Evaluation of Air Quality Models with Near-Road Monitoring Data: Technical Report

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16. Abstract

Air dispersion models (air quality models) are used in evaluation of transportation projects to ensure their compliance with federal regulations including the National Environmental Policy Act and transportation conformity quantitative hot-spot analysis requirements. The literature indicates a wide range of variabilities involved in the modeling process for the particulate matter (PM) hot-spot analysis. Sparse real-world data have limited the ability to evaluate the variabilities involved in the PM hot-spot analysis process. Availability of near-road monitoring data has provided a new source of data to address this gap.

The objective of this study was to perform a modeling evaluation of the regulatory hot spot analysis and conduct a data research of the near-road monitoring observations to evaluate the potential association between the near-road $PM_{2.5}$ concentrations and the key parameters. The study was performed for two case study sites in Texas, namely Houston and Fort Worth. The modeling process evaluation consisted of investigating the model behavior and variabilities involved in the $PM_{2.5}$ hot-spot process through a series of sensitivity analyses.

The results of the modeling variability analysis highlighted significant variations of the estimated near-road concentrations as a result of typical modeling options and data sources used in conducting a $PM_{2.5}$ hot-spot analysis. The range of variability was highest for the model options, followed by model choice, and data source. In addition to sensitivity analysis, the data exploration indicated that the background concentration is the dominating factor in estimating the near-road $PM_{2.5}$ concentrations. Traffic volume and speed were found to have a relatively weak association with the near-road concentrations of $PM_{2.5}$ for the two case study sites. Wind direction and speed were found to have a stronger association with the concentrations; however, the lack of hourly near-road concentration data at the time of this study prevented a detailed analysis of this potential correlation at an hourly resolution.

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EVALUATION OF AIR QUALITY MODELS WITH NEAR-ROAD MONITORING DATA: TECHNICAL REPORT

by

Reza Farzaneh
Associate Research Engineer

Suriya Vallamsundar
Assistant Research Scientist

Rohit Jaikumar
Associate Transportation Researcher

Madhu Venugopal
Associate Research Scientist

Mohammad Askariyeh
Graduate Assistant in Research

Jeremy Johnson
Research Specialist II

Texas A&M Transportation Institute

and

Wen-Whai Li
Professor

Mayra C. Chavez
Graduate Research Associate

Ivan M. Ramirez
Graduate Research Assistant

The University of Texas at El Paso

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College Station, Texas 77843-3135

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INTRODUCTION

BACKGROUND AND RESEARCH GOAL

Federal transportation air quality regulations have increased the emphasis on near-road exposure to mobile source pollutants in recent years. Air dispersion models are used for assessing near-field impacts of mobile source emissions. These models are very important in ensuring that federally funded transportation projects can move forward in air quality non-attainment[1] and attainment-maintenance[2] areas. The adoption of quantitative project-level air quality analyses for transportation projects in the past decade has greatly increased the application of air dispersion models in transportation project assessment and documentation. Air dispersion modeling is now an important part of Texas Department of Transportation (TxDOT) procedures to ensure compliance with federal regulations including National Environmental Policy Act (NEPA) and transportation conformity requirements for hot-spot analysis.

Among the air dispersion models, the California LINE Source Dispersion Model (CALINE3) series of models and the American Meteorological Society (AMS)/Environmental Protection Agency (EPA) Regulatory MODel (AERMOD) are predominantly used for regulatory applications involving transportation sources. Since the mid-1990s, the CALINE3 series of models (CALINE3) and its variates CAL3QHC, CAL3QHCR) have been used extensively by the state departments of transportation (DOTs). These models were developed specifically for modeling roadway applications and have been validated against observations adjacent to roadways [1], [2]. AERMOD, initially developed for industrial sources, is currently recommended by EPA for a wide range of regulatory applications including highways in all types of terrain [3].

On July 14, 2015, EPA proposed to update its Guideline on Air Quality Models [3], which focused on replacing the CALINE3 series of models with AERMOD for transportation source applications. The revision impacts project-level transportation conformity quantitative hot-spot analysis conducted using either CAL3QHCR or AERMOD for particulate matter (PM) and project-level carbon monoxide (CO) hot-spot analysis performed using CAL3QHC. This shift from CALINE3 series to AERMOD has implications for TxDOT and Texas metropolitan planning organizations (MPOs) in terms of modeling skills availability, increased cost and effort, extended timeline for analysis, quality control, and interpretation of results.

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[1] A non-attainment area is an area found to have air quality worse than the levels specified in the National Ambient Air Quality Standards (NAAQS) as defined in the Clean Air Act Amendments of 1970.

[2] Attainment maintenance areas are geographic areas that were previously classified as nonattainment but are currently consistently meeting the NAAQS. Portion of the city of El Paso is currently designated as attainment maintenance for CO.

In response to EPA’s proposed revisions to the Guideline on Air Quality Models, the Federal Highway Administration (FHWA) and state DOTs stated concerns on the limited validation efforts for the model replacement rule related to transportation applications. One main reason cited for limited comparative studies is the lack of real-world measurements. Obtaining these measurements through air quality monitors can be expensive and requires detailed quality assurance processes. Moreover, limited model comparison studies in literature have mixed results, which points to not having a consistent trend or pattern between the model concentrations predicted by the CALINE3 model series and those by the AERMOD model, when comparisons were made to real-world field observations. On December 20, 2016, EPA passed the final rule revising the Guideline on Air Quality Models. For transportation applications, the final rule replaces CALINE3 models with AERMOD for refined mobile source applications including PM pollution ($PM_{2.5}$, PM_{10}) hot-spot analyses. EPA retained the use of CAL3QHC for CO hot-spot analyses, typically performed as a screening analysis. The transition period for the use of AERMOD for the refined modeling applications was extended to 3 years. The effective date for the final regulation on Guidelines on Air Quality Models is May 22, 2017 [4].

Another development in the federal air quality regulations landscape is the establishment of near-road monitoring requirements throughout the United States for monitoring near-road pollutant concentration levels. The past roadside monitoring and modeling studies [5], [6] have exhibited that vehicular pollutants decay to background levels within a few hundred meters from the edge of the roadway. Near-road exposures have recently been documented to cause an array of health effects, such as asthma, reduced lung function, adverse birth outcomes, and pulmonary mortality. In February 2010, EPA established a new primary (i.e., health-based) 1-hour nitrogen dioxide (NO_2) NAAQS of 100 ppb and retained the current primary annual NAAQS of 53 ppb [7].

EPA has also announced new minimum monitoring requirements for the NO_2 monitoring network in support of the new 1-hour NO_2 NAAQS. The primary objective of the requirement is to establish a base of monitors to characterize NO_2 concentrations in near-road environments across the country so that ambient concentrations, relative to the NAAQS can be assessed. As part of the requirement, state and local air monitoring agencies are required to install near-road monitors at locations where peak hourly NO_2 concentrations are expected to occur within the near-road environment in larger urban areas. Factors such as traffic volumes, fleet mix, roadway design, traffic congestion patterns, local terrain or topography, and meteorology are taken into consideration in determining where a required near-road NO_2 monitor should be placed. A secondary objective of the requirement is to establish a near-road monitoring network to support multipollutant monitoring efforts ($PM_{2.5}$, CO). EPA also encourages states to measure other pollutants, meteorology, and traffic volume. Currently, there are six near-road monitoring stations in Texas, all located in major urban areas. These monitoring sites record data on ambient air concentration of select pollutants and meteorological conditions; two of the six sites measure multiple pollutants.

The new monitoring requirements have resulted in the availability of high-quality and continuous ambient monitoring data from several near-road sites nationwide. These data can potentially be used for a number of applications, including policy activities related to NAAQS, understanding the impact of roadways on air quality especially for near-road exposure along high traffic roads, and refining and verifying methods and models used to estimate near-road concentrations and exposures.

This research project, *Evaluation of Air Quality Models with Near-Road Monitoring Data,* was conducted by researchers at the Texas A&M Transportation Institute (TTI) and the University of Texas at El Paso for TxDOT to provide insight into the regulatory-oriented hot-spot analysis and the impact of traffic activities on near-road PM concentration. The project goal is twofold:

- Provide TxDOT with an evaluation of the variabilities of the modeling process of the regulatory PM hot-spot analysis for key parameters.
- Conduct a data exploration of the near-road monitoring observations to evaluate the potential association between the near-road $PM_{2.5}$ concentrations and the key factors.

PROJECT SCOPE AND CONTEXT

This project focused on the near-road concentrations of $PM_{2.5}$, especially the evaluation of the potential association between $PM_{2.5}$ and key traffic, meteorology, and background concentration parameters and the variability of the hot-spot modeling process as a result of different input parameters including the model choice (AERMOD versus CAL3QHCR). It is envisioned that the work of this project would benefit TxDOT and its partner agencies by providing the necessary information to:

- Prioritize the resources needed for project-level and hot-spot analysis.
- Evaluate and interpret the modeling results from a hot-spot analysis, especially for the range of potential variabilities.
- Use near-road monitoring data to understand the extent of the potential impact of traffic on $PM_{2.5}$ in the near-road environment.

Researchers performed a sensitivity analysis for the regulatory-oriented $PM_{2.5}$ hot-spot analysis. For the modeling part, the team focused on CAL3QHCR, which is used extensively by state DOTs and AERMOD, which is EPA’s preferred dispersion model for near-road applications and is scheduled to become the only regulatory-approved dispersion model for “refined modeling in transportation conformity determinations” in May 2020.

Currently, ambient pollutant concentrations collected at six near-road monitoring sites in Texas’ major urban areas. This monitoring is being undertaken by Texas Commission on Environmental Quality (TCEQ) in response to the federal requirements in support of the required ambient air monitors in the near-road environment. Researchers performed data research of the near-road monitoring observations to evaluate the potential association between the near-road PM concentrations and the key traffic, meteorology, and background concentration parameters.

Researchers used a case study approach that consisted of the following major steps:

- Assess the state-of-practice and define and establish case studies. A case study is considered as a specific extent of the highway relative to a selected near-road monitoring station, over a particular time period (e.g., hours or days).
- Perform modeling for the case studies. The modeling process involved a series of tasks, including characterizing traffic activity, mobile source emissions modeling, and dispersion modeling.
- Perform sensitivity analysis. The team conducted a sensitivity analysis to evaluate the variabilities/uncertainties involved in the modeling components of the hot-spot process. This analysis translated to assessing the variabilities of the modeling results as a result of changes to key input parameters from each of the modeling components of traffic, emissions, air dispersion, meteorology, and background concentration.
- Perform data research. Researchers obtained and complied one year of data for 24-hour averaged near-road $PM_{2.5}$ concentrations from monitoring stations and their corresponding traffic, meteorology, and background concentration data. The used statistical tools and data exploration methods in an interactive visual software environment, Power BI, to characterize the potential correlation between these key factors and the near-road concentrations of $PM_{2.5}$.
- Analyze case study results. The results obtained from multiple model runs of the emissions and air dispersion models shall be compiled and the variabilities involved in the $PM_{2.5}$ concentrations obtained from the models shall be assessed and qualitatively evaluated with the observations obtained from near-road monitoring stations. The intent of this step is to bridge the two elements (i.e., modeling and near-road observations) to understand the potential impacts of traffic and other key factors on the near-road $PM_{2.5}$ concentrations in a broader decision-making context.

RESEARCH PLAN

Figure 1 shows the research plan and the task flow. Task 1 is a state-of-practice assessment, which is followed by the development of a case study protocol in Task 2. Modeling case studies to characterize the variability of $PM_{2.5}$ hot-spot modeling results were conducted in Tasks 3. The data research on the near-road $PM_{2.5}$ monitoring data was performed in Task 4. The research methodologies, results, and recommendations are compiled and presented as a final project report and a project summary report.

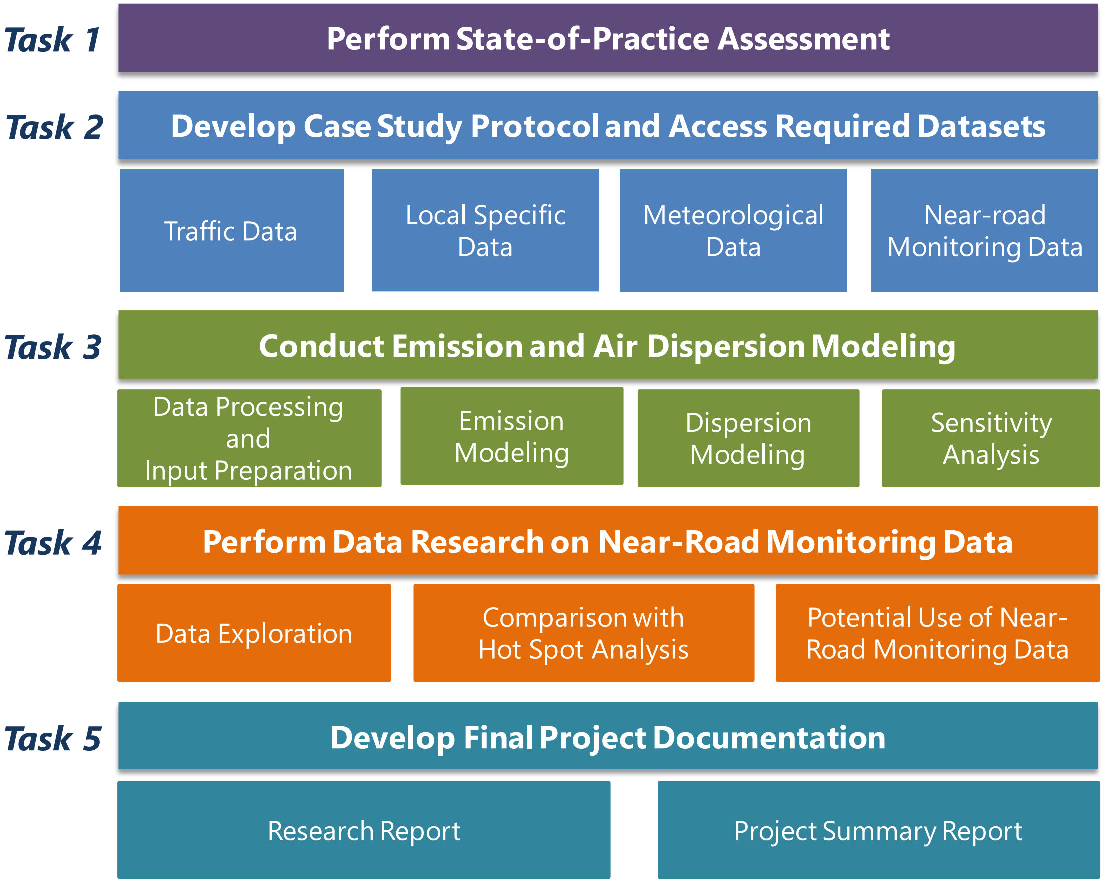

Figure 1. Project Tasks.

ORGANIZATION OF REPORT

The project tasks are discussed in the following seven chapters. Chapter 2 is a comprehensive assessment of the state-of-the-practice, followed by Chapter 3, which outlines the study design and case study protocol development. Chapter 4 discusses the findings from the near-road monitoring data exploration effort, and Chapter 5 covers the modeling approach and data used for the sensitivity analysis of the modeling process. Chapter 6 presents the results of the modeling sensitivity analysis, and Chapter 7 discusses a qualitative evaluation of the modeling results for the data from near-road monitoring sites. Chapter 8 discusses the findings and conclusions for the work performed in this project and areas for future research.

CHAPTER 2:
LITERATURE REVIEW AND STATE-OF-PRACTICE

INTRODUCTION

An extensive literature review and state-of-practice assessment was conducted as part of this project, covering the following topics:

- Air dispersion models, regulatory requirements, and a literature review of studies focused on model validation, model performance or sensitivity to key parameters and a model comparative assessment between AERMOD and CALINE3 model series.
- Key modeling components involved in air dispersion modeling, including a review of traffic data sources, model input data sources and process of emission, and air dispersion modeling, and background concentration.
- Near-road pollutant dispersion patterns, history, and regulations behind establishing near-road monitoring stations followed by recent studies focused on the pollutant data collected from the near-road monitoring stations.

This chapter summarizes key findings from the literature review and state-of-practice.

AIR QUALITY MODELS AND REGULATORY CONTEXT

This section overviews air dispersion modeling, followed by their regulatory requirements. As the focus of this research project is limited to air dispersion models that are used for project-level transportation conformity and NEPA analysis of transportation projects, detailed model descriptions are provided only for the AERMOD and CALINE3 series of models. The section also describes the broad differences between AERMOD and CALINE3 (specifically CAL3QHCR) and the section concludes with a review of model evaluation studies in the literature.

Air Dispersion Models

Air dispersion models are widely used to estimate how airborne pollutants, emitted from stationary or mobile sources, disperse in the atmosphere and how their concentrations vary over time and space. An air dispersion model is a mathematical simulation that describes the transportation and dispersion of air pollutants in the atmosphere. These concentration estimates are often used as proxies for assessing localized air quality and human health impacts. Pollutant dispersion depends on several factors that include the fate and transport[3] properties of pollutants, meteorological and land use conditions, and strength of the emission source. The air dispersion model produces pollutant concentration estimates for specific averaging time periods, and for

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[3] Fate and transport properties relate to the physical and chemical processes that impact the dispersion of pollutants in the atmosphere and how these pollutants may be altered while they are transported.

any number of pre-defined receptor locations (usually placed at an average human breathing height).

There are four main types of models for modeling pollutant concentration:

- Gaussian plume dispersion model.
- Atmospheric box model.
- Source apportionment model.
- Computational fluid dynamics model.

Among these models, Gaussian models are more widely used because of their simplicity and ease-of-use. These models are developed based on the assumption that dispersion is a mechanical process that tends to disperse in certain directions and at certain rates during dispersion. Gaussian models assume that emissions and meteorological conditions are in a steady state over the model time step, which is typically based on an hourly time step. This approach results in a resolved plume with the emissions distributed throughout the plume according to a Gaussian distribution. Though steady-state Gaussian models conserve the mass of the primary pollutant throughout the plume, they can still take into account a limited consideration of first-order removal processes (e.g., wet and dry deposition) and limited chemical conversion (e.g., OH oxidation) [3]. Due to the steady-state assumption, Gaussian plume models are generally considered applicable to distances less than 50 km (31.07 mi), beyond which modeled predictions of plume impact are likely conservative [8]. The locations of these impacts are expected to be unreliable due to changes in meteorology that are likely to occur during the travel time. These simplifying assumptions of Gaussian based models, while limiting their application for more complex and large-scale applications, have made them the most popular tools for near-field analysis such as project-level, localized hot-spot analysis [8].

Regulatory Context of Dispersion Models

Air dispersion models have regulatory applications in ensuring compliance of federally supported projects with NAAQS, as set forth by EPA. These models also have a significant role in determining the effect of projects on the human environment within the context of NEPA. Other regulatory applications include new source review and prevention of significant deterioration regulations. These models are addressed in Appendix A of the EPA's *Guideline on Air Quality Models* (also published as Appendix W of 40 CFR Part 51 [3]). In the latest revisions to the Guidelines on Air Quality Models (Appendix W), EPA has replaced CALINE3 model series (CALINE3, CAL3QHC, and CAL3QHCR) with AERMOD as the preferred model for refined modeling for mobile source applications. Previously, EPA's transportation conformity guidance for PM hot-spot analyses [9] listed both CAL3QHCR and AERMOD as approved dispersion models for highway and intersection projects. However, the new revisions [3] to Guidelines on Air Quality Models replaced CAL3QHCR with AERMOD for PM hot-spot analyses. For assessing CO impacts for NEPA analysis, screening techniques using CAL3QHC are recommended by EPA given the relatively low CO background concentrations (BC) nationwide.

CALINE3 Series and AERMOD Model Description and Evolution

As the focus of this research project is limited to CALINE3 series and AERMOD, detailed descriptions are only provided for these models in this section.

CALINE Series of Models

The California LINE Source Dispersion Model is a near-roadway Gaussian air-dispersion model developed by the California DOT and designed to predict air pollutant concentrations near-roadways for emissions from vehicles operating under free-flow conditions. Different versions of the CALINE model were developed over time, while the initial version of CALINE3 was authorized by EPA in 1980 to be used for nonreactive pollutants near the highways. Several enhancements were made on CALINE3 model, resulting in CAL3QHC, CAL3QHCR, and CALINE4 models to be developed. The CALINE3 was incorporated into the more refined CAL3QHC and CAL3QHCR models, and they are collectively referred to as CALINE3 series of models. The CALINE3 series has been recognized as appropriate for regulatory use in specific roadway applications for CO and PM analyses. CALINE4 model was approved by EPA for use only in the state of California.

CALINE3 uses a series of finite line elements (sources) to represent highway links and sums up the incremental concentration from each element. However, it does not permit the direct estimation of the contribution of emissions from idling vehicles [10]. CAL3QHC enhances CALINE3 by incorporating methods for estimating queue lengths and the contribution of emissions from idling vehicles. The model permits the estimation of total air pollution concentrations from both moving and idling vehicles. CAL3QHCR, a refined version of CAL3QHC, uses the same basic algorithm as the CAL3QHC model. Enhancements include incorporation of up to a year of detailed meteorological data, along with vehicular emissions, traffic volume, and signalization data in one run, whereas CAL3QHC was designed to process one hour of meteorological, emissions, traffic, and signalization data in a single run. CAL3QHCR incorporates various concentration-averaging algorithms (1-hour, 8-hour, 24-hour, and annual concentrations), compared with the maximum hourly average algorithm in CAL3QHC. CAL3QHCR has some built-in assumptions, mostly related to the model application. Wind speed should be at least one meter per second (m/s), and speeds below 1 m/s have not been validated for the model. The model is also highly sensitive to very low mixing heights [9].

AERMOD

The AMS/EPA Regulatory MODel was introduced as EPA’s preferred dispersion model in 2005 after a 10-year cooperation between EPA and AMS. AERMOD represents an advance in the formulation of a steady-state, Gaussian plume model. AERMOD was developed as a replacement for the EPA's Industrial Source Complex (ISC) Model, ISC3, by incorporating parameterization of the planetary boundary layer (PBL) and a few other minor modifications. PBL is the turbulent air layer next to the earth's surface that is affected by the surface heating and friction from its contact with the planetary surface. Vertical mixing and turbulence are strong in this layer. Above the PBL is the free atmosphere, which is nonturbulent or only intermittently turbulent. Height of the PBL typically ranges from a few hundred meters at night to 1 to 2 km during the day. There are two types of PBL: the convective boundary layer (CBL) and the stable boundary layer (SBL). CBL is driven by surface heating during the daytime and has moderate to strong vertical mixing, whereas SBL is driven by surface cooling during nighttime and has little or no vertical mixing. AERMOD uses Gaussian distribution in both the horizontal and the vertical directions in the SBL, similar to CAL3QHC. For the CBL, AERMOD uses Gaussian distribution in the horizontal and bi-Gaussian distribution in the vertical direction, and the concentration is calculated as a weighted average of two distributions [11]. Other minor modifications to ISC3 include the modeling of plume interaction with terrain, surface releases, building downwash, and urban dispersion [12].

AERMOD uses a more advanced method to characterize stability compared to CALINE model series. AERMOD uses a continuous function called Monin-Obukhov length to characterize atmospheric stability. AERMOD can model several sources and receptors, handling multiple years of meteorological data simultaneously, and offers options for varying emission rates by different time scales, such as by season, month, and hour-of-day. AERMOD has the option of modeling roadway links in the form of area or volume sources. The three-dimensional volume source representation of a line source would well characterize the initial vertical plume dispersion (e.g., rail lines, conveyor belts). Whereas, the two-dimensional area source representation of a line source is suitable for characterizing ground-level sources with no plume rise (e.g., viaduct, storage piles) [13]. There are two regulatory components for AERMOD: the meteorological preprocessor (AERMET) and the terrain data preprocessor (AERMAP). Other non-regulatory components of AERMOD include AERSCREEN, which is the screening version of AERMOD; AERSURFACE, surface characteristics preprocessor; and BPIPRIME, a multibuilding dimensions program for PRIME applications.

Review of Studies on Model Evaluation

Although AERMOD and CAL3QHCR are Gaussian-based models, they fundamentally differ in the way atmospheric stability is represented. Atmospheric stability is a measure of the amount of vertical turbulence in the atmosphere, which translates into its ability to mix pollutants. AERMOD incorporates the concept of PBL based on more recent atmospheric science, compared to CALINE3 where stability is represented by discrete stability classes—from A (unstable) to F (stable) [14]. CALINE3 models were developed specifically for modeling roadway applications and have been validated against observations adjacent to roadways [1],

[10]. Although AERMOD was initially developed for point sources, AERMOD has been approved for a wide range of regulatory applications including roadways. Table 1 lists major differences between AERMOD and CALINE series models (CAL3QHC/CAL3QHCR). Review of studies in literature on model evaluation is broadly discussed under three categories, namely model validation, model performance or sensitivity to key parameters, and model comparative assessment between CALINE3 model series and AERMOD. This section summarizes studies that focused on different aspects of dispersion models including validation and performance evaluation.

Table 1. Differences between CALINE Series Models and AERMOD.

Description	CALINE Series Models (CAL3QHC/CAL3QHCR)	AERMOD
Model Formulation	Gaussian based model designed to model vehicular queues at signalized intersections	Gaussian based model based on recent atmospheric science with PBL parameterization
	Atmospheric stability is represented by discrete stability classes A (unstable) to F (stable) developed by Pasquill	AERMOD uses a more advanced method to characterize stability; it uses a continuous function called Monin-Obukhov length to characterize atmospheric stability.
Modeling Options	Represents all sources as line sources	Flexible in representing different types of sources as point, line, area, and volume sources
	CAL3QHC: one hour of meteorological data CAL3QHCR: A single year of meteorological data can be incorporated at a time. For refined PM analyses that require multiple model runs to cover a period of five years, this translates to processing a total of 20 model runs.	Multiple years of meteorological data can be processed simultaneously. For refined PM analyses, this translates to a single model run for five years of meteorological data.
	CAL3QHC: Concentration estimates produced for a maximum hourly averaging period CAL3QHCR: 1-hour, 8-hour, 24-hour, and annual averaging period	Optional Output (maximum, average) in any desired time frame (1-hour, 8-hour, 24-hour, annual)

Description	CALINE Series Models (CAL3QHC/CAL3QHCR)	AERMOD
Modeling Components	Meteorological preprocessor for CAL3QHC/CAL3QHCR is Meteorological Processor for Regulatory Models (MPRM)	Meteorological preprocessors AERMET, AERSURFACE and AERMINUTE. Terrain preprocessor AERMAP. Multibuilding dimension program BPIPRIME.
Model Inputs		
Traffic Volume	Y	Y
Emission Factors	Y	Y
Signalization Data	Y	
Wind Speed and Direction	Y	Y
Temperature, Surface Roughness	Y	Y
Stability Class	Y	N
Albedo, Bowen ratio, Sky Cover, Precipitation, Relative Humidity, Sea Level and Station Pressure	N	Y

Model Validation

Since the mid-1990s, the CALINE model series have been used extensively by several state DOTs. These models were developed specifically for modeling roadway applications and have been validated against observations adjacent to roadways [1], [10]. The model verification was conducted using the data from the following five separate field studies:

- Caltrans Intersection study (CO measurement at an intersection in Sacramento in 1980) [15].
- Caltrans Highway 99 Tracer Experiment (an extensive tracer study along a section of Highway 99 in Sacramento, in 1981–1982).
- General Motors Sulfate Dispersion Experiment (A tracer study to simulate traffic flow of 5,462 vehicles per hour along a four lane freeway in Michigan, in 1975) [16].
- Illinois EPA Freeway/Intersection Study (measurements of CO concentrations at two different urban sites located outside of Chicago in 1978) [17].
- EPA NO_2/O_3 Sampler Siting Study (continuous monitoring of NO, NO_2, and O_3 along a section of the San Diego Freeway in Los Angeles, in 1978) [18].

Several of these studies were based on tracer gas releases. The verification methods included six statistical measures of (a) the ratio of the largest 5 percent of the measured concentrations to the largest 5 percent of the predicted concentrations, (b) the difference between the predicted and measured proportion of exceedances of a concentration threshold or air quality standard, (c)

Pearson's correlation coefficient for the paired measured and predicted concentrations, (d) the temporal component of Pearson's correlation coefficient, (e) the spatial component of Pearson's correlation coefficient, and (f) the root-mean-square of the difference between the paired measured and predicted concentrations.

The AERMOD modeling system has been extensively evaluated across a wide range of scenarios based on numerous field studies, including tall stacks in flat and complex terrain settings, sources subject to building downwash influences, and low-level non-buoyant sources [19]. These studies involve four short-term tracer studies and six conventional long-term sulfur-dioxide (SO_2) monitoring data bases in various settings. The purpose of these studies was to be sure that AERMOD has been tested in the various types of environments for which it will be used. These field studies include: The Prairie Grass Study [20], The Kincaid SF6 Study [21], The Indianapolis Study [22], The Kincaid SO_2 Study [23], The Lovett Power Plant Study [24], The Baldwin Power Plant Study [25], The Clifty Creek Power Plant Study [26], The Martins Creek Steam Electric Station Study [27], The Westvaco Corporation Study [28], and The Tracy Power Plant Study [29]. The evaluation of AERMOD's performance with real-world data is based on the robust highest concentration (RHC)[4] statistics. It was concluded that AERMOD has shown consistently good performance, based on the RHC metric, consistently within the range of 10 to 40 percent [3].

Model Performance or Sensitivity to Key Parameters

In terms of model sensitivity to key input parameters, Zhou and Sperling [28] showed that CAL3QHC under predicted pollutant concentrations of CO and NOx in densely populated cities with mixed traffic and high-rise buildings for a case study in China. The modeled estimates that CO concentrations for the uncovered (open) road segment was about 25 percent below measured values. For the covered arterial (overhead expressway), the model values only accounted for 25 percent of the actual measured concentrations because the overhead expressway formed a closed space, altering in unpredicted ways the dispersion of emissions. Gokhale and Raokhande [29] found PM concentrations from CAL3QHC to match the measured concentrations reasonably well in a case study in India. Abdul-Wahab [30] found CAL3QHC to under predict CO concentrations by around 15 percent to the measured values at an urban intersection in Muscat, Oman. Validation of CAL3QHC in this study was done by reference to real measurements at eight receptors sites. Possible reasons for the under prediction could be explained by certain default assumptions (e.g., default vehicle fleet composition data that assume that the vehicle fleet in Oman is similar to that in the United States) used to run the CAL3QHC model. Jacomino et al. [31] found CAL3QHC to under predict PM concentration compared to monitored concentration in a case study in Brazil, which they attributed to the presence of street

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[4] RHC is a statistical estimator for the highest concentration. It is determined from a tail exponential fit to the high end of the frequency distribution of observed and predicted values. The number of points used for the fit is arbitrary, but usually ranges between 10 and 25.

canyons and contributions from other non-road sources. Fractional bias of −0.1 for PM_{10} and −0.3 for $PM_{2.5}$ was obtained by comparing the modeled with monitored concentrations, which indicates that the model is underestimating the maximum observed value.

Zou et al. [32] evaluated the sensitivity of AERMOD and found that urban/rural dispersion coefficients and terrain conditions have limited influence on the model's performance. Long et al. [33] evaluated the sensitivity of AERMOD to input parameters in the San Francisco area for three source types, including a turbine source (elevated), a backup diesel generator (ground level point source), and a gas dispensing facility (volume source). They found AERMOD results to be very sensitive to surface roughness compared to solar radiation, cloud cover, urban population, ambient temperature, and albedo, whereas the sensitivity to surface roughness varied as a function of the source type. Previous studies have shown that AERMOD is highly sensitive to wind speed and direction [34] and to surface roughness length [35], [36]. Faulkner et al. [35] found pollutant concentrations from AERMOD to be sensitive to surface roughness (very sensitive to values below 0.4 m), wind speed (very sensitive to values below 10 m/s), temperature, albedo, and cloud cover. Schroeder and Schewe [37] showed how different study radii and different locations of the meteorological towers affected the surface roughness, which in turn affected the concentration estimates. All these studies show the importance of incorporating accurate site-specific meteorology and topography data in the modeling analysis.

Model Comparison

Model comparison studies are broadly covered under two categories, namely studies that focus on comparing only the modeled estimates between different models and studies that compare the modeled estimates with real-world data. In terms of model comparison without real-world observations, many studies [38]–[41] were conducted to compare the modeled concentrations between AERMOD and CALINE3 model series for passive roadway sources. Claggett [38] presented a comparison of three modeling procedures for predicting pollutant concentrations near highways using (i) CAL3QHCR, (ii) AERMOD with a defined emission source area (AERMOD AREA), and (iii) AERMOD with a defined emission source volume (AERMOD VOLUME). Trends in model predictions are presented in terms of normalized concentrations (concentrations × wind speed / emission rate). Variations in normalized concentration predictions were presented as a function of downwind distance, atmospheric stability, and wind angle with respect to the highway. The CAL3QHCR, AERMOD AREA, and AERMOD VOLUME modeling procedures exhibited widely differing prediction trends. The study found AERMOD AREA source characterization to render the highest concentrations at roadside followed by CAL3QCHR and AERMOD VOLUME source characterization.

Lin and Vallamsundar [42] conducted a modeling of motor vehicle generated PM in Illinois's $PM_{2.5}$ nonattainment and maintenance areas with a focus on identifying data needs and gaps in $PM_{2.5}$ hot-spot modeling. The major finding was that many factors (including model selection, meteorological condition, calendar year, geographic location, and traffic conditions) were at work in various degrees in the case of $PM_{2.5}$ hot-spot modeling. Vallamsundar and Lin [40] performed a comparative assessment between CAL3QHCR, and AERMOD area source characterization in predicting near-highway $PM_{2.5}$ concentrations based on PM quantitative project-level hot-spot analysis for a highway case study in Joliet, Illinois. The study found that the AERMOD area source characterization produce higher predictions of annual average $PM_{2.5}$ concentrations by a factor of 2.1 compared to CAL3QHCR. Difference in concentration estimates was attributed to the fundamental difference between the two models (i.e., the way atmospheric stability was represented).

Radonjic et al. [41] performed a model inter-comparison of CAL3QHCR, ISCST3, AERMOD, and CALPUFF for a hypothetical road segment and examined different averaging periods and land use conditions. The authors used CAL3QHCR as a reference model for comparative assessments because it has been widely validated against field observations around roadway sources. The study found that CALPUFF buoyant source best approximates CAL3QHCR followed by ISCST3 while AERMOD was found to over predict by up to a factor of four to six (depending on the averaging period and surface roughness). The authors highlighted the need to incorporate a line source algorithm in ISCST3 and AERMOD to make the results more reliable and modeling easier.

In a model comparison study for predicting benzene concentrations at a roadway intersection, Westerlund and Cooper [39] found AERMOD volume source characterization to produce the highest concentration followed by CAL3QHC, CAL3QHCR, and AERMOD AREA source characterization. By changing just, the source characterization type from area to volume in AERMOD, the study found the predicted one-hour and annual maximums to increase roughly by 100 percent and 560 percent, respectively. The study suggested a refinement to AERMOD for use as a highway model and that could potentially be addressed by the inclusion of some type of line source characterization (as in CALINE models). AERMOD model, although based on more recent science than CAL3QHCR, was fundamentally developed for point source applications, and there is still much uncertainty about its use as a highway model, which could be potentially addressed.

Model comparison studies validated against real-world field observations for roadway sources are limited. Literature points to three studies [38], [43], [44] that validated AERMOD and CALINE3 series of models with observed concentrations. Heist et al. [43] performed a model inter-comparison study to assess the abilities of AERMOD (area and volume sources), CALINE3, CALINE4, and other air dispersion models (ADMS, and RLINE) in capturing near-road tracer gas concentrations. Model estimates were compared to on-site measurements from two experimental studies performed in Idaho and California. Overall the study found all models except CALINE3 series, to have similar overall performance statistics, while CALINE3 series produced larger degree of scatter in their concentration estimates. AERMOD appeared to have the best performance among all models evaluated, generating the closest estimates to the measured highest concentrations. Heist et al. [43] suggested that the differences might be related to how the dispersion parameters were characterized in the models. While CALINE3 and CALINE4 based dispersion parameters on the Pasquill–Gifford stability categories, RLINE, ADMS, and AERMOD derive their dispersion parameters from the more advanced Monin–Obukhov similarity theory.

Contrary to the findings from the study by Heist et al. [43], Chen et al. [39], and Clagget and Bai [33] found AERMOD to under predict PM concentrations compared to observed data. Chen et al. [44] compared modeled estimates with observed concentrations at a sampling site in Sacramento, CA. While the study found CALINE4 and CAL3QHC results paired in space and time to match the observed concentrations moderately well, AERMOD was found to under-predict the observed concentrations. However, Chen et al. did not recommend CALINE4, and CAL3QHC for estimating concentrations at places where stable, steady-state meteorological conditions are not achieved. Nevertheless, the authors suggested, based on the evidence, that AERMOD appears to under predict concentrations and the fact that more meteorological data and user effort are required to run AERMOD, that either CALINE4 or CAL3QHC should be the first choice for project-level analyses. Clagget and Bai [38] found both CAL3QHCR and AERMOD to under predict the observed $PM_{2.5}$ concentration at a signalized intersection in Sacramento, CA. The study found that model predictions made by CAL3QHCR were greater than the measured values by a factor of two whereas AERMOD significantly under predicted the values.

Many studies have pointed out significant variability in the predicted AERMOD concentrations for inert pollutants, depending on the source type used [38], [45], [46]. Some studies have reported similar findings (i.e., higher concentrations predicted with an area source characterization) while others have reported the opposite (i.e., higher concentrations predicted with a volume source characterization). Pasch et al. [46] conducted an analysis on a hypothetical freeway widening project, and showed an AERMOD area-source characterization to produce PM concentrations 2.6 times higher than that predicted by using a few (i.e., 22) large volume sources for characterizing the freeway; however, the concentration difference was reduced to only 10 percent higher if a large number of (i.e., 968) small volume sources were used for characterizing the freeway. Claggett and Bai reported that higher PM concentrations were predicted by AERMOD for a signalized intersection in California when the emission source was characterized as an area source as opposed to a volume source. Clagget [38] found AERMOD AREA source characterization to produce highest concentrations at roadside followed by CAL3QCHR and AERMOD VOLUME source characterization. Schewe [37] reported 1.8 to 3.8 times higher concentration predictions from AERMOD for highways configured as volume sources than those configured as area sources.

KEY COMPONENTS OF PM HOT-SPOT ANALYSIS

This section discusses the key modeling components involved in air dispersion modeling. The models and approaches described here include those used for meeting regulatory requirements (conformity and NEPA analyses). Also, the section presents the overall framework for traffic, emissions, and dispersion modeling, followed by details of each modeling component in the subsequent subsections.

Overall Framework

Air dispersion modeling of roadway emissions requires several types of input data, including traffic, emission rates, meteorological, and other project-specific data. Figure 2 shows the overall framework including the key modeling components involved in air dispersion modeling. Modeling roadways as a source of emissions for both emissions and air dispersion modeling require traffic data as input. Major sources of traffic data used for emissions and air dispersion modeling include the federal Highway Performance Monitoring System (HPMS) database, TxDOT's Statewide Traffic Analysis and Reporting System (STARS-II) database, metropolitan area travel demand models (TDM), and traffic from project-level analysis. Other traffic sources that are being explored include vehicle and truck GPS probe data.

Emission rates required for air dispersion modeling are obtained through emission modeling using the EPA's MOVES emission model. The MOVES emission model uses traffic data such as speed, volume, fleet mix, and other locally specific data related to meteorology, vehicle age distribution, and fuel parameters, to generate total emissions (in grams) or emission factors (grams per mile or grams per vehicle) at the roadway link level.

The dispersion of the traffic related emissions in the atmosphere is modeled using CAL3QHCR and AERMOD models. The source (roadway link) specific emission rates from the MOVES model are passed on to the air dispersion models and are assigned project-specific dimensions, orientations, and properties to reflect site conditions. Site-specific meteorological and land use conditions are incorporated into the air dispersion models. Based on the implementation of the Gaussian dispersion process, air dispersion models (CAL3QHCR and AERMOD) estimate pollutant concentrations at discrete receptor locations.

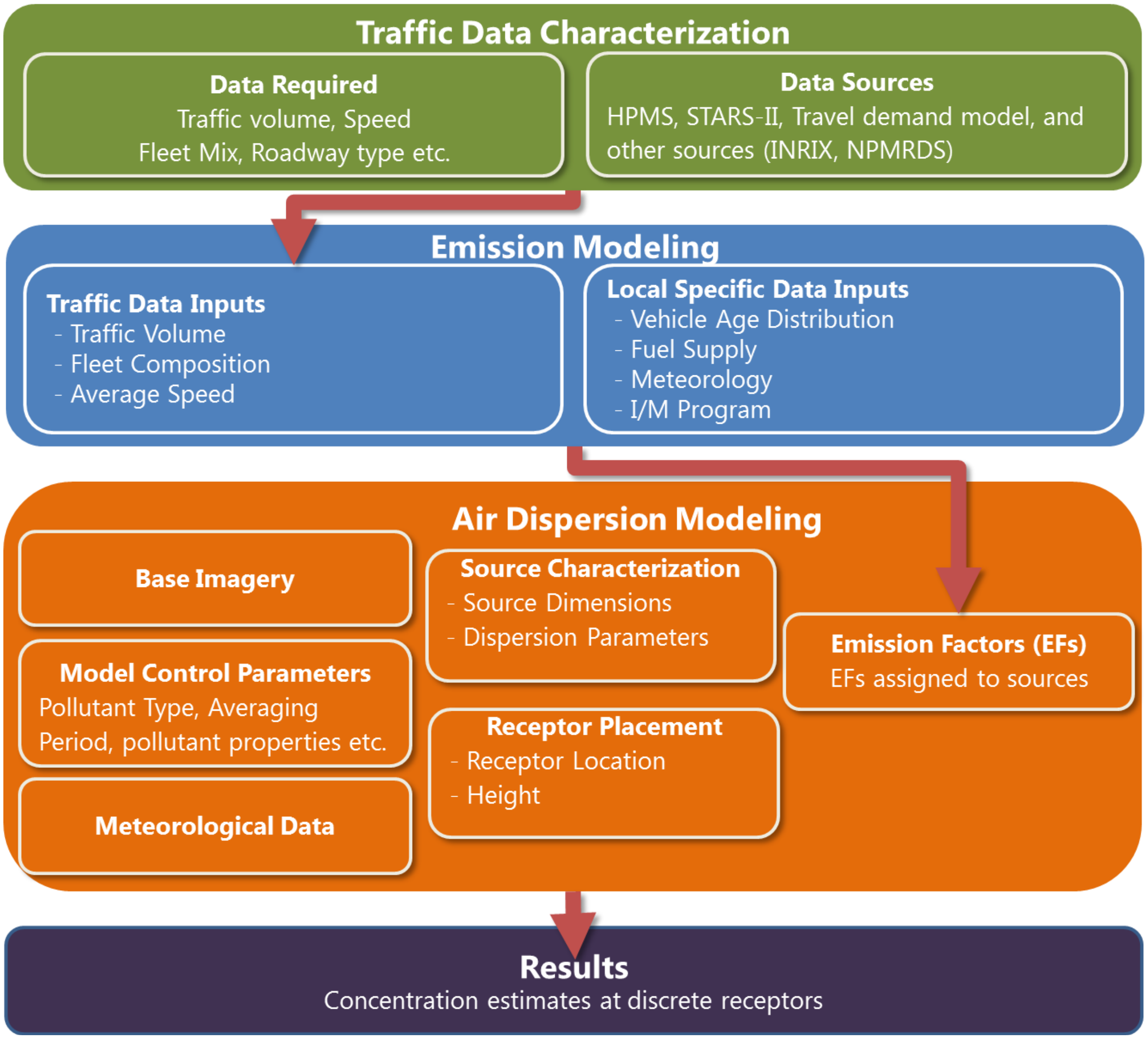

Figure 2. Overall Modeling Framework.

Traffic Data Characterization

This section overviews traffic data that are required for emissions and air dispersion modeling including data from traffic simulation models and use of traditional and emerging sources of traffic data.

Traditionally, the traffic data for air quality analysis come from regional TDM and case-specific traffic analysis based on short-term (e.g., 24 hours) observations. However, non-traditional sources of traffic data have steadily gained ground in the past few years, both in terms of quantity/coverage and quality. These data sources are easier to access (e.g., web-based) and provide hourly or sub-hourly details of the traffic on a section of the road. Traffic data, at a minimum, include traffic volumes and speeds, and fleet composition at the roadway link level. The traffic data must be consistent with the location and timeframe of the desired analysis. Listed below are the sources of traffic data that researchers have access to and will use in this project:

- TDM.
- HPMS.
- TxDOT STARS-II.
- National Performance Research Data Set (NPMRDS).
- INRIX data.

TDM is considered the traditional traffic data sources for NEPA air quality analyses. HPMS is a national dataset used by the FHWA to support decisions on the physical condition, safety, service, efficiency of the national highway system, and federal highway funding, but is also used by organizations such as the EPA, MPOs, and transportation researchers. STARS-II data expand upon the data collected in Texas for the HPMS. The data are used to meet FHWA reporting requirements and for validation of TDM. NPMRDS and INRIX provide traffic data derived from vehicle probe-based data collected from mobile phones, vehicles, and portable navigation devices. Figure 3 summarizes each of these data sources.

