*\*\*\*

ME STARTING

ME SURFFILE laxh6.SFC

ME PROFFILE laxh6.PFL

\*\* ID YEAR Location

ME SURFDATA 9999 2006 LAX

ME UAIRDATA 3190 2006 LAX

\*\* Base elevation of weather tower

ME PROFBASE 42 METERS

\*\* AERMOD will READ this data range only

\*\* Note: Check for Leap Year

ME STARTEND 08 01 01 08 12 31

\*\* AERMOD will PROCESS this day range only

\*\* Jan

Dec

ME DAYRANGE 1/2 1/15 2/1 2/15 3/1 3/15 4/1 4/15 5/1 5/15 6/1 6/15 7/1 7/15 8/1 8/15 9/1 9/15 10/1  
10/15 11/1 11/15 12/1 12/15

ME FINISHED

\*\*\*\*\*

OU STARTING

\*\* This file will provide the 24-hour average concentration at each receptor, for each day analyzed (36 days)

\*\* OU POSTFILE 24 3236 PLOT PLT\_TOTAL\_08BL\_24.PLT

\*\* This file will provide the overall average concentration for each receptor (total time period is 36 days x 24 hours/day)

OU PLOTFILE PERIOD 2791 2791\_AM2008.PLT

OU FINISHED

\*\*\*\*\*

**PM PEAK PERIOD AERMOD INPUTS:**

\*\* AERMOD Version 11103

CO STARTING

CO TITLEONE 2791 PM2008BL

\*\* Model DEFAULT options are used & pollutant concentrations are determined  
CO MODELOPT DFAULT CONC

\*\* Pop Defined Urban Name  
CO URBANOPT 4500 2791

CO AVERTIME PERIOD

CO POLLUTID FINEPM25

CO ERRORFIL ERROR.ERR

CO RUNORNOT RUN

CO FINISHED

\*\*\*\*\*

SO STARTING

\*\* Location File  
SO INCLUDED 2791\_PM\_SO.SOU

\*\* Parameters File  
SO INCLUDED PM2008\_PARAMETERS.DAT

\*\* Variable Emission Rates by Hour of Day  
SO INCLUDED EMISFACT.EMF

\*\* Urban Name & Sources modeled with urban effects  
SO URBANSRC 2791 0-190312

\*\* Mandatory - Groups sources together in a single run

\*\* GrpID Source Range  
SO SRCGROUP 2791 0-190312

SO FINISHED

\*\*\*\*\*

RE STARTING

\*\* RE ELEVUNIT METERS

RE INCLUDED 2791\_RE.REC

RE FINISHED

\*\*\*\*\*

ME STARTING

ME SURFFILE laxh6.SFC

ME PROFFILE laxh6.PFL

\*\* ID YEAR Location

ME SURFDATA 9999 2006 LAX

ME UAIRDATA 3190 2006 LAX

\*\* Base elevation of weather tower

ME PROFBASE 42 METERS

\*\* AERMOD will READ this data range only

\*\* Note: Check for Leap Year

ME STARTEND 08 01 01 08 12 31

\*\* AERMOD will PROCESS this day range only

\*\* Jan

Dec

ME DAYRANGE 1/2 1/15 2/1 2/15 3/1 3/15 4/1 4/15 5/1 5/15 6/1 6/15 7/1 7/15 8/1 8/15 9/1 9/15 10/1  
10/15 11/1 11/15 12/1 12/15

ME FINISHED

\*\*\*\*\*

OU STARTING

\*\* This file will provide the 24-hour average concentration at each receptor, for each day analyzed (36 days)

\*\* OU POSTFILE 24 3236 PLOT PLT\_TOTAL\_08BL\_24.PLT

\*\* This file will provide the overall average concentration for each receptor (total time period is 36 days x 24 hours/day)

OU PLOTFILE PERIOD 2791 2791\_PM2008.PLT

OU FINISHED

\*\*\*\*\*

## **EXHIBIT C**

Sample AERMOD Output File

**2008 AERMOD OUTPUT:**

\* AERMOD ( 11103): 2791 2008BL

01/31/14

\* MODELING OPTIONS USED:

15:12:21

\* RegDFAULT CONC

ELEV

\* PLOT FILE OF PERIOD VALUES FOR SOURCE GROUP: 2791

\* FOR A TOTAL OF 4900 RECEPTORS.