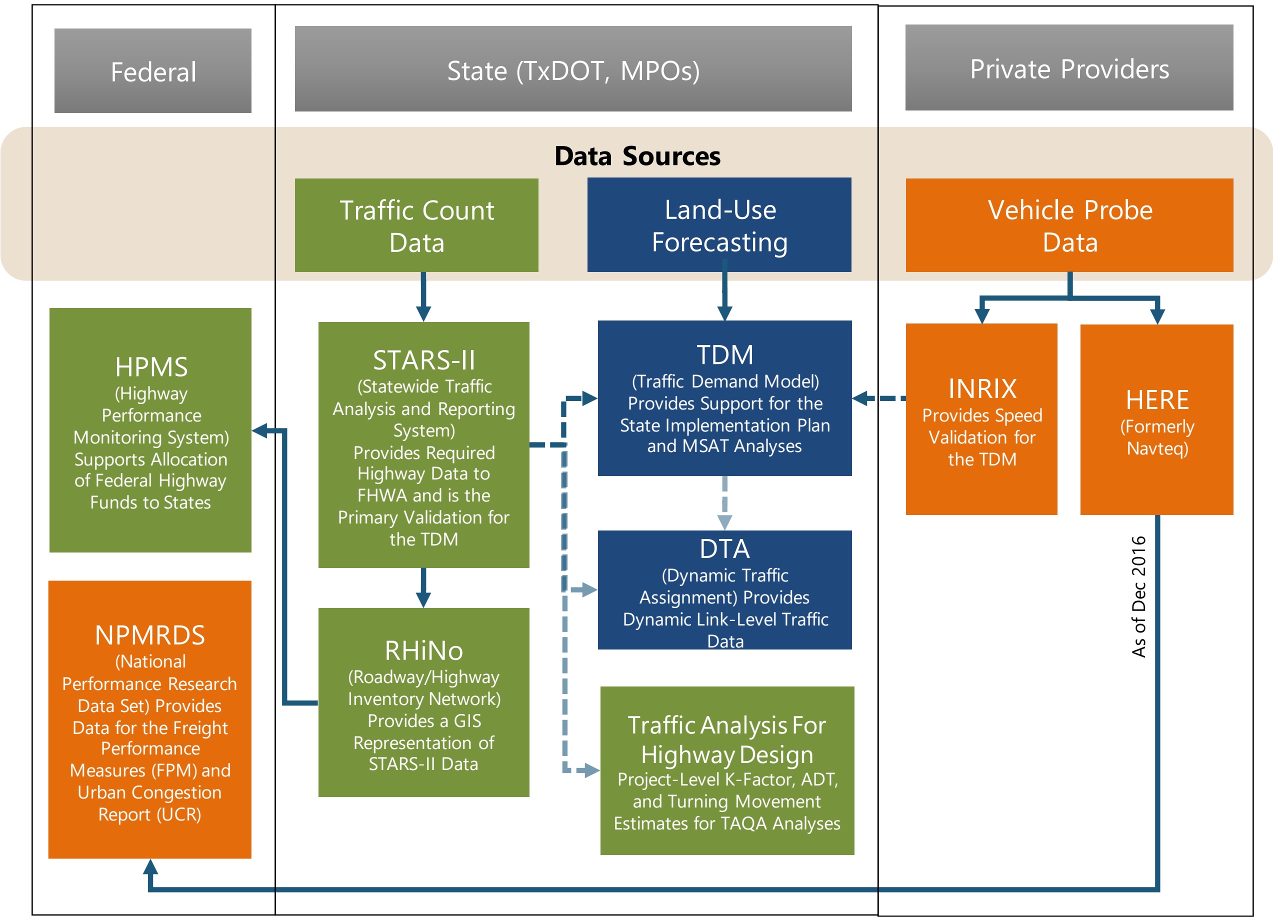

Figure 3. Traffic Data Sources and Uses.

Emission Modeling

Transportation-related sources of pollution can typically be classified as on-road, referring to vehicles used for moving passengers and/or freight, and off-road, referring to vehicles and equipment used for purposes other than on-road such as aircraft and locomotives [47]. The Clean Air Act (CAA; 42 U.S.C. 7401) is the comprehensive federal law that regulates air emissions from on-road and off-road sources and defines the EPA’s responsibilities for protecting public health and improving the nation’s air quality [48]. CAA requires EPA to set and enforce clean air standards that contribute to the improvement in human health. Also, CAA requires EPA to develop and regularly update emissions factors and emissions estimation models for all emissions sources in the United States. EPA has employed several emissions estimation models that are used in the support of emissions estimation to suffice these mandates.

EPA’s newest emission model, MOVES, has improved capabilities compared to its predecessors and has replaced the EPA’s MOBILE macroscopic emission model for regulatory emission estimation purposes.

The key distinctive features of MOVES that are perceived superior to its predecessors are:

- It uses a modal based approach rather than an average speed-based approach for emission rate estimation.
- It uses a MySQL database management versus an external excel spreadsheet data management system.
- It has the capability to estimate emissions at geographical scale ranging from national, regional, or county level to a single roadway link.
- It can be used to estimate both emissions and emission rates.
- It includes more sophisticated greenhouse gas and energy consumption estimation methods.

MOVES uses a modal-based approach to estimate emissions compared to the average speed-based driving cycle approach used in MOBILE. A modal based approach refers to developing emission rates for a unique combination of modes (or bins) based on vehicle operating conditions and vehicle characteristics. The bins that classify vehicle activities according to vehicle characteristics are called source bins. These characteristics correspond to weight class, fuel type, technology, standard, and horsepower range. The bins that classify vehicle activities according to vehicle operating conditions are called operating mode bins. These characteristics correspond to speed and vehicle specific power. Vehicle specific power refers to the power demand placed on the engine. After distributing the vehicle activities into source and operating mode bins, MOVES estimate the fraction of vehicle activities in each of these bins, and then develops a unique emission rate for each combination of bins.

A significant feature available in MOVES is the ability to support quantitative project-level emissions assessments using detailed travel activity data. The MOVES project-scale analysis function is the most spatially explicit modeling level in MOVES as it calculates emissions from a single roadway link, a group of specific roadway links, and an off-network common area (e.g., transit terminal or park-and-ride lot).

MOVES requires inputs from two broad categories illustrated in Figure 4:

- Site-specific traffic information, including traffic volumes, fleet composition, and vehicle activity at the roadway link level.
- Local-specific inputs, including regional-level vehicle age distribution meteorology, fuel supply, and inspection/maintenance (I/M) program parameters.

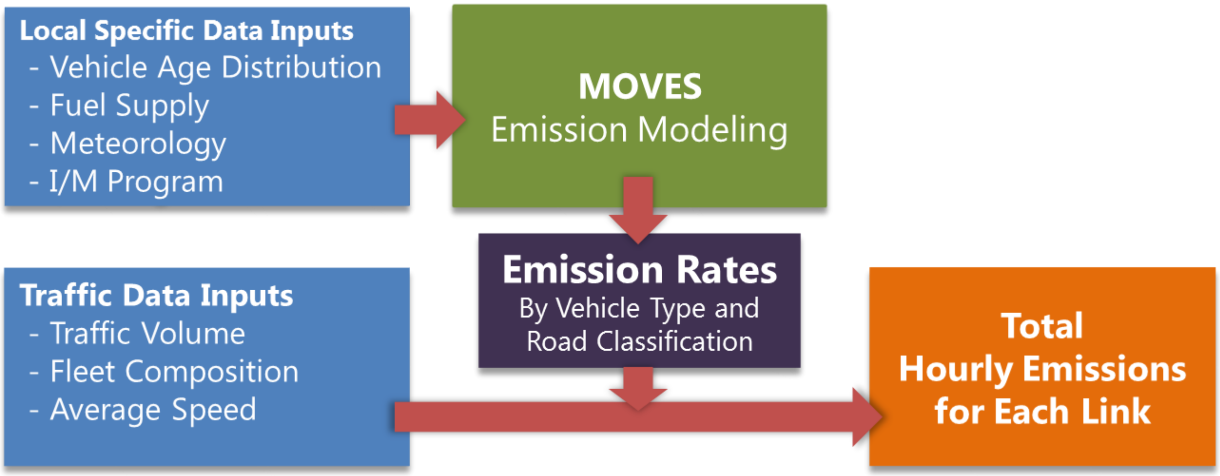

Figure 4. MOVES Emission Modeling.

Air Dispersion Modeling

AERMOD and CAL3QHCR estimates pollutant dispersion with a Gaussian-based equation that incorporates factors that account for the rate the plume disperses in each direction, reflection from the ground and plume rise [14]. The dispersion modeling process consists of three broad steps as shown in Figure 5.

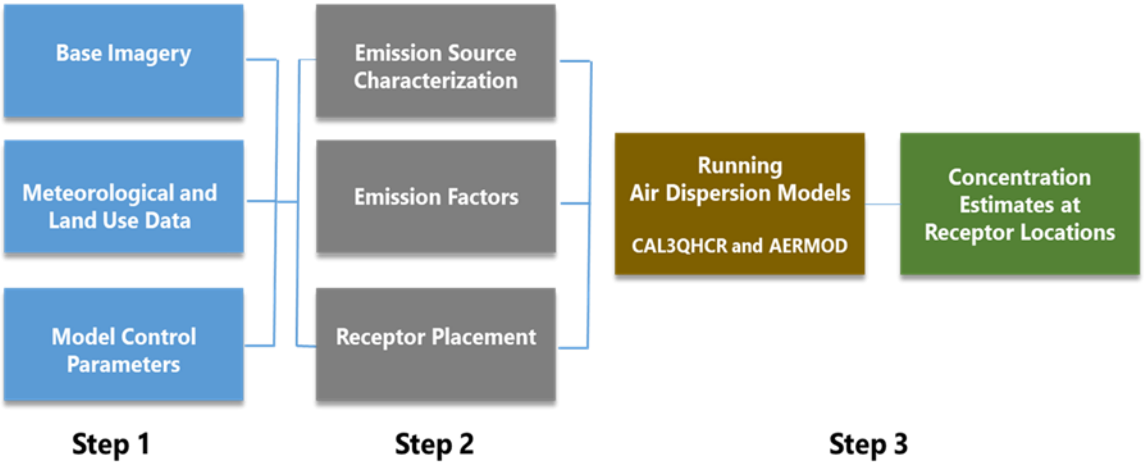

Figure 5. Air Dispersion Modeling Process.

Step 1: consists of obtaining the base imagery, specifying model control parameters, securing emission, meteorological, and land use data. Base imagery shows the geographical locations corresponding to the study area and helps in geographically coding the sources and receptors. The model control parameters refer to specifying the pollutant type, pollutant properties, and averaging period, etc. Three types of data are required for processing the meteorological data, namely: 1) land use data that represent surface characteristics, 2) surface data collected at airports by the National Weather Service (NWS), and 3) upper air sounding data collected by NWS [49]. The land use data are obtained from the U.S. Geological Survey (USGS) Land Use database [50]. The raw data are processed by different meteorological preprocessors depending on the air dispersion model. The preprocessors for AERMOD corresponds to AERMET, AERMAP, AERMINUTE, and AERSURFACE and for CAL3QHCR the preprocessor used is MPRM. The preprocessors convert the emissions into a format compatible for the air dispersion model.

Step 2: consists of characterizing the emission sources (roadway links) and placing receptors. The emission source (roadway link) characteristics are defined based on the roadway link orientation, geometry, and travel activity. Pollutant concentration levels are calculated at discrete receptor locations, placed at an average adult breathing height of 1.8 m.

Step 3: Running Dispersion Model: consists of running the air dispersion model with files obtained from the first and second stage. The air dispersion models produce pollutant concentration estimates for the desired averaging time period at all receptors. Table 2 lists the input parameters required for air dispersion modeling.

Detailed description of the steps, and input data preparation involved with air dispersion modeling is provided in Chapter 5.

Table 2. Input Data Parameters for Air Dispersion Modeling.

Modeling Parameters	Inputs
Base Imagery	Geographical locations corresponding to the study area. Base imagery can be in form of electronic CADD drawings, shape files, or satellite imagery.
Model Control Parameters	Pollutant: $PM_{2.5}$, CO or NO_x Averaging Period: hourly, 24 hours or annual Pollutant Properties: deposition and settling Land use types: urban or rural to incorporate the urban heat island effect
Emission Factors (EFs)	EFs are normalized with reference to time and source dimensions. CAL3QHCR requires EFs in form of grams per vehicle mile (grams/mile) and AERMOD requires EFs in form of grams per second per source area (grams/sec-m^2) for area source type characterization.
Source Characterization	Sources are defined based on: Roadway link orientation, Physical dimensions of roadway links, and Travel activity that corresponds to volume and speed. CAL3QHCR can model roadway sources as line segments. AERMOD can model roadway sources as a series of volume or area sources. Area source type approach will be used for this project.
Receptor Characterization	Receptors are placed at a finer spacing near the sources and the spacing is increased with distance from the source. Receptors are placed at an average human breathing height.
Meteorology data	Three types of data required for processing meteorological data consist of: Surface data that measure characteristics of lower layers of the atmosphere Upper air data that measure characteristics that changes with height in the atmosphere Land use data that represent surface characteristics Options for meteorological data TCEQ preprocessed AERMOD compatible data Use of CAL3Rmet for converting AERMOD compatible data to be compatible for CAL3QHCR Raw data will be processed through AERMET and MPRM to be compatible for AERMOD and CAL3QHCR

Background Concentration

Background air quality includes pollutant concentrations occurring due to area-wide or regional sources. BC accounts for a significant portion of the PM concentration with studies showing BC to account for 90–95 percent of near-road PM concentration. The contribution of roadway emissions to the near-road $PM_{2.5}$ concentrations varies significantly due to the uncertainties and variabilities involved in local meteorology, traffic activity, vehicle fleet, source-receptor geometry, time, day, and season of the year. DeWinter et al. [51] reported that proximity to a high traffic roadway results only in a small increment of $PM_{2.5}$ concentrations (an average of 1.2 $\mu g/m^3$ with a standard deviation of 0.2 $\mu g/m^3$) from the BC recorded at other urban-scale locations. This increment represents, on average, a 13 to 15 percent increase depending on how close the near-road monitor is away from the roadway. Vallamsundar and Lin [52] estimated that only approximately 5 percent of the near-road $PM_{2.5}$ can be attributed to the emissions from the road segment, based on a project-level MOVES-AERMOD emission and air dispersion modeling analysis. A recent study conducted in Netherlands suggested that the urban $PM_{2.5}$ and PM_{10} concentrations are dominated by the regional background and PM emission from local sources contribute less than 15 percent to the near-road sites [53].

Determination of the regional PM BC, thus is an important step in the PM hot-spot process as the BC is combined with project specific incremental concentrations to determine the design value and compliance with the air quality standards. As required in EPA's guidelines for transportation conformity hot-spot analysis, the analysis must calculate project-specific contribution and background concentration using EPA's recommended procedures. The project-specific contribution is estimated through the use of MOVES emission and AERMOD air dispersion modeling [9]. The compliance with the NAAQS is then determined by comparing the design value (or the sum of the modeled concentration from the project and the background concentration) to the respective NAAQS. Design value is conceptually defined as the sum of the modeled representative concentration resulted from the project and the background concentration. Therefore, the success of a compliance study depends on a reliable background concentration estimate. An overestimated background concentration will inevitably result in overestimation of the air quality impacts and potentially jeopardize the implementation of a transportation project whereas an underestimation will underestimate the impacts and unintentionally increase risks to the public's health.

Sources that are included in the background concentration are different for different pollutants with PM typically involving more complex types of emissions sources. PM hot-spot regulations require the background monitor to be as representative of the project area as possible considering similar density/mix of sources, land use, topography, etc. The simplest and most common approach is to use ambient monitoring data from surrounding monitoring stations located predominantly upwind (based on meteorological conditions) of the case study area to provide information about BC from sources around the case study. In situations where a single ambient monitor is not sufficiently representative of the project area, several monitors surrounding the project area could be used by interpolating the ambient data using a weighted inverse distance averaging or advanced geo-statistical approaches. Closest monitors often located predominantly upwind (based on meteorological conditions) from the case study are likely to be representative. For predicting future background concentration, chemical transport models or using an on-road mobile source adjustment factor are recommended.

Studies in literature have used different approaches to estimate the background monitor based on either ambient monitoring data or modeling results. The FHWA study to evaluate mobile source air toxics in the near-roadway environment suggested a background station to be located approximately 1000 m (approximately 3000 ft) [54] from the roadway and not located near any major pollutant source. Olvera et al. [55] estimated the background concentration from the same near-road monitoring station under certain considerations that correspond to hours when the traffic activity is minimal or absent such as overnight time periods and based on the upwind-downwind relationship between the monitor and the roadways such as when the monitor is in the upwind direction from the roadways. McKendry [56] identified ambient monitoring stations that represent regional level of air pollutants and are not affected by local emission sources, called relatively clean sites, using a literature review of local activities and observed concentrations.

The Transportation Pooled Fund Study, conducted by Sonoma Technology, determined the background concentration based on a set of concentrations obtained from different ambient monitoring stations located within a specific radius covering interested area [57]. In this regard, they used the average concentrations of ambient monitoring stations located at areas with radius of 25, 50, and 100 km. Two difference approaches were used to calculate the background concentration at different radius near the near-road monitoring station. The two approaches correspond to: 1) Distance-based approach in which the difference between the regional concentrations measured at ambient monitoring stations within different radii of the near-road monitoring station and 2) Correlation-based approach in which the difference between the ambient monitoring stations and the near-road monitoring station are weighted by the extent of correlation between the near-road monitoring station and the surrounding ambient stations such that if a near-road site and a regional site are influenced by the same regional conditions, total concentrations at the two sites should be highly correlated.

Regional-scale air quality models have been used to estimate background concentration, such as the Community Multiscale Air Quality (CMAQ). These models are used to simulate the transport and formation of air pollutants formed by chemical reactions among precursor species that are emitted from various sources. The primary issues with using such regional models is the issue of double counting the contribution from local sources (or contribution from the project). Arunachalam et al. combined space-time ordinary kriging of observations with outputs from the CMAQ model [58]. This technique was applied to support an exposure study in Detroit, Michigan, for $PM_{2.5}$ and NO_x. In order to eliminate the problem of double counting the contribution from local sources, the study employed two regional model simulations: one for the base case, in which all emission sources are included, and one in which the emissions modeled for the local source are excluded. The difference in concentrations between these two simulations provided an estimate of the background concentration excluding the contribution from the local source.

NEAR-ROAD AIR QUALITY

This section reviews literature on near-road pollutant dispersion patterns and overviews near-road and ambient monitoring stations established in Texas. Also, this section describes the history and regulations behind establishing near-road monitoring stations followed by recent studies focused on the pollutant data collected from the near-road monitoring stations.

Near-Road Pollutant Concentrations

Traffic-related air pollution has a profound impact on human health because of the quantity of pollutants emitted and the relatively proximity between the source and the population. Prior studies have documented the adverse impacts of traffic-related air pollution on cardiovascular health in adults [59]–[61]. Emerging evidence suggests that close residential proximity to traffic is particularly harmful to children. Schoolchildren living 30–300 m from a major roadway have increased arterial stiffness [62], increased carotid intima-media thickness [63], decreased academic performance [64], increased absenteeism [65], and increased clinical asthma symptoms [66]. According to the 2015 national household survey, 16.88 million households in the United States lived within half a block from a four-or-more-lane highway, railroad, or airport in 2011. This implies that approximately 43.5 million people were exposed to high levels of traffic emissions in 2011, using an average people per household of 2.58 for that year. The numbers are consistent with a widely quoted statistic of 22 million total housing units and 45 million of the population living near traffic facilities [67], [68]. EPA recognized the potentially detrimental effects of air pollution on public health and established NAAQS to a) provide air pollution data to the general public in a timely manner, b) support compliance with ambient air quality standards and emissions strategy development, and c) support for air pollution research studies.

Observations of pollutant concentrations at near-road monitoring stations are affected by many factors related to transportation (such as traffic volume, vehicle fleet, vehicle age and maintenance, speed, emission control device), local meteorology (such as wind direction, wind speed, temperature, pressure), terrain topography (such as roadway-receptor configuration, road condition, source, and receptor elevations), and presence of other local sources. Karner et al. [5] analyzed 41 roadside monitoring studies between 1978 and 2008 and concluded that almost all pollutants decay to background levels at a distance 115 m to 570 m from the edge of the road and the decay rate varies from one pollutant to another except $PM_{2.5}$, which achieved the background level by 990 m. This may not seem to agree well with the estimates derived from a typical Gaussian line source model, especially for $PM_{2.5}$. Venkatram et al. [6] examined the effect of wind direction on near-road concentration observations by analyzing data from three near-road pollution measurements and by using the AERMOD dispersion model. Using the line source algorithm built in the AERMOD model, Venkatram et al. [6] showed that the concentration of an inert pollutant decays rapidly to less than 1/5 of its initial strength, 100 m in the direction normal to the roadway. For a short-lived pollutant,[5] the off-road concentration would be reduced to 1/10 of its initial strength.

Recently, Cahill et al. [69] conducted a near-road air quality study using the highway safety flare as a unique source tracer for the fine PM emissions from a highly traveled roadway. Fine PM was found to be essentially undiluted at distances well beyond 200 m. The discrepancy was attributed to many uncontrollable factors, such as the existence of sound walls for at-grade

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[5] Due to evaporation, photolysis, chemical reaction, deposition, among other mechanisms.

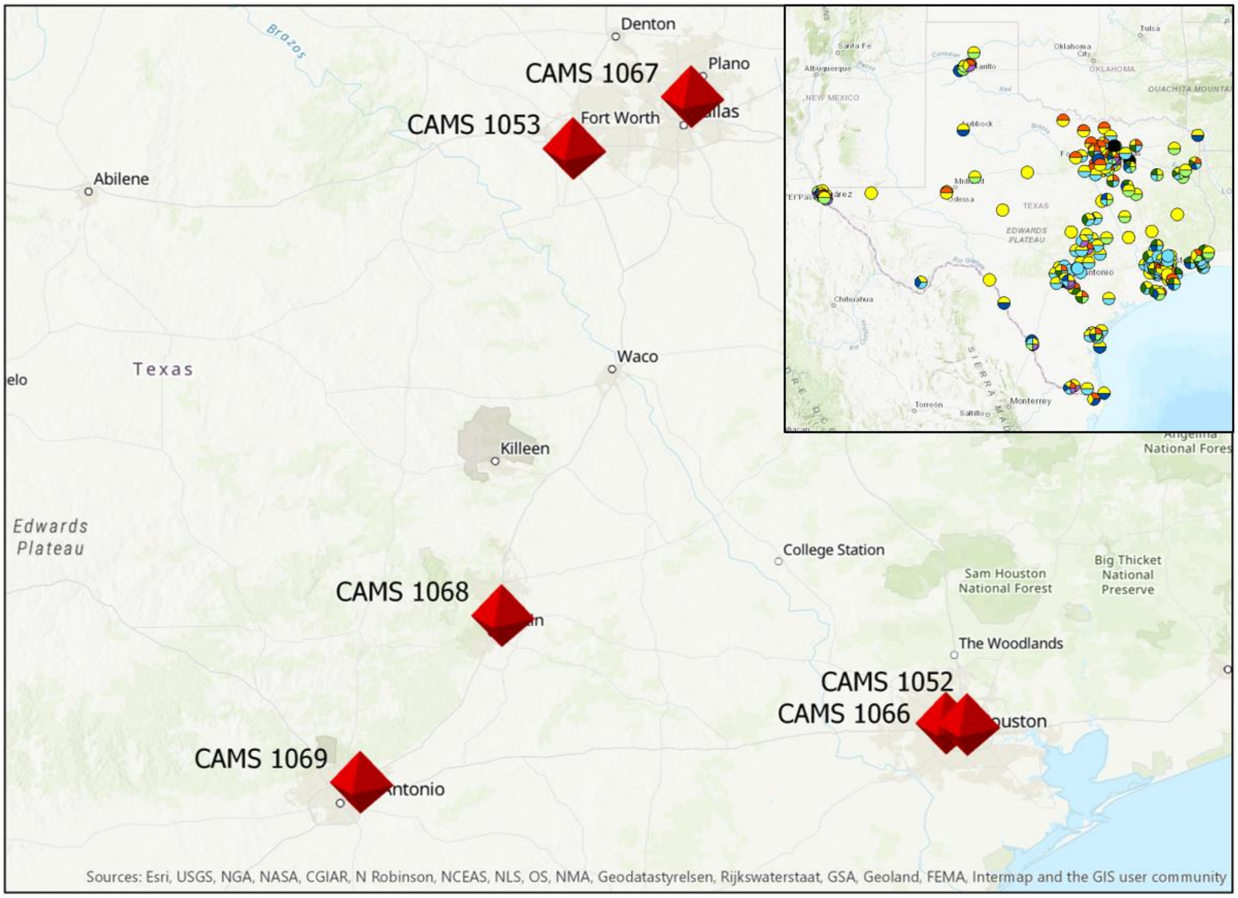
freeways, elevated or filled section of a freeway, canopy vegetation, and classification of atmospheric stability condition. Nevertheless, this gross mismatch between the downwind concentrations and the model estimates shows the need for further model improvement.

Near-Road Monitoring Stations and Regulatory Processes

The following covers the information on near-road monitoring stations in Texas and the regulatory requirements for pollutants that are being measured.

Near-Road Monitoring Stations in Texas

In response to the EPA's near-road air pollution monitoring requirements, TCEQ [70] first focused on complying with the directly applicable federal requirements listed in 40 CFR Part 58, Appendix D, Section 4.3.2 by primarily prioritizing potential sites based on annual average daily traffic (AADT) ranking (Phase 1). TCEQ considered road segment fleet equivalent AADT (FE-AADT) rankings, but did not rely solely on FE-AADT in the prioritization of potential sites since FE-AADT is not a specific siting requirement under [68]. TCEQ then reevaluated each roadway segment and viability in Phase 2. TCEQ using these criteria selected six locations for placing the near-road monitoring stations. While NO_x (including NO, and NO_2 as required by the Code of Federal Register [71]) and CO are recorded hourly, only integrated 24-hour average $PM_{2.5}$ samples are required to be collected every 6th days but TCEQ expanded their sampling program by collecting integrated $PM_{2.5}$ sample every 3rd day. Surface meteorological parameters such as wind direction, wind speed, temperature, and atmospheric pressure are collected hourly at these stations. Figure 6 shows the distribution of these monitors (6 out of the 25 are near-road monitors) in Texas.



Sources: Esri, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap and the GIS user community

Figure 6. Near-Road and Ambient Monitoring Stations in Texas.

Regulatory Requirements for Nitrogen Dioxide (NO_2)

The Code of Federal Register [68] requires one microscale near-road monitor in each core based statistical area (CBSA) with a population of 500,000 or more persons to be located near a major road with high AADT counts. An additional near-road monitor is required in each CBSA with a population of 2,500,000 or more persons. In Texas, these new regulations resulted in the need for eight new near-road monitors. In the first phase, one near-road monitor was placed in each of the designated CBSAs of Houston, Dallas, Austin, and San Antonio by January 2014. In the second phase, TCEQ deployed additional near-road monitors in CBSAs of Houston and Dallas (one each) by January 2015. The final phase includes one near-road monitor to be deployed in each of the CBSAs of El Paso and McAllen-Edinburg-Mission by January 2017.

During the selection process, TCEQ received AADT and Fleet Equivalent (FE) AADT rankings from TxDOT. The above-referenced CFR regulation states “The near-road NO_2 monitoring stations shall be selected by ranking all road segments within a CBSA by AADT and then identifying a location or locations adjacent to those highest ranked road segments, considering fleet mix, roadway design, congestion patterns, terrain, and meteorology, where maximum hourly NO_2 concentrations are expected to occur.” Therefore, TCEQ first sorted the list of road segments provided by TxDOT in descending order by AADT ranking. Through coordination with the EPA Region 6, boundaries for ranked road segments were defined as encompassing the area along the roadway of the traffic counting sensors up to the point of a major roadway intersection or significant traffic divergence. TCEQ then conducted a physical site reconnaissance to locate potential sites within that segment. Additional logistical factors required by Code of Federal Register [72] were also considered, including distance from obstructions, power availability, and sufficient space to accommodate the monitoring station and equipment [73].

Regulatory Requirements for Carbon Monoxide (CO)

The Code of Federal Register [74], [75] require high sensitivity CO monitors at National Core Multipollutant Monitoring Stations (NCore) sites and at one Type 2 Photochemical Assessment Monitoring Station (PAMS) site (or maximum ozone precursor emissions impact site) per ozone nonattainment area, which also collect data on three carbonyl compounds (formaldehyde, acetaldehyde, and acetone) every three hours during the O_3 monitoring period. The Code of Federal Register [76] also requires the deployment of CO monitors at near-road sites in CBSAs of greater than 1,000,000 people. In compliance with the near-road requirements, TCEQ deployed CO monitors at the Fort Worth California Parkway North (AQS 484391053) in Dallas-Fort Worth-Arlington CBSA and Houston North Loop (AQS 482011052) in Houston-The Woodlands-Sugar Land CBSA in early 2015.

Regulatory Requirements for Particulate Matter of 2.5 Micrometers or Less ($PM_{2.5}$)

The Code of Federal Register [77] requires $PM_{2.5}$ monitoring in Metropolitan Statistical Areas (MSA) with populations greater than 500,000 people and in MSAs with lower populations if measured $PM_{2.5}$ design values for an MSA are within 85 percent of the $PM_{2.5}$ annual average NAAQS of 12 $\mu g/m^3$. In addition, the Code of Federal Register [7] requires a minimum of one $PM_{2.5}$ sampler in each CBSA with a population equal to or greater than 2,500,000 people to be located at a near-road NO_2 monitoring station. Furthermore, the Code of Federal Register [74] requires $PM_{2.5}$ monitoring at NCore sites. This requirement resulted in the need to add a $PM_{2.5}$ monitor at five of the new sites including Houston North Loop CAMS 1052 and Fort Worth California Parkway CAMS 1053 [73].

Review of Studies Focusing on Near-Road Data

In response to increased evidence between near-road air pollution exposure and adverse health effects, in 2010, EPA established requirements for a new national air quality monitoring network that include the characterization of NO_2 in the near-road environment. Specifically [68], requires microscale near-road NO_2 monitors for CBSAs with populations of 500,000 or more persons. An additional near-road NO_2 monitoring station is required for any CBSA with a population of 2,500,000 persons or more, or in any CBSA with a population of 500,000 or more persons that has one or more roadway segments with 250,000 or greater AADT counts to monitor a second location of expected maximum hourly concentrations. The requirement to install near-road NO_2 monitoring stations in CBSAs having populations between 500,000 and 1 million by January 1, 2017, was removed by EPA on December 30, 2016 [71]. This was because of two factors, namely (a) current near-road monitoring exhibited air quality levels in urban areas with larger populations to be below the NO_2 NAAQS; and (b) near-road NO_2 concentrations is not expected to be above the health-based NAAQS in smaller urban areas. This action does not change the requirements for near-road NO_2 monitors in more populated areas (greater than one million persons), area-wide NO_2 monitoring, or monitoring of NO_2 in areas with susceptible and vulnerable populations.

The near-road NO_2 monitoring stations should be selected by ranking all road segments within a CBSA by AADT and then by identifying a location or locations adjacent to those highest ranked road segments, considering fleet mix, roadway design, congestion patterns, terrain, and meteorology, where maximum hourly NO_2 concentrations are expected to occur and siting criteria can be met in accordance with the Code of Federal Register [68]. In addition, measurements at required near-road NO_2 monitor sites using chemiluminescence Federal Reference Methods (FRMs) must include at a minimum: NO, NO_2, and NO_X. The Code of Federal Register [76], [77] further requires that at least one $PM_{2.5}$ monitor and one CO monitor to be collocated at a near-road NO_2 station.

EPA initiated a near-road pilot study immediately after the promulgation of the 2010 NO_2 monitoring requirements to better understand the selection of monitoring sites and distribution of pollutant concentrations. The pilot study concluded that near-road NO_2 concentrations tended to be highest at locations nearest the roadway and near those roads with highest traffic [46]. The study also discovered that near-road NO_2 concentrations in five studied cities were all less than the one-hour NAAQS for NO_2 and that the average near-road NO_2 concentrations were higher than the BC observed at non-near-road sites.

The State of Maryland conducted a three and a half-year study at a Maryland State Highway Administration monitoring site [78]. The study concluded that there were no exceedances of the 24-hour or annual NAAQS for $PM_{2.5}$ during the studied period and that the near-road $PM_{2.5}$ concentrations were consistently higher than that measured at background locations. The Maryland study also suggested that the $PM_{2.5}$ impacts of traffic emissions are not immediately noticeable at a distance of 150 m (500 feet) from the roadway and that approximately 14 percent of $PM_{2.5}$ collected at the near-road site could be attributed to the roadway sources, based on source apportionment analysis and AERMOD air dispersion modeling. The contribution of roadway emissions to the near-road $PM_{2.5}$ concentrations could vary significantly due to the uncertainties and variabilities involved in local meteorology, traffic count, vehicle fleet, source-receptor geometry, time, day, and season of the year. Near-road PM monitoring sites are exposed not only to the traffic emissions from the immediately adjacent road segments but also to the PM emissions from other point, area, and mobile sources in the regional, urban, and local environments.

Near-road air quality data became more available in the United States since 2014 when state and local air pollution control agencies began to collect NO_2, CO, and $PM_{2.5}$ data and reported to the EPA's Air Quality System (AQS) database. At the request of Washington State DOT, Sonoma Technology [79] gathered, processed, and conducted a national-scale review of near-road air pollutant concentrations using the 2014–2015 AQS data. The database developed represents the best available and most complete data for near-road monitors in the United States since they were quality-controlled by the air monitoring agencies and certified by the states. Sonoma Technology also gathered state-reported AADT of the major roads associated with each of the official near-road monitoring stations to understand how concentrations varied by factors such as location, distance to roadway, and traffic volume at the near-road monitors.

It was discovered that CO concentrations were typically 1 ppm or less, although several comparatively high CO concentrations (greater than four ppm) were observed at near-road locations in three cities. All the one-hour values were well below the CO one-hour NAAQS of 35 ppm. Of the 66 locations with sites reporting NO_2 data to AQS, only three one-hour daily maximum NO_2 concentrations and five hourly observations were above the NAAQS of 100 ppb for NO_2. For $PM_{2.5}$ data, sites in Denver, Colorado; Houston, Texas; Long Beach, California; Ontario, California; and Phoenix, Arizona, recorded $PM_{2.5}$ annual averages for 2015 greater than the annual average NAAQS of 12 $\mu g/m^3$. However, of these sites, only Long Beach and Ontario reported a full year of data for 2015, while Houston had three quarters of the year of data. There were 33 days in 2015 at 12 near-road locations that had 24-hour $PM_{2.5}$ concentrations above 35 $\mu g/m^3$. Only three of the sites, Denver, Ontario, and Long Beach, had a 98th percentile of 24-hour $PM_{2.5}$ concentrations greater than 35 $\mu g/m^3$. Phoenix had a 98th percentile of 34.5 $\mu g/m^3$.

CO concentrations at near-road monitoring stations were consistently detected at levels well below the NAAQS as demonstrated in the Sonoma Technology [79] and near-road air monitoring data reported by TCEQ, as discussed in the following section. Similarly, majority of near-road NO_2 concentrations (except for a few marginal readings <1 percent of the data) measured by the near-road monitoring stations are found to be lower than the NAAQS. $PM_{2.5}$, on the other hand, does appear to have relatively higher readings and thus require additional evaluation. It is important to understand how these high near-road $PM_{2.5}$ concentrations relate to traffic, urban-scale concentrations and meteorology, and what the predictors of high near-road concentrations are [46]. Building upon the data collected from the near-road monitors, researchers from Sonoma Technology plan to perform comparisons between near-road measurements, and modeling results using AERMOD and CAL3QHCR. Two case study sites will be selected from the candidates in the database based on data availability, roadway configuration, traffic volumes, and the relationship between near-road and regional air quality measurements. Their intention is to select project/facility types that are appropriate for model-to-monitor comparisons, are of interest to state DOTs, and represent different project/facility types.

SUMMARY

This chapter summarizes the findings from the literature review and state-of-practice assessment covering background information on key subjects including overview of air dispersion models, studies that focused on model validation and performance evaluation, and comparative assessments between AERMOD and CALINE3 model series. The chapter summarizes the literature on near-road pollutant dispersion patterns and near-road and ambient monitoring stations established in Texas.

Overall, the findings of model comparative assessment with a focus on transportation applications indicate highly mixed results for all models, depending on the averaging period, source type, case study setting (i.e., land use and meteorological conditions), and the analytical approach. This could be, in part, due to limited model comparison studies focusing on comparing modeled estimates with real-world field observations. The literature review highlights a need for more detailed model comparative assessment with real world data to assess the performance of EPA-recommended air dispersion models, which is especially critical for regulatory applications such as the transportation conformity and NEPA analysis of transportation projects. The emergence of a rich source of real-world air quality data from near-road monitoring stations, combined with traffic, emission, and air dispersion modeling, has created an opportunity to address this need.

This chapter has highlighted two key challenges for the analyses performed in this project. The first is the near-road monitor concentrations of $PM_{2.5}$ that were available at the time of this project are measured at a 24-hour averaging period once every three days. The second is that the detailed traffic activity data in the proximity of the near-road monitoring station are not always available. The following chapters explain how these challenges were overcome during the modeling and data analysis steps.

CHAPTER 3:
STUDY DESIGN AND CASE STUDY PROTOCOLS

INTRODUCTION

Task 2 of this research project focused on developing the study design and case study protocols for evaluating the air dispersion models. This chapter briefly discusses the methodology, study design, metrics used in the selection of the case study sites, and key input data parameters and their data sources.

METHODOLOGY

From the literature review, researchers found two main domains characterizing near-road pollutant concentrations. First domain relates to the near-road monitoring stations established by EPA based on an increased epidemiological evidence of traffic related air pollutant and adverse health effects in the near-road environment. This requirement resulted in the availability of high-quality and continuous near-road concentration and weather data as several near-road sites nationwide are operational and measuring complete years of pollutant levels around the country. The near-road data have been increasingly used for several applications including the near-road exposure assessment, evaluation of low-cost sensors, roadside barrier design, etc. Next domain is air dispersion models that are an important component in regulatory processes to ensure compliance with air quality standards and for localized exposure and concentration assessment.

The objective of this research project is to evaluate the air dispersion modeling process (specifically the PM hot-spot analysis) and qualitatively evaluate the process and the uncertainties involved with the near-road concentration data. Researchers developed two tracks for achieving this objective:

- **Track 1- Data Research:** exploration of the near-road monitoring observations to evaluate the potential association between the near-road PM concentrations and the key traffic, meteorology, and background concentration parameters. This near-road data research resulted in an understanding of the contributing factors and identifying the conditions that result in high near-road PM concentrations.
- **Track 2- Modeling:** dispersion modeling to investigate the model behavior and variabilities involved in the PM hot-spot process through a series of sensitivity analyses. The study results shall help to communicate the uncertainties involved in the hot-spot process with the decision makers and the public and help to interpret the results in the proper context.

Combining the two tracks, researchers qualitatively assessed the results from the different modeling scenarios with the near-road monitoring data and evaluate the potential of using near-road monitoring data in lieu or in conjunction with modeling to meet the requirements of the PM hot-spot analysis for transportation projects. Researchers employed a case-study-based approach for both tracks. A case study is considered as a specific extent of the roadway relative to a selected near-road monitoring station, over a particular time period. A set of evaluation criteria were used by researchers to identify the case study sites. As part of case study protocol development, researchers identified tools, input parameters, and data sources for performing modeling (Task 3) and data exploration research (Task 4). Figure 7 shows an overview of the study design and case study protocols developed by researchers and is described in the following sections.

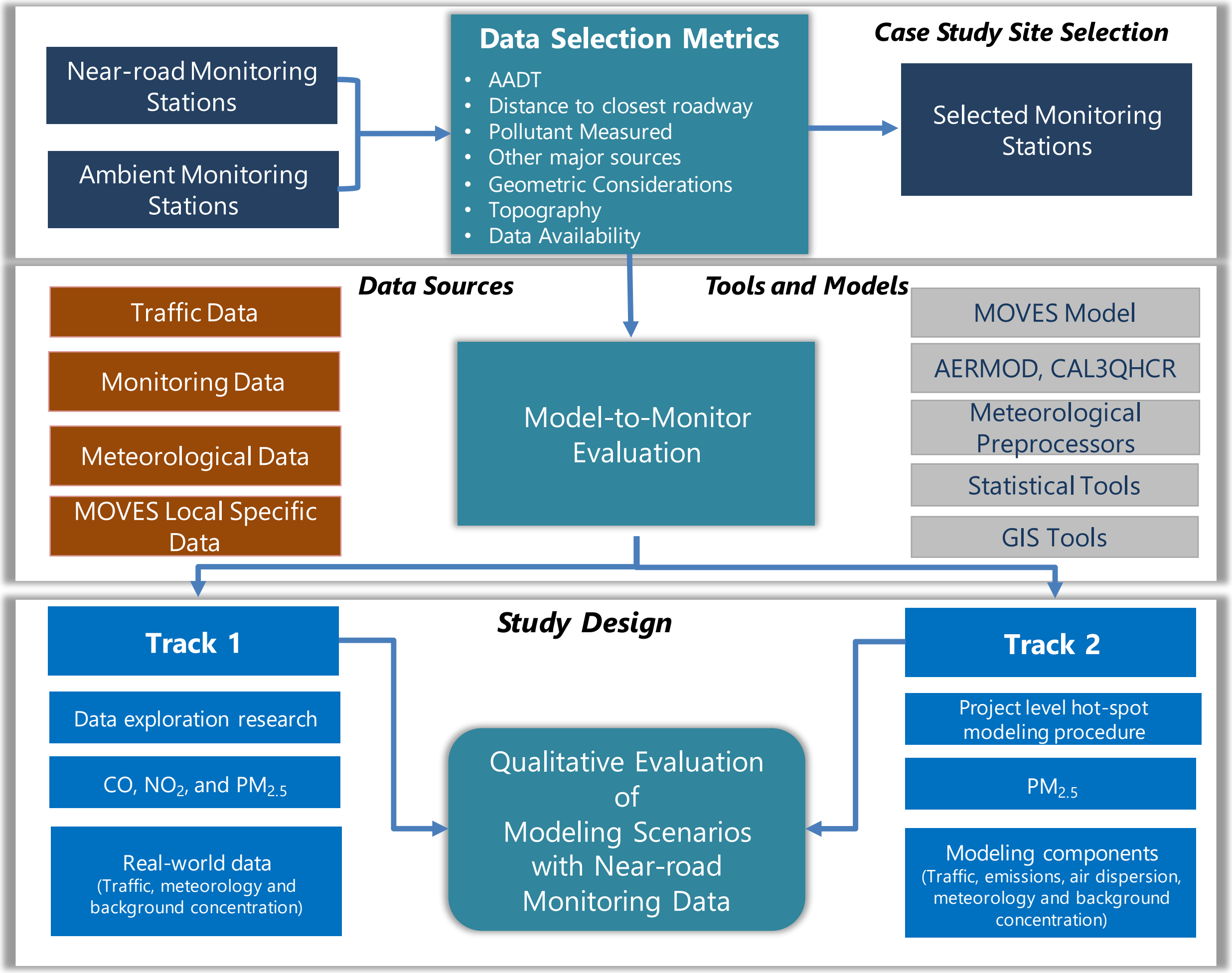


Figure 7. Overall Modeling Framework.

DATA SELECTION METRICS

Researchers used the following data quality metrics as listed in Table 3 for selecting the appropriate case study site location.

Table 3. Data Selection Metrics for Case Study Site Selection.

Data Quality Metrics	Description
AADT	As the objective is to evaluate near-road pollutant concentrations, sites with a higher AADT are considered so that the impact from the roadways are greater. FHWA study [54] suggested a threshold of 150,000 AADT for monitoring site selection. The study also suggested the site location should be selected for which traffic count and/or fleet mix are expected to vary substantially on a time-of-day, day-of-week, and seasonal scale. Federal Title 40 CFR Part 58 [7] requirement stipulates that sites must be deployed near major roadways with high AADT counts with consideration to fleet mix, roadway design, congestion patterns, terrain, and meteorology.
Distance to closest highway	Monitoring sites should be located closer to a major roadway. Federal Title 40 CFR Part 58 [7] requires the near-road monitoring site to be located within 50 m of the road segments and away from obstructions or obstacles. An FHWA study suggested site locations should not be selected for which other major sources are within 1 kilometer of any of the monitoring site. These major sources may include large arterial roadways (AADT > 25,000), large industrial operations, and combustion sources.
Pollutant Measured	Availability of specific pollutant monitoring data.
Presence of major sources other than highway	Monitoring sites should be selected away from potentially confounding air pollution sources other than highways. The presence other sources will make the interpretation of the impact of roadway emissions difficult.
Geometric considerations	Sites with a complicated geometry (such as multiple ramps, multiple freeways at different elevations, etc.) could make the characterization of the impact of roadway emissions contribution difficult.
Topography	Relatively flat terrain helps in ensuring the roadway emissions impact the monitoring site in an unperturbed manner. An FHWA study recommends site locations be selected where the average terrain does not exceed 5 percent grade over any 100 m section of land within 300 m distance from the roadway where the monitoring site is located.
Data availability	Data availability, quality, and resolution is a key consideration for both site selection and performing the model-to-monitor evaluation. Such data refers to traffic measures (AADT, speed and fleet mix), meteorological data, and monitoring data.

Researchers used geographic information system (GIS) data, traffic, land use, and meteorological data to help with the site selection process. ArcGIS 10.3 was used to create the maps showing the case study site location and WRPLOT View by Lakes Environment[6] was used to create wind rose plots for the meteorological data. A summary of the near-road air monitoring stations in Texas are listed in Table 4 according to the data selection metrics provided in Table 4.

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[6] WRPLOT is a commercial software to help with the plotting of the wind roses based on the meteorological data.

Table 4. Data Selection Metrics at the Near-Road Monitoring Stations.

AQS Number	481131067	482011066	484531068	480291069	484391053	482011052
TCEQ CAMS	**1067**	**1066**	**1068**	**1069**	**1053**	**1052**
Site Name	Dallas LBJ Freeway	Houston Southwest Freeway	Austin North Interstate 35	San Antonio Interstate 35	Fort Worth California Parkway North	Houston North Loop
Core Based Statistical Area	Dallas-Fort Worth-Arlington	Houston-The Woodlands-Sugar Land	Austin-Round Rock	San Antonio-New Braunfels	Dallas-Fort Worth-Arlington	Houston-The Woodlands-Sugar Land
2015 Population	7,102,796	6,656,947	2,000,860	2,384,075	7,102,796	6,656,947
Phase	1	1	1	1	2	2
AADT Ranking	15	1	7	21	36	46
FE-AADT Ranking	7	1	10	3	90	46
Pollutants Monitored	NO_x	NO_x	NO_x, CO, $PM_{2.5}$	NO_x, CO, $PM_{2.5}$	NO_x, CO, $PM_{2.5}$	NO_x, CO, $PM_{2.5}$
Distance to Nearest Traffic Lane (m)	24	24	27	20	15	15

Only two stations, Stations 1052 (Houston North Loop) and 1053 (Ft Worth), meet the data selection metrics in terms of having quality assessed $PM_{2.5}$ monitoring data. While NO_x (including NO, and NO_2 as required by the Code of Federal Register) and CO are recorded hourly, $PM_{2.5}$ samples are collected at 24-hour averaging period one-in-three days for Houston and Fort Worth. The near-road monitoring stations at Austin and San Antonio recently started monitoring $PM_{2.5}$ at an hourly averaging period from fall 2018, but these monitors were not considered for this study.

INPUT DATA

This section overviews the key input data parameters and their associated data sources:

- **Traffic Activity Data:** Traffic activity such as flow, speed, etc. and vehicle characteristics such as age distribution, fuel type, vehicle-mix on the major roads near the monitoring stations are crucial for model-to-monitor evaluation. The traffic data must be compatible with spatial and temporal attributes of the concentration data from the near-road monitors. These key traffic activity data parameters correspond to traffic volume, traffic speed, vehicle miles traveled mix, hourly and seasonal travel factors. The data sources from which traffic volume information can be obtained in close proximity to the monitoring stations corresponds to TDM, TxDOT permanent traffic recorder stations, TxDOT saturation and local traffic counts, and emerging data sources such as NPMRDS, Roadway/highway inventory network (RHiNo), INRIX, etc.
- **MOVES Local-Specific Input Data:** MOVES requires inputs from two broad categories 1) Site-specific traffic information, including traffic volumes, fleet composition, and vehicle activity at the roadway link level, and 2) Local-specific inputs, including regional-level vehicle age distribution meteorology, fuel supply, and I/M program parameters. The first category of data is obtained from traffic activity data sources and the second category of data are obtained from the inputs used for regional state implementation plan emission inventories from TCEQ.
- **Meteorological Data:** Meteorology and land use data are a major factor that affect pollutant dispersion in the atmosphere. One of the key factors in producing credible pollutant concentration estimates is the use of meteorological data that are as representative as possible of the case study site. Raw meteorological data are obtained from the databases maintained by the National Climatic Data Center (NCDC) and U.S. Department of the Interior. The raw data are processed using meteorological preprocessors such as AERMET, AERSURFACE, AERMINUTE, and MPRM. Details of meteorological data processing are provided in Appendix A. TCEQ has pre-processed meteorological data [80] in one-year and five-year data sets for all 256 counties in Texas using AERMET version 12345.
- **Monitoring Data:** near-road pollutant concentrations corresponding to $PM_{2.5}$, NO_x (including NO and NO_2), and CO are obtained from the near-road monitoring stations. On-site meteorological parameters measured at the near-road monitoring station included wind speed, direction, dry bulb temperature, and relative humidity. Atmospheric stability, which is a key factor influencing the mixing and dilution of pollutants, is obtained from processing the meteorological data obtained from the closest weather station from the near-road monitoring stations. Onsite traffic data are obtained from the TxDOT STARS-II traffic counter located close to the near-road monitoring stations. BC include pollutant concentrations occurring due to area-wide or regional sources. BC data are obtained from

the surrounding ambient monitoring stations located upwind and near the near-road monitoring stations.

Modeling components and tools employed are described in detail in Chapter 5.

STUDY DESIGN

This section outlines the study design used by researchers to evaluate the air quality models in the context of the PM hot-spot modeling process. The study design consists of two main goals as listed below:

- Communicate the uncertainties involved in the PM hot-spot modeling process with the public and decision makers and help to interpret the results in the proper context. Researchers employed sensitivity analyses to characterize the modeling process's behavior in response to variability in select input parameters.
- Understand conditions where relatively high *near-road* PM concentrations have been observed. Researchers used a data exploration approach to assess the variations in near-road concentrations for key parameters related to traffic, meteorology, and background concentration.
- Qualitatively evaluate the modeling scenario results with the near-road concentrations.

Researchers developed two tracks to address the goals listed above.

Track 1: Data Exploration Research

Researchers used a data research approach to assess the variations in near-road concentrations for key parameters related to traffic, meteorology, and background concentration. The data research resulted in an understanding of the relationship and potential correlation between the near-road concentrations for key factors related to traffic activity, meteorology, background concentration, and other factors. The data research included the following key parameters to assess the association with the near-road concentration data:

- Near-road Monitoring Data.
  - $PM_{2.5}$.
  - CO.
  - NO_2.
- Traffic Activity Data.
  - Volume.
  - Speed.
- Meteorological Data.
  - Wind Speed.
  - Wind Direction.

  - Atmospheric Stability.
  - Background Concentrations.

Data research was conducted for 120 days in calendar year 2016 for both Fort Worth and Houston sites. These days correspond to the days when $PM_{2.5}$ measurements were made. In consultation with the project committee, the year 2016 was chosen because this was when the first full year of near-road monitoring data was available. Traffic, meteorological, and background concentration data corresponding to the days of $PM_{2.5}$ measurements were obtained. Researchers used statistical analyses methods to quantitatively characterize the associations between these key factors and characterized trends and conditions that led to high concentration events and the potential contribution from on-road mobile sources.

Track 2: Modeling

The modeling components or steps involved in a PM hot-spot process are listed below:

- Traffic data characterization.
- Emission modeling.
- Meteorological data processing.
- Air dispersion modeling.
- Background concentration estimation.

The uncertainties within each step can propagate through the entire modeling chain. For example, traffic volume and speed data may come from traffic management systems, regional TDM, and traffic microsimulation models. Emission quantities generated by EPA's mobile source emission model, MOVES, require local inputs for key parameters such as vehicle fleet characteristics, fuel parameters, etc. Air dispersion models typically require emission quantity input, meteorology, land use surface, traffic volume and speed, and receptor location input. The different sets of input parameters, data sources, and data resolution contribute to a great amount of uncertainty of PM hot-spot analyses' results. Studies have shown a careful selection of input parameters for all steps is required to avoid undesired variability in the concentration results [32], [37]. Characterizing the sensitivity associated with the individual modeling components and the impact on the overall modeling chain helps TxDOT and its partner agencies to:

- Better prioritize modeling and data resources by focusing modeling efforts on those inputs that have the greatest impact on the overall modeling results.
- Effectively communicate the uncertainties of the modeling results with the public and decision makers.

Researchers used a series of sensitivity analysis to evaluate the variabilities/uncertainties involved in the modeling components for both the case study sites. This translates to assessing the sensitivities of the models' outputs to key input parameters from each of the modeling components as listed above. For the baseline scenario, researchers used parameters according to the PM hot-spot process. The alternative scenarios focused on the methods and values that are not strictly defined in the regulatory guidance documents. Researchers identified the following parameters categorized by the modeling components for the alternative scenarios:

- **Traffic Activity Data—**Traffic data considering different averaging period.
- **Emission Modeling:**
    - Different level of detail in the fleet mix data (regional versus site specific data).
    - Meteorology (regional versus site specific data).
- **Air Dispersion Modeling:**
    - Model selection (AERMOD or CAL3QHCR).
    - Source type (area or volume sources in AERMOD, line sources in CAL3QHCR).
    - Urban heat island effect.
    - Source definition.
- **Meteorological Data:**
    - One-year onsite versus 5-years off-site data.
    - Offsite meteorological data classified by different surface roughness.
- **Background Concentration—**Different methods to calculate background concentration using single, multiple, or same near-road monitor.

Key differences between Track 1 and Track 2 in terms of objectives, and parameters evaluated, are shown as a flowchart in Figure 8. Findings obtained from Track 1 and Track 2 will be combined to qualitatively assess how the regulatory hot-spot process compares with the near-road monitoring data and assess the potential of the near-road monitoring data to be used in lieu or in conjunction of modeling (Figure 9). Background concentration representing pollutant concentrations occurring due to regional sources accounts for a significant portion of near-road $PM_{2.5}$ concentrations. The near-road monitoring stations measures pollutant concentrations occurring from a combination of localized sources (especially from roadways due to their proximity) and regional sources. The air dispersion models estimate the incremental concentration specifically coming from roadway sources and is combined with the background concentration obtained from ambient monitoring stations. Due to this, qualitative model evaluation is performed by comparing the near-road monitoring data with the modeled results combined with and without the background concentration.

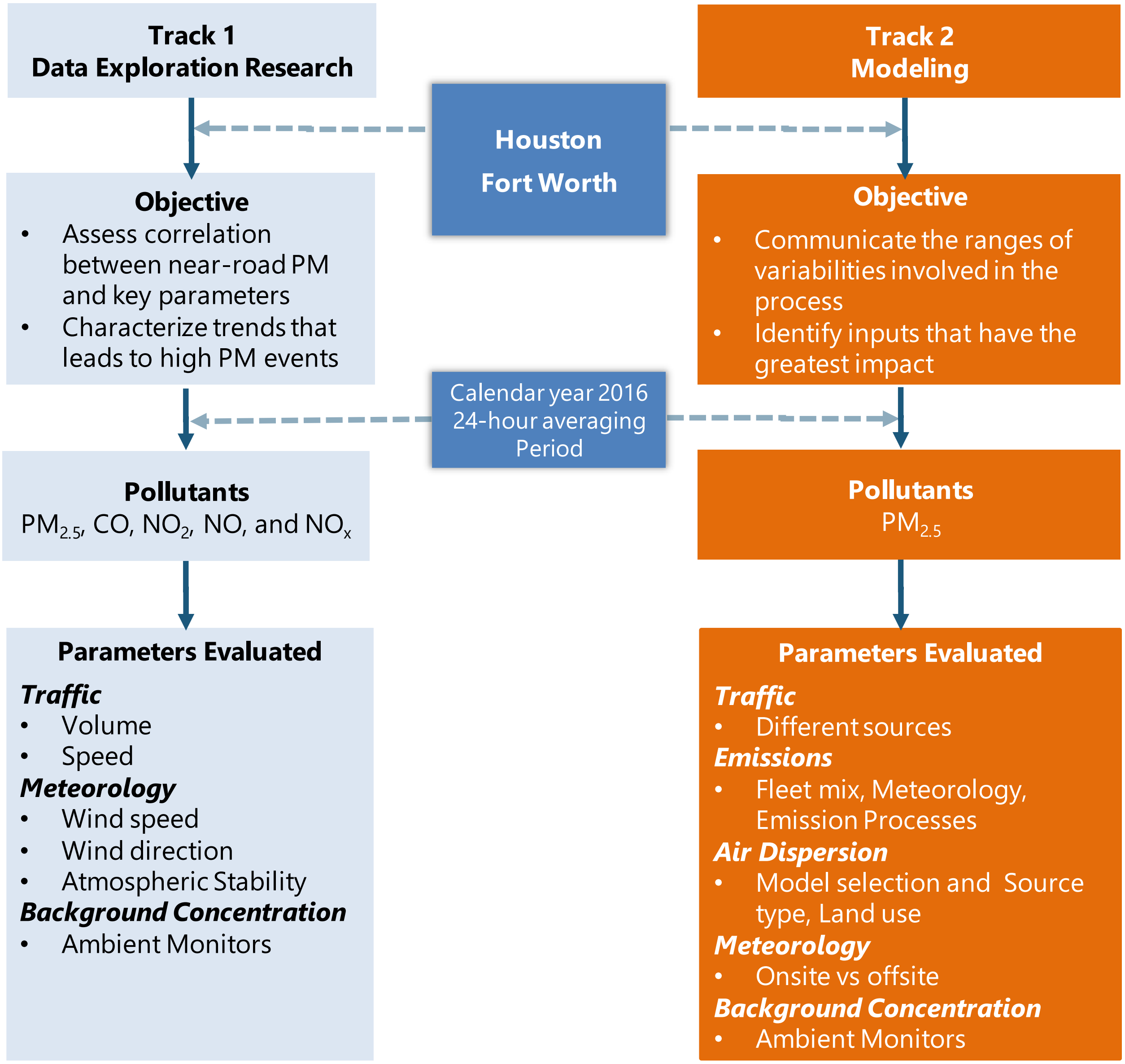


Figure 8. Key Differences between Track 1 and Track 2.

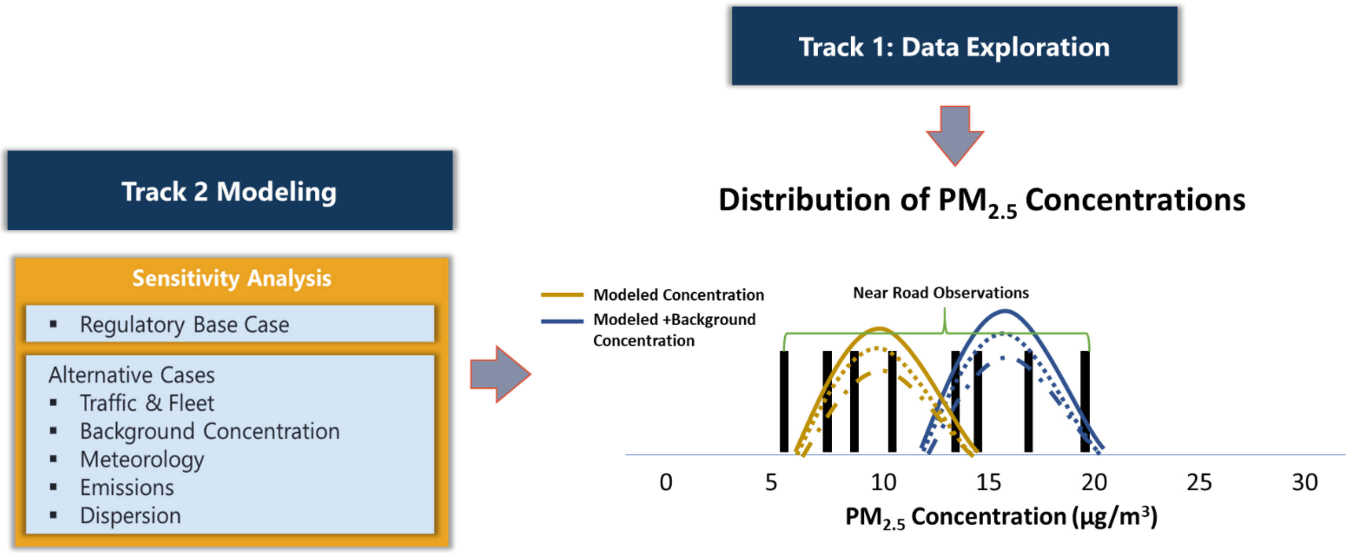


Figure 9. Study Design: Track 1 and Track 2.

SUMMARY

For the selection of case study sites, researchers considered different selection metrics and selected two sites (Houston and Fort Worth) for detailed analysis. The research work is divided into two parallel tracks. Track 1 corresponds to performing a data exploration research to evaluate associations between near-road monitoring data and key traffic, meteorology, and background concentration. Track 2 corresponds to evaluating the variabilities involved in the different modeling components of the PM hot-spot analysis process. The following chapters cover each track in further detail.

CHAPTER 4:
DATA EXPLORATION RESEARCH

INTRODUCTION

This chapter uses data exploration research to assess the variations in near-road concentrations for key parameters related to traffic activity, meteorology, and regional background concentrations. The data exploration effort showed the relationship and potential correlation between the near-road concentrations for key factors related to traffic activity, meteorology, background concentration, and other factors.

Researchers evaluated the near-road monitoring data collected at the two near-road monitoring stations (Houston [Continuous Air Monitoring Station (CAMS) 1052] and Fort Worth [CAMS 1053]) and the potential associations between near-road monitoring concentrations and key parameters. As the next step, the data evaluated in this chapter will be combined with the modeling results from Chapter 5 and Chapter 6 focused on evaluating the uncertainties involved in the different modeling components in the context of the PM hot-spot process. The two chapters will be combined to assess how the different modeling scenarios qualitatively compare with the near-road data in Chapter 7.

This chapter documents the researchers' efforts and findings from Task 4. Methods and Data section describes the methods and data inputs used for Task 4 for both the near-road monitoring stations followed by a discussion of the results obtained in Results section. Finally, the summary and next steps are provided in Summary section.

METHODS AND DATA

This section overviews the methods and data used for data exploration research conducted as part of Task 3. It overviews the methods followed by a description of the data. The different tools used for the analysis are also discussed in this section.

Methods

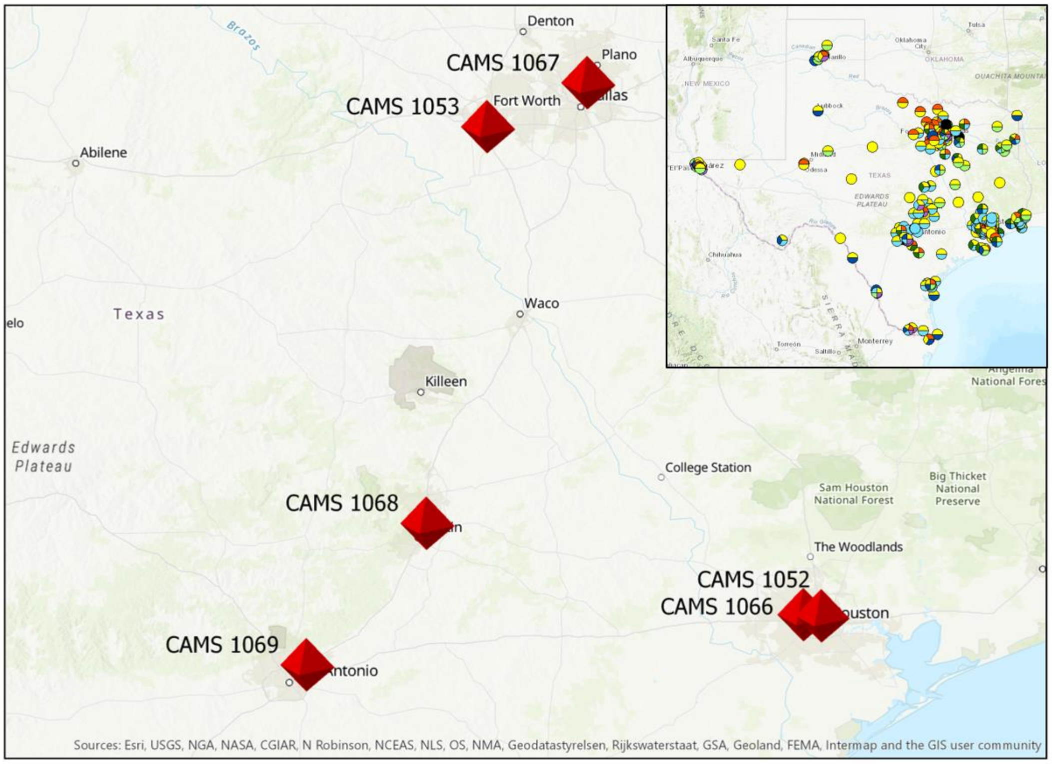
In Task 4, researchers performed a detailed assessment of the Houston and Fort Worth near-road monitoring stations for the year 2016 along with real-time onsite monitored meteorological variables and traffic activity data. The assessment focused on gaining a better understanding of the relationship and potential correlation between the near-road $PM_{2.5}$ concentrations for key factors related to traffic activity (volume, speed, fleet mix, time of day), meteorology (wind speed, wind direction, atmospheric stability), and background concentration.

The main objectives of Task 4 are to 1) analyze how the near-road concentration levels compare with the National Ambient Air Quality Standards (NAAQS), 2) examine the association between near-road concentrations, traffic activity parameters, and meteorological conditions, and 3) compare the near-road concentrations with surrounding ambient concentration levels, evaluate the difference between the two, and assess the near-road increment. The *near-road increment* refers to the contribution from traffic and is computed as a difference between the near-road concentration and the surrounding background concentration. The assessment is performed using statistical and data mining tools that helped characterize the trends and conditions that contributed to high near-road $PM_{2.5}$ concentration levels, influence of key parameters, and their interrelationships.

Data Acquisition

Near-Road Monitoring Data

In accordance to the Code of Federal Register [77], TCEQ installed 21 24-hour $PM_{2.5}$ FRM monitors and 47 continuous $PM_{2.5}$ monitors in 2015 and expected to expand the total number of FRM monitors to 25 throughout the state. Figure 6 shows the distribution of these monitors (6 out of the 25 are near-road monitors) in Texas.



Sources: Esri, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap and the GIS user community

Figure 10. Near-Road and Ambient Monitoring Stations in Texas.

Houston North Loop CAMS is located north of the I-410 Highway in Harris County, Texas, and was activated on April 13, 2015. Samplers at this site include CO, NO/NO_2/NO_x, $PM_{2.5}$, temperature, wind direction, wind speed, and peak wind gust. The distance of this site to the nearest traffic lane of I-410 is 15 m (approximately 49 ft), and the sampling probe height is 4 m above the ground. The monitor is located 1.5 miles west of a major I-610 and I-45 interchange.

Figure 11 shows the location of the Houston site. As visualized in Figure 11, predominant wind direction is from the southeast to northwest. The wind data indicated that the station was downwind of the highway emissions approximately 60 percent of the time.

The Fort Worth California Parkway North near-road emissions monitor is located at 1198 California Parkway North, TX, 76115. It has an elevation of 214.9 m from the sea level and currently monitors CO, NO_x including NO and NO_2, $PM_{2.5}$, temperature, wind speed, wind direction, and peak wind gust. The distance of this site to the nearest traffic lane of I-20 is 15 m (approximately 49 ft). As shown in Figure 12, predominant wind direction is from the southeast to northwest.

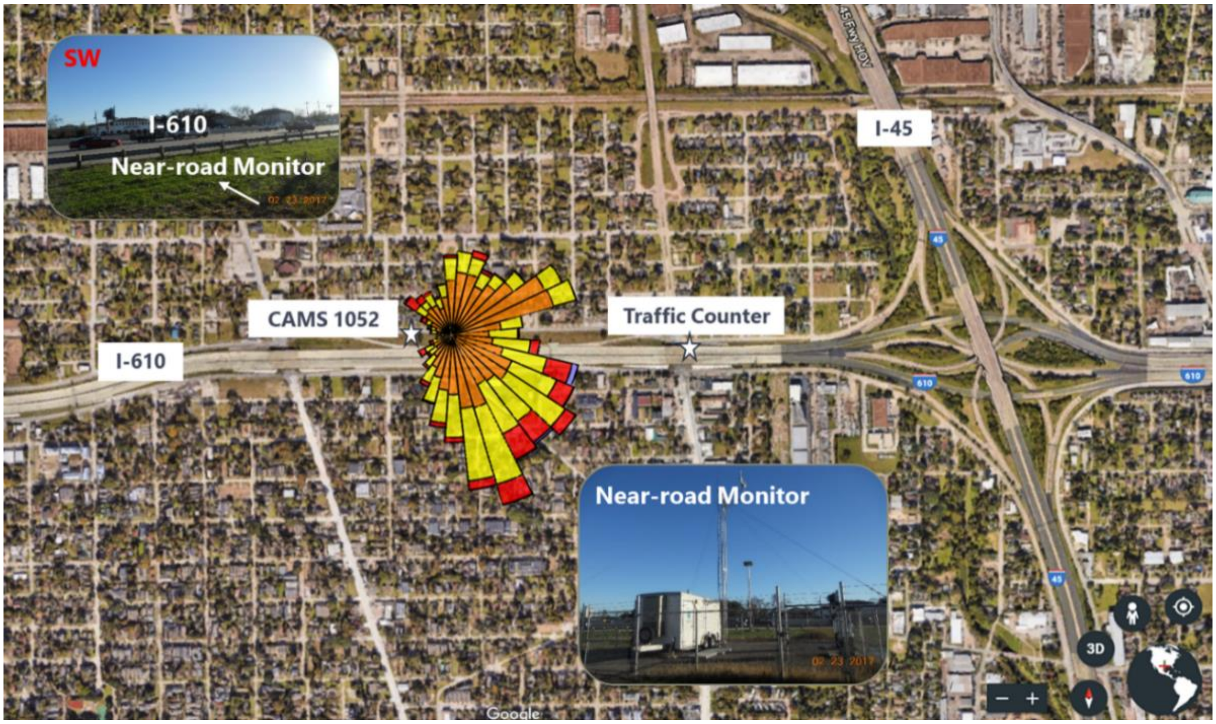


Figure 11. Location of Houston Near-Road Monitoring Station.

Figure 12. Location of Fort Worth Near-Road Monitoring Station.

Traffic Activity Data

Onsite traffic data were obtained from the TxDOT STARS-II traffic counter located close to the near-road monitoring stations. STARS II supports a broader range of traffic measurements, at increased spatial and temporal resolutions than are available within the federal HPMS. The STARS-II data are available through a public web browser provided to TxDOT by MS2 Transportation Traffic Analytics [81] using the Transportation Data Management System Software [82]. Data include traffic volume, vehicle classification, speed, and weigh-in-motion and are available in detail report (e.g., AADT by year, AADT by day of week by month for year, average hourly traffic by day of week for year) or in listing report formats (e.g., AADT by day of week by direction for month or year). The parameters used for data exploration include AADT, traffic speed, fleet mix, and FE-AADT. FE-AADT is calculated as follows:

$$\text{FE AADT} = (\text{AADT} - \text{HD counts}) + (\text{HD counts} * 10)$$

The “10” value in the equation is the Heavy Duty (HD) to Light Duty vehicle NO_x emission ratio. This is based on an interpretation of NO_x emission factors from EPA’s regulatory MOVES model using national defaults [83].

Traffic data were obtained from the TxDOT counters (Figure 13) located on I-610 (westbound STARS-II ID - 102SP157WBSR and eastbound STARS-II ID - 102SP157EBSR). These counters are located at about 130 m south of the Houston near-road monitor (CAMS 1052). Hourly estimates of traffic volume for 2016 for each direction of the highway were used. Fleet mix data were also obtained from a TxDOT traffic counter (STARS-II ID HP852) located 1.2 miles west of the near-road monitoring station. The fleet mix data were available only for 2015 and are used assuming the same fleet mix for the analysis year of 2016. In case of Fort Worth near-road monitoring station, the closest traffic counter (STARS-II ID S297) is located 5 miles away as shown in Figure 14. Due to the lack of any traffic counters near the Fort Worth site, the counter located 5 miles is used for the data exploration effort.

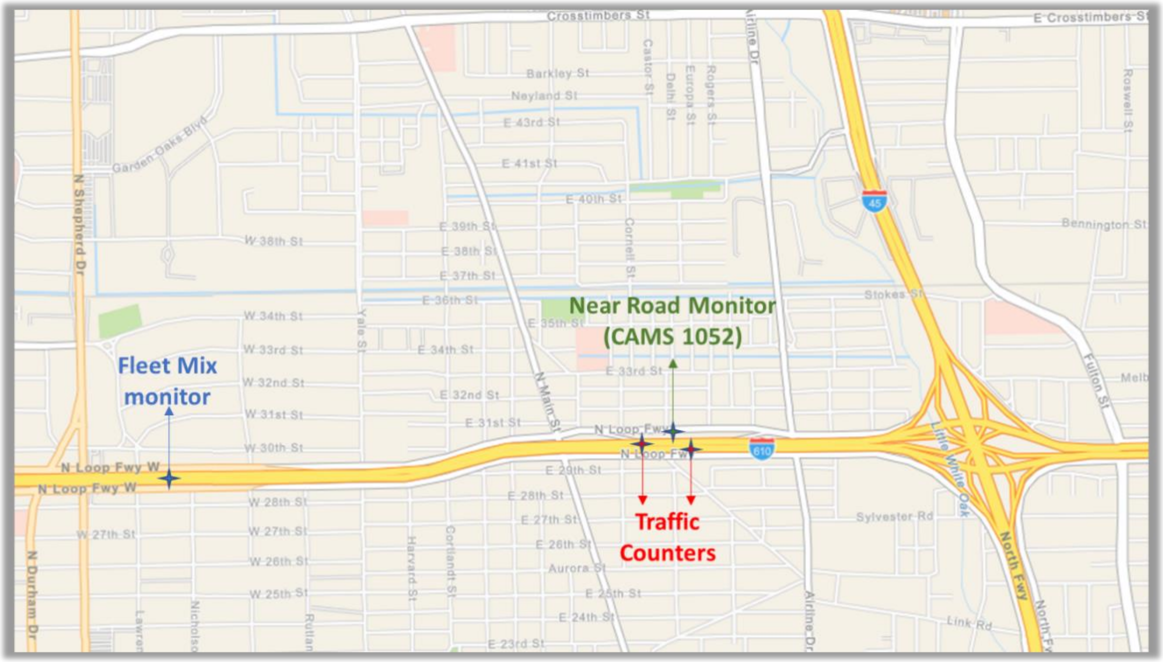


Figure 13. Location of TxDOT (STARS-II) Traffic Counters near Houston Monitor.

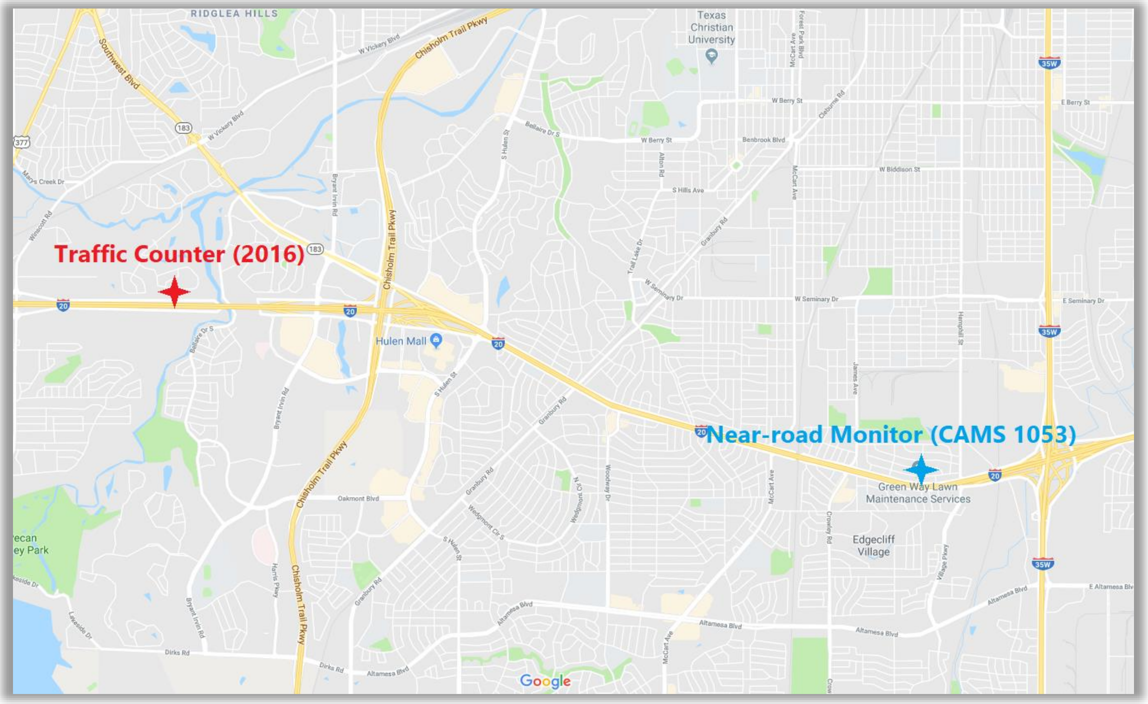


Figure 14. Location of TxDOT (STARS-II) Traffic Counter near Fort Worth Monitor.

Meteorological Data

On-site meteorological parameters measured at the near-road monitoring station included wind speed, direction, dry bulb temperature, and relative humidity. Atmospheric stability, which is a key factor influencing the mixing and dilution of pollutants, is obtained from processing the surface and upper air data using AERMET, AERSURFACE, and AERMINUTE tools (*24*). The range of wind direction was divided into downwind and upwind categories. The wind direction in the range between 90^{o}–180^{o} and 180^{o}–270^{o} is classified as downwind and between 0^{o}–90^{o} and 270^{o}–360^{o} is classified as upwind. For Houston site, surface data were obtained from the International Airport of Houston (IAH), and upper air data were obtained from Lake Charles (LCH). For Fort Worth site, surface data were obtained from Fort Worth Meacham Airport (KFTW) and upper air data were obtained from Fort Worth upper air station (FTW). Detailed description of the meteorological data processing is provided in Chapter 6.

Background Concentration Data

Background concentrations (BC) include pollutant concentrations occurring due to area-wide or regional sources. BC data are obtained from the surrounding ambient monitoring stations located upwind and near the near-road monitoring stations. Four ambient monitoring stations (CAMS 1, 35, 403, and 416) within a 20-mile distance are used as shown in Figure 15. The wind patterns are quite similar between the near-road and other CAMS stations southeast to CAMS 1052. However, for the Clinton station (C403), wind pattern is dominated more in southwest direction.

This may be due to a possible drainage northwest-southeast that exists between Houston metropolitan area and Galveston Bay by the Gulf of Mexico.

Background concentrations for the Fort Worth near-road monitoring station was obtained from two ambient monitoring stations, Midlothian OFW (CAMS 52), Denton Airport South (CAMS 56), and Haws Athletic Center (CAMS 310) located within a radius of 20 miles from CAM1053. The wind patterns for CAMS 52 and CAMS 56 ambient stations are similar to that of CAMS 1053 as shown in Figure 16. CAMS 310 station does not record meteorological data. The BC data are used to determine the near-road $PM_{2.5}$ increment computed as the difference between the near-road concentrations and the background concentration. Chapter 5 provides a detailed description of the background concentration data processing.

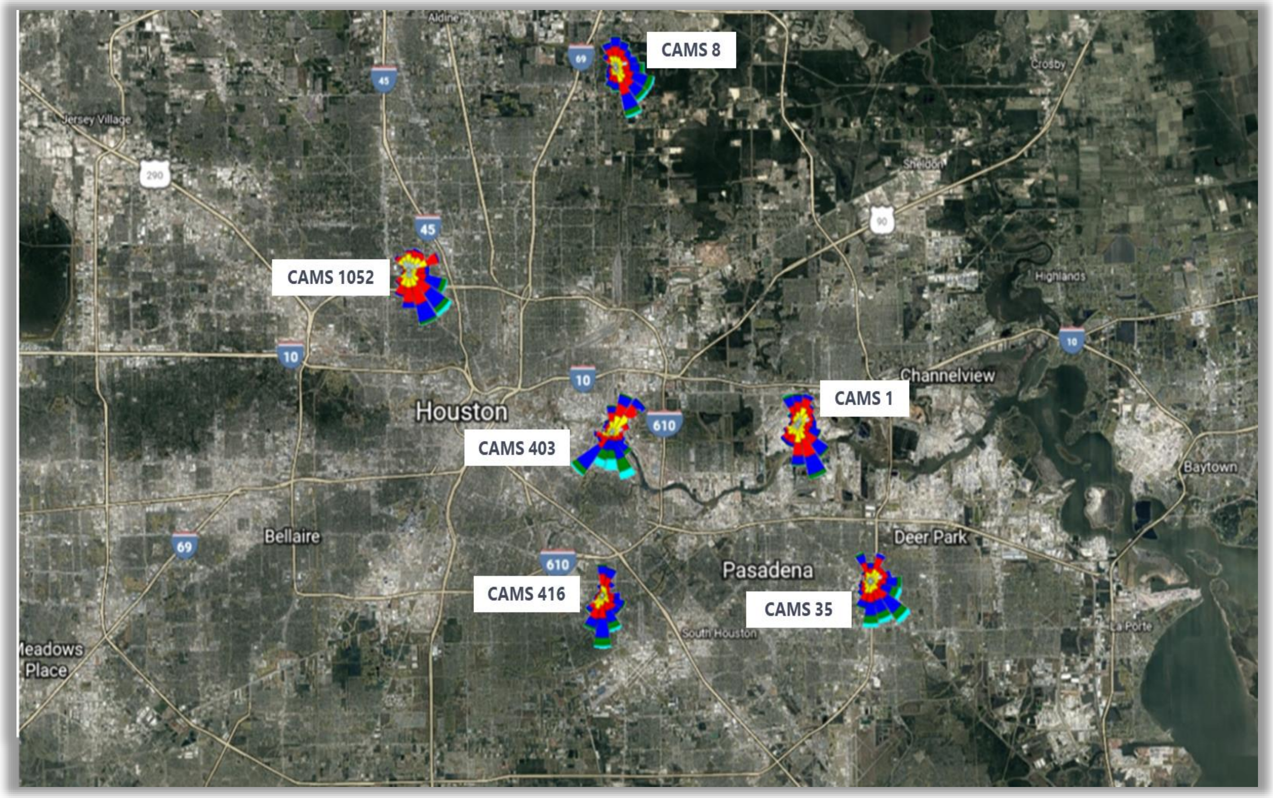


Figure 15. Ambient Monitoring Stations Surrounding Houston Near-Road Monitor.

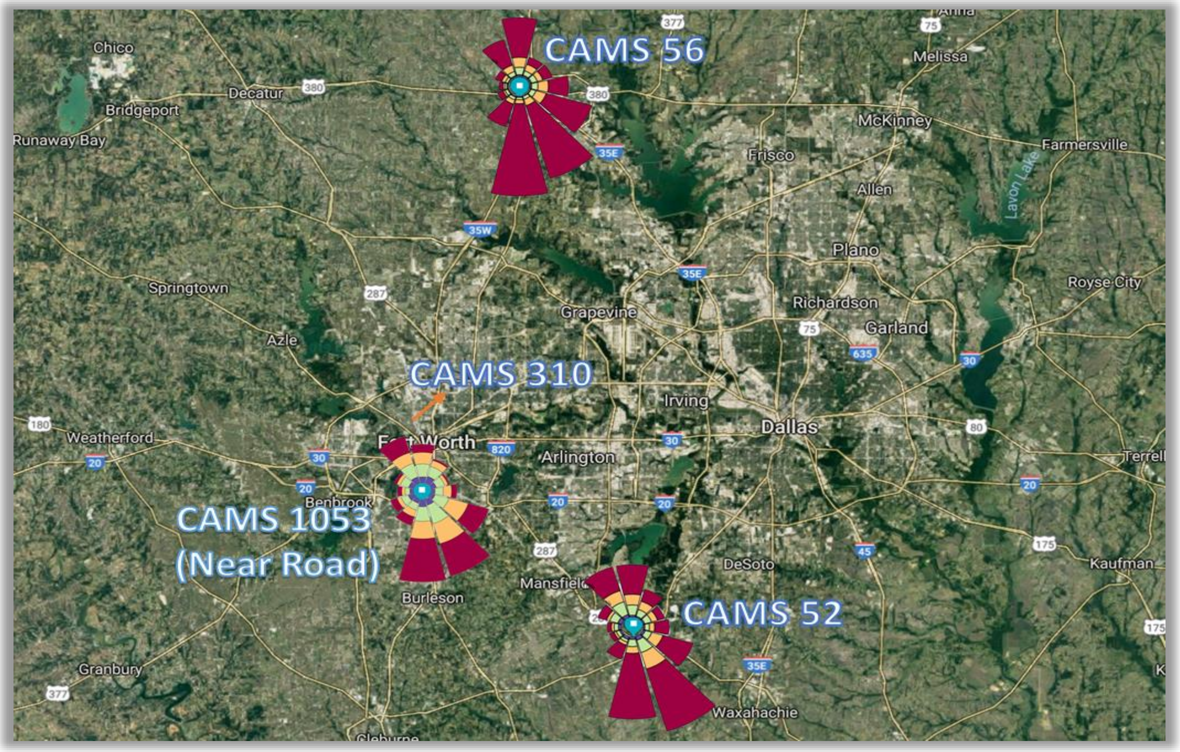


Figure 16. Ambient Monitoring Stations Surrounding Fort Worth Near-Road Monitor.

Tools and Methods

Data analytics tools were used to analyze, summarize, and compare data. Descriptive methods are used to describe and analyze the data. These methods include frequency, measures of central tendency represented by the mean, median, and mode, and percentages showing the proportioning of the data. Methods such as correlation and regression are used to describe the relationship between different variables and the direction and strength of the relationship. Correlation matrices are used to analyze the relationship between multiple variables. Power BI (Business Intelligence) was used to clean and combine the data from different sources and relational databases were established. Initial data exploration and visualizations were performed inside Power BI to identify the bivariate relationships between different variables. The ‘openair’ package for R was used inside Power BI to generate advanced visualizations such as wind roses and polar plots to evaluate multivariate relationships.

RESULTS

This section presents the results and findings from the data exploration effort. It discusses the distribution of near-road concentrations followed by an assessment of the near-road data with meteorology, near-road data with traffic, and near-road data with background concentration. Because the focus of this study is the $PM_{2.5}$ emissions, a detailed assessment is provided for $PM_{2.5}$. Other pollutants were evaluated at lower level of details.

Distribution of Near-Road Pollutants

The near-road monitoring data were compared with the NAAQS levels. This comparison is for only research purposes and not meant to assess or verify attainment status as designated by EPA. The near-road sites investigated in this study do not have sufficient data to determine whether a NAAQS violation may have occurred. NAAQS calculations require three years of valid monitoring data.

Figure 17 and Figure 18 show the distribution of NO_2, CO, and $PM_{2.5}$ in the form of a frequency distribution and box plot where the red dotted lines indicate the NAAQS levels. Based on the data for 2016, both Houston and Fort Worth site do not appear to have high concentrations at a frequency enough to violate the NAAQS.

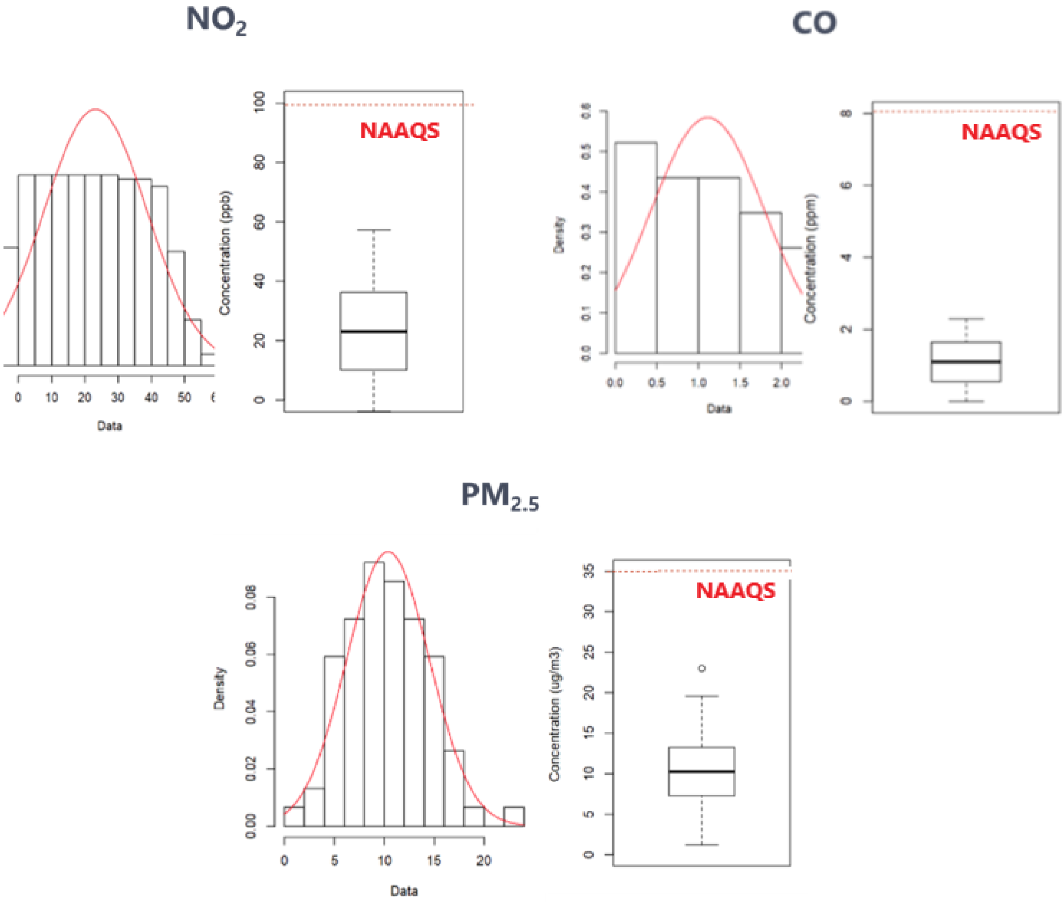


Figure 17. Relative Frequency and Statistics of Air Pollutants Monitored at Houston Site.

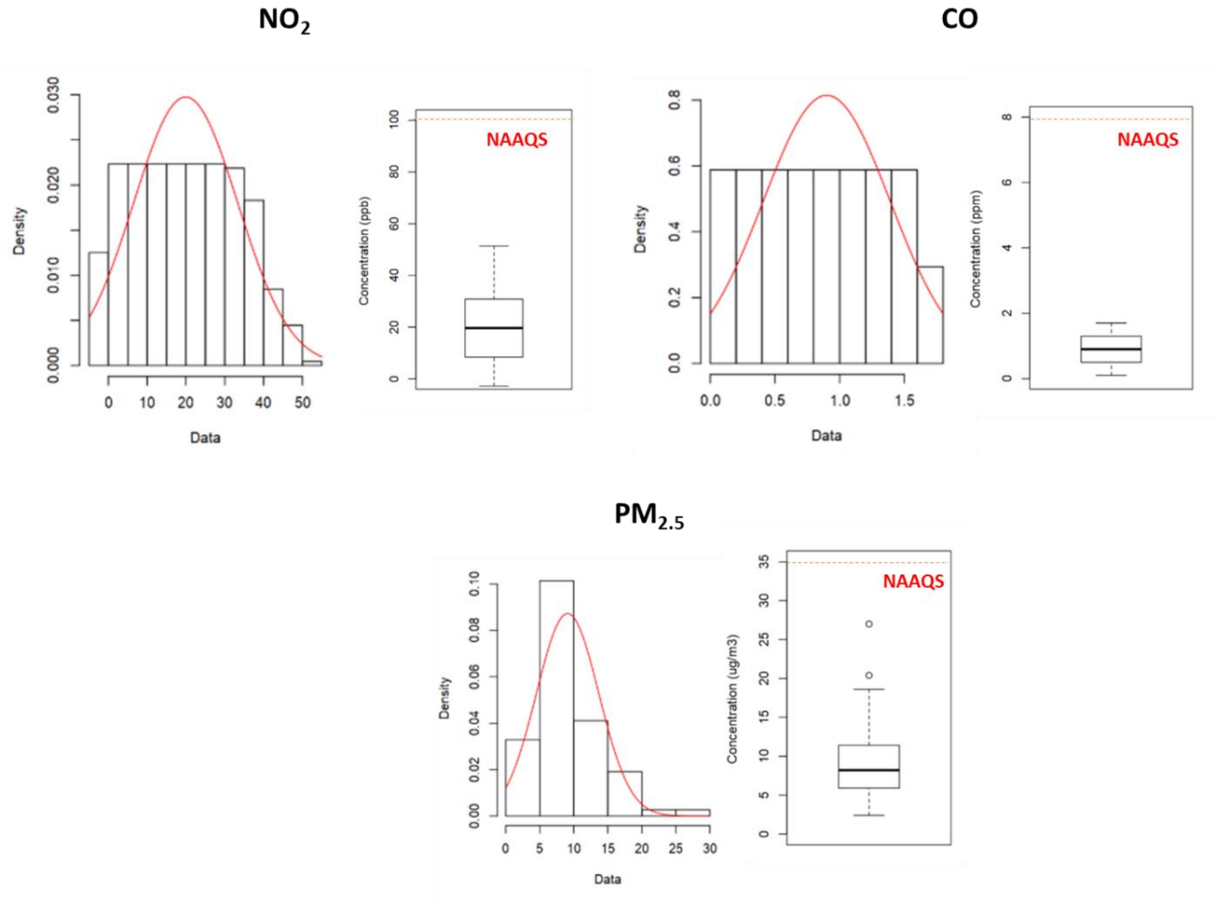


Figure 18. Relative Frequency and Statistics of Air Pollutants Monitored at Fort Worth Site.

Near-Road Concentration and Meteorology

Meteorology has a strong impact on the pollutant dispersion. Researchers evaluated the influence of key meteorological parameters on near-road concentrations. Figure 19 shows the wind rose plot that represents the frequency of occurrence of wind direction and wind speed categories for both near-road stations. The predominant wind direction for both stations is from the southwest to northeast, and both stations are downwind of the highway emissions for more than 50 percent of the time based on the data collected for 2016.