\* FORMAT: (3(1X,F13.5),3(1X,F8.2),2X,A6,2X,A8,2X,I8.8,2X,A8)

\* X Y AVERAGE CONC ZELEV ZHILL ZFLAG AVE GRP NUM HRS NET ID

\*

X	Y	AVERAGE CONC	ZELEV	ZHILL	ZFLAG	AVE	GRP	NUM	HRS	NET ID
368689.36539	3785748.28159	0.02643	223.40	223.40	0.00	PERIOD	2791	00000576	2791	
368789.36539	3785748.28159	0.02625	223.40	223.40	0.00	PERIOD	2791	00000576	2791	
368889.36539	3785748.28159	0.02604	223.60	223.60	0.00	PERIOD	2791	00000576	2791	
368989.36539	3785748.28159	0.02579	224.20	224.20	0.00	PERIOD	2791	00000576	2791	
369089.36539	3785748.28159	0.02547	225.30	225.30	0.00	PERIOD	2791	00000576	2791	
369189.36539	3785748.28159	0.02512	226.50	226.50	0.00	PERIOD	2791	00000576	2791	
369289.36539	3785748.28159	0.02482	227.00	227.00	0.00	PERIOD	2791	00000576	2791	
369389.36539	3785748.28159	0.02473	227.50	227.50	0.00	PERIOD	2791	00000576	2791	
369489.36539	3785748.28159	0.02478	228.50	228.50	0.00	PERIOD	2791	00000576	2791	
369589.36539	3785748.28159	0.02471	228.50	228.50	0.00	PERIOD	2791	00000576	2791	
369689.36539	3785748.28159	0.02465	228.50	228.50	0.00	PERIOD	2791	00000576	2791	
369789.36539	3785748.28159	0.02463	228.60	228.60	0.00	PERIOD	2791	00000576	2791	
369889.36539	3785748.28159	0.02460	228.60	228.60	0.00	PERIOD	2791	00000576	2791	
369989.36539	3785748.28159	0.02463	228.60	228.60	0.00	PERIOD	2791	00000576	2791	
370089.36539	3785748.28159	0.02446	228.60	228.60	0.00	PERIOD	2791	00000576	2791	
370189.36539	3785748.28159	0.02304	228.60	228.60	0.00	PERIOD	2791	00000576	2791	
370289.36539	3785748.28159	0.02080	228.10	228.10	0.00	PERIOD	2791	00000576	2791	
370389.36539	3785748.28159	0.01966	227.60	227.60	0.00	PERIOD	2791	00000576	2791	
370489.36539	3785748.28159	0.01966	227.70	227.70	0.00	PERIOD	2791	00000576	2791	
370589.36539	3785748.28159	0.02030	227.70	227.70	0.00	PERIOD	2791	00000576	2791	
370689.36539	3785748.28159	0.02035	227.70	227.70	0.00	PERIOD	2791	00000576	2791	
370789.36539	3785748.28159	0.02084	227.70	227.70	0.00	PERIOD	2791	00000576	2791	
370889.36539	3785748.28159	0.02160	227.40	227.40	0.00	PERIOD	2791	00000576	2791	
370989.36539	3785748.28159	0.02152	226.70	226.70	0.00	PERIOD	2791	00000576	2791	
371089.36539	3785748.28159	0.02087	226.80	226.80	0.00	PERIOD	2791	00000576	2791	
371189.36539	3785748.28159	0.01984	226.80	226.80	0.00	PERIOD	2791	00000576	2791	
371289.36539	3785748.28159	0.01877	227.20	227.20	0.00	PERIOD	2791	00000576	2791	
371389.36539	3785748.28159	0.01792	227.80	227.80	0.00	PERIOD	2791	00000576	2791	
371489.36539	3785748.28159	0.01734	227.80	227.80	0.00	PERIOD	2791	00000576	2791	
371589.36539	3785748.28159	0.01696	227.80	227.80	0.00	PERIOD	2791	00000576	2791	
371689.36539	3785748.28159	0.01659	227.80	227.80	0.00	PERIOD	2791	00000576	2791	
371789.36539	3785748.28159	0.01605	227.00	227.00	0.00	PERIOD	2791	00000576	2791	
371889.36539	3785748.28159	0.01551	227.30	227.30	0.00	PERIOD	2791	00000576	2791	
371989.36539	3785748.28159	0.01505	228.50	228.50	0.00	PERIOD	2791	00000576	2791	
372089.36539	3785748.28159	0.01448	228.90	228.90	0.00	PERIOD	2791	00000576	2791	
372189.36539	3785748.28159	0.01388	228.90	228.90	0.00	PERIOD	2791	00000576	2791	
372289.36539	3785748.28159	0.01332	228.90	228.90	0.00	PERIOD	2791	00000576	2791	
372389.36539	3785748.28159	0.01287	228.90	228.90	0.00	PERIOD	2791	00000576	2791	