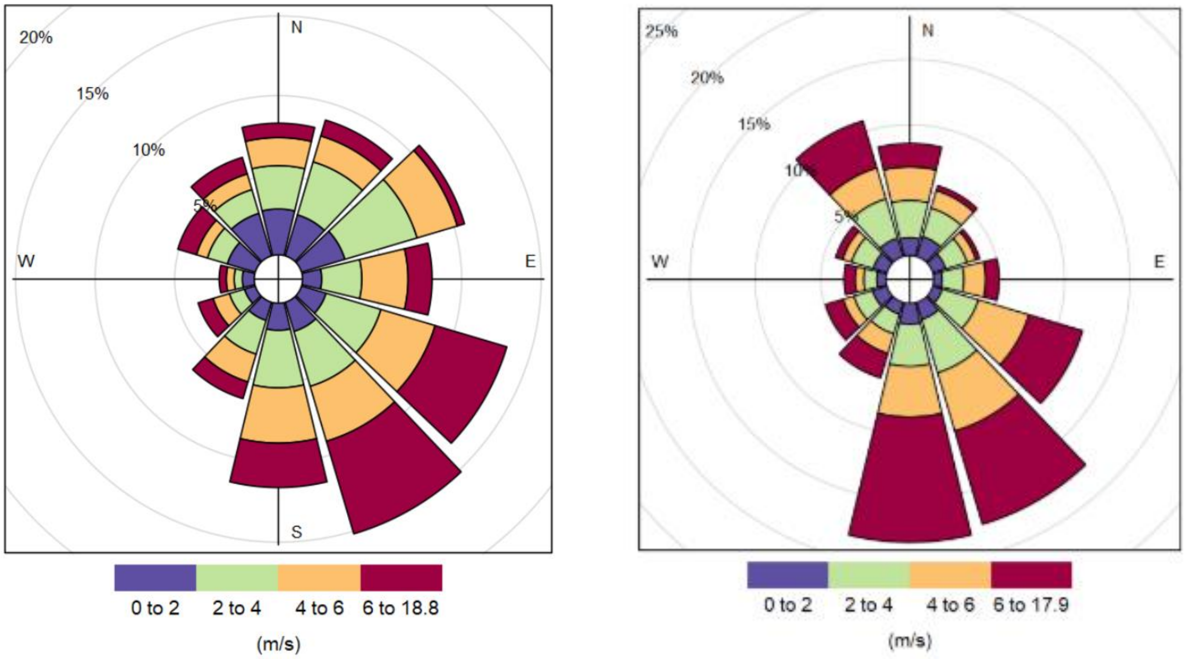


Figure 19. Wind Rose for a) Houston Site; b) Fort Worth Site

Polar concentration plots that present the frequency of occurrence of pollutant concentrations categorized by wind direction and wind speed for CO, NO_2, and $PM_{2.5}$ are shown in Figure 20 and Figure 21 for Houston and Fort Worth sites, respectively. For the Houston site, high CO concentrations were observed when the station was downwind of the traffic emissions, with the highest observed when winds are blowing from the southeast. Ninety-six percent of highest NO_2 readings occurred when the station was downwind from the highway and further NO_2 peaking observed during evening peak hours (4–10 p.m.). Compared to CO and NO_2, $PM_{2.5}$ is more distributed in the southeast and southwest quadrant, which implies there could be other factors influencing its distribution. Peaking for all the pollutants are found to occur during wind speeds lower than 5 mph.

For the Fort Worth site, high NO_2 and CO concentrations are also observed during low wind conditions (wind speed lower than 5 mph) and to some extent in the predominant direction as shown in Figure 21. However, unlike the Houston site, a clear indication of majority of high concentrations occurring when the station is downwind of highway emissions is not observed with the Fort Worth site. For $PM_{2.5}$, peak concentrations are observed in the predominant southeast direction when the winds are blowing over the highway in contrast to the Houston site, indicating traffic could be a contributor of $PM_{2.5}$ at the Fort Worth site.

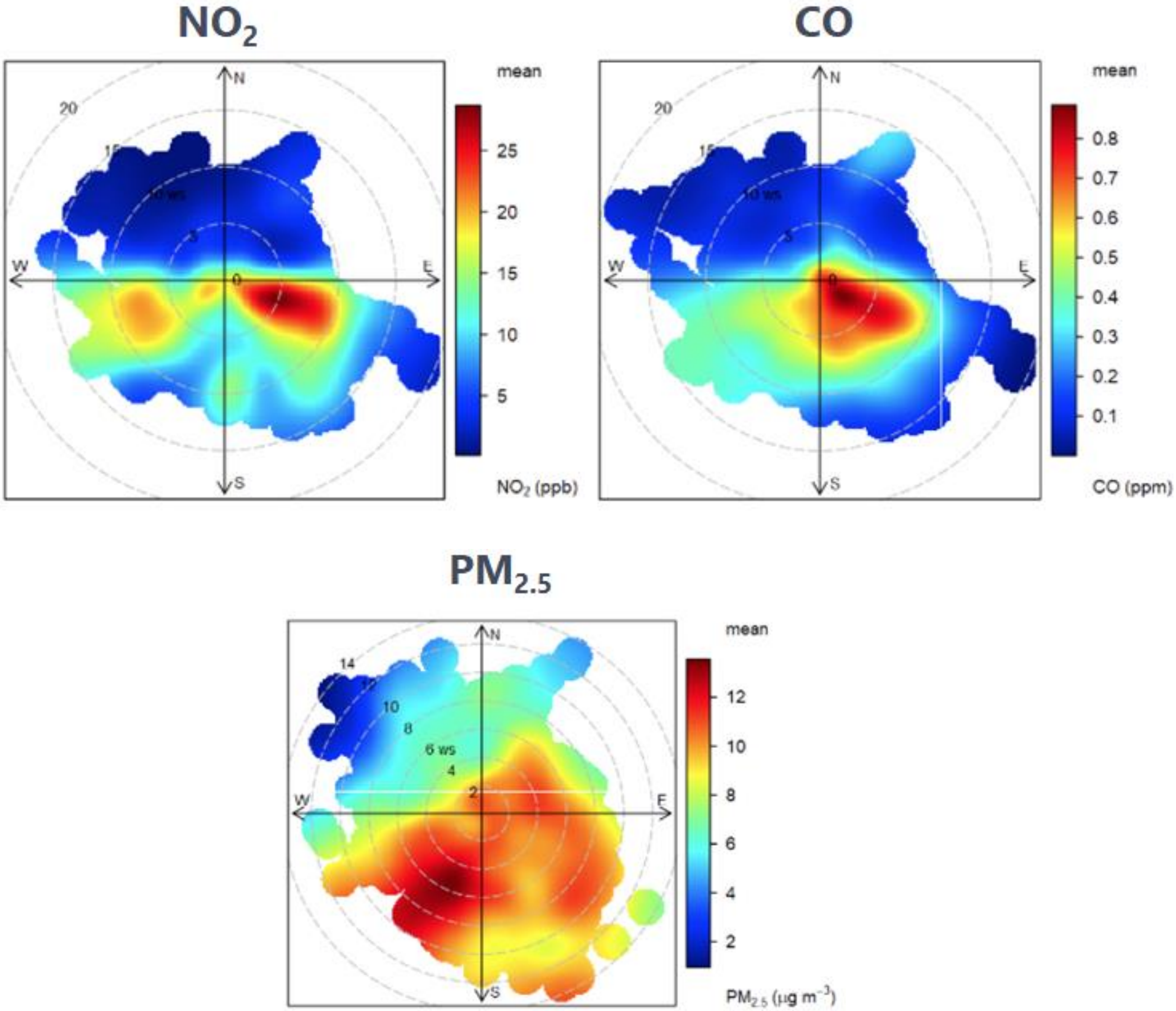


Figure 20. Polar Concentration Roses for Houston Site.

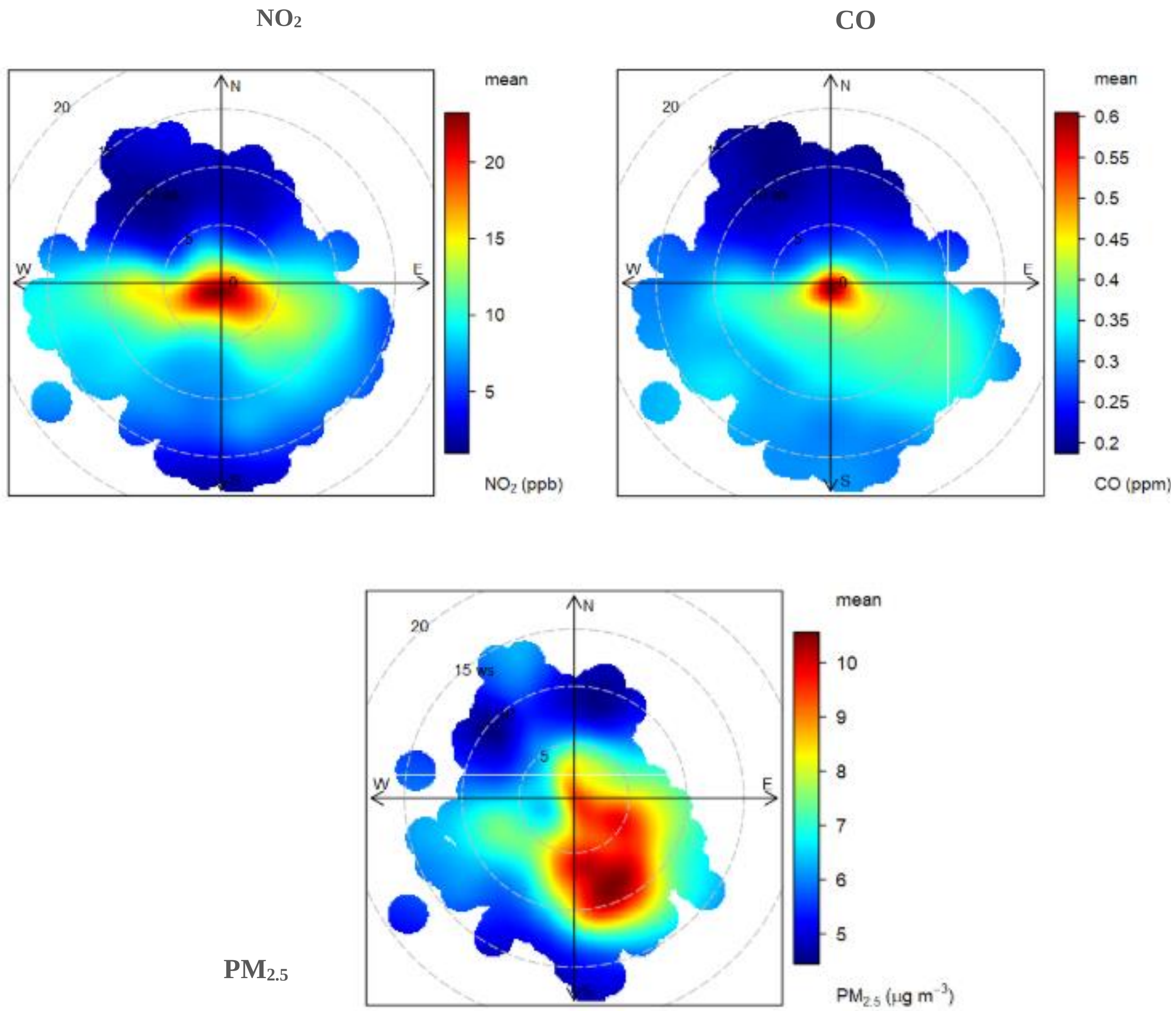


Figure 21. Polar Concentration Roses for Fort Worth Site.

Atmospheric stability affects the dispersion of vehicle emissions downwind of the roadways and is governed by heat and momentum forces in the environment. Atmospheric stability is classified into unstable (convective conditions), stable (low transport and dispersion), and neutral (in-between). AERMOD uses a continuous function called Monin-Obukhov length to characterize atmospheric stability. The three categories of stability represented as a function of the Monin-Obukhov length are defined as follows:

- Extremely unstable (0 to −100 m).
- Unstable (−100 to −105 m).
- Stable (0 to 105 m), and neutral (greater than 105 m).

Figure 22 shows the hourly distribution of atmospheric stability classes for the Houston site. The near-road $PM_{2.5}$ concentration trends that were monitored for the highest 10 days in 2016 were compared to the corresponding trends of the hourly BC and atmospheric stability conditions as shown in Figure 23. This trend comparison suggests that although high concentration levels seem to correspond with stable conditions, a clear trend is not observed between the parameters.

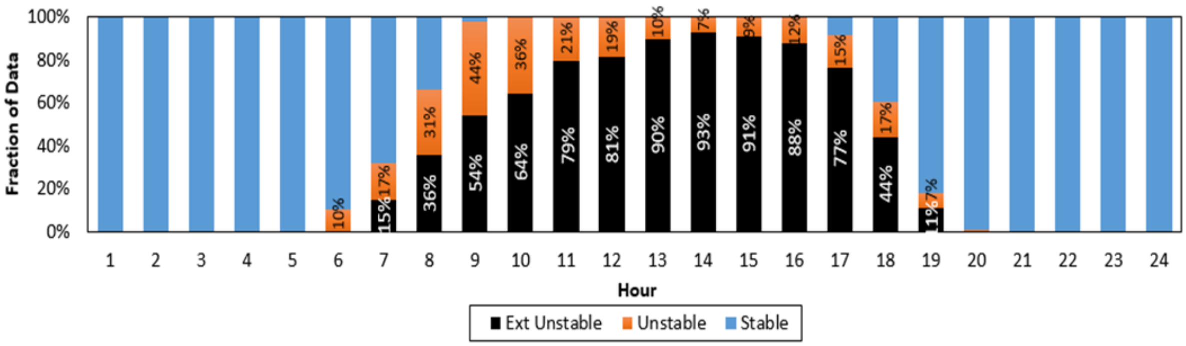


Figure 22. Distribution of Atmospheric Stability Classes for Houston Site.

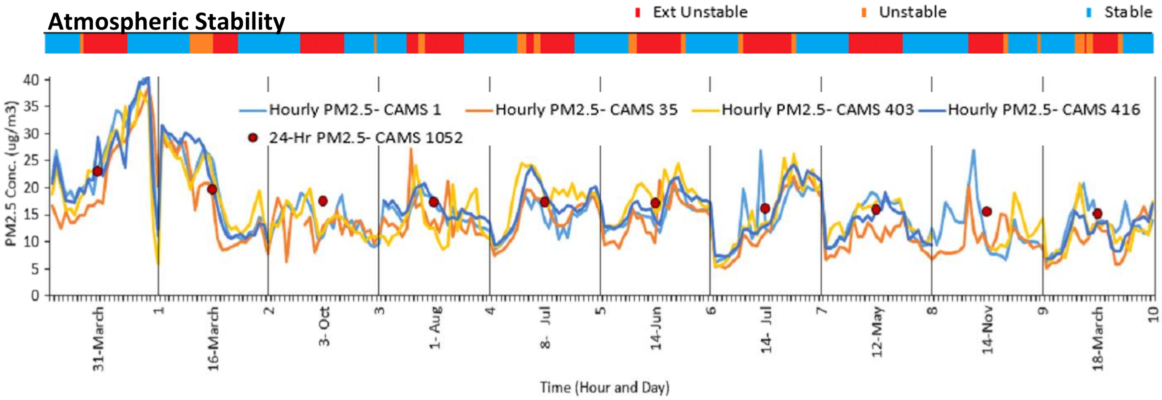


Figure 23. Variation of Houston Near-Road $PM_{2.5}$ with Atmospheric Stability and Background Concentration.

Near-Road Concentration and Traffic Activity

The near-road $PM_{2.5}$ concentrations are evaluated against AADT, FE-AADT, and number of trucks as shown in Figure 24. High $PM_{2.5}$ concentration values (i.e., greater than 15 ug/m^3) are observed when AADT value is about 200,000 or FE-AADT is 300,000 (corresponding to 12,000 truck AADT). The very low R^2 obtained from linear regression plots indicate a weak correlation between near-road $PM_{2.5}$ and traffic metrics. A similar trend was observed for Fort Worth site with a low R^2 value and high $PM_{2.5}$ concentrations at AADT above 100,000 vehicles as shown in Figure 25. Due to the lack of data on vehicle classification, variation of the near-road concentrations at Fort Worth site is presented only for AADT.

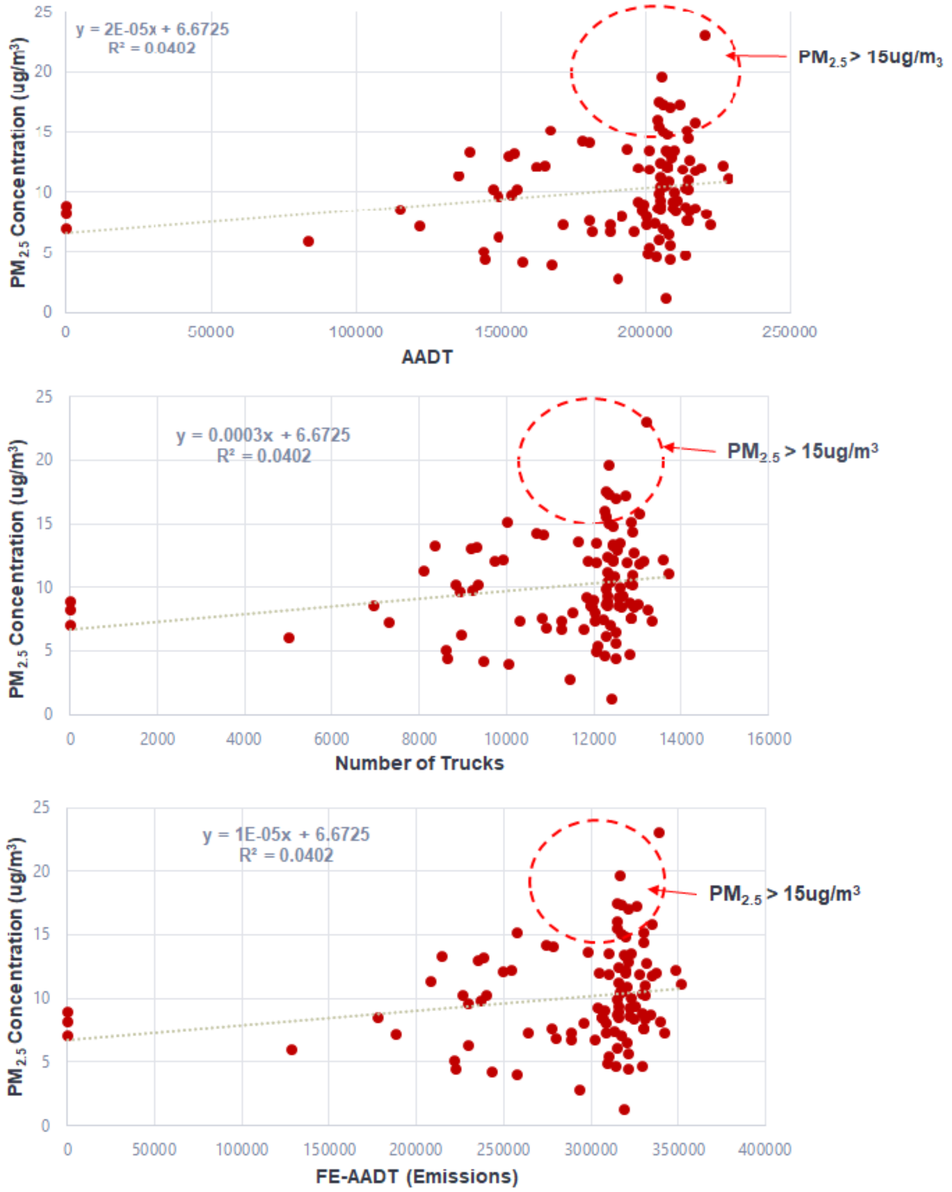


Figure 24. Variation of Near-Road PM$_{2.5}$ with Traffic Activity for Houston Site.

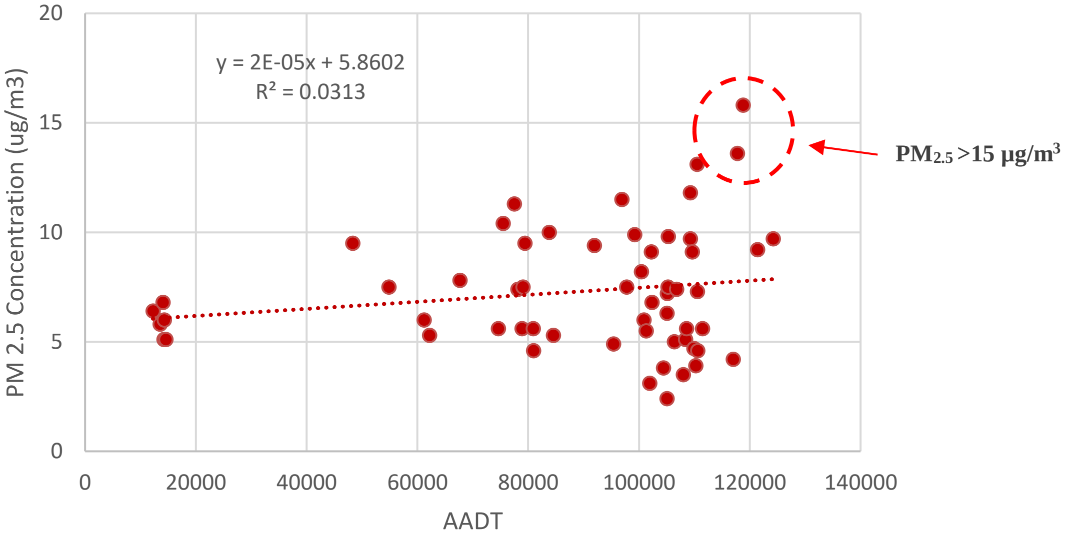


Figure 25. Variation of Near-Road $PM_{2.5}$ with Traffic Activity for Fort Worth Site.

A very slight increase in R^2 is found when the near-road increment is combined with AADT (Figure 26), which indicates a minor influence of traffic activity on the near-road measurements for the Houston site. But no such increase in R^2 is noted for the Fort Worth site. The traffic counter is located relatively far from the near-road monitor.

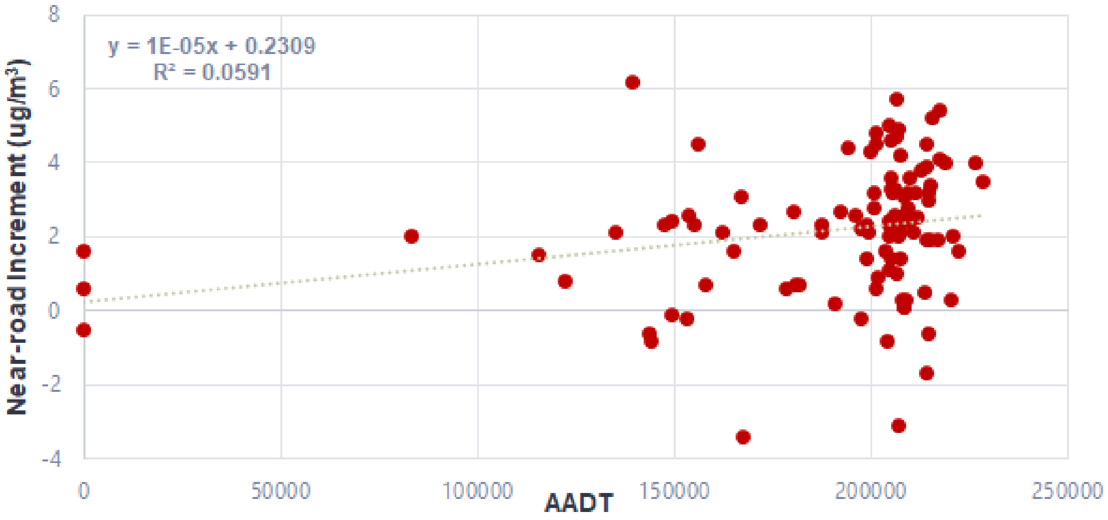
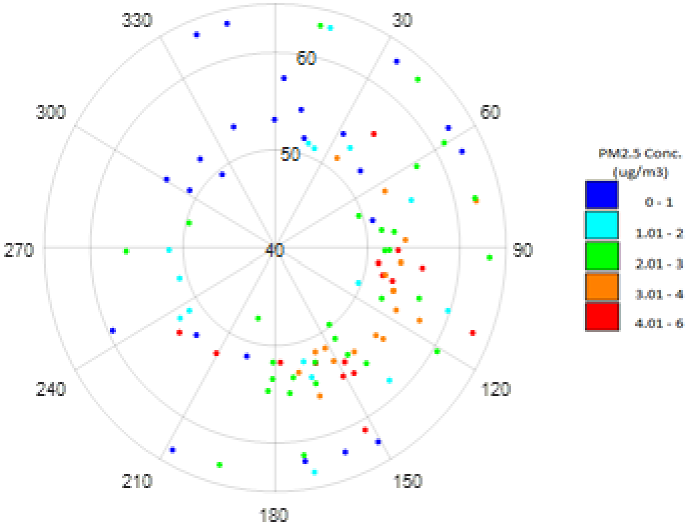


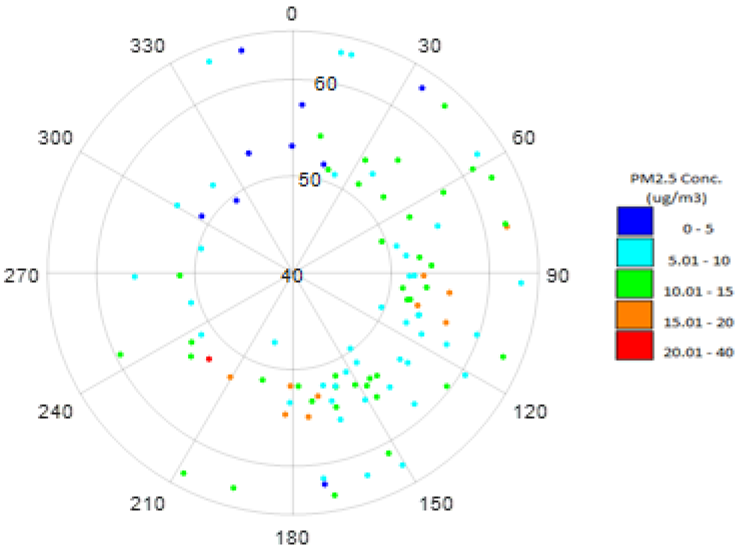
Figure 26. Variation of Near-Road $PM_{2.5}$ Increment with Traffic Activity for Houston Site.

As seen in both Figure 25 and Figure 26, data points are found to cluster around AADT of around 200,000 indicating a low day-to-day variation level of traffic activity. The weak correlation presented here is consistent with the findings from DeWinter et al. [51].

Evaluation of traffic speed is performed only for the Houston site due to the lack of speed data for Fort Worth site. Figure 27 shows variation of near-road $PM_{2.5}$ and near-road increment $PM_{2.5}$ with traffic speed through concentration roses where the dots with different colors represent $PM_{2.5}$ concentrations of varying magnitude, and the quadrants represent the wind direction, and the circles represent traffic speed obtained from the traffic counter. Similar to the traffic volume, high $PM_{2.5}$ values are found to cluster around traffic speed ranging between 50 to 60 mph. The near-road $PM_{2.5}$ concentration data used in this study are 24-hour averages. It is expected that a data set with a higher time resolution (e.g., hourly records) would better explain the potential effect of influential variables.



Near-road $PM_{2.5}$



Near-road Increment

Figure 27. Variation of Near-Road and Near-Road Increment $PM_{2.5}$ with Traffic Speed.

Near-Road and Background Concentrations

Figure 28 and Figure 29 compare near-road $PM_{2.5}$ to that measured at other regional stations for Houston and Fort Worth sites, respectively. The regional monitoring stations record the $PM_{2.5}$ concentrations in hourly averaged format. The near-road $PM_{2.5}$ concentrations are found to exhibit a strong similarity with various regional CAMS stations with R^2 ranging from 0.83 to 0.91. This finding is in line with other studies that found the near-road concentrations to be dominated by background concentrations.

Figure 30 and Figure 31 show a timeseries of the 24-hour $PM_{2.5}$ concentrations at near-road stations and at the hourly data from other regional stations for the same day. The 24-hour averaged $PM_{2.5}$ concentrations obtained at both the near-road stations exhibits a strong similarity to the regional CAMS stations. However, both near-road monitors are found to measure higher $PM_{2.5}$ concentrations compared to the surrounding ambient monitoring stations. Researchers calculated an average near-road increment of 1.98 $\mu g/m^3$ or 19.39 percent and 0.54 $\mu g/m^3$ or 6.5 percent for the Houston and Fort Worth sites, respectively. These near-road increments are comparable with the average near-road increment of 15 percent estimated by DeWinter et al. [51] and less than 22 percent increment reported by Karner et al. [5].

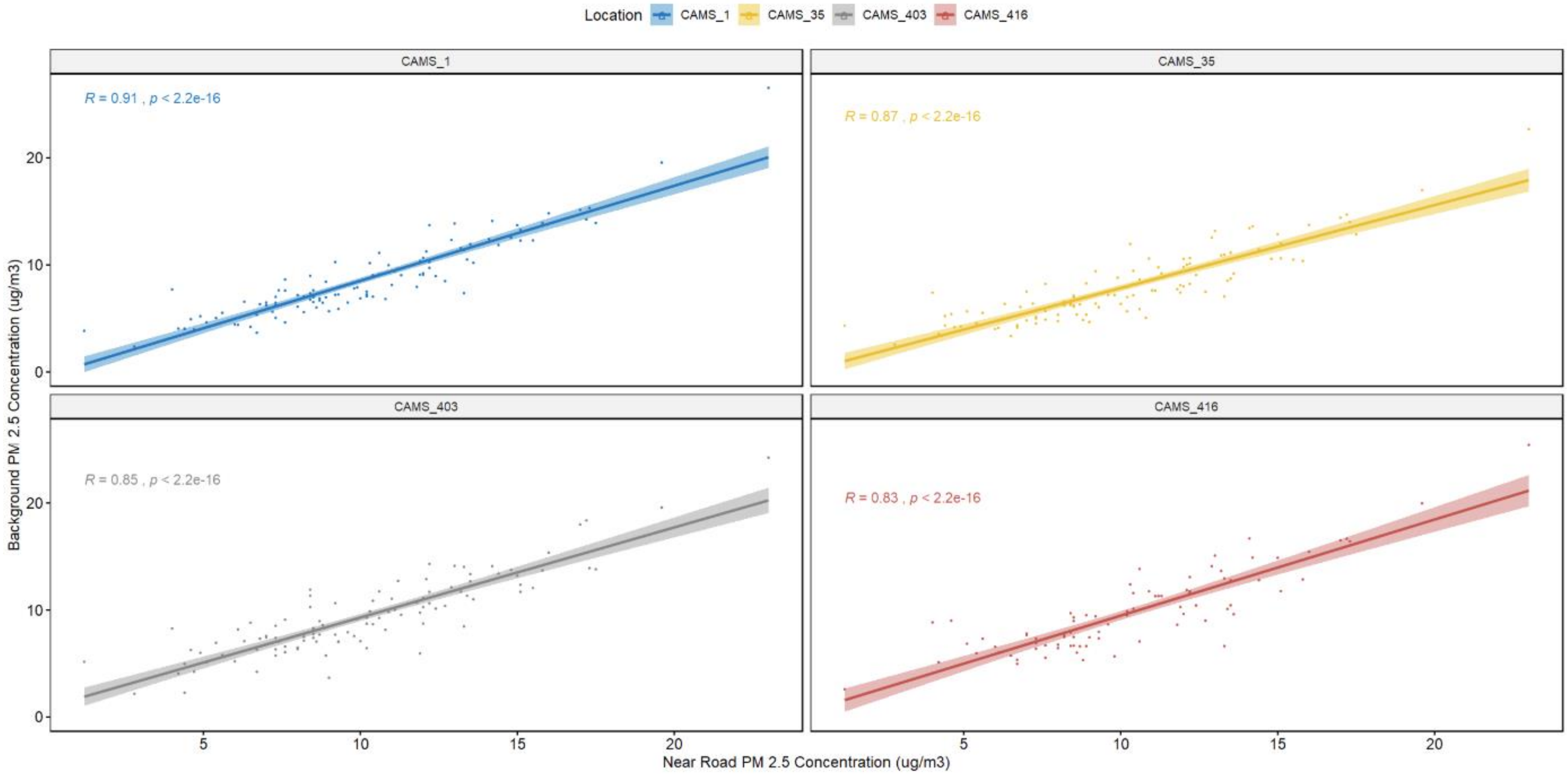


Figure 28. Variation of Near-Road $PM_{2.5}$ with Background Concentration at Houston Site.

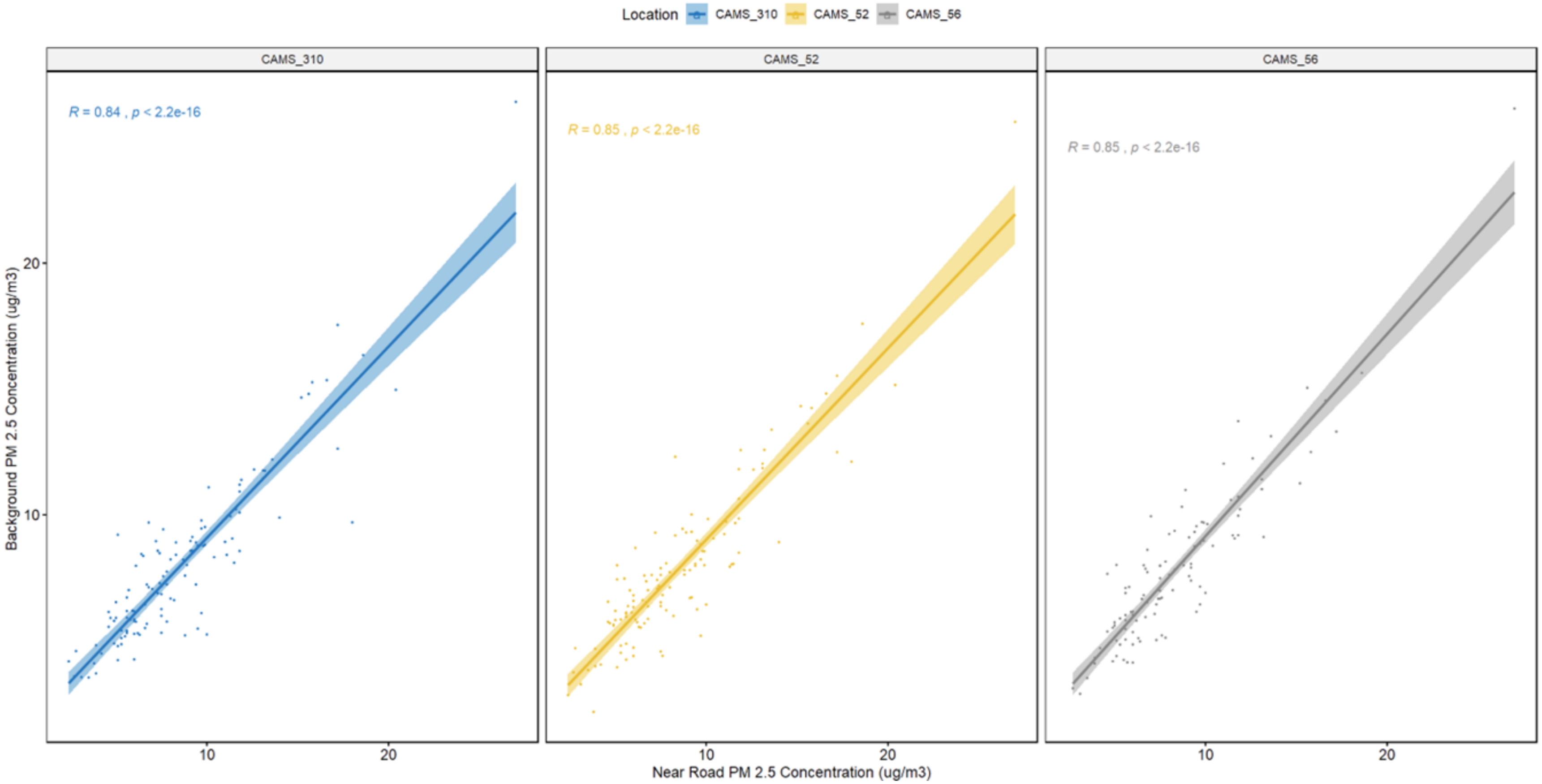


Figure 29. Variation of Near-Road $PM_{2.5}$ with Background Concentration at Fort Worth Site.

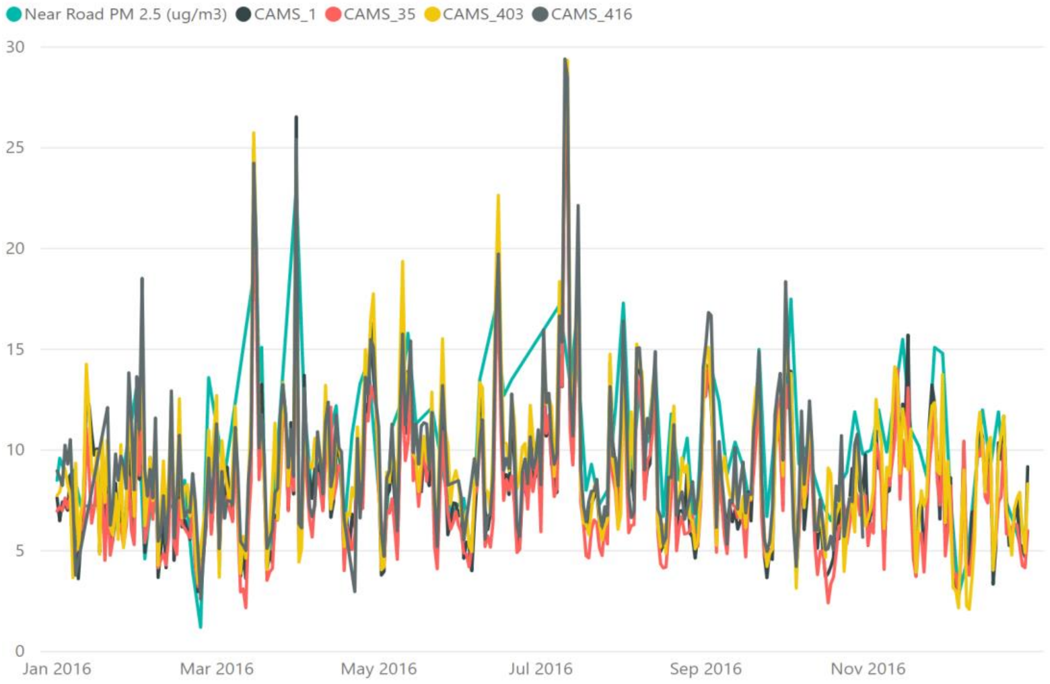


Figure 30. Comparison of 24-Hour $PM_{2.5}$ Concentrations at Houston Site to that Measured at Other Regional Stations.

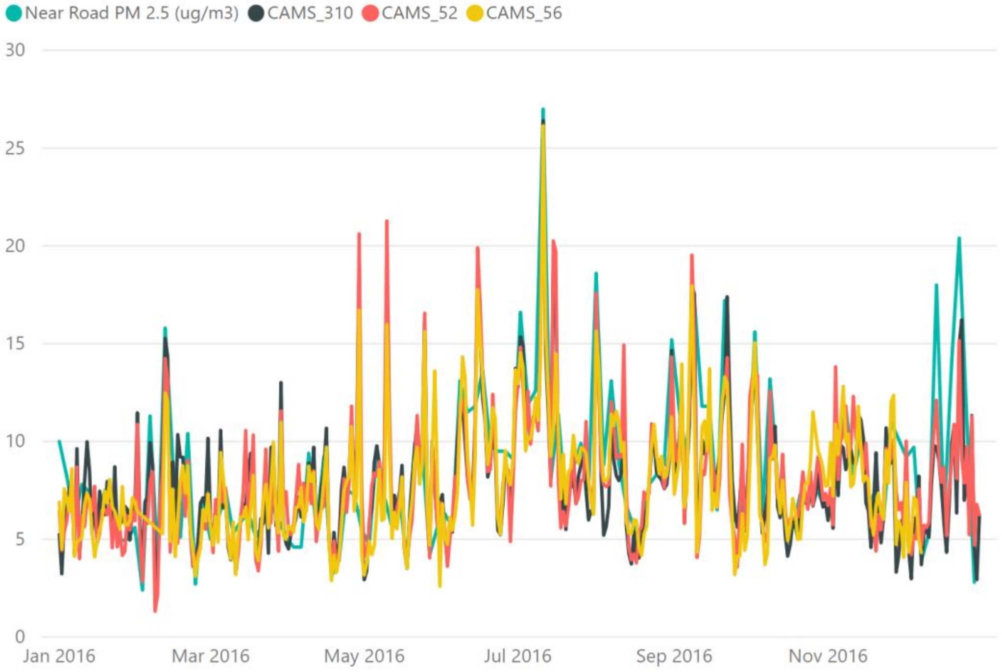


Figure 31. Comparison of 24-Hour $PM_{2.5}$ Concentrations at Fort Worth Site to that Measured at Other Regional Stations.

Correlation Matrix

A correlation matrix is developed for near-road $PM_{2.5}$ concentrations that are categorized by wind direction categories. The wind direction in the range between 90^o–180^o and 180^o–270^o are classified as downwind and between 0^o–90^o and 270^o–360^o are classified as upwind. The matrix represents the correlation between variables and each cell in the matrix represents the strength of the correlation.

Figure 32 and Figure 33 show the correlation matrix for $PM_{2.5}$ against key parameters categorized by upwind and downwind directions for Houston and Fort Worth sites, respectively. Unlike CO and NO_2 where different parameters are identified as influential under different wind direction conditions, only background concentration is found to have an impact on $PM_{2.5}$ in both wind directions. This indicates a very strong correlation between near-road $PM_{2.5}$ and regional background concentrations.

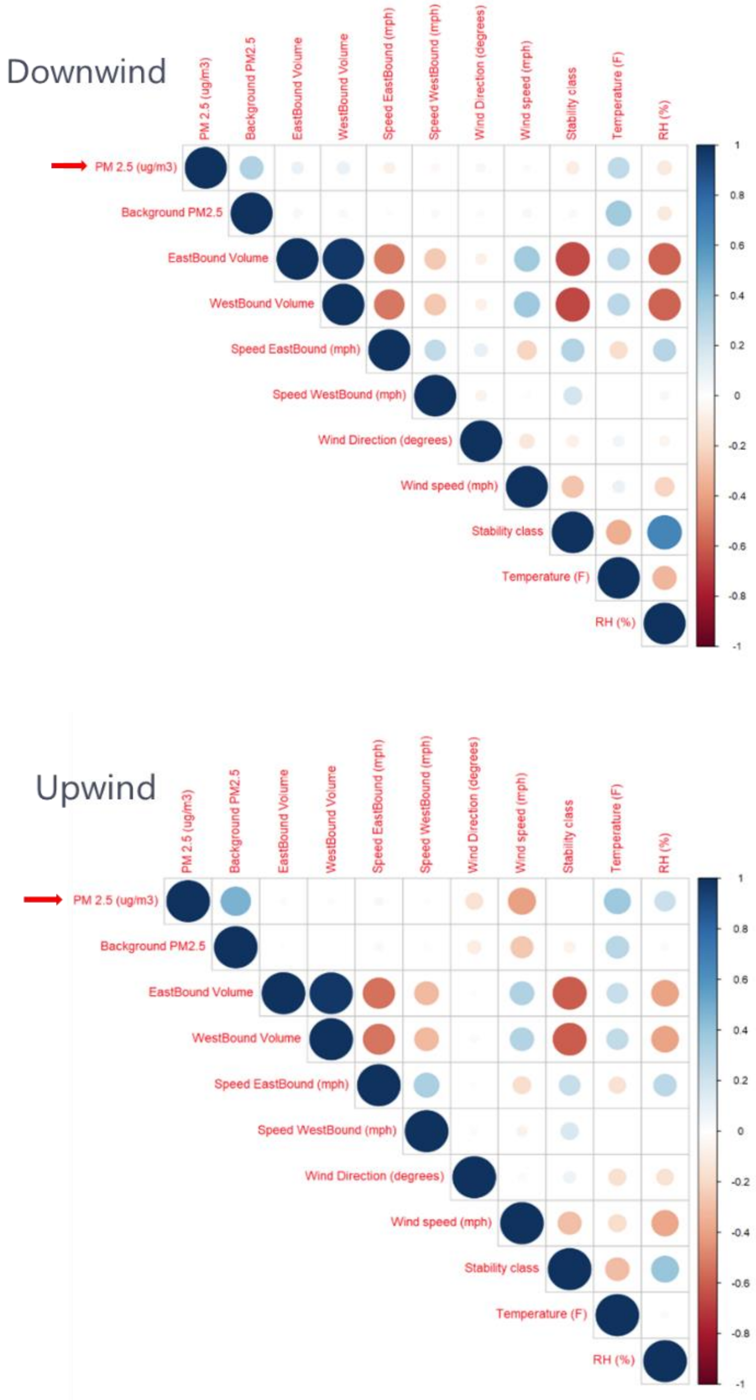


Figure 32. Correlation Matrix for $PM_{2.5}$ for Houston Site.

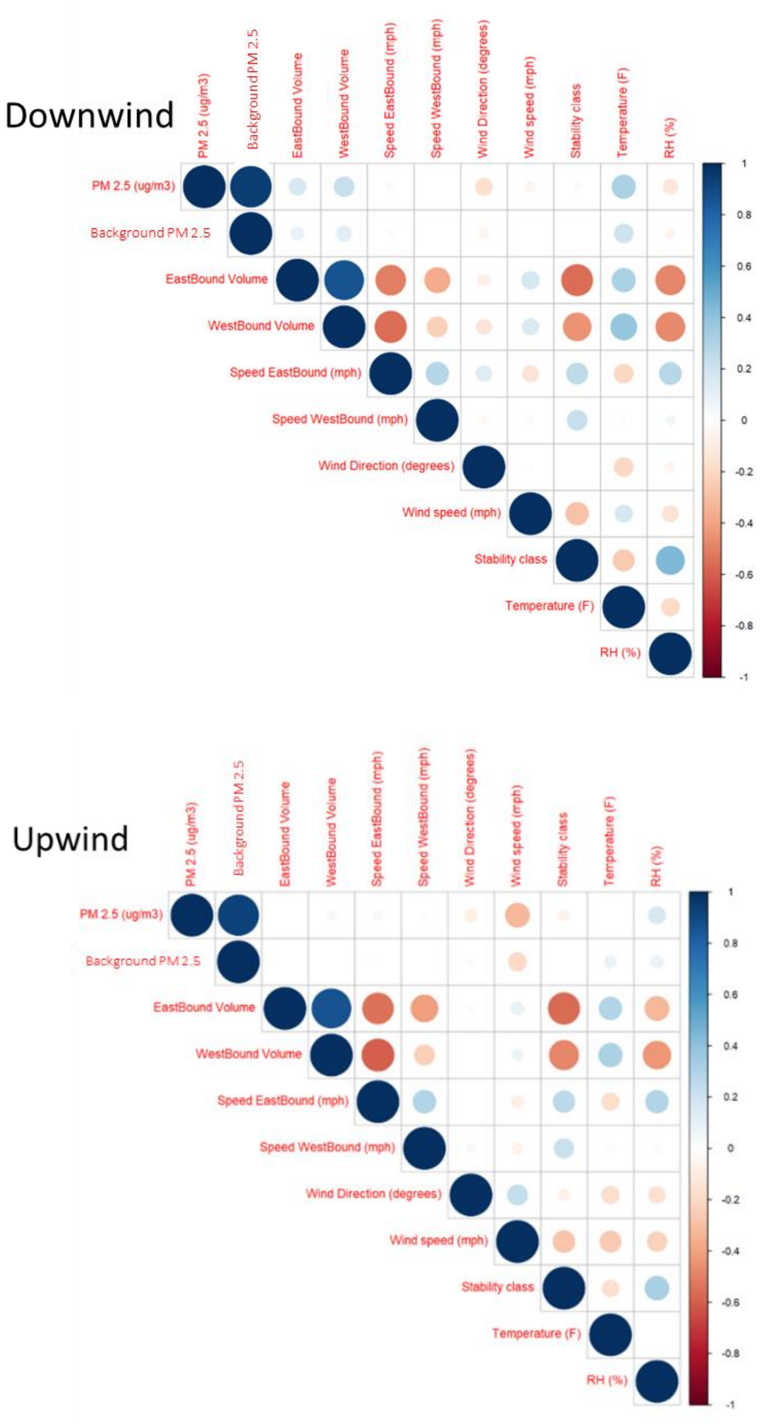


Figure 33. Correlation Matrix for $PM_{2.5}$ for Fort Worth Site.

SUMMARY

A comprehensive analysis was performed to evaluate the near-road monitoring data for key meteorological, traffic, and background concentration data. Researchers used statistical methods and data analytics tools to perform data exploration research on near-road concentration data recorded in 2016 by the Houston and Fort Worth near-road monitoring stations. Key findings from this chapter are as follows:

- NAAQS: Based on the data collected for 2016, the near-road monitoring stations in Houston and Fort Worth did not appear to have high concentrations of CO, $PM_{2.5}$, and NO_2 at a frequency enough to violate the NAAQS.
- Meteorology: Both wind direction and wind speed are found to have an impact on CO and NO_2, with high concentrations occurring during low wind speeds and downwind conditions (i.e., when the monitor is downwind from the roadway in the southeast direction). This observation indicates that traffic could be a major factor influencing the distribution of CO and NO_2 concentrations during the downwind conditions. $PM_{2.5}$ is more distributed in the southeast and southwest quadrant, which implies there could be other factors influencing its distribution. A clear association between all pollutant concentrations and atmospheric stability was not observed.
- Traffic: A very weak correlation was observed between the traffic parameters (AADT, FE-AADT, truck volume, and traffic speed) and $PM_{2.5}$ concentrations. However, traffic parameters are found to have an influence on NO_2 and CO concentrations during downwind conditions.
- Background Concentration: Results showed that the coefficient of determination (R^2) to vary between 0.83 and 0.91 for near-road $PM_{2.5}$ and background $PM_{2.5}$ concentrations monitored at surrounding monitoring stations. The changes in near-road $PM_{2.5}$ concentrations are found to correlate more with the changes of surrounding background levels values than by any other parameters. On average, there was a 12.8 percent (1.32 $\mu g/m^3$) increment at near-road stations compared to ambient monitoring stations. The findings obtained in this study are consistent with prior studies that found near-road $PM_{2.5}$ concentration to be dominantly influenced by regional background concentration levels compared to traffic and meteorological parameters.

CHAPTER 5:
MODELING APPROACH AND DATA

INTRODUCTION

This section discusses the key modeling components involved in air dispersion modeling. The models and approaches described here include those used for meeting regulatory requirements (conformity and NEPA analyses). Figure 34 shows the flow of data in the overall framework used for modeling.

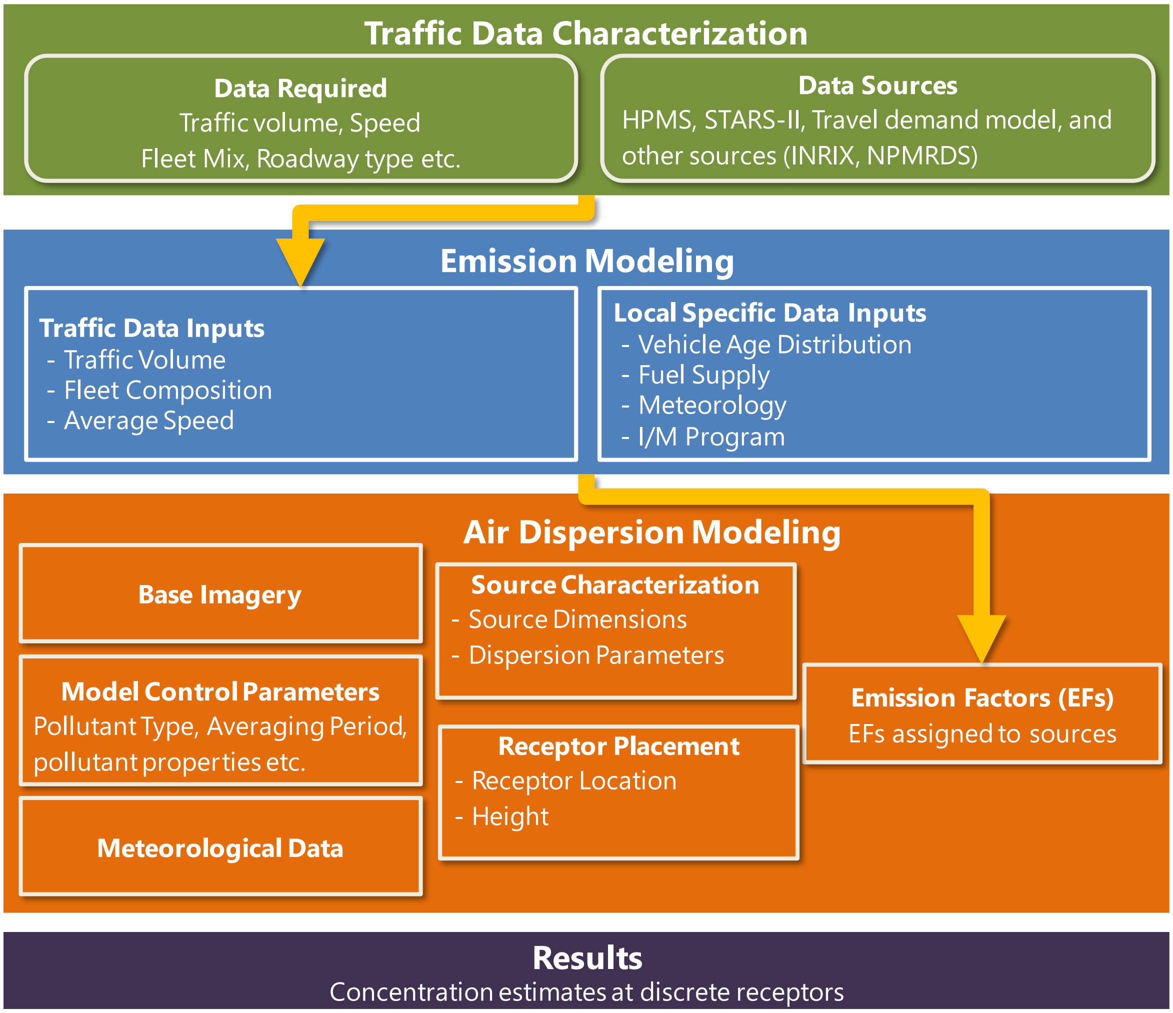


Figure 34. Flow of Data for Modeling.

Air dispersion modeling of roadway emissions requires several types of input data, including traffic, emission rates, meteorological, and other project-specific data. Modeling roadways as a source of emissions for both emissions and air dispersion modeling require traffic data as input. Major sources of traffic data used for emissions and air dispersion modeling include the federal

HPMS database, TxDOT's STARS-II database, metropolitan area TDM, and traffic from project-level analysis.

Emission rates required for air dispersion modeling are obtained through emission modeling using the EPA's MOVES emission model. The MOVES emission model uses traffic data such as speed, volume, fleet mix, and other locally specific data related to meteorology, vehicle age distribution, and fuel parameters, to generate total emissions (in grams) or emission factors (grams per mile or grams per vehicle) at the roadway link level. The dispersion of the traffic related emissions in the atmosphere is modeled using CAL3QHCR and AERMOD models. The source (roadway link) specific emission rates from the MOVES model are passed on to the air dispersion models and are assigned project-specific dimensions, orientations, and properties to reflect site conditions.

Site-specific meteorological and land use conditions are incorporated into the air dispersion models. Based on the implementation of the Gaussian dispersion process, air dispersion models (CAL3QHCR and AERMOD) estimate pollutant concentrations at discrete receptor locations. Determination of the regional PM BC is an important step in the PM hot-spot process as the BC is combined with project specific incremental concentrations to determine the design value and compliance with the air quality standards [9]. Design value is conceptually defined as the sum of the modeled representative concentration resulted from the project and the background concentration. The project-specific contribution is estimated using MOVES emission and AERMOD air dispersion modeling [9]. BC is estimated using concentrations measured by surrounding ambient monitoring stations. Statistical and GIS tools are used for data analyses of the modeled estimates. This chapter describes the different modeling components and their corresponding data requirements and sources.

TRAFFIC ACTIVITY DATA

Researchers examined the available traffic data for the study areas. The team determined that the traffic activity data were not available for all the links in the study areas, so they used outputs of regional TDM for both case study sites. TDM network for the 12-county DFW area was provided by the North Central Texas Council of Governments (NCTCOG). Similarly, the 8-county TDM outputs for Houston Galveston area was provided by Houston Galveston Area Council (HGAC). The TDM outputs were provided for AM peak, PM Peak, Off Peak, and night time. The links were processed to estimate hourly traffic outputs using TTI TDM link-based method [84]. The roadway network links and associated traffic data (volume, speed) close to the Houston and Fort Worth near-road monitoring sites were extracted as shown in Figure 35 and Figure 36 and further processed for dispersion modeling analysis.

Figure 35. Roadway Network Links Extracted from TDM for Fort Worth.

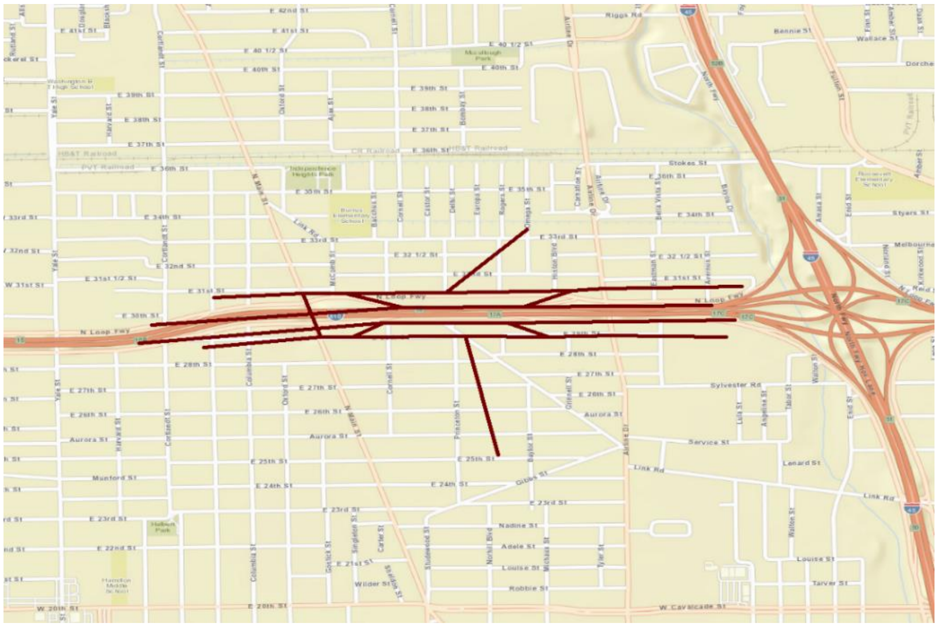


Figure 36. Roadway Network Links Extracted from TDM for Houston.

TDM outputs extracted correspond to the traffic volume and traffic speed. Following PM hotspot analysis guidelines for a worst-case scenario, maximum hourly traffic volume in each of four daily time periods (morning peak [6–9 a.m.], midday [9 a.m.–4 p.m.], evening peak [4–7 p.m.], and overnight [7 p.m.–6 a.m.]) and for corresponding volume weighted average speed for each time period (four periods) were obtained and used in emission estimation process.

MOVES MODELING

Emission rates required for air dispersion modeling are obtained through emission modeling using the EPA's MOVES (MOVES2014a) emission model. MOVES requires information for vehicle types, ages, fuel types, and the emissions parameters to estimate emission rates. Researchers used the latest MOVES2014a inputs in combination with TTI's State Implementation Plan-quality inventory development methodology, designed for use with MOVES. MOVES RunSpecs or MRS provides instructions for how and what data to be used for estimating emission rates. Table 5 provides the RunSpecs information used for estimating emission rates that were used in this study. One RunSpec and one county database per area are required for each MOVES run. Each RunSpec was designed to produce a separate, corresponding MOVES output database (i.e., one output database per run). There were 64 MRS input files and 64 county databases, and correspondingly 64 MOVES input and output databases, produced under this task.

Table 5. Input Parameters for MOVES2014a Runs.

Input Item	Description
Run Specification	
Scale	Project Scale
Calculation Type	Emission Rate
Geographic Bounds	Tarrant County, Harris County TX
Time Period	Analysis Years: 2016 Seasons: Summer (July), Fall (Oct), Spring (April), Winter (Jan) Time-of-day: AM Peak (6–9 a.m.), PM Peak (4–7 p.m.), Midday (9 a.m.–4 p.m.), and Overnight (8 p.m.–6 a.m.)
Road Type	Rural and Urban Restricted and Unrestricted Access
Vehicle Type	All
Pollutant Type	$PM_{2.5}$
Emission Process	Running Exhaust, Crankcase Running Exhaust, Brake and Tire Wear
Project Data Manager (Project Specific Input Data)	
Link Length	One mile
Average Speed	Ranging from 2.5 mph to 75 mph at 1 mph increment

Additionally, re-suspended dust emissions factors from paved roads (i.e., TDM roadway links) were developed according to Equation 2 in AP-42 section 13.2.1 [85]. Finally, MOVES composite emission factors are combined with re-suspended emission rates for each link for each time period and season to be processed under dispersion modeling tools.

AIR DISPERSION MODELING

In this study both AERMOD and CALINE 3 were used to model two urban sites at Houston and Fort Worth, Texas. Figure 37 shows the dispersion modeling process, which consists of three steps, as described below.

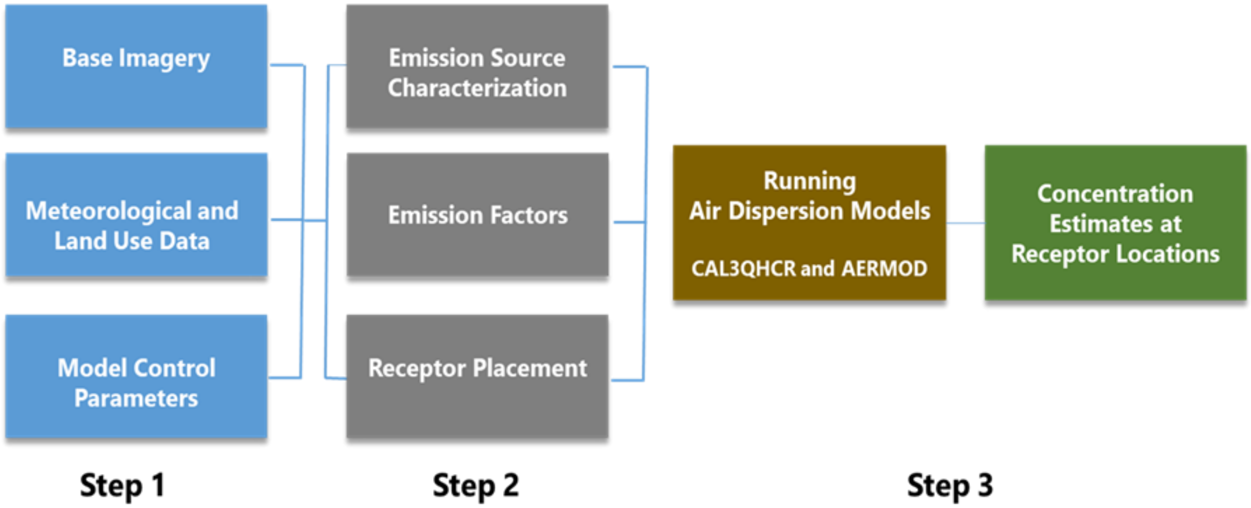


Figure 37. Air Dispersion Modeling.

Step 1

This step consists of assembling the base imagery, processing meteorological and land use conditions specific to the case study site, and specifying model control parameters.

Base Imagery

Base imagery of the case study site is obtained from Google Earth. The base imagery helps with placing and geographically coding the sources and receptors.

Meteorological and Land Use Data

Meteorological and land use conditions are a major factor that affects pollutant dispersion in the atmosphere. Three types of data are required for processing the meteorological data, namely:

- Surface data that measure characteristics of lower layers of the atmosphere.
- Upper air data that measure characteristics that change with height in the atmosphere (such as temperature).
- Land use data that represent surface characteristics.

According to the EPA’s *Guideline on Air Quality Models* (40 CFR Appendix W to Part 51), “the meteorological data used as input to an air quality model should be selected on the basis of spatial and climatological (temporal) representativeness as well as the ability of the individual parameters selected to characterize the transport and dispersion conditions in the area of concern" [3]. The use of 5 years of adequately representative (off-site) NWS meteorological data or at least 1 year of site-specific meteorological data is required. As part of Task 3, the team developed the meteorological inputs using both methods for the case study sites (i.e., the five consecutive years [2012–2016] of off-site meteorological data using nearby NWS airport data and the two years [2015–2016] of on-site meteorological data using site-specific data).

The raw data are processed using meteorological preprocessors to produce data in a format compatible for AERMOD, and CAL3QHCR. Preprocessors used for AERMOD correspond to AERMINUTE, AERSURFACE and AERMET, and MIXGHT and PCRAMMET for CAL3QHCR. Process of generating model compatible meteorological data is provided in Appendix A.

Specific to the AERMOD model, TCEQ produces pre-processed AERMOD-compatible off-site meteorological data for all counties in the state of Texas. For each county, TCEQ produces three sets of meteorological data corresponding to three categories of surface roughness (low, medium, and high). Based on the surface roughness obtained through processing of case study site-specific land use data, appropriate meteorological data were recommended to be used. Surface roughness values ranging from 0.001 m to 0.1 m represent the low surface roughness category, values ranging from 0.1 m to 0.7 m represent medium surface roughness. and high surface roughness category represent surface roughness length values ranging from 0.7 to 1.5 m [70].

Model Control Parameters

In addition to assembling data corresponding to emissions, meteorology, and land use, the first step also consists of defining the model control parameters for the air dispersion model.

General Parameters

The model control parameters are used to specify the pollutant type ($PM_{2.5}$), pollutant properties (no deposition and settling), and averaging period (hourly, 24-hours and annual) for which the concentration estimates are modeled.

Urban Heat Island Effect

The land use designation in air dispersion models is represented in two ways:

- Use of meteorological data from a representative urban/rural site.
- Use of dispersion option for indicating use of urban heat island.

For urban areas, the model activates the urban heat effect, a term used to describe urban areas that are hotter than nearby rural areas, especially at night, mainly because of heat retention by urban materials. Because of this heat retention, the vertical motion of the air is increased through convection, thereby leading to the increased dispersion of pollutants [86]. CAL3QHCR allows the user to prompt the urban heat island effect by specifying U for urban and R for rural land use in the input file. AERMOD accounts for urban dispersion effects by activating a switch as on for urban and off for rural areas and also requires the urban area population to determine the degree of urban heat island effect occurring in a specific urban area.

Step 2

This step involves characterizing the emission sources (i.e., adjacent roadway links), processing emission factors in a format compatible for air dispersion modeling and placing receptors.

Source Characterization

AERMOD can model roadway line source as a series of volume or area sources. CAL3QCHR models roadway links only as line sources. Sources in both models are defined based on the:

- Travel activity that corresponds to volume and speed.
- Physical dimensions.
- Orientation.

For example, a single source can be used for a roadway link if the entire link has the same travel activity and no change in geometry. However, for a curved link with the same travel activity, more than one source is required to be used to preserve the geometry. The BREEZE AERMOD and BREEZE ROADS models, commercial propriety software developed by Trinity Consultants Inc., which provides an unaltered, user-friendly, window-based version of the EPA-approved AERMOD model with pre- and post-processors, is used to help with the source and receptor coding with AERMOD and CAL3QHCR, respectively.

Dispersion Parameters

The following dispersion parameters are used in AERMOD air dispersion modeling, based on the methodology specified in the EPA guidance [9]:

- *Initial Vertical Dispersion Coefficient*
  According to EPA hot-spot guidance [13], the initial vertical dispersion dimension is assumed to be about 1.7 times the average vehicle height, to account for the effects of vehicle-induced turbulence. For light-duty vehicles, this height is about 2.6 m, using an average vehicle height of 1.53 m, or 5 ft. For heavy-duty vehicles, this height is about 6.8 m, using an average vehicle height of 4.0 m. The AERMOD User's Guide recommends that the initial vertical dispersion coefficient (σzo) to be estimated for a surface-based area/volume source by dividing the initial vertical dimension by 2.15. For typical light-duty vehicles, this figure corresponds to a σzo of 1.2 m. For typical heavy-duty vehicles, this figure corresponds to a σzo of 3.2 m. For roadway links having a

combination of light-duty and heavy-duty traffic, the guidance recommends the coefficient to be calculated as a combination of their respective σzo values by using a traffic volume-weighted or emissions-weighted average.

- *Source Release Height*
  Source release height is the height at which wind effectively begins to affect the plume and is estimated from the midpoint of the initial vertical dimension. For moving light-duty vehicles, this is about 1.3 m. For moving heavy-duty vehicles, it is 3.4 m. Similar to σzo, the source release height for roadways with a combination of light duty and heavy-duty vehicles is calculated using a traffic volume-weighted or emissions-weighted average.
- *Emission Rates from MOVES*
  Characterization of emission sources consists of defining their dimensions and designating the rate at which the source produces emissions. Emission rates obtained from MOVES are converted into a format compatible for the air dispersion model and the source type used. AERMOD requires a composite ER (in grams/sec/m^2) for the area source approach and ER (in grams/sec) for volume source approach. CAL3QCHR requires ER in form of grams/vehicle-mile.
- *Receptor Placement*
  Receptors are locations in the study area where an air dispersion model estimates pollutant concentration. As per the EPA guidance, receptors should be located throughout the study area in publicly accessible areas where high PM concentrations would be expected. Receptor spacing near the source (roadways) should be of sufficient resolution to capture the concentration gradient around the locations of maximum-modeled concentrations. Receptors are placed at a height of 1.8 m above the ground. For evaluating modeling results with the near-road data, receptors are placed at the near-road monitoring location for both study sites. In addition, concentration contour maps are generated by placing grid receptors at varying spacing from the roadway links.

Step 3

This step consists of multiple runs of the air dispersion models using files prepared in Steps 1 and 2. Model outputs include pollutant concentration estimates at different averaging time period. The annual average concentrations presented in this study are all-period averages of non-zero hourly concentrations.

BACKGROUND CONCENTRATION

Background air quality includes pollutant concentrations occurring due to area-wide or regional sources. The EPA's guidance on hot-spot analysis states that BC should be as representative as possible for the area where the project site is located. Ideal BC for a near-road site without the influence of traffic emissions are rarely available. For an area surrounded by multiple background ambient $PM_{2.5}$ monitors, EPA recommended that the data should be analyzed by statistical or mapping methods to develop a BC for use in the hot-spot analysis. Four methods, based on either a single station or multiple stations, are recommended by EPA for developing the BC. However, no specific guidance was provided on which method is preferred for an area.

In this study, researchers used seven methods to estimate BC for the case study sites. Four of the methods are suggested by EPA for BC estimation. The data used in this analysis were obtained from onsite weather station at the near-road monitoring location and multiple urban-scale stations surrounding the two case study sites. Statistical analyses and performance of each method were compared to determine the best approach for BC estimation. To test the methods, one station is designated as the target station and its data were treated as observations while the data from other stations were used to developed background concentration estimates. In other words, the $PM_{2.5}$ concentration, $x_{i,j}$, represents a concentration observed at station i and at a time step j.

$x_{i,j}$ = $PM_{2.5}$ concentrations, $i = 1, \ldots, m$ and $j = 1, \ldots, n$
where
m: Number of stations
n: Number of data records

The methods are described as follows.

Method 1: Single Station Estimate

$$y_{i,j}^{s} = x_{k,j} \ (k \neq i) \tag{4}$$

The single station approach looks for a station that best represents the background concentration for the project site. Factors to be considered in selecting the best representative background site for the project site include distance to the project area, located upwind and similarity in terms of land use, meteorological, and mix of sources. Surface or boundary layer parameters such as surface albedo, Bowen ratio, and roughness for the sites were obtained from the National Land Cover Dataset and processed using the AERSURFACE model. The surface characteristics within 5 km of all site were judged to be very similar. A close look of the land use distribution indicates that most of the sites can be described as residential communities of high and low intensity combined with moderate commercial, industrial, and transportation facilities. Without a clear distinction in the topologic and meteorological conditions among these sites, the most representative single station was selected based only on the shortest distance to the project site.

Method 2: Arithmetic Mean

The arithmetic mean approach provides an estimate by taking the average of concurrent data from all available background sites:

$$y_{i,j} = \frac{1}{m-1}\left[\left(\sum_{k=1}^{m} x_{k,j}\right) - x_{i,j}\right] \tag{5}$$

Method 3: Weighted Mean Estimate by Inverse Distance

This method provides an average weighted by the inverse of the distance to the study site. The distance matrix is defined as $Distance_{i,k} = Distance\ between\ station\ i\ and\ k$ and the weighting factor Weight1i,k is:

$$Weight1_{i,k} = \frac{\frac{1}{Distance_{i,k}}}{\sum_{\substack{k=1\\k\neq i}}^{m}\frac{1}{Distance_{i,k}}}, k \neq i \tag{6}$$

and $Weight1_{i,k} = 0, if\ k = i$

The estimate zi,j is obtained as:

$$z_{i,j} = \sum_{k=1}^{m}(x_{k,j} \cdot Weight1_{i,k}) \tag{7}$$

Method 4: Weighted Mean by Inverse Distance Squared

This method is similar to Method 3 except the weighting factor is represented by the inverse of the distance to the square. The weighting factor Weight2i,k is defined as:

$$Weight2_{i,k} = \frac{\frac{1}{(Distance_{i,k})^2}}{\sum_{\substack{k=1\\k\neq i}}^{m}\frac{1}{(Distance_{i,k})^2}}, k \neq i \tag{8}$$

and $Weight2_{i,k} = 0, if\ k = i$

The estimate wi,j is:

$$w_{i,j} = \sum_{k=1}^{m}(x_{k,j} \cdot Weight2_{i,k}) \tag{9}$$

Method 5: Normalized Arithmetic Mean Estimate

This method seeks to preserve the trend of the time series data at each station by normalizing the time series data at each station by its own annual average. The normalized data Xi,j becomes:

$$X_{i,j} = \frac{x_{i,j}}{\frac{1}{n}\sum_{j=1}^{n} x_{i,j}}, i = 1, \cdots, m, j = 1, \cdots, n \tag{10}$$

The normalized estimate becomes Yi,j and the estimate can be retrieved by multiplying Yi,j by the annual average of yi,j:

$$Y_{i,j} = \frac{1}{m-1}\left[\left(\sum_{k=1}^{m} X_{k,j}\right) - X_{i,j}\right] \tag{11}$$

$$y^N_{i,j} = Y_{i,j} \cdot (\frac{1}{n} \cdot \sum_1^n y_{i,j}) \tag{12}$$

Method 6: Normalized Inverse Distance Estimate

Similar to Method 5, the normalized inverse distance estimate is Zi,j and the estimate can be retrieved by multiplying Zi,j by the annual average of yi,j:

$$Z_{i,j} = \sum_{k=1}^m (X_{k,j} \cdot Weight1_{i,k}) \tag{13}$$

$$z^N_{i,j} = Z_{i,j} \cdot (\frac{1}{n} \cdot \sum_1^n z_{i,j}) \tag{14}$$

Method 7: Normalized Inverse Distance Squared Estimate

The normalized inverse distance squared estimate Wi,j and the estimate wi,j is:

$$W_{i,j} = \sum_{k=1}^m (X_{k,j} \cdot Weight2_{i,k}) \tag{15}$$

$$w^N_{i,j} = W_{i,j} \cdot (\frac{1}{n} \cdot \sum_1^n w_{i,j}) \tag{16}$$

Appendix B presents detailed discussions of the methodology.

OTHER TOOLS AND METHODS

Data analytics tools were used to analyze, summarize, and compare data. Descriptive methods are used to describe and analyze the data. These methods include frequency, measures of central tendency represented by the mean, median, and mode, and percentages showing the proportioning of the data. Methods such as correlation and regression are used to describe the relationship between different variables as well as the direction and strength of the relationship. Correlation matrices are used to analyze the relationship between multiple variables. Power BI (Business Intelligence) was used to clean and combine the data from different sources and relational databases were established. Initial data exploration and visualizations were performed inside Power BI to identify the bivariate relationships between different variables. The ‘openair’ package for R was used inside Power BI to generate advanced visualizations such as wind roses and polar plots to evaluate multivariate relationships.

Over the recent year, the availability of GIS data has increased both in quantity and quality. Moreover, the realization of easy-to-use GIS software and GIS tools has made application of GIS-based decision support tools more practical. ArcGIS has been one of the most population software widely used for GIS applications and will be used for this project. ArcGIS will be used to create the maps used in the near-road monitoring siting, case study site selection process, characterization of traffic data, selection of suitable meteorological stations, etc. Table 6 shows the GIS data inputs and data sources for this project. Numerous map layers are created, and the near-road monitoring site selection criteria were applied to select the near-road monitoring sites for the model-to-monitor evaluation. Traffic data from different sources and other spatial data related to roadway network and topography are combined with the near-road monitoring locations to decide the appropriate traffic data source for characterizing traffic near the near-road monitoring station. Location of surface and upper air stations are combined with the near-road monitoring stations to select the appropriate stations for obtaining meteorological data specific to the case study site. In addition to these applications, GIS will be also be used in form of base imagery to help with the coding of emission sources and receptors.

Table 6. GIS Data Inputs and Sources.

Data Input	Source	Comments
Traffic Data	TxDOT	Traffic Counts, AADT, RHiNo, STARS, etc.
	MPO and Local Governments	Local Traffic Counts, TDM
	Other Data Sources	INRIX, NPMRDS, Google, etc.
Road Network	TxDOT	Current and Future
	MPO	Current and Future
Topography	TCEQ	Geocoded based on X and Y coordinates obtained from TCEQ https://www.tceq.texas.gov/airquality/monops/sites/air-mon-sites
Near-road Monitoring Station Locations	Google Earth	https://www.google.com/earth/
	TCEQ	Air monitoring location and parameters collected
Pollutant Concentration	TCEQ/EPA	https://www.tceq.texas.gov/airquality/monops/sites/air-mon-sites
Aerial Imagery	Google Earth	https://www.google.com/earth/
Presence of other air pollution sources, water bodies and points of interest	Land Use (U.S. Geological Survey)	https://www.usgs.gov/
Meteorology	TCEQ	https://www.tceq.texas.gov/permitting/air/nav/datasets.html
	NCDC	https://www.ncdc.noaa.gov/data-access/land-based-station-data/land-based-datasets/automated-surface-observing-system-asos

SUMMARY

This chapter overviews the different modeling components involved in the PM hot-spot modeling process. Track 2 of this research project is focusing on evaluating key modeling parameters within each of these modeling components. The following chapters overview the different modeling scenarios and the results obtained.

CHAPTER 6:
MODELING SCENARIOS AND RESULTS

INTRODUCTION

Task 3 of this research project focused on evaluating the air dispersion modeling process of PM hot-spot analysis. Researchers used a series of sensitivity analyses to investigate the variabilities in AERMOD and CAL3QHC models' outputs in the context of regulatory PM hot-spot analysis. The modeling components included in the sensitivity analyses correspond to traffic activity, emissions estimation, air dispersion modeling, meteorology information, and background concentration as described in Chapter 5. As part of the sensitivity analysis, researchers set-up a baseline case ("baseline") that corresponds to the regulatory PM hot-spot analysis process (i.e., all parameters are defined according to the PM hot-spot analysis requirements). Alternative scenarios are set-up based on alternative methods and values corresponding to each of the key modeling components. The sensitivity analysis was performed for the Fort Worth and Houston near-road monitoring stations measuring. This chapter describes the different modeling scenarios developed and the results obtained for both the case study sites.

MODELING SCENARIOS

Researchers developed different modeling scenarios corresponding to the key modeling components involved with the PM hot-spot process. The modeling components correspond to traffic activity characterization, emission modeling, air dispersion modeling, meteorological data, and background concentration. The different input parameters evaluated correspond to those parameters that are ambiguous or not clearly defined to state agencies or practitioners when implementing the hot-spot modeling process following the EPA guidance. These scenarios are discussed in this section.

Traffic Data Characterization

EPA recommends a minimum of 16 MOVES runs necessary for a PM hot-spot modeling to capture changes in emission rate due to changes in ambient conditions [87]. These 16 models runs correspond to four weekday time periods as morning peak AM (6–9 a.m.), midday MD (9 a.m.–4 p.m.), evening peak PM (4–7 p.m.), and overnight ON (7 p.m.–6 a.m.) for four representative months as January (winter season), April (spring), July (summer), and October (fall). To account for the worst-case scenario, the peak-hour traffic in each period was used as a constant rate for all the hours in the corresponding period. Results from each of the four hours from four periods were extrapolated to cover the entire day and the results of these 16 model runs were extrapolated to cover the whole year. To test the sensitivity of the traffic data, three scenarios were considered:

- Baseline Scenario: Use the peak-hour traffic for four time periods.
- Scenario 1: Use average hour traffic for four time periods.
- Scenario 2: Use hourly traffic for 24 hours.

Emission Modeling

For MOVES emission analysis, EPA guidance recommends using inputs consistent with inputs used for regional emission analysis. These inputs correspond to meteorology, fuel supply, and age distribution. Alternative scenarios were set up to evaluate the difference based on local case study specific MOVES inputs:

- Baseline Scenario: MOVES inputs consistent with inputs used for regional emission analysis.
- Scenario 3: Case-study specific input corresponding to meteorological (temperature and humidity) data obtained from near-road onsite parameters.

Meteorological Data Processing

Onsite versus Offsite Meteorological Data

For PM hot-spot analysis, EPA recommends using either one year of onsite meteorological data or five years of latest available offsite meteorological. Specific to Texas, TCEQ produces AERMET processed meteorological data for three sets of surface roughness. Depending on the site-specific surface roughness (SR), the appropriate data are used. Researchers selected the following scenarios:

- Baseline Scenario: On year of onsite meteorological data.
- Scenario 4: Five years of offsite meteorological data corresponding to offsite low surface roughness.
- Scenario 5: Five years of offsite meteorological data corresponding to offsite medium surface roughness.
- Scenario 6: Five years of offsite meteorological data corresponding to offsite high surface roughness.

Land Use Designation

Guidelines on deciding the urban/rural representativeness of a source are given in [88], in which a land use classification or population density method should be employed. In most cases the first approach may suffice. If not, the latter approach may be taken. In reality, a project site may be situated in an area that is ambiguous to either definition above. In that case, a different designation of the project site will affect the model results. The question is by how much. To evaluate the effect of an incorrect land use designation, the team developed Scenario 7 to evaluate the impact of land use designation of a modeling site on the near-road $PM_{2.5}$

concentration levels—Scenario 7: Land use designation was changed from urban to rural while traffic parameters and site geometry were unchanged.

Air Dispersion Modeling

Source Type

EPA guidance recommends modeling roadway links as area or volume sources for PM hot-spot analysis. Table 7 lists the difference between the two sources.

Table 7. Difference between Area and Volume Sources in AERMOD.

	Area Source in AERMOD	Volume Source in AERMOD
Definition	Area sources are flat, two-dimensional spaces from which emissions originate. They are more appropriate for near ground level sources with no plume rise (viaduct, storage piles).	Volume sources are three-dimensional spaces from which emissions originate. They are more appropriate for line sources, which have some initial plume depth (rail lines, conveyor belts).
Algorithm	Area sources models emissions with a uniform distribution across the roadway link and are not distributed beyond the edge of a roadway link. Area sources does not incorporate the plume meander algorithm that accounts for the laternal back-and-forth shifting of an emission plume under low wind conditions.	Volume sources model emissions with a Gaussian distribution, that represents a decrease in emission density, both horizontally and vertically as the distance from the roadway increases. Volume sources incorporates the plume meander algorithm.
Exclusion Zone	Area sources does not have the exclusion zone and can calculate concentrations at receptors within the source.	Volume sources have an exclusion zone where concentrations are not calculation, in other words if a receptor is located in the exclusion zone, volume source will not calculate any concentrations at that receptor. Exclusion zone is the region ((2.15 × Sigma Y) + 1 meter)) from the center of the volume.
Runtime	A fewer number of area sources are required to represent a given roadway link compared to volume source as shown in Figure 38.	More volume sources are required to represent a given roadway link compared to area sources. Because of a larger number of sources required to characterize a given link, processing times are longer both in terms of model set-up and run time.

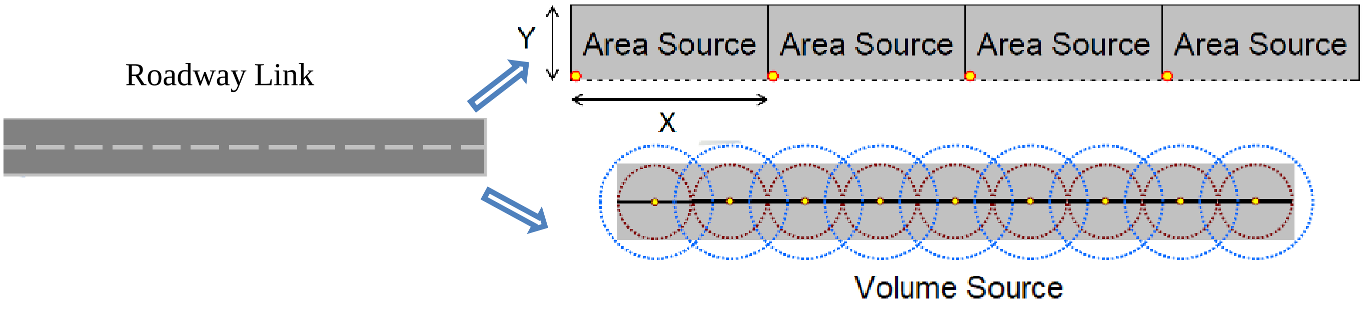


Figure 38. Area and Volume Source Representation of a Roadway Link.

Scenario 8 was designed to evaluate the differences in concentration estimates using area and volume source characterization—Scenario 8: roadway links were characterized as volume sources.

Model Comparison

Comparison was made to evaluate the variation in outputs between CAL3QHCR and AERMOD:

- Scenario 9: CAL3QHCR was used to estimate the near-road concentrations. Input parameters were consistent with AERMOD baseline (Baseline Scenario).
- Scenario 10: this scenario was set up to evaluate CAL3QHCR with offsite meteorological data.

Based on these parameters listed above different scenarios were developed as shown in the Table 8.

Background Concentration

For both case study sites, the annual average $PM_{2.5}$ concentrations developed from different methods (described in Chapter 5 and Appendix B) are evaluated using different performance metrics. These metrics used in this study are described below:

- *Normalized Mean Bias* (*NMB*) is a measure of the average deviation from actual observation (between -1 and ∞). The NMB represents the average model bias normalized by the mean of observations, with considering (positive and negative) direction of the errors.
- *Normalized Mean Error* (*NME*) is a measure of the averaged absolute deviation without considering direction of differences between prediction and observation (between 0 and ∞). Contrary to the NMB, in the NME the absolute deviations are summed instead of the differences, and we have equal weight of underestimation and overestimation.

- *Normalized Root Mean Square Error* (*NRMSE*) is a measure of the square root of the average of the squared differences between prediction and actual observation (between 0 and ∞). The root mean squared error (RMSE) represents standard deviation of the differences between predicted and observed values. In RMSE, the squared differences are averaged, and the measure gives a relatively high weight to large errors compared with the mean error.

In practice, the statistics are based on finite samples of several sets of concentrations, and do not represent sampling variability. Researchers used a statistical technique known as *bootstrapping* to account for the sampling variability in the predictions [89]. The bootstrap is a resampling method to estimate standard error of a specific performance measure computed from resampled dataset. The bootstrap procedure follows the basic steps:

1) *Resample a given data set a specified number of times.* In other words, generate new estimates $x_{i,j}^{(1)},\ x_{i,j}^{(2)}, \cdots, x_{i,j}^{(B)}$ where B is the bootstrap sample size (e.g., B=5,000).
2) *Calculate a specific statistic from each sample* (i.e., calculate 5,000 sets of the estimates for each method). For example, generate $y_{i,j}^{(1)},\ y_{i,j}^{(2)}, \cdots, y_{i,j}^{(B)}$ and calculate 5,000 sets of NRMSE based on the prediction using inverse distance.
3) *Find the standard deviation of the distribution of that statistic.* Bootstrapped standard deviations are obtained to compare sampling variabilities of the statistic (i.e., NRMSE) between the seven methods.

For both case study sites, the annual average $PM_{2.5}$ concentrations developed from different methods were found, in general, acceptable except the single station approach that is selected based on shortest distance to a target station. Normalized methods appear to perform better than non-normalized methods with higher accuracy. Among the normalized methods, predictions made by normalized inverse distance squared method appear to be slightly better than other models, based on the statistical metrics for annual, 24-hr, and highest 10 24-hr average $PM_{2.5}$ concentrations.

MODEL SET-UP

Table 8 shows the modeling scenarios developed for both case study sites. Table 9 and Table 10 list the modeling parameters used for the Fort Worth and Houston sites, respectively. Figure 39 and Figure 40 show the model set-up for the Fort Worth and Houston sites, respectively.

Table 8. Scenario Development.

Scenario	**Model**	**Traffic**	**Emissions**	**Meteorology**	**Dispersion Parameters**	**Notes**
Baseline	AERMOD	Maximum	Regulatory MOVES inputs	Onsite (1 year)	Area	*Baseline for all runs*
Scenario 1	AERMOD	Average	Regulatory	Onsite	Area	*Effect of using different traffic inputs*
Scenario 2	AERMOD	Hourly	Regulatory	Onsite	Area	
Scenario 3	AERMOD	Maximum	Onsite MOVES Inputs	Onsite	Area	*Effect of using different inputs for emission estimation*
Scenario 4	AERMOD	Maximum	Regulatory	Offsite (5 years) (Low SR)	Area	*Effect of using different meteorological data for dispersion modeling*
Scenario 5	AERMOD	Maximum	Regulatory	Offsite (Med SR)	Area	
Scenario 6	AERMOD	Maximum	Regulatory	Offsite (High SR)	Area	
Scenario 7	AERMOD	Maximum	Regulatory	Onsite	Area, Rural	*Effect of urban heat island effect*
Scenario 8	AERMOD	Maximum	Regulatory	Onsite	Volume	*Effect of different source type in AERMOD*
Scenario 9	CAL3QHCR	Maximum	Regulatory	Onsite (1 year)	Line	*Effect of different meteorological data with different dispersion model*
Scenario 10	CAL3QHCR	Maximum	Regulatory	Offsite (5 years)	Line	

*SR: Surface Roughness

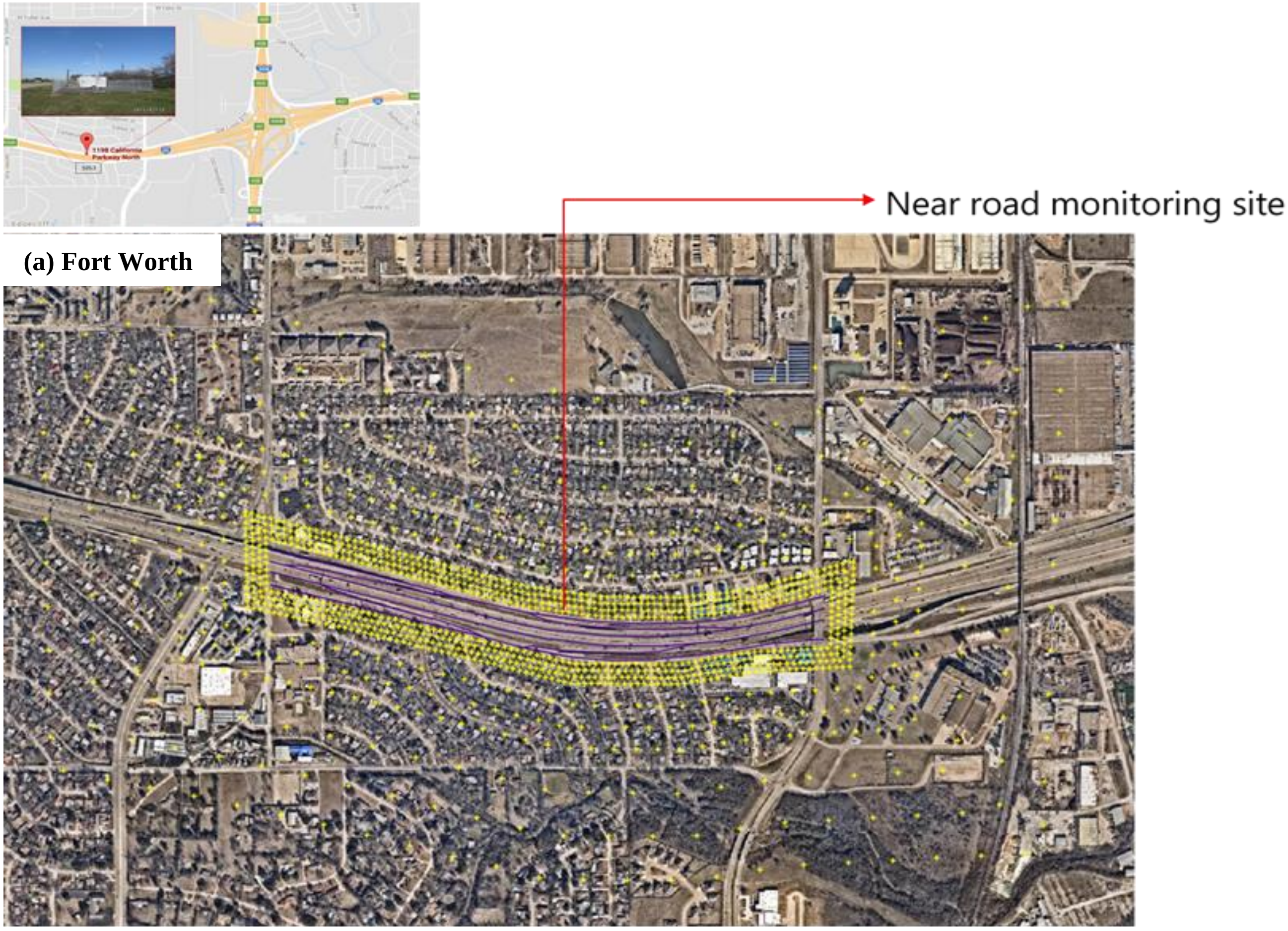


Figure 39. AERMOD Area Source and Receptor Placement for Fort Worth.