## **EXHIBIT D**

Final Defense Presentation Slides

"In an undeveloped country don't drink the water.  
In a developed country don't breathe the air."


Jonathan Rabar

**Regional Scale Dispersion Modeling & Analysis of Directly Emitted Fine Particulate Matter from Mobile Source Pollutants**  
Using AERMOD



by **SETH CONTRERAS**


UNIVERSITY OF CALIFORNIA, IRVINE  
INSTITUTE OF TRANSPORTATION STUDIES  
JANUARY 2013



**WHERE DO PEOPLE LIVE?**  
&  
**WHY?**



**RESEARCH NEEDS & CHALLENGES**




- The "Missing Link"
- State-of-the-Practice
- Dispersion Models

**OBJECTIVES**

1. Quantity PM2.5 population exposure at a regional level;
2. Integrate our framework into the Regional Transportation Planning Process;
3. Investigate local mitigation strategies; &




**AIR DISPERSION MODELING**

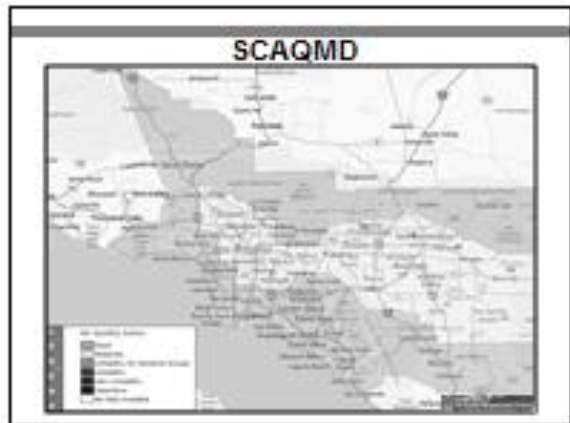
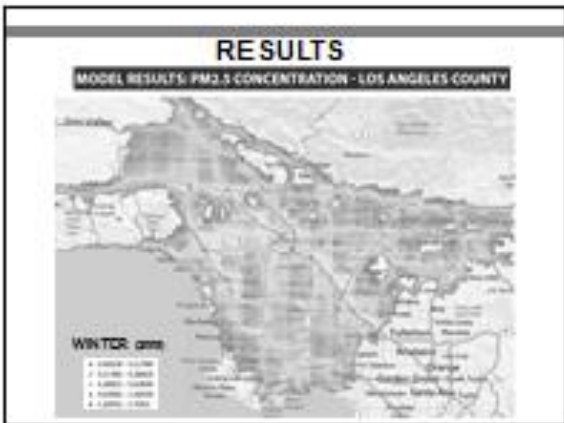
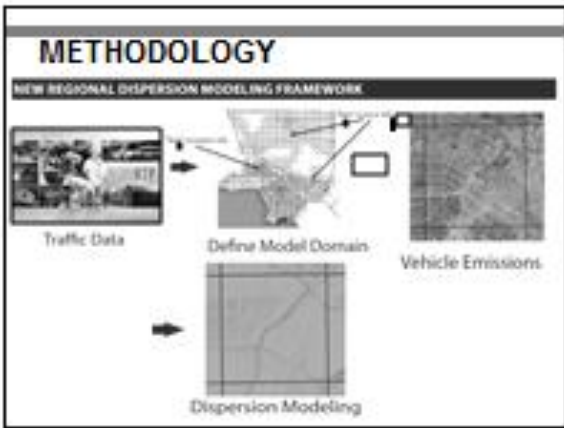
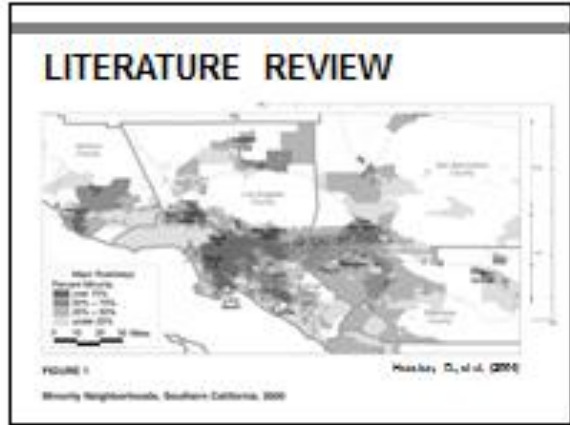
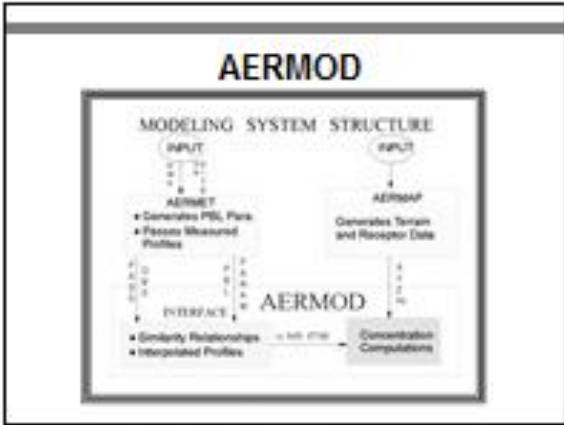