Figure 40. AERMOD Area Source and Receptor Placement for Houston Site.

Table 9. Input Data Parameters for Fort Worth Site.

Modeling Parameters	Inputs
Base Imagery	– Google Earth image covering the case study extent
Model Control Parameters	– Pollutant: $PM_{2.5}$ – Averaging Period: 24 hours and annual – Pollutant Properties: No deposition and settling – CONC: Specifies that concentration values will be calculated – FLAT: Specifies that the terrain is flat
Meteorology	– Offsite pre-processed meteorological data consisting of surface, upper air and land use data representative of case study location is obtained from TCEQ for five years (2012 to 2016) – A year (2016) of raw surface data is obtained from Fort Worth Meacham Airport, upper air data at Fort Worth, and site-specific meteorological parameters (such as dry bulb temperature, wind direction, and wind speed) are obtained from the Fort Worth near-road monitoring station
Source Characterization	– Sources are defined based on (1) travel activity (2) physical dimensions and (3) orientation – AERMOD Area source: case study site was modeled with a total of 59 area sources – AERMOD Volume source: case study site was modeled with a total of 2606 volume sources – CAL3QHCR Line source: case study was modeled with 57-line sources
Emission Factor	– ERs from MOVES – ERs are normalized with reference to time, and source properties (dimensions, volume) to produce ERs in grams/sec/m^2 for area source and grams/second for volume source approach in AERMOD, grams/vehicle-mile for line source approach in CAL3QHCR – EMISFACT-HROFDY: This option is to specify a variable emission rate for the sources. The rates vary by the hour of the day
Dispersion Parameters	– Source release height was set at 1.487 m and an initial vertical dispersion of 1.384 m were used – URBANOPT: Sources are modeled as urban to account for the urban heat island effect – Urban roughness length of 1 m is used, and MSA population of 6,426,214 for AERMOD. For CAL3QHCR modeling, surface roughness was set to 0.01 m as the default value
Receptor Characterization	– Receptors positioned at a height of 1.8 m, are placed at the near-road monitoring station for sensitivity analysis – For contour plot showing the spatial concentration distribution, grid receptors are placed starting at 5 m–50 m at a spacing of 15 m, 50 m–200 m at a spacing of 50 m, and 100 m–500 m at 100 m spacing resulting in a total of 1,272 receptors
Output	– $PM_{2.5}$ estimates at 24-hr averaging period at all receptor locations are estimated

Table 10. Input Data Parameters for Houston Site.

Modeling Parameters	Inputs
Base Imagery	– Google Earth image covering the case study extent
Model Control Parameters	– Pollutant: $PM_{2.5}$ – Averaging Period: 24 hours and annual – Pollutant Properties: No deposition and settling – CONC: Specifies that concentration values will be calculated – FLAT: Specifies that the terrain is flat
Meteorology	– Offsite pre-processed meteorological data consisting of surface, upper air and land use data representative of case study location is obtained from TCEQ for five years (2012 to 2016) – A year (2016) of raw surface data is obtained from George Bush Intercontinental Airport, upper air data at Houston, and site-specific meteorological parameters (such as dry bulb temperature, wind direction, and wind speed) are obtained from the Houston near-road monitoring station
Source Characterization	– Sources are defined based on (1) travel activity, (2) physical dimensions, and (3) orientation – AERMOD Area source: case study site was modeled with a total of 29 area sources – CAL3QHCR Line source: case study was modeled with 29-line sources
Emission Factor	– ERs from MOVES – ERs are normalized with reference to time, and source properties (dimensions, volume) to produce ERs in grams/sec/m^2 for area source and grams/second for volume source approach in AERMOD, grams/vehicle-mile for line source approach in CAL3QHCR – EMISFACT-HROFDY: This option is to specify a variable emission rate for the sources. The rates vary by the hour of the day.
Dispersion Parameters	– Source release height was set at 1.487 m and an initial vertical dispersion of 1.384 m were used – URBANOPT: Sources are modeled as urban to account for the urban heat island effect – Urban roughness length of 1 m is used, and MSA population of 6,490,180 for AERMOD. For CAL3QHCR modeling, surface roughness was set to 0.01 m as the default value.
Receptor Characterization	– Receptors positioned at a height of 1.8 m and are placed at the near-road monitoring station for sensitivity analysis – Grid receptors were placed in the same fashion as that for the Fort Worth site
Output	– $PM_{2.5}$ estimates at 24-hr averaging period at all receptor locations are estimated

MODELING RESULTS

Figure 41 shows concentration maps showing the $PM_{2.5}$ dispersion patterns around the near-road monitoring location. Higher concentrations are obtained close to Interstate I-20 on the eastbound traffic direction. For model evaluation, only results obtained at the receptor location corresponding to the near-road monitoring station were evaluated.

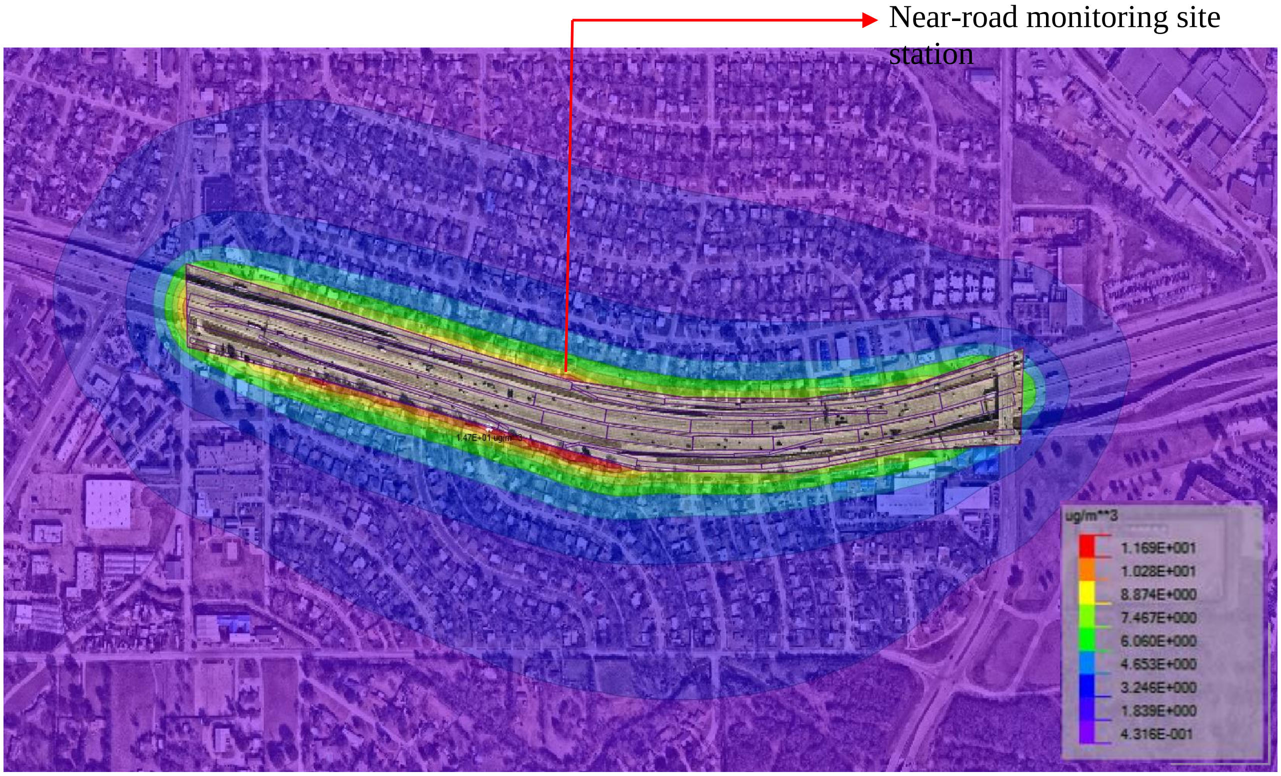


Figure 41. $PM_{2.5}$ Concentrations around the Fort Worth Near-Road Monitoring Station.

The modeling results for different scenarios were extracted and imported into Power BI[7] software for data analysis. A series of contour plots, time series plots, and model statistics corresponding to mean, median, standard deviation, 98th percentile, and ratio[8] of modeling results without background concentration to the near-road monitoring data were developed to understand the influence of different parameters on the model performance. The results for different scenarios for Fort Worth and Houston are listed in Table 11 and Table 12, respectively.

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[7] Power BI is a data visualization software provided by Microsoft.

[8] The modeling results are compared with the near-road monitoring data only in the context of the PM hot-spot analysis and not to evaluate the models with respect to the near-road data.

Table 11. Model Statistics for Different Scenarios at Fort Worth Site.

Scenario	Average Concentration (μg/m^3)	98th Percentile Concentration (μg/m^3)	Percent variation from Baseline (%)	Uncertainty Area
Baseline	12.91	31.86		Baseline
Scenario 1	12.20	32.02	−5.50%	Traffic Parameters
Scenario 2	11.21	29.04	−13.17%	
Scenario 3	12.91	31.86	0.00%	Emissions
Scenario 4	12.31	31.29	−4.65%	Meteorology
Scenario 5	11.14	29.88	−13.71%	
Scenario 6	10.43	28.42	−19.21%	
Scenario 7	13.75	39.04	6.51%	Land Use
Scenario 8	11.78	30.09	−8.75%	Air Dispersion Parameters
Scenario 9	11.56	29.37	−10.46%	
Scenario 10	10.46	27.95	−18.98%	

Table 12. Model Statistics for Different Scenarios at Houston Site.

Scenario	Average Concentration (μg/m^3)	98th Percentile Concentration (μg/m^3)	Percent variation from Baseline (%)	Uncertainty Area
Baseline	12.87	27.36		Baseline
Scenario 1	11.39	24.63	32.73	Traffic Parameters
Scenario 2	11.38	24.34	33.08	
Scenario 3	12.91	27.42	−0.82	Emissions
Scenario 4	12.84	29.42	1.86	Meteorology
Scenario 5	11.5	25.85	32.02	
Scenario 6	10.51	23.71	53.99	
Scenario 7	13.73	33.76	−17.81	Land Use
Scenario 8	12.59	25.65	3.05	Air Dispersion Parameters
Scenario 9	12.22	26.86	15.23	
Scenario 10	10.84	24.91	47.40	

Traffic Activity Data

Sensitivity analysis was conducted to evaluate the effect of different aggregation of traffic activity inputs on concentrations estimates. Baseline scenario based on EPA's recommendation of peak-hour traffic in each of four time periods was compared alternative scenarios with using average traffic in each of four time periods and hourly traffic for each hour of the day. Use of hourly traffic estimates and modeling each hour of the day resulted in concentrations that are found to be 66 percent lower than using four distinct time periods with peak traffic estimates. Use of average traffic data compared to peak traffic data for four time periods resulted in lower concentrations by 21 percent.

MOVES Modeling

Sensitivity analysis was done by using temperature and humidity values measured at the case study site compared to inputs consistent with regional emission analysis. The concentration difference was found to be less than 1 percent between the runs.

Meteorology

EPA guidance recommends the use of either one year of onsite or latest available five years of offsite meteorological data for PM hot-spot analysis. Sensitivity analyses found the offsite meteorological data to produce lower concentration estimates by 27 percent for Houston and 47 percent for Fort Worth. The difference was found to be similar for both AERMOD and CAL3QHCR models. Further, sensitivity analysis was conducted to evaluate the difference in using different offsite data categorized by low, medium, and high surface roughness (SR). Both the case study sites were found to belong to the medium SR category. Incorrectly using the low SR data instead of medium SR was found to produce higher concentration estimates by 43 percent for Houston and 58 percent for Fort Worth. On the other hand, using the high SR data instead of medium SR was found to produce lower concentration estimates by 31 percent for Houston and 35 percent for Fort Worth. The results are expected because as the SR (i.e., height of obstacles to the wind flow) increases, the concentration estimates decrease because of increased dispersion and mixing of pollutants.

Land Use

The study also found that AERMOD to be sensitive to the urban/rural classification of a case study site. Urban/rural classification of a site is determined using corresponding meteorological data and activation of urban/rural switch. Sensitivity analysis was conducted to evaluate the difference in concentration through an incorrect switch activation. Both case study sites were found to be urban and the corresponding urban meteorological data were used. However, the switch was set to rural, and the results were found to be 18 percent higher for Houston and 22 percent for Fort Worth compared to the correct urban switch.

Air Dispersion Parameters

Choice of Source Type in AERMOD

Studies have pointed out significant variability in the predicted AERMOD concentrations for inert pollutants, depending on the source type used [38], [46], [90]. Some studies have reported similar findings (i.e., higher concentrations predicted with an area source characterization), while others have reported the opposite (i.e., higher concentrations predicted with a volume source characterization). Pasch et al. [46] conducted an analysis on a hypothetical freeway widening project, and showed AERMOD area source characterization to produce 2.6 times higher PM concentrations compared with a few (i.e., 22) large volume sources; however, the concentration difference was only 10 percent higher for area sources compared with many (i.e., 968) small volume sources. Claggett and Bai [38] found AERMOD area source characterization to produce highest concentrations at roadside followed by CAL3QCHR followed by AERMOD volume source characterization. Schewe [90] reported 1.8 to 3.8 times higher concentration predictions from AERMOD for highways configured as volume sources compared with those configured as area sources. Similar to studies, this study found volume sources to produce concentration estimates by 26 percent lower compared to area sources for the Fort Worth site.

Choice of Air Dispersion Model

EPA previously recommended use of either AERMOD or CAL3QHCR for conducting PM hot-spot analyses [3]. In December 2016, EPA replaced CAL3QHCR and approved the use of only AERMOD model for refined PM hot-spot analysis and provided a transition period of 3 years for the revision [40]. Sensitivity analysis was conducted to evaluate the difference in concentration estimates between AERMOD and CAL3QHCR models. Comparison between the models found AERMOD area sources to result in higher estimates by 58 percent for Fort Worth and 22 percent for Houston. For model comparison, there has been mixed reviews in literature. While Clagget [38], Vallamsundar and Lin [40], and Rajonic et al. [41] found AERMOD to produce higher concentrations compared to CAL3QHCR, a study by Westerlund and Cooper [39] found CALINE3 models to produce higher concentrations compared to AERMOD. For model comparison with field observations, Chen et al. [44] compared CALINE4, CAL3QHCR, and AERMOD for near-road $PM_{2.5}$ and found a moderate match only between CALINE, CAL3QHCR with observed concentration as AERMOD underestimated $PM_{2.5}$ concentrations. Heist et al. [43] performed a model inter-comparison between RLINE, AERMOD, ADMS, and CALINE models for simulating near-road pollutant dispersion. Overall, they found all models except CALINE to have similar overall performance statistics, while CALINE produced larger degree of scatter in their concentration estimates.

Background Concentration

Accurate estimation of background concentrations is a critical component for estimating the design value to show compliance with NAAQS for transportation conformity hot-spot analysis.

Seven methods were evaluated (with four of them suggested by EPA) for estimating background concentration using data from multiple background ambient monitoring stations and by resampling of the same data set using bootstrapping technique. For the two identified project areas in Texas, the $PM_{2.5}$ pollution pattern at the surrounding ambient monitoring stations are similar. The annual average $PM_{2.5}$ concentration developed from different methods are, in general, acceptable except the single station approach that is selected based on shortest distance to a target station. Normalized methods were found to be performing better than non-normalized methods with higher accuracy. Among the normalized methods, predictions made by normalized inverse distance squared method appear to be slightly better than other models, based on the statistical metrics for annual, 24-hr, and highest 10 24-hr average $PM_{2.5}$ concentrations.

SUMMARY

The process of PM hot-spot analysis involves emissions and dispersion modeling that is combined with traffic and background concentration data. Several variables (traffic activity data, emission rates, land use, meteorology, etc.) that are inputs into these modeling components have a high degree of variability to them. Further, due to the presence of several modeling components in the framework, discrepancies at each component can tend to propagate through the entire modeling chain leading to uncertainty in the results. Possible sources of error or uncertainty could occur in the input data preparation, assumptions, and model formulation. The goal of Track 2 is to investigate the model behavior and uncertainties involved in the PM hot-spot modeling process through a series of sensitivity analyses. The analyses evaluated changes in the modeled $PM_{2.5}$ estimates for changes in key input parameters corresponding to traffic activity, emissions estimation, air dispersion modeling, meteorology information, and background concentration.

The findings obtained through these modeling exercises points to the fact that there are many factors (e.g., traffic data aggregation, type of meteorological data, background concentration estimation, and land use) that impact the PM concentration estimates at various degrees, both at an individual modeling component level and cumulative on the entire modeling chain. In addition, quality assurance at every step of the modeling process is required to avoid questionable variations in the near-road concentrations and the resulting design values. The relation between modeling and decision-making can be improved by reporting the modeling results in terms of distribution or ranges in addition to reporting the single value result. This would provide decision-makers an idea of the level of uncertainty associated with the results. Communicating the uncertainty levels would demonstrate that the purpose of the modeling chain is not to output a single value but rather to provide information on the range of expected outcomes (such as a confidence interval) and their associated probabilities. The following chapters combine track 1 and track 2 and describe the qualitative evaluation of the modeling scenarios with the near-road monitoring data.

CHAPTER 7:
QUALITATIVE EVALUATION

INTRODUCTION

This chapter discusses the qualitative evaluation of the modeling results with the near-road monitoring data. The evaluation was performed for all the modeling scenarios as discussed in Chapter 6. Statistical methods and data analytics tools are used to perform the evaluation for both case study sites.

MODELING SCENARIOS

Modeling scenarios developed for the case study sites corresponding to the key modeling parameters in the PM hot-spot process are shown in Table 8, Chapter 6. These scenarios can be broadly grouped into three major sources of variability as shown in Table 13.

Table 13. Scenario Categorization.

Source of Variability	Modeling Component	Scenario	Dispersion Model	Description
		Baseline	AERMOD	Baseline for all runs
Data Source	Traffic Parameters	Scenario 1		Effect of using different traffic inputs
		Scenario 2		
	Emissions	Scenario 3		Effect of using different inputs for emission estimation
	Meteorology	Scenario 4		Effect of using different meteorological data for dispersion modeling
		Scenario 5		
		Scenario 6		
Model Option	Land Use	Scenario 7		Effect of urban heat island effect
	Air Dispersion	Scenario 8		Effect of volume source type
Model Choice		Scenario 9	CAL3QHCR	Effect of different meteorological data with different dispersion model
		Scenario 10		

Scenarios corresponding to variability in the data source related to different averaging or resolution such as traffic data averaging, and effect of using local-specific inputs for emission estimation are grouped under Data Source variability. Scenarios corresponding to variability resulted from different options within the model, such as use of volume source type and rural or urban land use in AERMOD, are grouped under Model Option. Scenarios corresponding to variability caused by using a different air dispersion model (CAL3QHCR) are categorized under Model Choice.

Variability analyzed for the background concentration are considered separately from these scenarios mainly because of background's significant proportion of near-road $PM_{2.5}$ compared to roadway contribution. As discussed in Chapter 5, among the seven different methods used to estimate the background concentration, estimations made by the normalized inverse distance squared method found to be slightly better than other models for both study sites. Accordingly, the background concentrations estimated by this method is used for all scenarios to calculate the expected near-road $PM_{2.5}$ concentrations (i.e., background + roadway traffic contribution from the modeling results).

The expected near-road $PM_{2.5}$ concentrations are qualitatively assessed with the measurements from the near-road monitoring station for the same sampling days. Qualitative evaluation is performed because of the uncertainties involved in separating the near-road concentration into concentrations caused by the roadways (modeled by air dispersion models) and concentration occurring due to area-wide sources (captured by ambient monitoring stations). Qualitative assessment is performed in the form of box plots and density histograms providing a visual comparison between modeling results and near-road monitoring data.

DESIGN VALUES AND HOT-SPOT ANALYSIS

In the regulatory air quality analysis context, the air quality design value for a specific criteria pollutant is defined as "the mathematically determined pollutant concentration at a particular site" that must be reduced or maintained at or below the corresponding NAAQS to assure attainment [91]. EPA sets the primary NAAQS thresholds based on assessments of pollutants' adverse health effects. NAAQS thresholds for ambient $PM_{2.5}$ has two components [92]:

- An annual average value over a 3-year period, which mainly focuses on the protection from long-term exposures.
- A 24-hour averaging period that is designed to provide protection against days with high peak concentrations (i.e., short-term exposure).

A design value used in conjunction with a short-term-oriented NAAQS threshold therefore must look at the upper end of the distribution of ambient concentrations to provide appropriate protection against the expected adverse effect for the majority of the population that is particularly susceptible to the negative impacts of the pollutant. In the case of $PM_{2.5}$ emissions, the short-term design value is calculated using the average of three consecutive years' 98th percentile concentrations of 24-hour values for each of those years.

The $PM_{2.5}$ design values are used for two main regulatory applications:

- Area designation: which is based on ambient monitoring observations to determine the level of control needed to reduce the pollutant concentration to the NAAQS levels.
- Conformity analysis and determination: which is mainly based on emissions modeling results for future years (in the case of regional conformity) and/or air dispersion modeling results for a specific change to the transportation network (in the case of hot-spot analysis for project level conformity).

The use of a single statistics (e.g., 98th percentile or the mean) as a design value has been very effective in regulatory applications that require comparing modeling results to a NAAQS threshold. However, for applications such as model performance evaluations and variability assessments, it is very important to perform such evaluations based on more information on the underlying data distributions. Frequency distribution histograms are a very common and important method of visualizing data to inspect a sample population's data for its underlying distribution. In the context of model performance evaluation and sensitivity analysis of dispersion models' outputs, a histogram is a critical tool for:

- Investigating the trend of the data from the overall shape of the frequency distribution.
- Identifying outliers and understanding their potential effect on the design values.
- Detecting and explaining changes in underlying data even if the design value does not change.

To better demonstrate the changes of the modeling results and how they qualitatively compare to field observations, researchers report the results as histograms with the mathematical 98th percentiles of the distributions identified on them. The 98th percentiles shown on the histograms in this chapter are not calculated according to EPA's recommended hot-spot analysis methodology that requires multiple years of data; they are rather meant to serve as indicators of the upper end of the expected concentrations.

RESULTS

The concentration outputs from dispersion models represent the incremental changes in $PM_{2.5}$ concentrations as a result of the modeled sources (i.e., the $PM_{2.5}$ from vehicles). These incremental values were combined with the estimated background concentrations for each sampling day calculated using the normalized inverse distance square method methodology as described in Chapter 5.

Box Plots

The comparison between the different scenarios (model results combined with background concentration) and the near-road monitoring station data for Fort Worth and Houston are shown in box plots in Figure 42, and Figure 43, respectively.

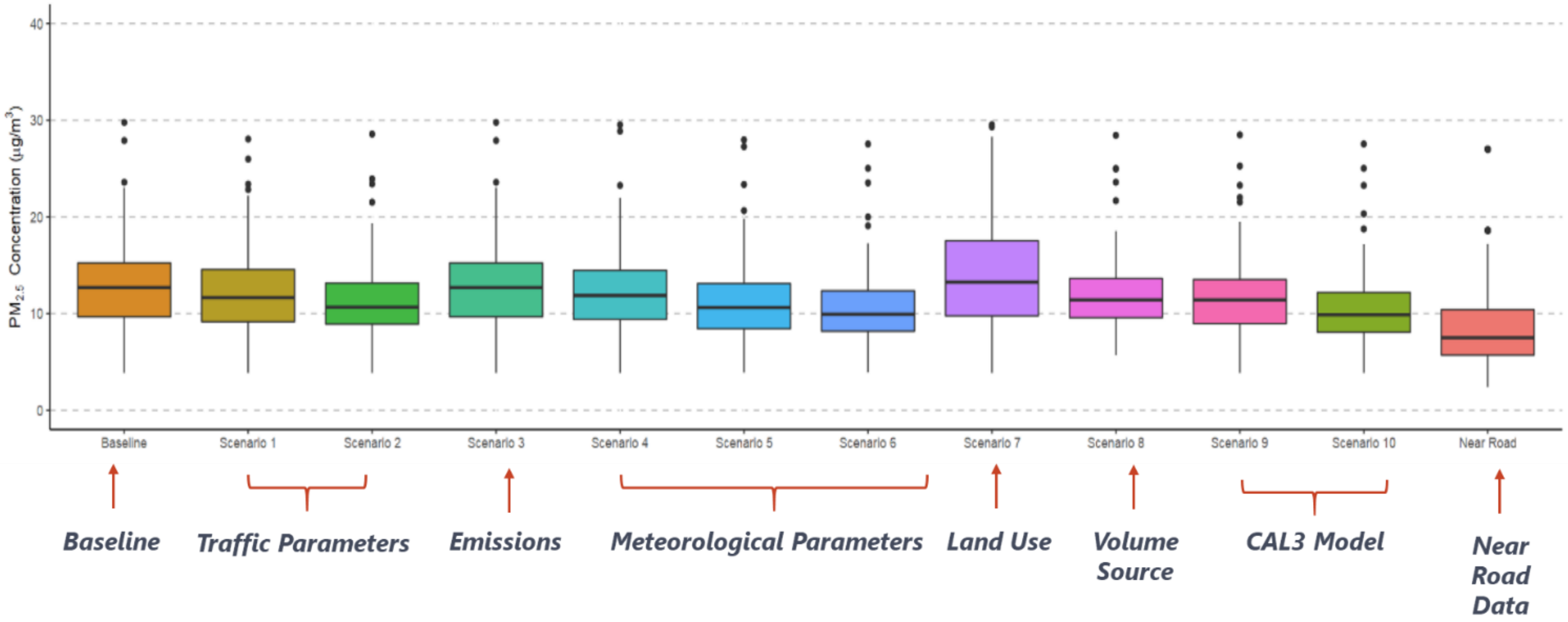

Figure 42. Boxplot of Model Results and Near-Road Monitoring Concentrations – Fort Worth.

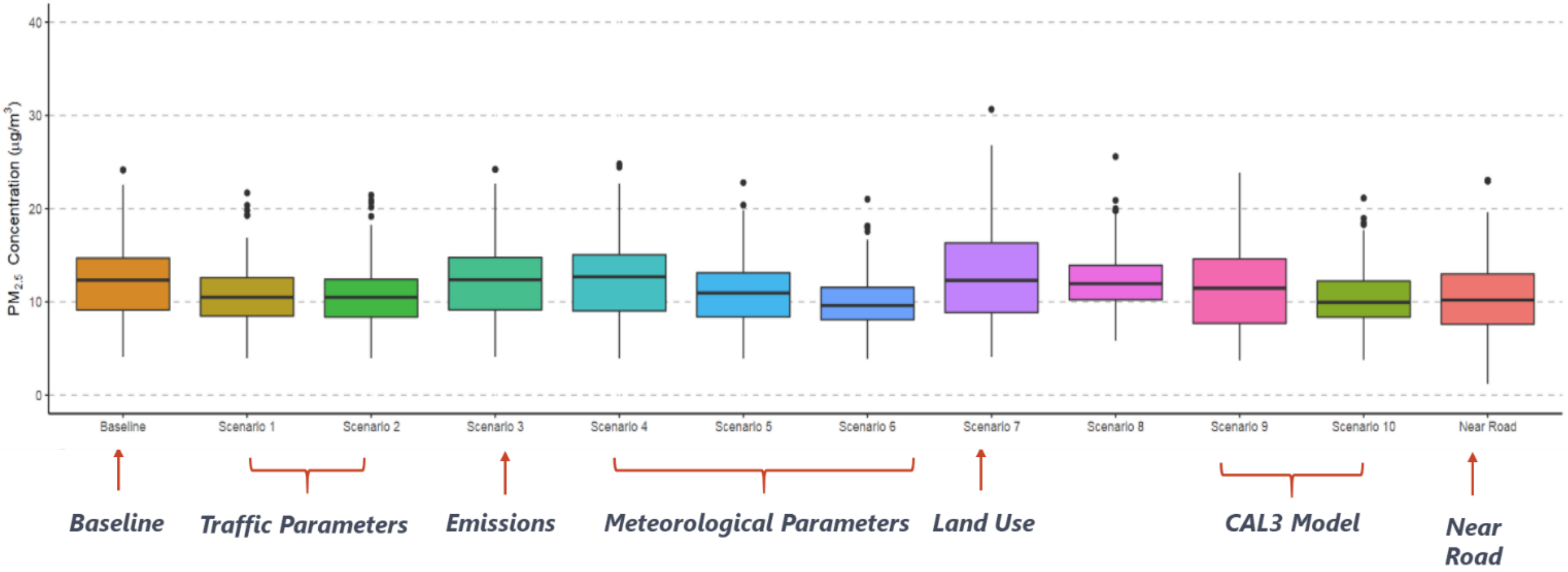

Figure 43. Boxplot of Model Results and Near-Road Monitoring Concentrations – Houston.

Box plot is a compact way of visually presenting the data, comparing distributions and identifying outliers. A box plot displays a few key statistical metrics, corresponding to the median, quartiles, interquartile range, and potential outliers. The bottom of each box represents the first quartile (25th percentile), top of the box is the third quartile (75th percentile), and the line in the middle is the median (50th percentile). The size of the box shows the variability involved in the data (i.e., bigger box indicates higher data variability). The box plot has whiskers above and below each box to give additional information about the spread of the data. Whiskers are drawn from the upper and lower hinges indicating the variability outside the interquartile range.

In both Figure 42 and Figure 43, the combined model and background concentrations are consistently higher than the observed values from the near-road monitoring stations. All scenarios are positively skewed as they have a longer whisker in the positive direction than in the negative direction, implying that the mean is greater than the median. For the Fort Worth site, the median values for all scenarios are in the range of 11 to 14 μg/m^3 while the near-road data have a median of 7.5 μg/m^3. The median values for the Houston site are in the range of 10 to 13 μg/m^3, which are closer to median of the near-road data, which is 10 μg/m^3. The highest combined model and background concentrations are consistently higher than that of the highest concentrations observed at the near-road monitoring stations in both locations across all the scenarios. For the both sites, the highest values are found to approach a theoretical maximum of 30 μg/m^3.

With the exception of Scenario 7, all the scenarios have lower concentrations than the baseline for both the locations. Scenario 7 corresponds to selecting the rural land use pattern parameter within the AERMOD model, which yielded higher concentrations due to the lack of incorporation of the urban heat island effect. Using onsite specific parameters in the MOVES emission model (scenario 3) did not result in much variation compared to the baseline. Hence, scenario 3 is not further explored in detail in the following sections.

Density Histograms

In addition to box-plots, the results are also presented in density histograms, to estimate the probability distribution of the concentration. The height of each bar is proportional to the frequency of cases in each category, or area of each block is equal to the number of cases within each range. The distributions of the modeled combined with background concentration and the near-road monitoring data are overlaid on each other. The shape and spread of the two distributions help in the qualitative evaluation of model performance with the near-road data and the influence of different model parameters for different scenarios. Also, the 98th percentile values are annotated for each of the scenarios to better understand the figures. This 98th percentile corresponds to the numerical 98th percentile and is different from the 98th percentile recommended by EPA guidance for the PM hot-spot analysis process.[9] The section is divided into the different subsections representing the three sources of variability categories.

Data Source: Traffic Averaging

Results for scenario 1 (average traffic volume) and scenario 2 (hourly traffic volume) are shown in Figure 44 and Figure 45 for Fort Worth and Houston, respectively. Concentrations for both scenarios are found to be lower than the baseline case that uses the peak traffic volume for the entire time period. The distribution of Scenario 2, which is based on hourly traffic data without any aggregation, is closer to that of the observed near-road concentrations compared to scenario 1. These results could indicate that hourly traffic volume data may result in more realistic modeled concentrations.

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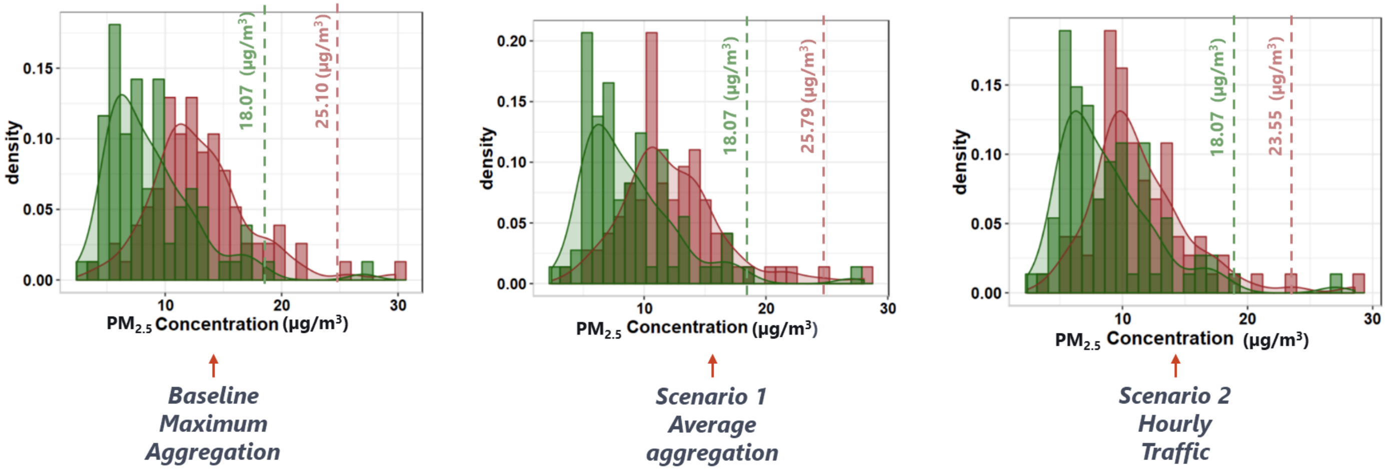
9 Researchers did not follow the procedure recommended by EPA hot-spot guidelines because our evaluation is conducted for one year of modeling, background concentration data and monitoring versus using three years of background concentration and averaging over five years of meteorological data.

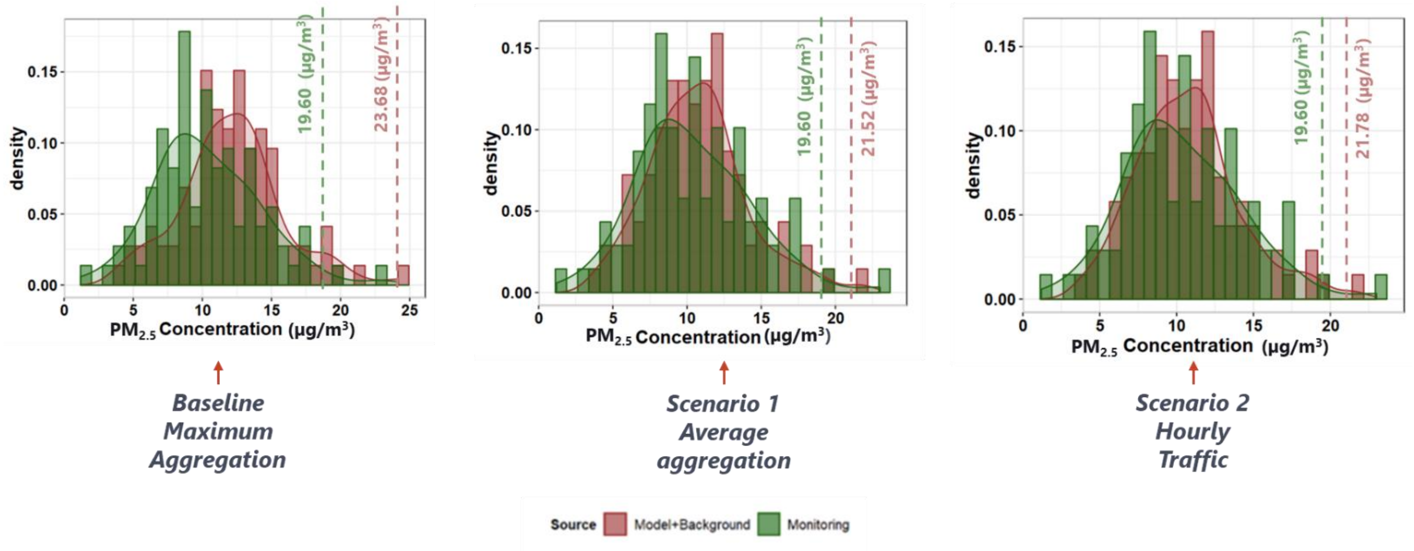


Baseline Maximum Aggregation

Scenario 1 Average aggregation

Scenario 2 Hourly Traffic

Figure 44. Comparison of Modeling Results for Different Traffic Aggregation Methods – Fort Worth.



Baseline Maximum Aggregation

Scenario 1 Average aggregation

Scenario 2 Hourly Traffic

Figure 45. Comparison of Modeling Results for Different Traffic Aggregation Methods – Houston.

Data Source: Meteorology

Figure 46 and Figure 47 represent the distributions of model results using different meteorological data compared with near-road data from Fort Worth and Houston, respectively. The concentrations are found to decrease with increasing surface roughness with minimum concentrations obtained for high surface roughness values. Comparing the offsite (medium SR) with the baseline onsite, the offsite meteorological data are found to be lower than the onsite scenario. This trend could be attributed to the higher wind speeds observed with the offsite data, which could have resulted in increased modeled dispersion and lower concentrations [93].

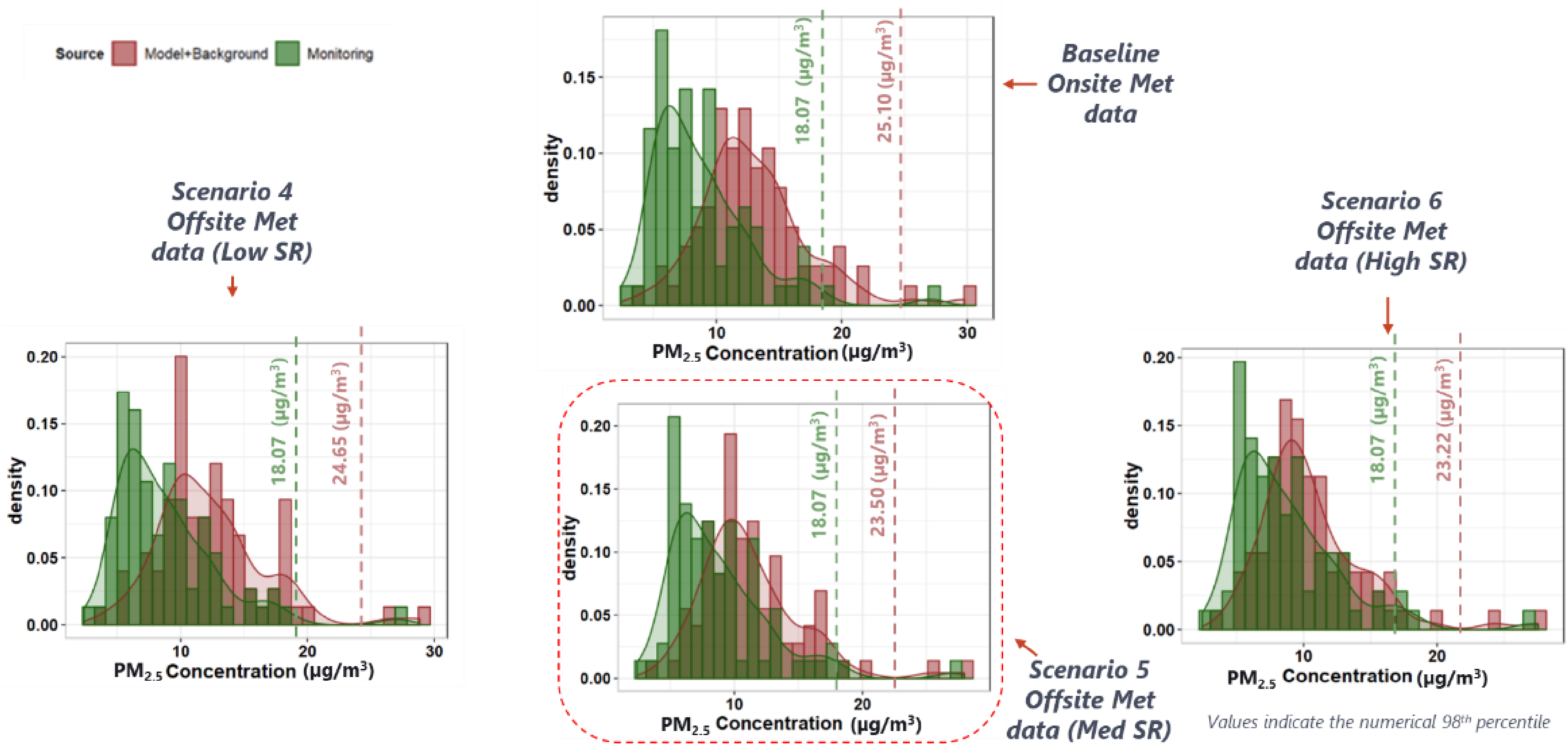


Figure 46. Comparison of Modeling Results for Different Meteorological Data – Fort Worth.

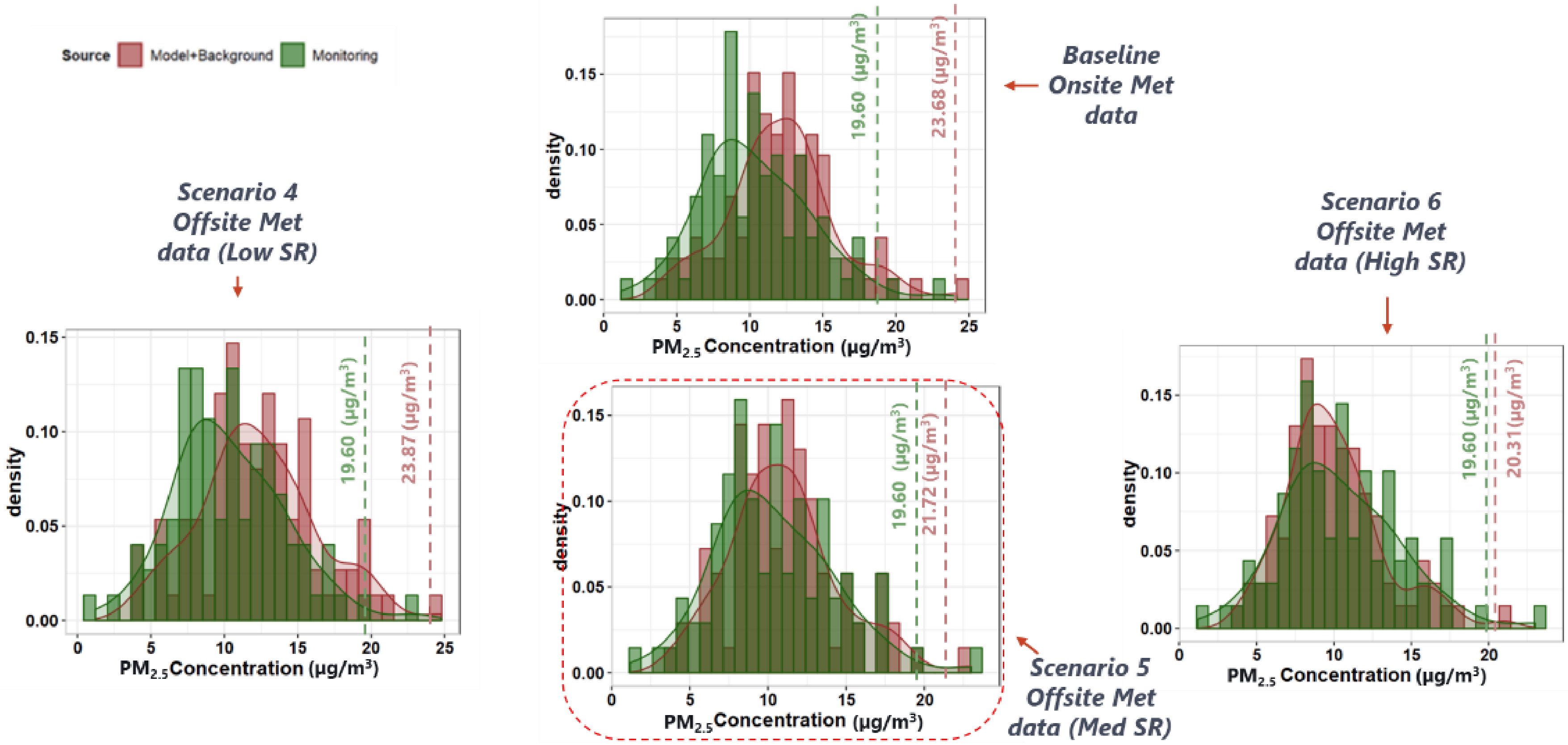


Figure 47. Comparison of Modeling Results for Different Meteorological Data – Houston.

Model Option: Source Type

The results from the volume sources in Scenario 8 are shown in Figure 48 and Figure 49 for Fort Worth and Houston, respectively. The 98th percentile concentrations for volume sources for both sites are found to be lower than that of the baseline. The lower concentrations using volume sources in AERMOD may be attributed to the different treatment of emission dispersion compared to area sources and the incorporation of plume meander algorithm for volume sources. The distribution corresponding to volume sources is found to be closer to the near-road concentrations when compared to the area sources.

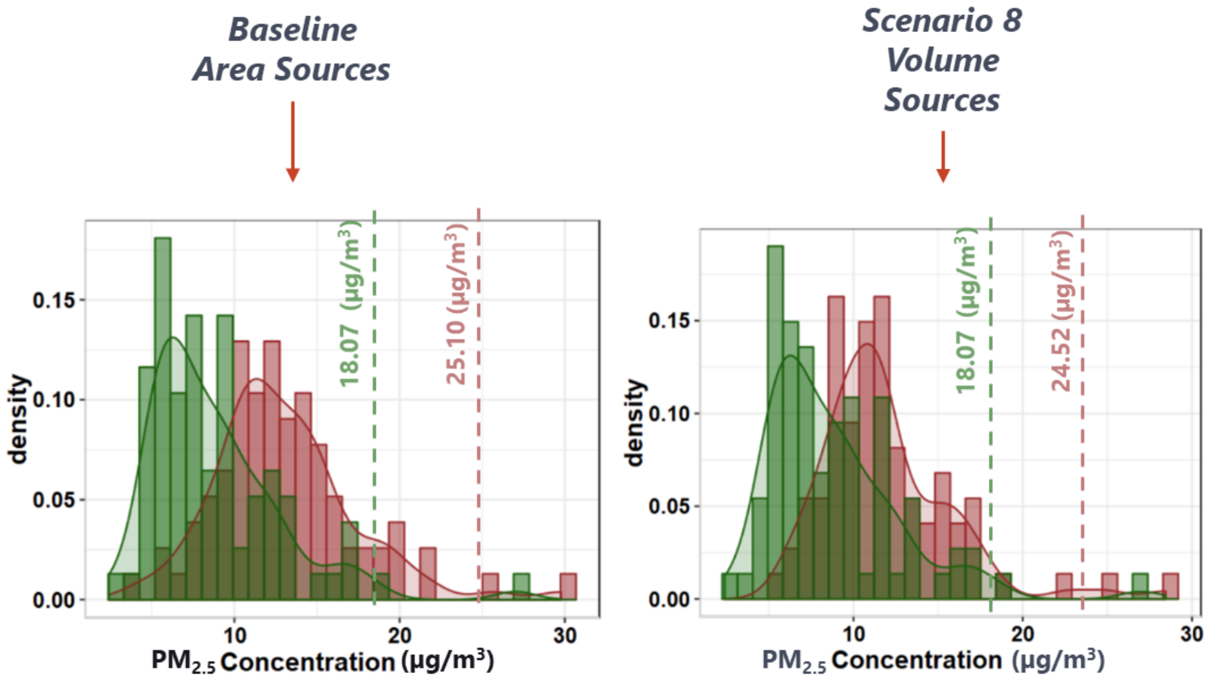


Figure 48. Modeling Results for Area and Volume Source Types – Fort Worth.

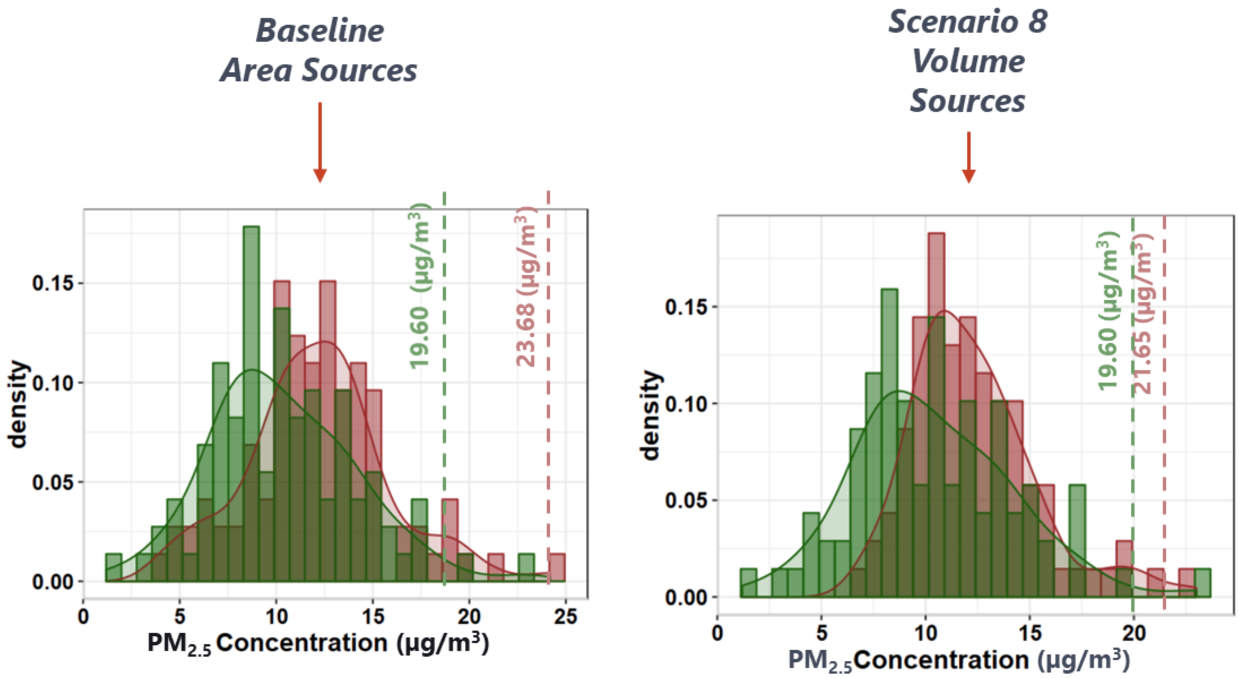


Figure 49. Modeling Results for Area and Volume Source Types – Houston.

Model Option: Land Use

The dispersion model configuration in AERMOD was changed to rural from urban to study the impact of urban heat island effect. The results show much higher concentrations for the rural case in comparison to the baseline as shown in Figure 50 and Figure 51 for Fort Worth and Houston, respectively. The lower concentrations in the urban setting are due to the incorporation of urban heat island effect in predicting the pollutant dispersion patterns. The implication of this finding is that if a project site is misclassified as rural then the resulting concentrations will not be representative of the site.

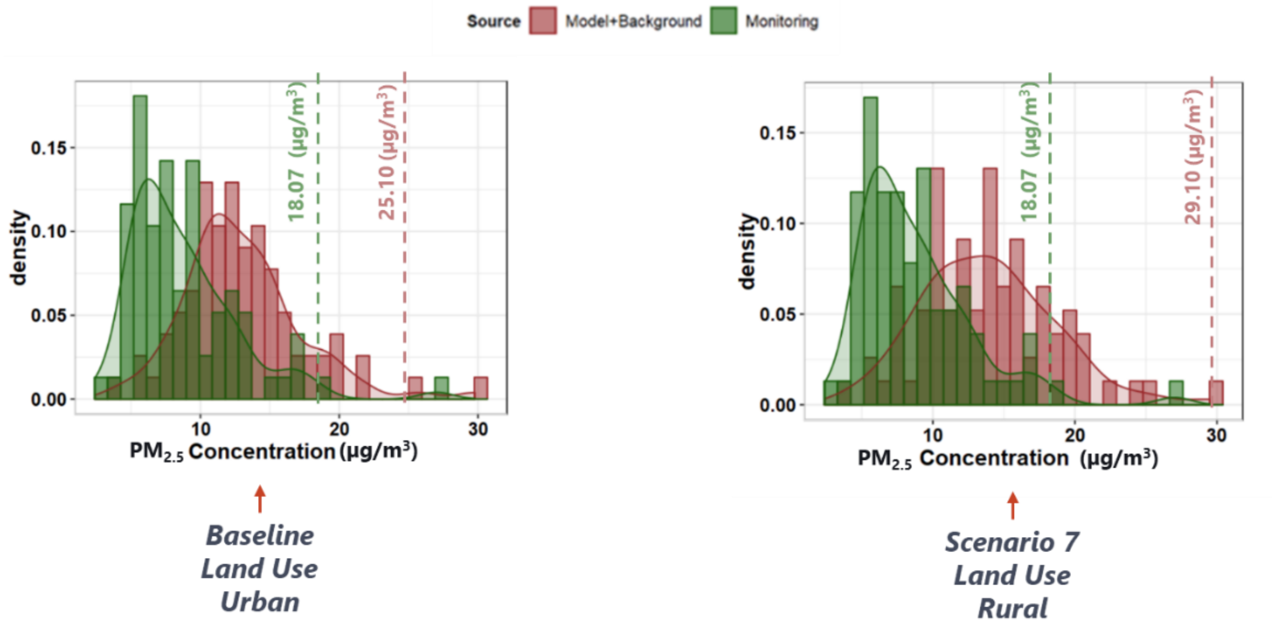


Figure 50. Modeling Results for Land Use Parameter in AERMOD – Fort Worth.

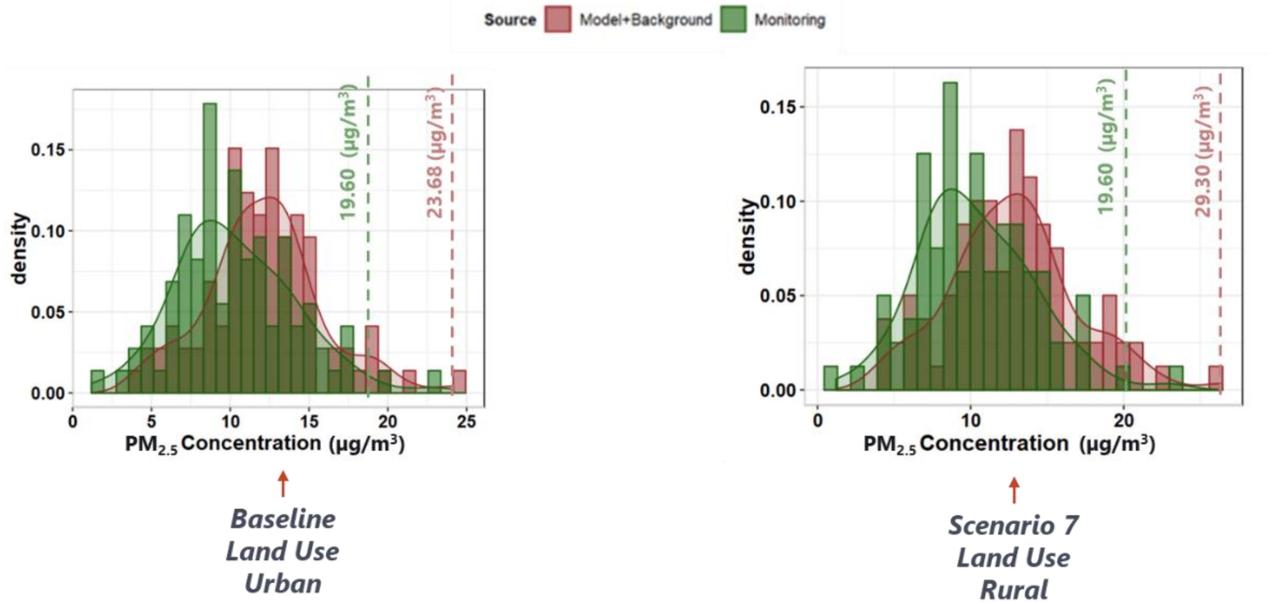
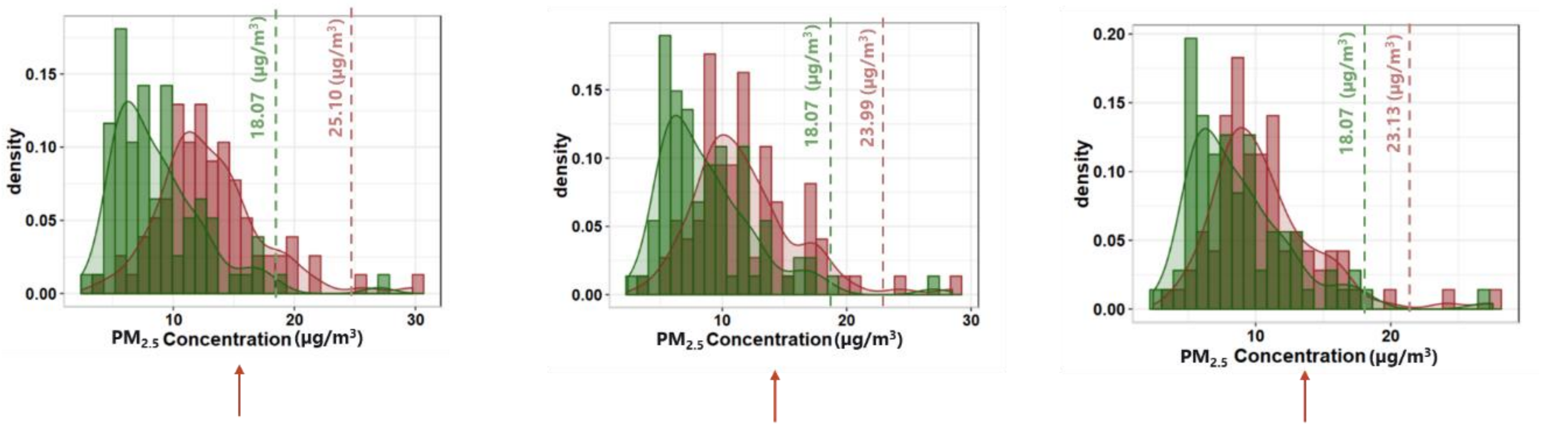


Figure 51. Modeling Results for Land Use Parameter in AERMOD – Houston.

Model Choice: CAL3QHCR + Meteorological Data

Two different modeling scenarios were performed using the CAL3QHCR model with onsite (Scenario 10) and offsite (Scenario 9) meteorological data. The results are shown in Figure 52 and Figure 53 for the Fort Worth and Houston sites, respectively. The concentrations are found to be lower compared to that of AERMOD for both sets of meteorological data. Implication of this finding is that concentration results could be completely different depending on which model is used. The difference in concentrations may be attributed to the difference in the underlying methodology, incorporation of parameters, and different treatment of the same parameter (such as atmospheric stability is represented by discrete classes in CAL3QHCR compared to a continuous value in AERMOD) by the two models. For the two sites studied in this project, the concentration distribution and the 98th percentile for CAL3QHCR model's results seem to match the distribution of the near-road concentration better than that of AERMOD model's results. Researchers acknowledge these results are site-specific and cannot be generalized without further detailed investigation using data from more sites.

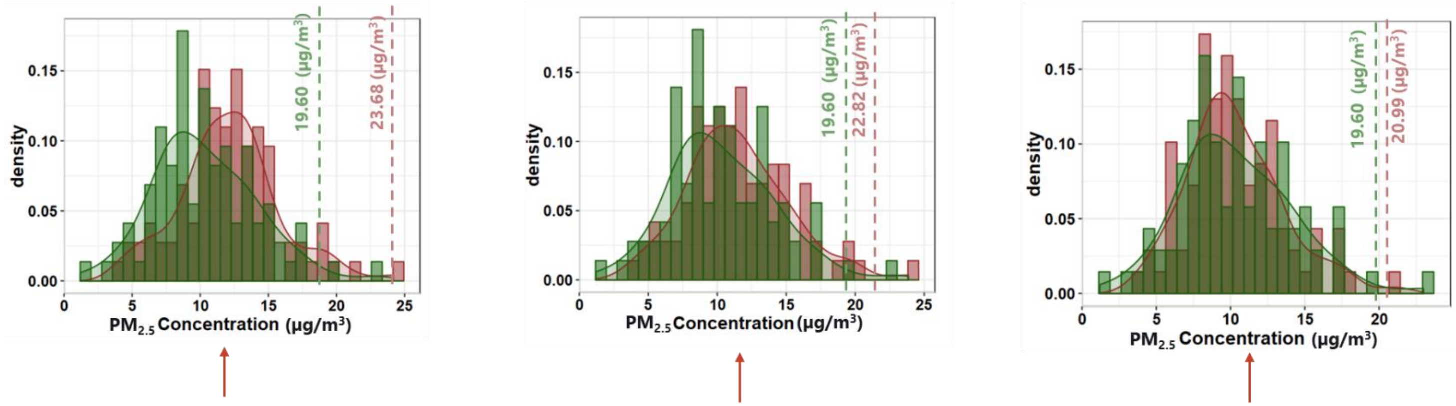


Baseline AERMOD Onsite Met data

Scenario 10 CAL3 model Onsite Met data

Scenario 9 CAL3 Model Offsite Met data

Figure 52. Modeling Results for AERMOD and CAL3QHCR – Fort Worth.



Baseline AERMOD Onsite Met data

Scenario 9 CAL3 Model Offsite Met data

Scenario 10 CAL3 model Onsite Met data

Figure 53. Modeling Results for AERMOD and CAL3QHCR – Houston.

KEY FINDINGS

Table 14 summarized the results for the different scenarios categorized by the source of variability. The results are highlighted in the relative order of priority in terms of low, medium, and high. Overall, the change in model options was found to have the maximum impact on the model results, with the AERMOD's land use parameter having the maximum impact of +8.5 μg/m^3 followed by source type (up to −4 μg/m^3). Medium impact was observed with variation in model choice with maximum impact for CAL3QHCR with offsite meteorological data (−3.7 μg/m^3) followed by CAL3QHCR with onsite meteorological data (−3.5 μg/m^3). The data sources had the lowest impact on the results although by a small margin, with meteorological data having the maximum impact −3.3. μg/m^3 followed by traffic aggregation methodology (−2.6 μg/m^3). Comparison between the modeled concentration combined with background concentration and the near-road concentration data in time series plots (over the entire sampling period) for both sites are provided in Appendix C.

Table 14. Range of Variability of Different Model Parameters.

Source of Variability	Scenarios	Average Range of Variability (compared to baseline)		Order of Priority
		Difference from Baseline (μg/m^3)	Difference from Baseline (%)	
Data	Traffic Averaging	**−2.6**	−25.3%	***Low***
	Meteorological Data	**−3.3**	−33%	
Model Choice	CAL3QHCR	**−3.5**	−37%	***Medium***
	CAL3QHCR (offsite)	**−3.7**	−42%	
Model Options	Land Use	**8.5**	+85%	***High***
	Source Type	**−4**	−41%	

The ranking of the order of priority is to help TxDOT and other stakeholders in prioritizing their resources to focus on preparing input data and quality control of the modeling results and interpretation of the results for the available resources. Results presented in this research study are based on only two case study sites. One major limitation in the study was the 24-hour resolution of the $PM_{2.5}$ concentrations measured at the near-road monitoring stations. Because of this limitation, the data exploration was not able to account for the hourly variabilities of parameters such as traffic activity, wind speed, and wind direction. A data exploration of near-road monitoring data collected at a finer resolution (e.g., hourly) can reveal the association between the key parameters and the near-road concentrations in more details and higher certainty. The results of the data exploration confirmed the dominance of the background concentration in calculating the 24-hour design value for the near-road 24-hour averaged $PM_{2.5}$ concentration for the study sites.

Together, the data exploration research and modeling analyses highlight the fact that both the near-road air quality and the PM hot-spot modeling process are complex, involving a myriad of parameters and factors on both the distribution and quantification of the PM concentrations. The results highlighted significant variation as a result of typical modeling options and data sources used in conducting a PM hot-spot analysis. These factors are found to impact both at an individual level and at a cumulative level. The availability of the near-road data presents an opportunity to qualitatively evaluate the different variabilities involved in the hot-spot process qualitatively. It is very important for the air quality modelers and stakeholders to be aware of these variations and interpret the results in the proper context.

CHAPTER 8:
FINDINGS AND CONCLUSIONS

This research project explored the potential of using the near-road concentration data measured at near-road monitors in evaluating the potential variabilities involved in the regulatory PM hot-spot process. The project involved the following main elements:

- State-of-the-practice review.
- Data exploration research of the near-road monitoring observations to evaluate the potential association between the near-road $PM_{2.5}$ concentrations and the key factors.
- Sensitivity analysis to evaluate the variabilities of the modeling process involved in the regulatory PM hot-spot analysis for key parameters.

The state-of-the-practice review highlights the emergence of real-world air quality data from near-road monitoring stations in the recent years that can be used for various applications. Also, it identifies a gap in the current research in evaluating the variabilities involved in the modeling components of the PM hot-spot process used to evaluate near-road pollutant concentration levels. Combining the two, this new source of real-world data can be explored to assess the variabilities involved with the PM hot-spot process. Two sites (Houston and Fort Worth) were selected based on different selection metrics for detailed data exploration (Track 1) and model sensitivity analysis (Track 2).

The key findings from this research project are as follows.

TRACK 1—DATA EXPLORATION

Researchers performed a data exploration research on the near-road monitoring data to evaluate the potential association between the near-field pollutant concentrations and key meteorological, traffic, and background concentration data. The key findings from the data exploration effort are summarized as follows:

- The descriptive statistics from the near-road monitoring stations indicate that at both sites the concentrations of CO, $PM_{2.5}$, and NO_2 appear to be below the NAAQS limits based on the data available. This simple comparison with NAAQS is only for research purposes and is performed as an initial step of understanding the range of the data.
- Both wind direction and wind speed are found to have an influence on CO and NO_2. Higher concentration levels are found to occur during low wind speeds and downwind conditions (i.e., when the monitor is downwind from the freeway). This observation demonstrates that traffic during downwind conditions could be a major factor influencing the distribution of CO and NO_2 levels. $PM_{2.5}$ concentrations were found to be more widely distributed in both southwest and southeast directions, indicating there could be other factors that influence the concentration distributions.

- A relatively weak correlation between freeway traffic parameters (AADT, FE-AADT, volume, and traffic speed) and near-road concentrations of $PM_{2.5}$ was observed. During the downwind conditions, traffic parameters are found to have more impact on NO_2 and CO levels.
- The determination coefficient (R^2) for near-road $PM_{2.5}$ and background $PM_{2.5}$ levels varied between 0.83 and 0.91. Changes in concentrations of near-road $PM_{2.5}$ are found to correlate more with changes in concentrations of nearby ambient monitors representing regional contribution than with any other parameters.
- On average, the near-road increment (i.e., the difference between the near-road concentration and background concentration) was found to be 2.4 $\mu g/m^3$ (or 12.8 percent). This increment could be attributed to the potential impact of traffic measured at the near-road monitors.

TRACK 2—MODELING SENSITIVITY ANALYSIS

Researchers formulated 10 scenarios to evaluate the variability for different data sources, model options, and model choices involved in the $PM_{2.5}$ hot-spot process. Researchers evaluated the scenarios in the form of probably density histograms and qualitatively compared the scenarios to the near-road monitoring data to investigate the key components affecting the sensitivity of the modeling process. The key findings from the modeling sensitivity analysis effort are summarized as follows:

- The modeling exercise points to the fact that are many factors in the PM hot-spot process that impact the estimated concentrations. These factors are found to affect the PM concentration estimates both at the individual modeling element level and cumulative across the entire modeling chain.
- The results highlight the importance of careful selection and processing of input parameters for activity/traffic, emissions, and air dispersion components. As highlighted by the sensitivity analysis, quality assurance at every step of the modeling process is required to ensure valid concentration results.
- The relationship between modeling and decision-making can be enhanced by reporting the outcomes of modeling in terms of distribution or ranges in addition to reporting the outcome of single design value. The distribution information would provide a better understanding of the variabilities in the modeling results and help interpret the results in the proper context.
- Communicating the modeling results in probability density histograms would help demonstrate that the modeling process produces a range of concentrations (i.e., a spectrum of likely concentrations) in addition to the single design value representing a specific risk to the human health as formulated by EPA.

In conclusion, the findings from this study provided a systematic assessment of the variabilities in the hot-spot modeling results as caused by different assumptions and parameters and provided an evaluation of the impact of traffic activities and other factors on the near-road $PM_{2.5}$ concentrations. Overall, the findings indicate that the background concentration is the dominating factor in estimating the near-road $PM_{2.5}$ concentrations. Traffic volume and speed were found to have a relatively weak association with the near-road concentrations. Wind direction and speed were found to have a correlation with the concentrations; however, the lack of hourly near-road concentrations data at the time of this study prevented researchers from a detailed analysis of this potential correlation at an hourly resolution.

The results of the modeling variability analysis highlighted significant variations of the estimated near-road concentrations as a result of typical modeling options and data sources used in conducting a PM hot-spot analysis. The range of variability was highest for the land use selection option (up to 8.5 $\mu g/m^3$) and lowest for traffic averaging method (up to 2.6 $\mu g/m^3$). Researchers used several methods to estimate the background concentration, including the recommended method in the PM hot-spot analysis guidance document. The background results from the two study sites showed a low variability among the different methods (up to 1.1 $\mu g/m^3$).

During this project, researchers identified several areas of future research that can build on the project findings and advance better understanding of the PM hot-spot modeling results and potential applications of near-road monitoring data in evaluating the net impact of traffic on the near-road environment. Potential areas of future research are as follows:

- The use of real-world travel time and traffic data obtained from radar sensors, GPS, cellphone, or similar sources to study detailed traffic behavior around the study sites. These data sources can provide data that are representative of real-world behavior, for a large sample of vehicles, in a cost-effective manner.
- Conducting further investigation of the near-road monitoring data to build a detailed understanding of the true impact of traffic activities on near-road air quality and potential improvements to the quantitative hot-spot analysis process. Researchers identified the following opportunities for further research on near-road monitoring data:
    - This study focused on the $PM_{2.5}$ concentrations. An opportunity exists to expand the data exploration to other pollutants that are being measured at the near-road monitoring stations (e.g., NO_2 and CO).
    - The near-road $PM_{2.5}$ monitoring data that were available at the time of this study had a 24-hour resolution. The lack of hourly near-road concentrations data limited the scope of the data research performed in this study. There are now two near-road monitoring sites in Texas (Austin and San Antonio) that measure $PM_{2.5}$ concentrations at an hourly resolution. A data exploration of these hourly observations can provide better understanding of the impact of traffic activity and other parameters on the near-road air quality.

  - At the time of this study, only one complete year of near-road concentration data was available. In addition to making a larger sample, the design values could be established using data from three or more complete years. The design value could be used for more detailed comparison with the modeling results.
- Accurate estimation of background concentrations is a critical component of estimating the design value in the hot-spot analysis. Researchers developed a novel approach to select the best methodology for a specific site. This approach is based on the evaluation of analytical seven methods using data from multiple background ambient monitoring stations and applying a resampling technique. This approach was applied to the two case studies performed in this project. The results showed a relatively low variability among the different methods, which may be caused by a relatively flat terrain and urban land use. It is recommended to evaluate the performance of the proposed approach for a more diverse set of areas and investigate potential trends and opportunities for streamlining this important step of the hot-spot analysis.
- The sensitivity analysis of the $PM_{2.5}$ hot-spot analysis modeling process that was conducted in this study included two case study sites that are in warm climate, urban land use, and in a relatively flat terrain. A modeling sensitivity analysis to include monitoring sites across a diverse set of geographic scales, configurations, climates, and land uses would provide a better understanding of the overall trends in near-road air quality. This knowledge would be very important in revising and streamlining the hot-spot analysis process.
- The availability of the near-road data has created an opportunity to explore whether the data can be used for screening purposes and streaming the hot-spot analysis for a particular pollutant.

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APPENDIX A: METEOROLOGICAL DATA

A detailed overview of the meteorological data processing for AERMOD, and CAL3QHCR is provided in sections A1, and A2, respectively. Section A3 overviews the methodology that was used to achieve consistency between the meteorological data files between the two models.

METEOROLOGICAL DATA PROCESSING FOR AERMOD

Meteorological conditions strongly impact the pollutant dispersion in the atmosphere. Three types of data are required for processing the meteorological data, namely, surface data that measure characteristics of lower layers of the atmosphere, upper air data that measure characteristics that change with height in the atmosphere (such as temperature), and land use data that represent surface characteristics. For this study, the raw meteorological and land use data were obtained from the following sources:

- Automated Surface Observing Stations (ASOS).
- National Weather Station databases (NWS).
- U.S. Geological survey land use database (USGS).

The ASOS and NWS databases are owned and maintained by NCDC and National Oceanic and Atmospheric Administration (NOAA) under the U.S. Department of Commerce [94]. USGS land use database is a national archive for remotely sensed images of Earth’s land surface maintained by the U.S. Department of the Interior [95]. USGS land use database is a national archive for remotely sensed images of Earth’s land surface maintained by the U.S. Department of the Interior. Figure A1 shows the process of meteorological data processing for AERMOD. The raw data are processed using meteorological preprocessors namely, AERMINUTE, AERMET, and AERSURFACE to produce data in a format compatible for AERMOD. High resolution wind data are processed by AERMINUTE preprocessor in the first step. One of the main concerns in using NWS surface data directly for AERMOD is the presence of high incidence of calm and missing wind data. AERMOD cannot accurately simulate dispersion with calm/missing winds. To reduce this, NCDC started archiving raw one-minute data logged by automated stations. AERMINUTE is used to process the one-minute data to produce hourly wind speed and direction averages to improve the quality of surface data obtained from the NWS. The second step consists of obtaining the land cover surface characteristics from the AERSURFACE preprocessor. AERSURFACE processes the land cover data (specific to the case study location) from the USGS database and produces surface characteristics.

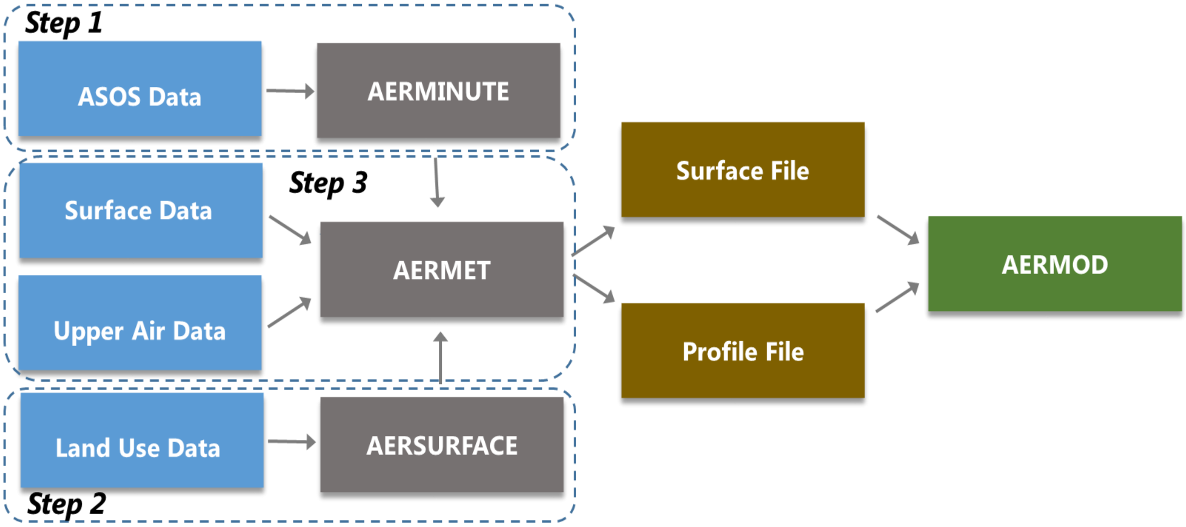


Figure A1. Meteorological and Land Use Processing for AERMOD.

These surface characteristics relate to the following parameters:

- Albedo: fraction of total incident solar radiation that is reflected back to space without absorption.
- Bowen ratio: amount of surface moisture conditions.
- Surface roughness (height of obstacles to the wind flow).

In the third step, AERMET incorporates surface and upper data from the NWS database and combines them with the hourly wind speed and direction averages produced by AERMINUTE and land cover surface data (albedo, surface roughness, and Bowen's ratio) from AERSURFACE to produce output files for AERMOD. The two files produced by AERMET consist of a boundary layer parameter (.SFC) file that includes turbulence parameters, mixing height, and friction velocity. The second file (.PFL) contains the vertical profile of winds, temperature, and standard deviation of the fluctuating components of the wind. These two files are directly incorporated into AERMOD. According to EPA [12], AERMET shall be used to preprocess all meteorological data, be it observed or prognostic, for use with AERMOD in regulatory applications, and the AERMINUTE processor, in most cases, should be used to process 1-minute ASOS wind data for input to AERMET when processing NWS ASOS sites in AERMET.

Meteorological Files Required by AERMET

Details of the input files required by AERMET meteorological preprocessor is provided in this section.

Surface Input

The surface input file is acquired from NCDC of NOAA. The hourly surface data for all available years are placed in a file transfer protocol server at the link ftp://ftp.ncdc.noaa.gov/pub/data/noaa/. The users can identify the desired stations and years of data by looking up the table in the file, isd_history.txt, located in the ftp site.

Onsite Input

The onsite input file has to be created based on what parameters are desired in accordance to input requirements as specified by EPA [96]. Each column of the created data set should represent one parameter. For this project, the parameters to be used are day, month, year, hour, precipitation amount, temperature, dew point temperature, wind speed, wind direction, standard deviation of horizontal wind, and relative humidity. The data for these parameters can be retrieved, as a CSV file, from NOAA’s Local Climatological Data at the link https://www.ncdc.noaa.gov/cdo-web/datatools/lcd. The Texas Commission on Environmental Quality (TCEQ) also provides a number of selected years of site-specific onsite data for many Texas air monitoring stations, and the parameters can also be found at their TAMIS website.

Upper Air Input

Upper air data are recorded at unevenly, sparsely distributed locations throughout the United States. Selection of the closest upper air data for use in air dispersion modeling requires special attention as only certain stations record data at a certain time so the closest upper air station to the point of interest can be far away from the modeling domain. The data can be retrieved from NOAA’s Radiosonde Database at https://ruc.noaa.gov/raobs/.

AERMINUTE Input

A potential concern related to the use of ISD meteorological data for air dispersion modeling is the often high incidence of calms and variable wind conditions. In the reporting of surface weather data, a calm wind is defined as a wind speed less than 3 knots and is assigned a value of 0 knots. In addition, the wind direction may be reported as missing if the wind direction varies more than 60 degrees during the 2-minute averaging period for the observation [97]. To reduce the number of calms and missing winds in the surface data, the 1-minute ASOS wind data are used to calculate hourly average wind speed and directions, which are used to backfill the missing data and calms in the ISD data. This ASOS minute data can be found in the NCDC database, the same link as the previously discussed surface data. The ASOS data contain both TD 6405 and TD 6406 formatted files. For the purpose of creating a meteorological file, the data start with 6405 followed by the desired year were used. As the ASOS minute files are unusually large, they need to be downloaded separately based on the months required.

AERSURFACE Input

The AERSURFACE processor is developed to compute surface characteristic values such as albedo, Bowen ratio, and surface roughness length, in a modeling domain for use in AERMET [98]. Similar to AERMINUTE, data from AERSURFACE can be created or simplified by dividing the area of study into different sectors and giving each sector an albedo, Bowen ratio, and surface roughness. For this project, the AERSURFACE program was run using National Land Cover Data from 1992 (NLCD 92) from the United States Geological Survey at the following link: https://www.mrlc.gov/viewerjs/.

Meteorological Files Generated by AERMET

Five consecutive years (2012–2016) of off-site surface meteorological data were generated for use in the dispersion modeling for both Houston and Fort Worth near-road case study sites. Two years (2015–2016) of site-specific meteorological parameters were generated from AERMET by using the on-site data from the near-road monitoring stations (TCEQ’s CAMS C1052 and C1053) in conjunction with respective upper air, ISD, and ASOS data. Each file is named with index codes in the following fashion:

File Name= Site_Surface_Upper_Year_SR.File
Site = Onsite or offsite
Surface = Station ID for surface data
Upper = Station ID for upper air data
Year = year of data in 2 digits
SR = Surface Roughness (High: 1 m; Medium: 0.5 m; Low: 0.05 m; S: Site-specific from AERSURFACE)
File = File extension, PFL for profile data and SFC for surface data
For example, File ONSITE_IAH_LCH_15H.SFC is the site-specific (ONSITE) hourly surface data (SFC) for the year of 2015 using upper air data from Lake Charles (LCH), surface data from Houston International Airport (IAH), and surface roughness of 1 m (H) for AERMOD modeling.

METEOROLOGICAL DATA PROCESSING FOR CAL3QHCR

Unlike AERMOD, CAL3QHCR can only process up to a year of hourly meteorological data. A meteorological file for CAL3QHCR must include wind vector (degrees), wind speed (meters/sec), ambient temperature (K), stability class, and mixing heights. These files can also be created using available EPA auxiliary meteorological processors and meteorological data. Data from the NWS or NCDC formatted data can be processed through EPA’s meteorological processors and accessory programs such as, the Meteorological Processor for Regulatory Models (MPRM), PCRAMMET, or RAMMET programs, as recommended by EPA [99]. However, currently NCDC has ceased to process NWS or NCDC formatted data for use in any of the meteorological processors.

Among the EPA-recommended meteorological processors, PCRAMMET is selected for this study because it has been widely used by EPA in preparing NWS data for use in the Agency's short-term air quality dispersion models such as CAL3QHCR, ISCST3, CRSTER, RAM, MPTER, BLP, SHORTZ, and COMPLEX1 [96]. The minimum input data requirements to PCRAMMET are the twice-daily mixing heights, hourly surface observations of wind speed and wind direction, dry bulb temperature, opaque cloud cover, ceiling height, and station pressure, if calculating dry deposition. These parameters can be obtained from the NCDC database with the exception of the twice-daily mixing heights. Since the NCDC no longer provides the mixing height data, it needs to be independently processed by using the EPA's Mixing Height Program (MIXHTS) program in conjunction with surface data and radiosonde upper air files [100].

Details of the input files required by PCRAMMET meteorological preprocessor is provided in this section.

HUSWO Surface Meteorological Data

Both PCRAMMET and MIXHTS can read surface meteorological data in either HUSWO, SCRAM, or CD-144 formats. Because the NCDC does not provide meteorological data in these readable formats, data must be arranged in one of these formats using a text editor or other methods. The HUSWO format was selected for this study to process on-site and off-site surface meteorological data.

A combination of LCD data and ISD was used for creating the surface meteorological data files for (a) its greater degree of completeness and inclusion of ceiling height and sky cover, required inputs for MIXHTS and (b) maintaining data consistency between AERMET and PCRAMMET outputs. Two years (2015–2016) of site-specific meteorological parameters (such as dry bulb temperature, wind direction, and wind speed) for the Houston site were obtained from the TCEQ CAM stations C1052 to develop site-specific meteorological files, and from C1053 for the Fort Worth site.

Table A1 shows the HUWSO format parameters in the meteorological data file, units, and the source and station code used to download meteorological data. Some parameters are not used in CAL3QHCR or MIXHTS but must be included in the HUSWO format chosen; these parameters are preserved in the file but filled with missing data identifiers. PCRAMMET assumes the HUSWO data were retrieved in English units. Therefore, wind speeds in HUSWO are converted from miles per hour to meters per second (m/s). Wind speeds below 1.0 m/s (calms included) are set to 1.0 m/s before computations are made in PCRAMMET [99]. Missing wind direction and wind speed values from the CAMS stations are replaced by the averages of the adjacent values, the previous and next hour of data. This missing data treatment was performed for time periods of less than 4 hours. Data missed for more than 4 hours are left untreated and flagged with missing data. This method is recommended by the EPA for data sets that are less than 90 percent complete [101].

Table A1. HUSWO Meteorological Data File.

	Parameter	Units	Data Source	Data Source Station
1	Station ID	Station Number (WBAN)	NCDC	IAH, FTW
2	Time	Year-Month-Day-Hour	NCDC	IAH, FTW
3	Global Radiation	Nearest Tenth Watt Per Meter Squared	-	-
4	Direct Radiation	Nearest Tenth Watt Per Meter Squared	-	-
5	Total Sky Cover	Amount of Sky Dome (In Tenths) Covered by Clouds. 99 = Missing	NCDC	IAH, FTW
6	Opaque Sky Cover	Amount of Sky Dome (In Tenths) Covered by Clouds. 99 = Missing	NCDC	IAH, FTW
7	Dry Bulb Temperature	Degrees Fahrenheit	TAMIS	C1052, C1053
8	Dew Point Temp	Degrees Fahrenheit	NCDC	IAH, FTW
9	Relative Humidity	Percent	NCDC	IAH, FTW
10	Station Pressure	Hundredths Of Inches	NCDC	IAH, FTW
11	Wind Direction	Degrees	TAMIS	C1052, C1053
12	Wind Speed	Miles Per Hour (Mph)	TAMIS	C1052, 1053
13	Visibility	Miles	NCDC	IAH, FTW
14	Ceiling Height	Feet	IEM	IAH, FTW
15	Present Weather	Code	NCDC	IAH, FTW
16	ASOS Cloud Layer 1	Sky Condition Code 00-09	-	-
17	ASOS Cloud Layer 2	Sky Condition Code 00-09	-	-
18	ASOS Cloud Layer 3	Sky Condition Code 00-09	-	-
19	Hourly Precipitation	Hundredths of Inches	NCDC	IAH,FTW
20	Snow Depth	Inches	NCDC	IAH, FTW

MIXHTS Mixing Height Data

MIXHTS requires two input files, the HUSWO surface file and a separate radiosonde upper air data file, which can be obtained from the National Oceanic and Atmospheric Administration (NOAA) database. The output of MIXHTS provides the mixing height data file needed for use in PCRAMMET. Missing mixing height values were found with the previously stated method of averaging the adjacent values from the previous and next entry of data.

Meteorological Files Generated by PCRAMMET

Meteorological files generated by PCRAMMET for CAL3QHCR modeling are named the same way as discussed in Section A.2 with additional identifier in the extension:

File Name= Site_Surface_Upper_Year_SR.File
Site = Onsite or offsite
Surface = Station ID for surface data
Upper = Station ID for upper air data
Year = year of data in 2 digits

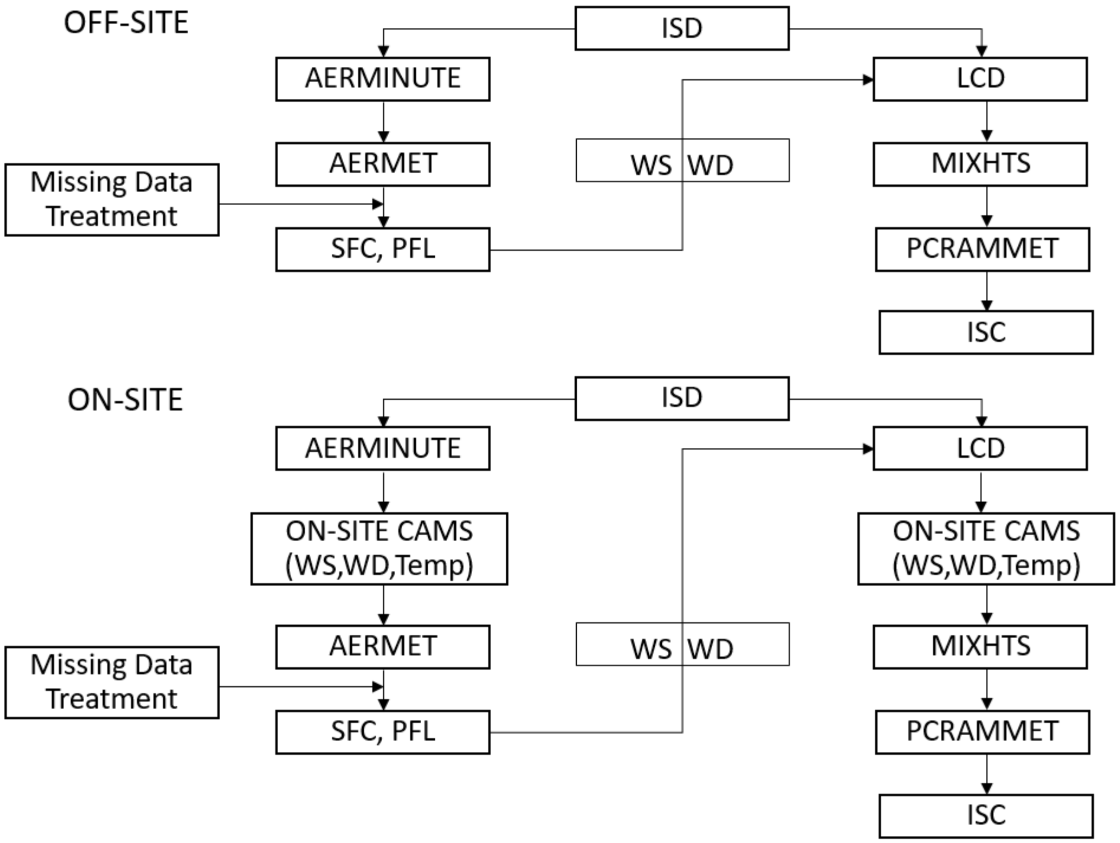
SR = Surface Roughness (N: not requires)
File = File extension, ISC for surface data.
For example, File ONSITE_IAH_LCH_15_N.ISC is the site-specific (ONSITE) hourly surface data (ISC) for the year of 2015 using upper air data from Lake Charles (LCH), surface data from Houston International Airport (IAH), and no specified surface roughness (N) for CAL3QHR modeling.

CONSISTENCY BETWEEN AERMET AND PCRAMMET OUTPUTS

In order to evaluate the sensitivities of non-meteorology related parameters (such as source characterization and time-varying emission) on the concentrations estimated by AERMOD and CAL3QHR, it is important to ensure consistent meteorological data files are used for both models. During the quality control process, researchers found that the hourly wind direction and wind speed generated by AERMET and PCRAMMET did not agree with each other completely. The ASOS 1-minute data are used to supplement the ISD surface hourly meteorological data in AERMINUTE because ISD hourly surface meteorological data often include high incidence of calms and variable wind conditions [97]. Although using the same ISD and ASOS data for the same site, the algorithms used by NCDC (for processing the LCD and ISD combination file) and by EPA (for processing the SFC file) to process the data appear to be different and may be the reason for the discrepancies in wind direction and wind speed. In addition, there are inherent differences in the reporting of wind speed among ISD, LCD, and TCEQ TAMIS. In reporting the wind speed, LCD reports only integer mile/hr. winds whereas ISD and TCEQ TAMIS report to one tenth of 1 m/sec.

In the treatment of calm condition, PCRAMMET assigns zero values for all wind speeds of less than or equal to 1 m/sec whereas AERMET not only assigns zero values but also defaults the wind direction to 0 degree for all wind speeds of less than or equal to 1 m/sec. On the contrary, the TCEQ TRAMIS database (for site-specific data) reports wind speed to 0.1 m/sec with no treatment of the wind direction. Both models treat the calm wind or missing meteorological data conditions similarly. Both models set the concentration values to zero for that hour and calculate the average by summing each valid (non-calm) 1-hour average concentration and dividing by the total number of non-calm hours or 75 percent of the total number of hours in the period, whichever is greater [2].

Consistency between the meteorological data files is achieved by replacing the wind speed and wind direction in the ISC data files (used in CAL3QHCR) with the corresponding values in SFC files (used in AERMOD) at the input stage of the CAL3QHCR file processing (i.e., before input into MIXHTS and PCRAMMET). Figure A2 shows the general procedure followed in this study in processing meteorological data from the input stage until the final stage data needed to ensure consistency between the dispersion models.