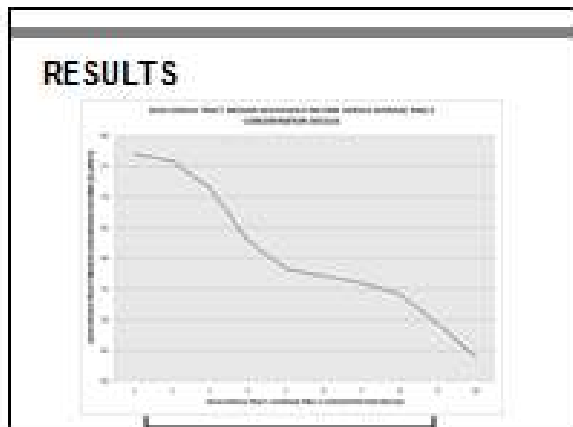
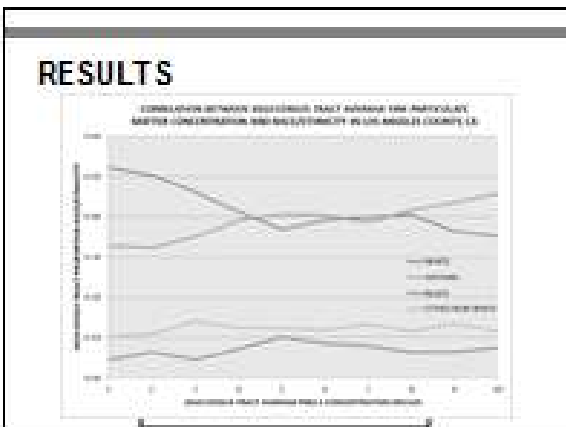
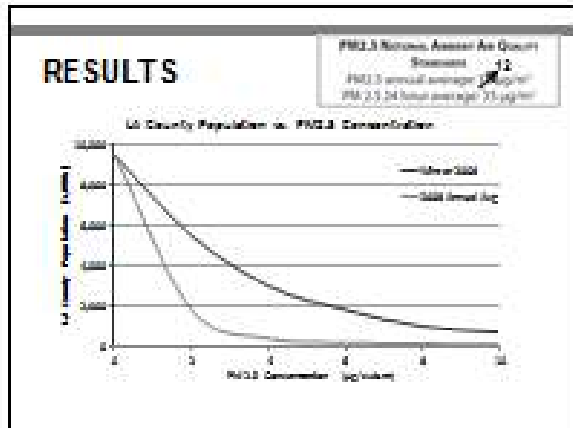
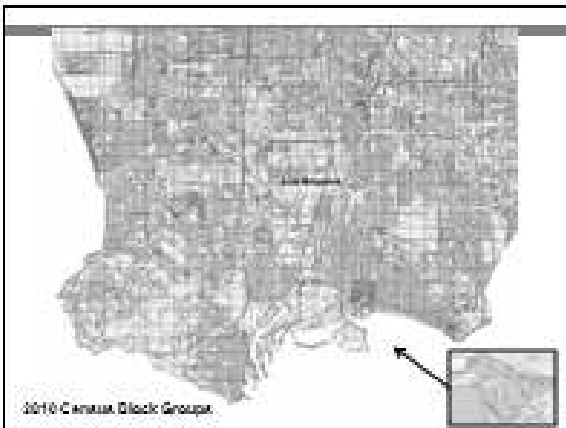
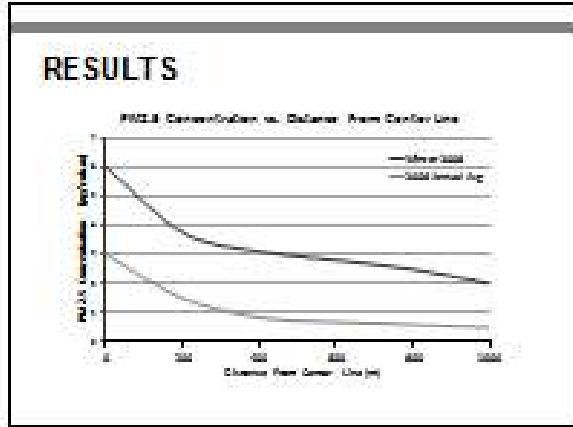
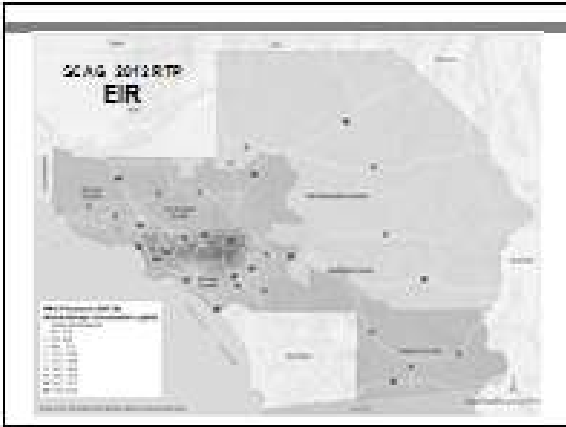
**AERMOD**

- AERMOD
- CALPUFF
- CALINE









## CONCLUSIONS

- I. Raster
- II. Practical Application
- III. Public Health

*"The complexity of fundamental human behavior clearly does not facilitate the development of theoretical constructs nor does it typically lead to consistency in empirical studies, with the result being a range of methodological approaches associated with a variety of partially developed theories."* -W. S. J. (2007)

*"All models are wrong but some are useful"* -G. E. H. (2007)

## FUTURE WORK

- I. SCAG Region
- II. 2015, AMPM, AUTO/TRUCK
- III. Additional PM<sub>2.5</sub> Sources
- IV. Model Validation
- V. Extend Buffer
- VI. Transportation Planning Process
- VII. Air monitoring locations



## ACKNOWLEDGEMENTS



## YOUR THESIS COMMITTEE

*The committee is made up of four people who will read your thesis and give you feedback on it.*



## **GLOSSARY**

**AERMOD** - American Meteorological Society & Environmental Protection Agency Regulatory Model

**ArcGIS** – Geographic Information System program developed by ESRI

**CALINE** - California Line Source Dispersion Model

**CALPUFF** - California Puff Model

**CALVAD** – California Air Resources Board Vehicle Activity Database

**CARB** – California Air Resources Board

**DEM** – Digital Elevation Model

**EJ** – Environmental Justice

**EMFAC2011** – California Air Resources Board 2011 Emission Factor Model

**EPA** – United States Environmental Protection Agency

**HPMS** – Highway Performance Monitoring System

**MOVES** – U.S. Environmental Protection Agency Motor Vehicle Emission Simulator

**MPO** – Metropolitan Planning Organization

**NAAQS** – National Ambient Air Quality Standards

**NOAA** – National Oceanic & Atmospheric Administration

**PeMS** – CALTRANS Performance Measurement System

**PM<sub>2.5</sub>** – Defined as Fine Particulate Matter less than 2.5 µm in diameter

**RTP** – Regional Transportation Plan

**SCAG** – Southern California Association of Governments

**SCAQMD** – South Coast Air Quality Management District

**USGS** – United States Geological Survey

**WIM** – California Weigh-In-Motion Data

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