SFC: AERMET output file	**WD:** Wind Direction
PFL: AERMET output file	**LCD:** Local Climatological Data
ISD: Integrated Surface Data system	**MIXHTS:** EPA’s Mixing Height Program
WS: Wind Speed	**ISC:** CAL3QHCR output file

Figure A2. Flowcharts for Consistency in Wind Direction and Wind Speed between AERMET and PCRAMMET Outputs.

APPENDIX B: BACKGROUND CONCENTRATION

A detailed discussion of the analysis and results are provided in this appendix.

RESULTS AND DISCUSSION

The TCEQ $PM_{2.5}$ monitoring network is designed to meet the SLAMS network and NCore requirements [70]. This monitoring network provides data for near-road and regional background applications. All background stations selected in this study were designed to support compliance with NAAQS and research in air pollution studies (Title 40 CFR Part 58, Appendix D). They are located at a distance clear of highway emissions (highway is considered as a roadway with more than 50,000) and are representative of the area's background concentration levels.

The 2-year quarterly time-series plots of the 24-hour average $PM_{2.5}$ concentrations measured in the Houston and Fort Worth areas are shown in Figure B1. Some high $PM_{2.5}$ episodes recurring around the same time of the year. For instance, high $PM_{2.5}$ days occurred around middle of March, May, June, and early July 7 each year for the Houston area, and around mid-June, and early July and October 8 for the Fort Worth area. Furthermore, the time series data for the background concentrations were noted to be strongly correlated with a well-defined trend for both the case study sites. This is an indication of persistent meteorology and emission patterns prevailing in both areas. A seasonal $PM_{2.5}$ episode is observed in both cities around the Independence Day when high traffic, intense outdoor BBQ activities, and excessive fireworks (all considered major sources of $PM_{2.5}$ emission) takes place.

ANNUAL AVERAGE $PM_{2.5}$ CONCENTRATIONS

The annual average concentration at each background station is listed in Table B1 for the Houston and Fort Worth areas. The annual average developed from the hourly data set was found to be slightly different from that developed from the 24-hr dataset due to the treatment of missing data in constructing the data set, as described in the previous section. Because the normalized methods (Methods 5, 6, and 7) preserve the same annual averages as the non-normalized ones (Methods 2, 3, and 4), their mean values and the comparison statistics are the same as their respective counterparts. These values are therefore not included in the tables. Annual averages for the same year was found to be varying within a narrow range (±10 percent from the all site average) for both cities. Annual averages at the same site fluctuate from one year (2015) to another (2016) with a magnitude of up to 15 percent. Given the small increment (<15 percent) in $PM_{2.5}$ concentrations observed at near-road monitors that can be attributed to the traffic emissions, this magnitude of variation is significant especially when it is used for PM design value calculation that hinges predominantly on the background concentration.

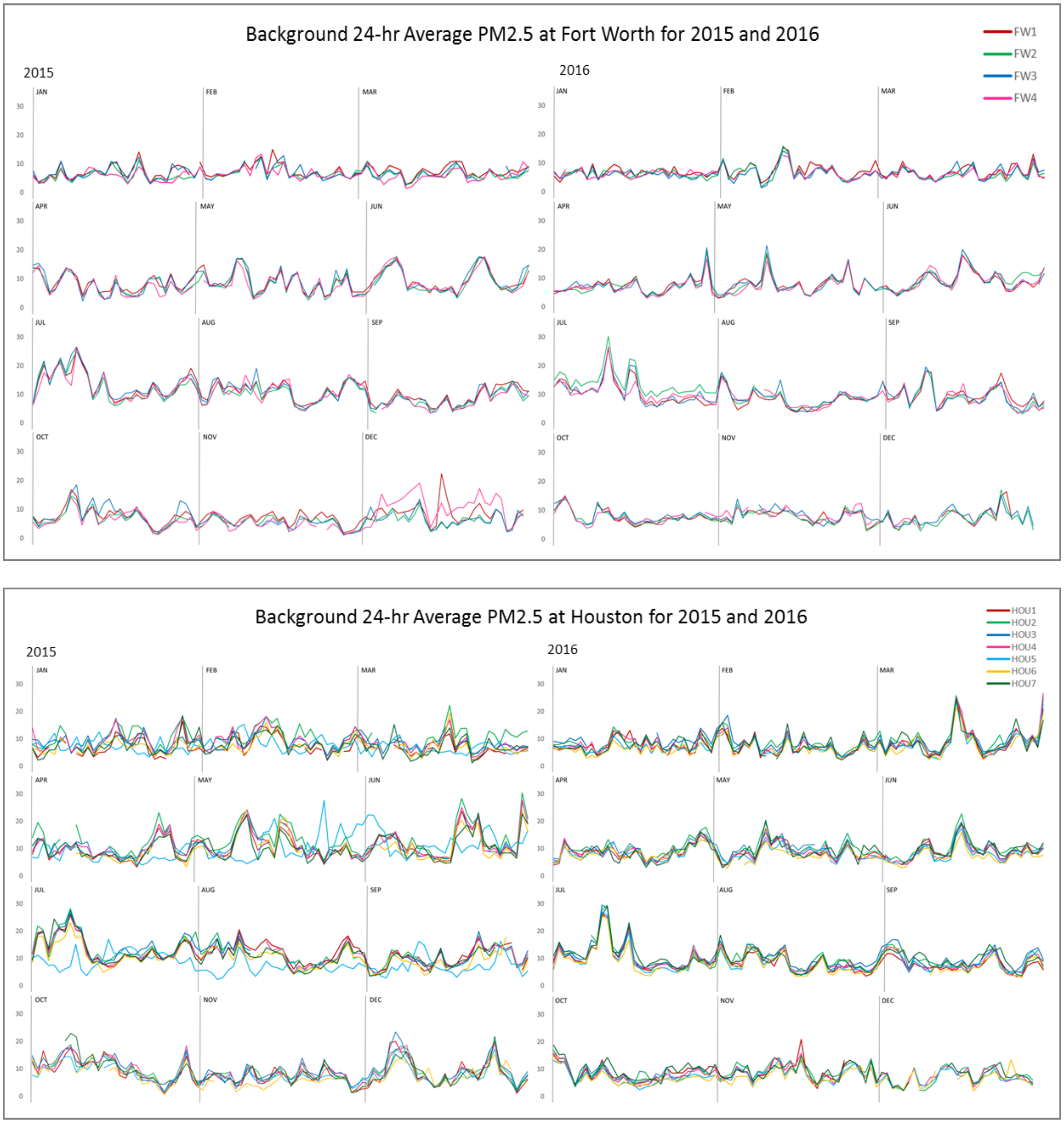


Figure B1. 24-hr Average PM2.5 Data for the Houston and Fort Worth Areas.

Table B1. Method Comparison Based on PM2.5 Annual Averages at 7 Sites in Houston.

			Annual Average, µg/m3					All sites	NMB	NME	RMSE	NRMSE
Method	1	2	3	4	5	6	7	Average	- - -	- - -	µg/m3	- - -
Hourly Data	Houston 2015											
Observation	**9.40**	**11.35**	**10.59**	**10.24**	**8.44**	**8.59**	**9.59**	**9.74**				
Method 1	10.24	10.24	11.35	11.35	10.24	8.44	9.40	**10.18**	0.04	0.09	1.00	0.10
Method 2, 5	9.80	9.47	9.60	9.66	9.96	9.93	9.77	**9.74**	**0.00**	0.10	1.14	0.12
Method 3, 6	10.02	9.87	10.14	10.17	10.09	9.86	9.78	**9.99**	0.03	0.08	1.01	0.10
Method 4, 7	10.23	10.16	10.67	10.72	10.14	9.69	9.78	**10.20**	0.05	**0.08**	**0.96**	**0.10**
24-hr Data												
Observation	**9.48**	**11.44**	**10.63**	**10.33**	**8.47**	**8.70**	**9.64**	**9.81**				
Method 1	10.33	10.33	11.44	11.44	10.33	8.47	9.48	**10.26**	0.05	0.09	1.03	0.10
Method 2, 5	9.87	9.54	9.68	9.73	10.04	10.00	9.84	**9.81**	**0.00**	0.10	1.15	0.12
Method 3, 6	10.10	9.94	10.22	10.24	10.17	9.92	9.85	**10.06**	0.03	0.08	1.02	0.10
Method 4, 7	10.30	10.23	10.75	10.79	10.22	9.75	9.85	**10.27**	0.05	**0.08**	**0.97**	**0.10**
Hourly Data	Houston 2016											
Observation	**8.62**	**9.87**	**9.86**	**8.88**	**8.19**	**7.72**	**9.33**	**8.93**				
Method 1	8.88	8.88	9.87	9.87	8.88	8.19	8.62	**9.03**	0.01	**0.07**	**0.68**	**0.08**
Method 2, 5	8.98	8.77	8.77	8.93	9.05	9.13	8.86	**8.93**	**0.00**	0.09	0.88	0.10
Method 3, 6	9.07	8.97	9.05	9.21	9.03	9.01	8.86	**9.03**	0.01	0.08	0.79	0.09
Method 4, 7	9.15	9.13	9.39	9.53	9.03	8.87	8.85	**9.14**	0.02	0.08	0.73	0.08
24-hr Data												
Observation	**8.69**	**9.96**	**9.96**	**8.97**	**8.25**	**7.79**	**9.41**	**9.00**				
Method 1	8.97	8.97	9.96	9.96	8.97	8.25	8.69	**9.11**	0.01	**0.07**	**0.69**	**0.08**
Method 2, 5	9.05	8.84	8.84	9.01	9.13	9.21	8.93	**9.00**	**0.00**	0.09	0.90	0.10
Method 3, 6	9.15	9.05	9.12	9.29	9.11	9.08	8.94	**9.11**	0.01	0.08	0.80	0.09
Method 4, 7	9.23	9.22	9.47	9.61	9.11	8.95	8.93	9.22	0.02	0.08	0.74	0.08
Hourly Data	Ft. Worth 2015											
Observation	8.91	7.86	8.46	8.08	---	---	---	**8.33**				
Method 1	8.08	8.08	7.86	7.86	---	---	---	**7.97**	-0.04	0.06	0.53	**0.06**
Method 2, 5	8.13	8.48	8.28	8.41	---	---	---	**8.33**	**0.00**	0.06	0.53	**0.06**
Method 3, 6	8.11	8.33	8.08	8.19	---	---	---	**8.18**	-0.02	**0.05**	**0.50**	**0.06**
Method 4, 7	8.09	8.26	7.96	8.03	---	---	---	**8.08**	-0.03	**0.05**	0.52	**0.06**
24-hr Data												
Observation	8.84	7.83	8.42	8.03	---	---	---	**8.28**				
Method 1	8.03	8.03	7.83	7.83	---	---	---	**7.93**	-0.04	**0.05**	0.52	**0.06**
Method 2, 5	8.10	8.43	8.24	8.37	---	---	---	**8.28**	**0.00**	0.06	0.52	**0.06**
Method 3, 6	8.07	8.29	8.04	8.15	---	---	---	**8.14**	-0.02	**0.05**	**0.49**	**0.06**
Method 4, 7	8.05	8.22	7.93	7.99	---	---	---	**8.05**	-0.03	**0.05**	0.51	**0.06**
Hourly Data	Ft. Worth 2016											
Observation	8.05	8.11	8.03	7.90	---	---	---	**8.02**				
Method 1	7.90	7.90	8.11	8.11	---	---	---	**8.01**	0.16	0.16	1.43	0.18
Method 2, 5	8.02	7.99	8.02	8.07	---	---	---	**8.02**	**0.00**	**0.01**	**0.11**	**0.01**
Method 3, 6	8.01	7.97	8.04	8.08	---	---	---	**8.03**	**0.00**	**0.01**	0.12	0.02
Method 4, 7	8.01	7.96	8.06	8.10	---	---	---	**8.03**	**0.00**	**0.01**	0.13	0.02
24-hr Data												
Observation	8.07	8.16	8.08	7.93	---	---	---	**8.06**				
Method 1	7.93	7.93	8.16	8.16	---	---	---	**8.04**	-0.01	0.02	0.18	0.02
Method 2, 5	8.06	8.03	8.05	8.11	---	---	---	**8.06**	**0.00**	**0.01**	**0.11**	**0.01**
Method 3, 6	8.05	8.01	8.08	8.12	---	---	---	**8.07**	**0.00**	**0.01**	0.13	0.02
Method 4, 7	8.04	7.99	8.10	8.14	---	---	---	**8.07**	**0.00**	**0.01**	0.13	0.02

The values for the performance metrics NMB, NME, RMSE, and NRMSE are shown in Table B1. Smallest number in each column is bold. The non-normalized and normalized inverse distance squared methods appear to provide the best estimates except occasionally (in the case of Houston sites in 2016) Method 1, based on the shortest distance to the target site and, also provided good estimates.

24-HR AVERAGE $PM_{2.5}$ CONCENTRATIONS

Overall sums of the performance measures across all sites for the 24-hr $PM_{2.5}$ concentration estimation are reported in Table B2 for both cities. NMB and NME for the 24-hr data represent the deviations of daily $PM_{2.5}$ concentrations from the observations. The bias from the observations are significantly reduced by normalized methods, as seen in the tables where NMBs and NMEs for normalized methods (Methods 5–7) are much less than that reported for non-normalized methods (Methods 1–4). On the contrary, the spread of model predictions for the 24-hr observations are shown by RMSE and NRMSE, where the smaller the value, the better the prediction. All normalized methods were found to perform better than the non-normalized methods, although the NRMSE values were different only slightly among the normalized methods. The method using normalized arithmetic mean has performed well for both areas in year 2015, based on the RMSE and NRMSE calculations. Accuracy has improved best (i.e., with having the smallest measure statistics) in the model predictions using normalized arithmetic mean for 2015 Houston, 2015 and 2016 Fort Worth data. Normalized inverse distance method was found to be most accurate in estimating 2016 Houston observations, based on either RMSE or NRMSE results. There is a significant tendency of overestimation in Houston Site 5, and moderate tendency in Houston Site 6 and Fort Worth Site 4 for year 2015.

NRMSE values by stations for both project areas and years are shown in Table B3. The NRMSE value for any method for Site 5 in Houston 2015 data was found to be 2–3 times greater than the rest of sites, up to 2 times for Site 6 of Houston and Site 4 of Fort Worth. This poor accuracy can be attributed to a few outliers in the data or different pollution pattern caused by local sources. As seen in Figure 15, Houston Site 5 (Deer Park) is located approximately 6 miles from the Tabbs Bay and 20 miles from the city center, whereas Houston Site 6 (Baytown) is located at where the Buffalo Bayou enters the Galveston Bay and is approximately 30 miles from the city center. These locations are constantly downwind of the daily sea breeze and are close to many petroleum refinery facilities. Their geographical locations being away from the city center and unique local emission sources maybe the reasons for the significant deviation in $PM_{2.5}$ concentrations compared to other stations, although the deviation was less noticeable in 2016. In general, single station method (Method 1) performs worse than the multiple stations methods.

Bootstrapped standard deviations based on the NRMSE for assessing the sampling variabilities in between the methods are shown in Table B2. Although normalized arithmetic mean and inverse distance methods have more improved accuracy than non-normalized methods, as shown in the summary of NRMSEs, the standard deviations of our normalized methods do not vary significantly compared with non-normalized methods.

Table B2. Summary of Performance Measures using Bootstrap Resampling.

	Year 2015					Year 2016				
Houston	**NMB**	**NME**	**RMSE**	**NRMSE**	**SD**	**NMB**	**NME**	**RMSE**	**NRMSE**	**SD**
Method 1	0.354	1.567	20.210	2.160	0.022	0.113	0.884	10.351	1.148	0.009
Method 2	0.082	1.355	17.086	1.798	0.018	0.061	0.918	10.342	1.155	0.008
Method 3	0.250	1.304	16.410	1.740	0.018	0.134	0.869	9.879	1.105	0.008
Method 4	0.388	1.310	16.558	1.761	0.018	0.214	0.872	9.948	1.112	0.008
Method 5	0.000	1.177	1.579	1.579	0.014	0.000	0.719	0.937	0.937	0.008
Method 6	0.000	1.177	1.582	1.582	0.014	0.000	0.699	0.911	0.911	0.008
Method 7	0.000	1.199	1.616	1.616	0.014	0.000	0.718	0.933	0.933	0.008
Ft. Worth										
Method 1	−0.162	0.654	7.957	0.964	0.016	−0.008	0.575	6.409	0.799	0.015
Method 2	0.012	0.548	6.617	0.800	0.016	0.000	0.458	5.040	0.628	0.011
Method 3	−0.059	0.542	6.575	0.796	0.015	0.002	0.471	5.205	0.649	0.011
Method 4	−0.104	0.543	6.632	0.803	0.015	0.004	0.491	5.450	0.680	0.012
Method 5	0.000	0.519	0.764	0.764	0.015	0.000	0.457	0.622	0.622	0.010
Method 6	0.000	0.521	0.766	0.766	0.015	0.000	0.470	0.641	0.641	0.011
Method 7	0.000	0.524	0.773	0.773	0.015	0.000	0.490	0.669	0.669	0.011

HIGHEST TEN 24-HR AVERAGE PM$_{2.5}$ CONCENTRATIONS

High 24-hour average PM$_{2.5}$ concentrations at near-road monitors are of particular interest to transportation engineers because a 24-hour PM$_{2.5}$ design value is defined by EPA as the average of the 98th percentile values in a year over 3 consecutive years. In determining if a transportation project is in compliance with the NAAQS, the sum of the 98th background concentration and the 98th percentile of the PM$_{2.5}$ concentration estimate predicted from air dispersion modeling of the transportation project enhanced emissions is compared to the NAAQS, regardless whether the 98th percentile background concentration occurs concurrently to the 98th percentile traffic emission induced PM concentration. These values encompass the 98th percentile value of a year's PM$_{2.5}$ record, which is the background 24-hr average concentration used in developing the PM$_{2.5}$ design value in a hot-spot analysis. Accuracy in the estimation of the highest ten 24-hr average concentrations are evaluated separately in terms of NRMSE. The all-site averaged NRMSE for the highest 10 24-hr averages are shown in Table B3.

Table B3. All Site Averaged NRMSE for the Highest 10 24-hr Averages.

	NRMSE			
Location	**Houston**		**Fort Worth**	
Method	**2015**	**2016**	**2015**	**2016**
1	0.22	0.11	0.17	0.17
2	0.20	0.11	0.16	0.11
3	0.18	0.11	0.16	0.12
4	0.17	0.11	0.16	0.12
5	0.21	0.11	0.16	0.11
6	0.19	0.11	0.16	0.12
7	0.17	0.11	0.16	0.12

Estimation by all the methods provides for the highest 10 values in a year except Method 1 were found to be good. Larger variability was observed in the calculated NRMSE values for Houston 2015 data due to poor quality of the data, as discussed previously, observed at two of the stations. Both Method 2 and Method 5 were observed to perform slightly better than other methods if one does not consider the Houston 2015 data. The comparison of observed and modeled $PM_{2.5}$ concentration estimates for Fort Worth Site 2 are shown in Figure B2. The highest five concentrations (data above the 98th percentile based on the available 252 days of data and circled in the figure) were captured quite well by all the methods while the peak values were overestimated by the worst method (Method 1). The comparison between predictions and observations at all sites for Methods 5 and 7 are illustrated in Figure B3. High concentrations observed at all sites are well captured by both methods. Although the differences between methods do not seem much (less than 20 percent), the impact on a hot-spot air quality conformity analysis could be significant because 1) the magnitude of this difference may be equivalent to or greater than the modeled concentration increment resulting from the project being analyzed for hot-spot analysis; and 2) the times of occurrences for the high background concentrations are predictable from the background stations such that the current application of a 98th percentile background concentration from other stations as the background concentration at a target site, regardless of the time of occurrence, may be overly conservative and inaccurate.

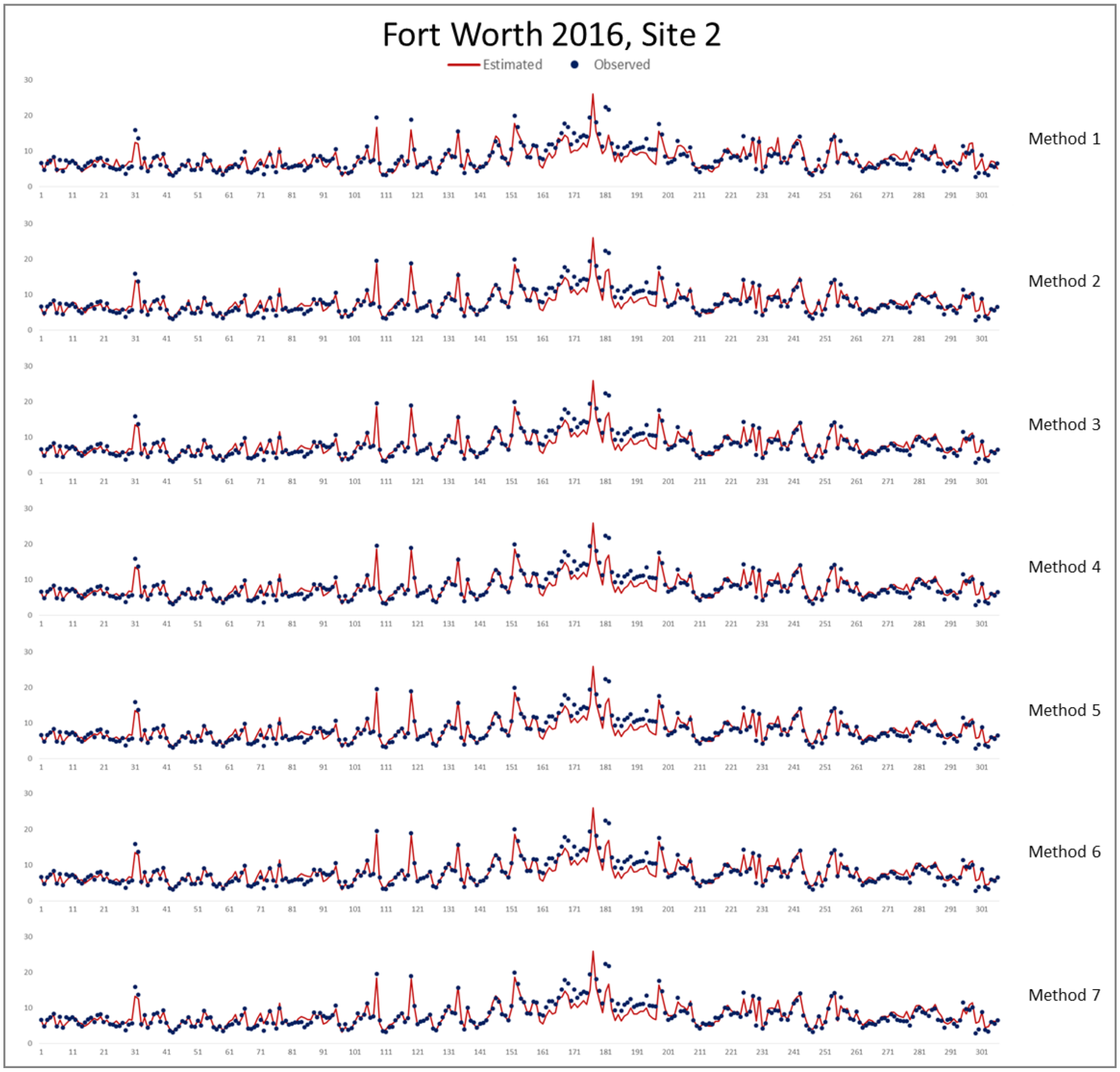
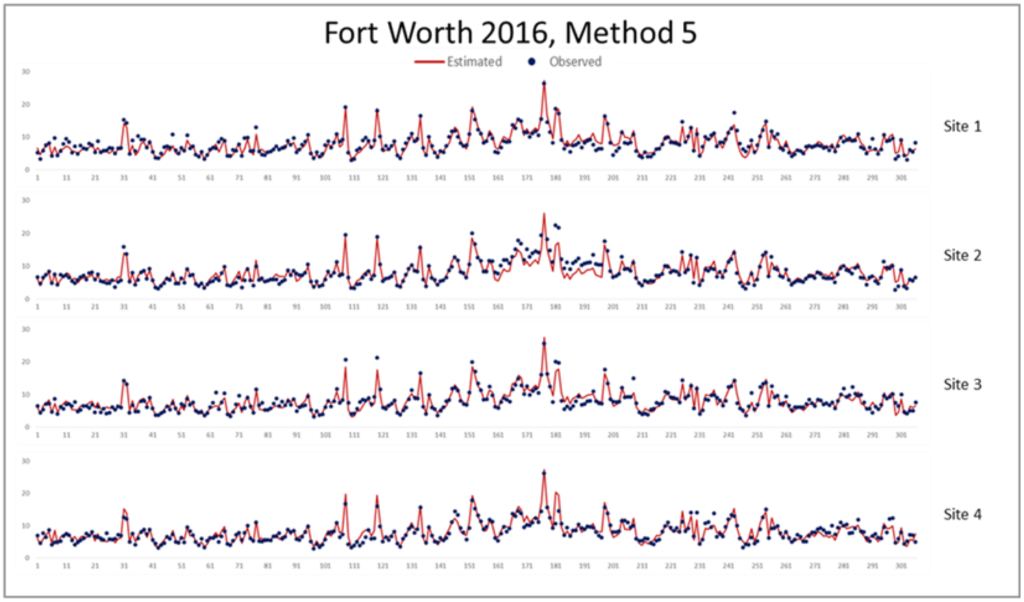
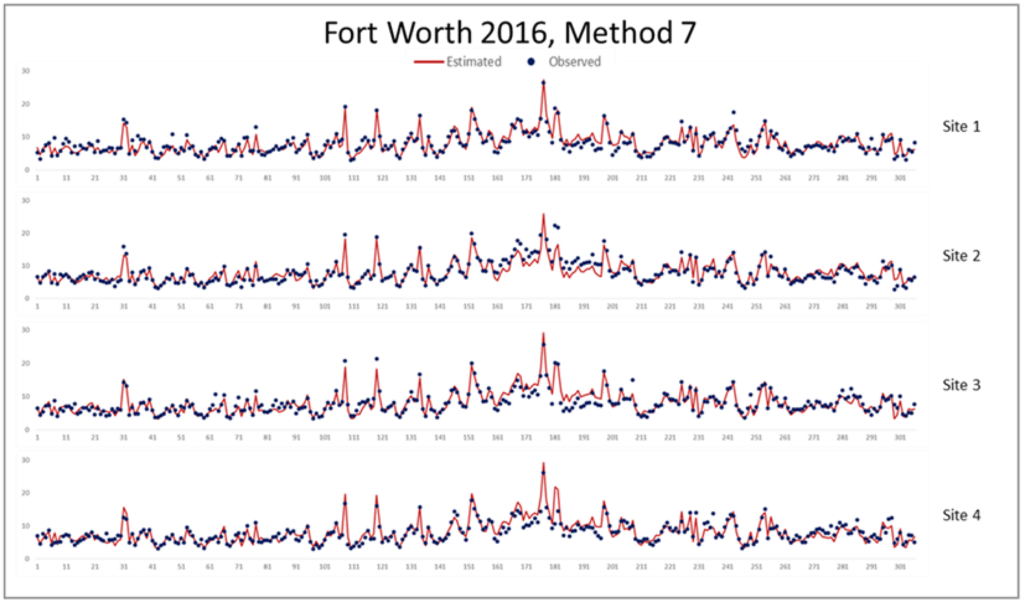


Figure B2. Comparison of Predicted vs. Observed $PM_{2.5}$ Concentrations by Different Methods.



a) Method 5



b) Method 7

Figure B3. Comparison of Predicted vs. Observed $PM_{2.5}$ Concentrations by Method 5 and Method 7 for the Fort Worth Sites.

APPENDIX C: TIME SERIES PLOTS

The comparison of time series plots between the modeled $PM_{2.5}$ concentration combined with the background concentration and the near-road monitor is provided in this appendix.

TRAFFIC AGGREGATION

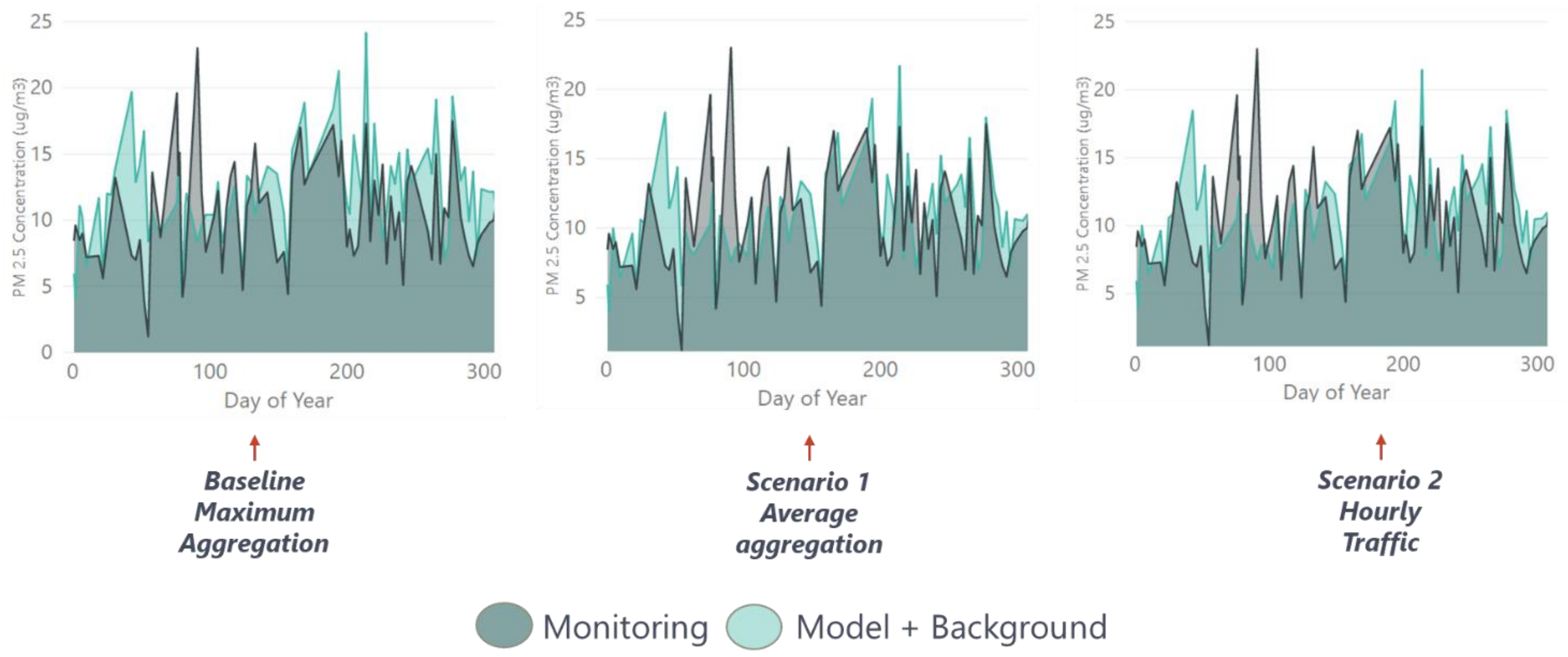
At Fort Worth site, the $PM_{2.5}$ concentration of near-road monitor are lower than that of the model with background over the entire year as seen from Figure C1 and Figure C2. At Houston site, the near-road monitor’s $PM_{2.5}$ concentration exceeded the model with background during the spring with few peaks, but overall the trend is lower across other seasons.

Baseline Maximum Aggregation

Scenario 1 Average aggregation

Scenario 2 Hourly Traffic

Figure C1. Effect of Traffic Data Aggregation for Fort Worth.



Baseline Maximum Aggregation

Scenario 1 Average aggregation

Scenario 2 Hourly Traffic

Figure C2. Effect of Traffic Data Aggregation for Houston.

METEOROLOGICAL DATA

The comparison of time series of $PM_{2.5}$ concentrations from near-road monitor and model with background for two sites are shown in Figure C3 and Figure C4. The variation of time series with use of different meteorological datasets are explored.

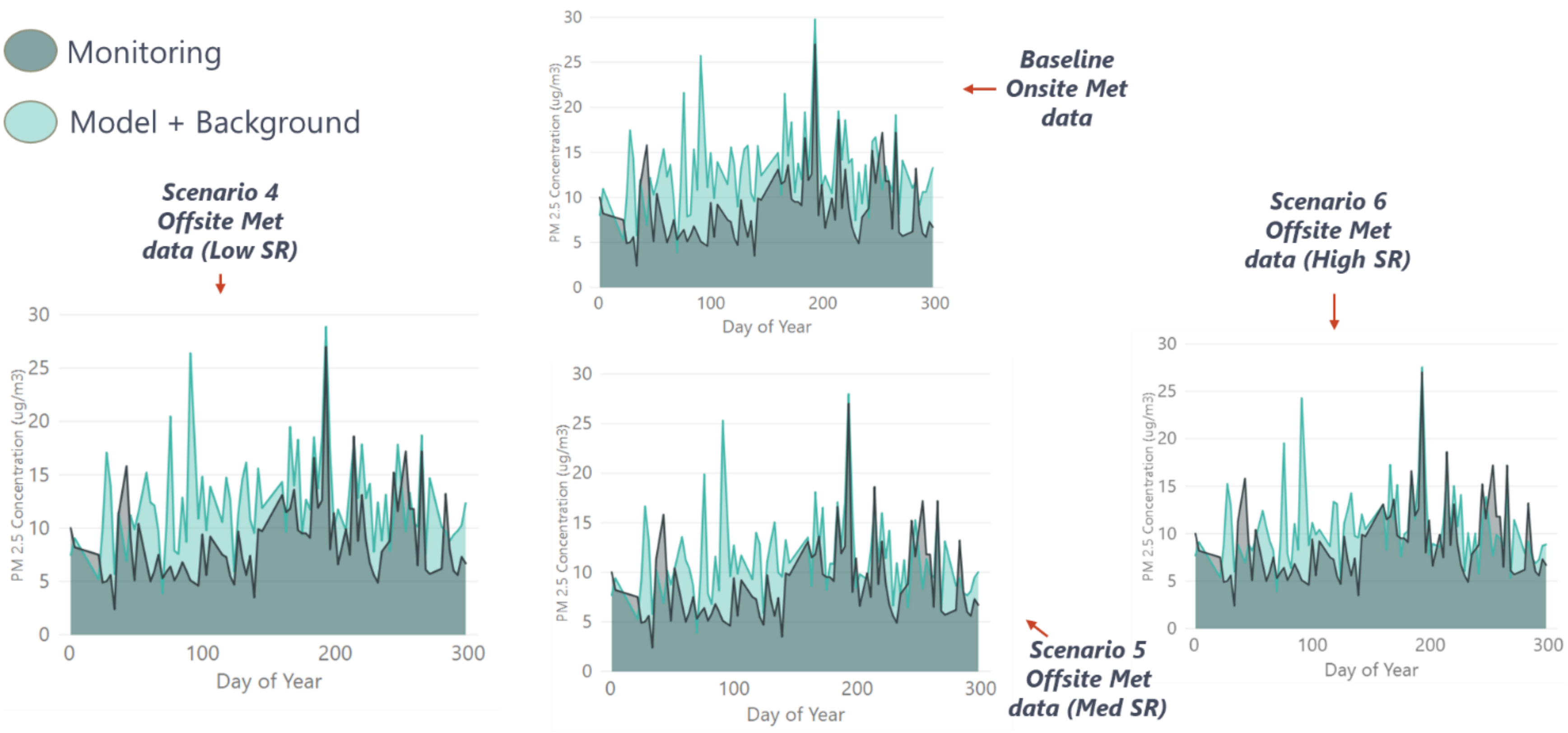
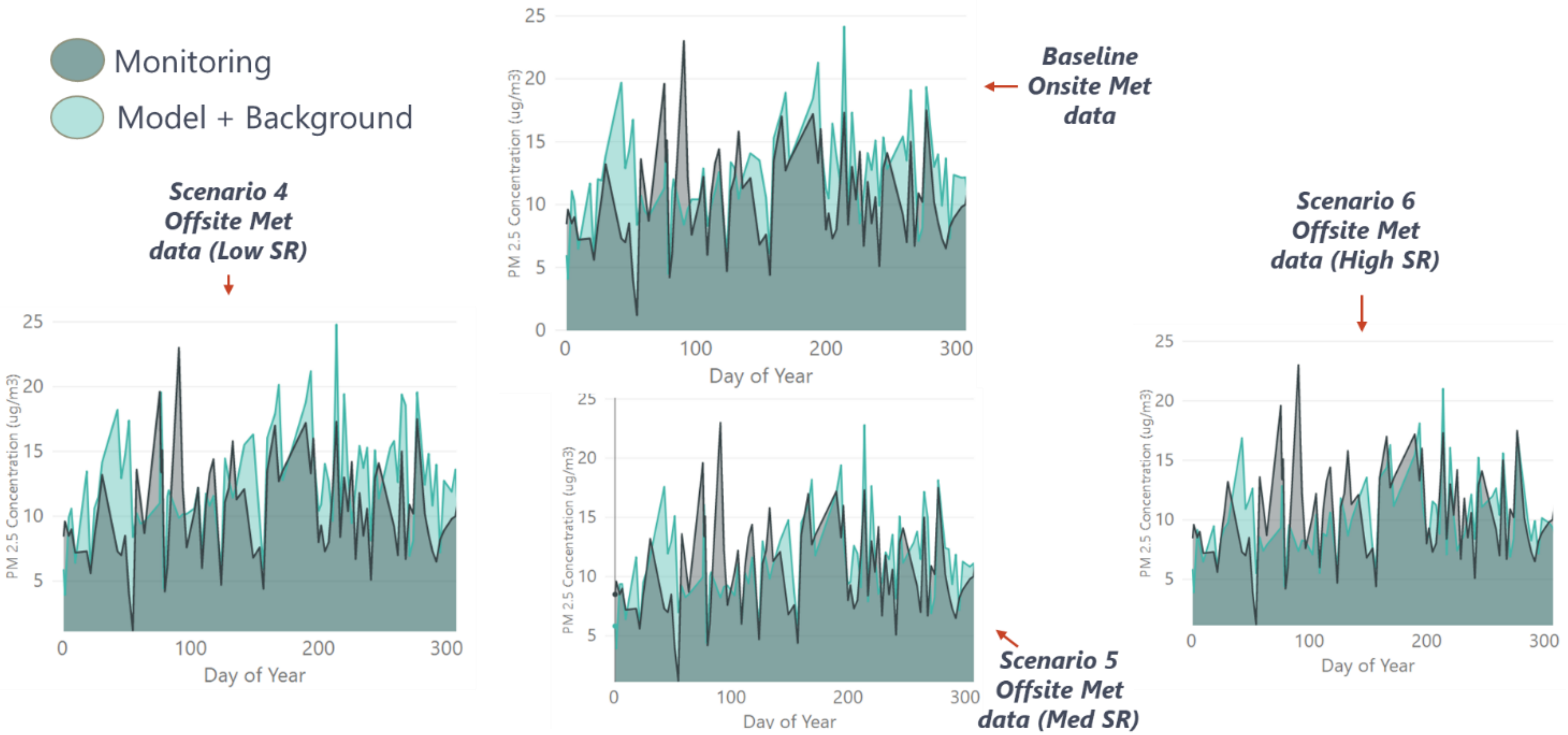


Figure C3. Effect of Meteorological Data for Fort Worth.



Baseline Onsite Met data

Scenario 4 Offsite Met data (Low SR)

Scenario 5 Offsite Met data (Med SR)

Scenario 6 Offsite Met data (High SR)

Figure C4. Effect of Meteorological Data for Houston.

SOURCE TYPE

The time series plots corresponding to Scenario 8, which uses volume sources instead of area sources of baseline are shown in Figure C5 and Figure C6 for Fort Worth and Houston site. The volume sources results are lower across all seasons in comparison to that of the area sources for both the sites.

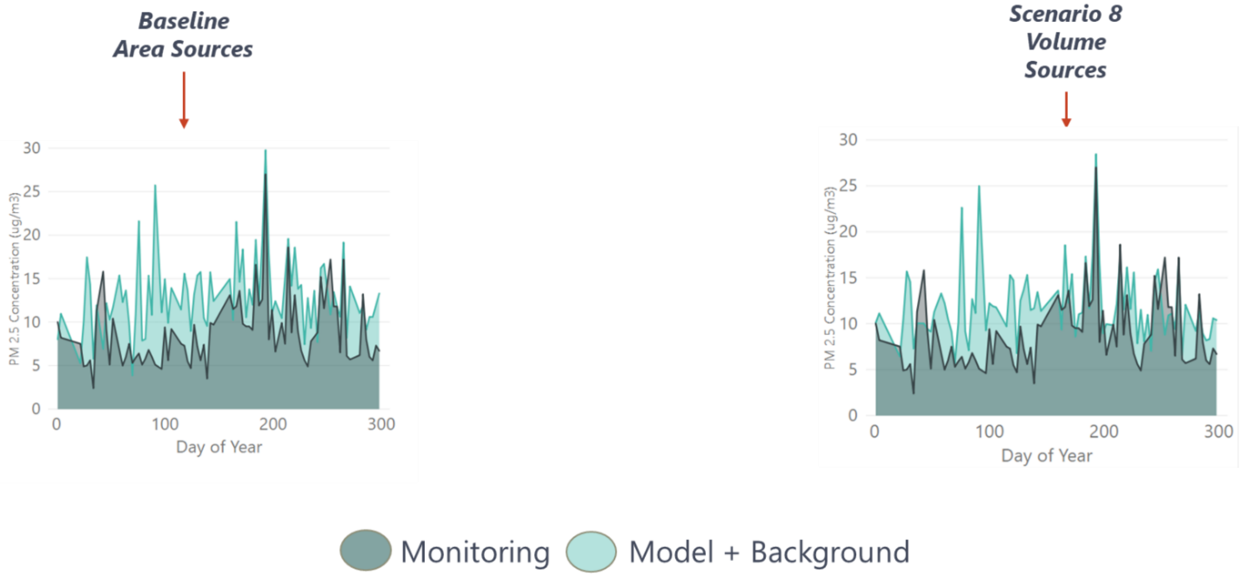


Figure C5. Effect of Source Type for Fort Worth.

Figure C6. Effect of Source Type for Houston.

LAND USE

To evaluate the effect of land use, the model configuration was changed from urban to rural for Scenario 7. The time series plots are shown in Figure C7 and Figure C8 for both the sites. The rural land use case resulted in a higher model prediction in comparison to the urban land use across all seasons for both the sites.

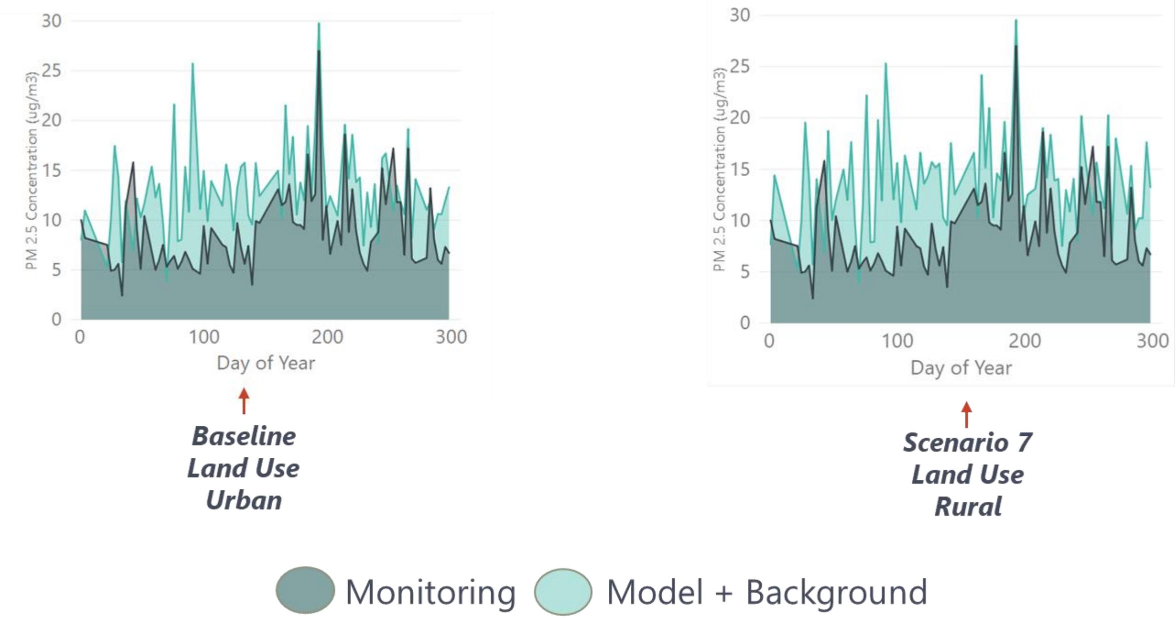


Figure C7. Effect of Land Use Type for Fort Worth.

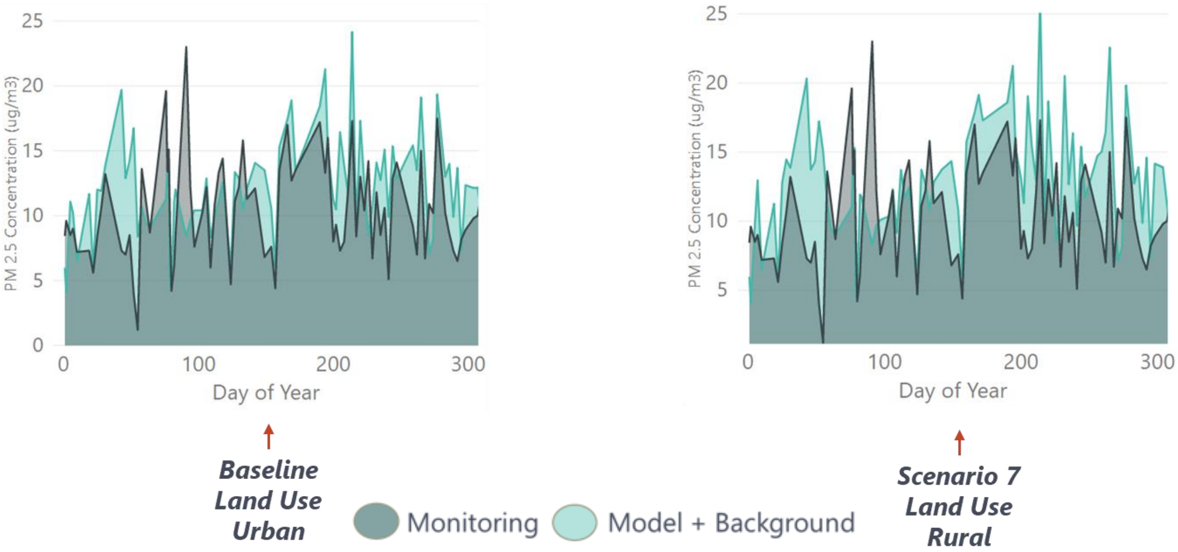
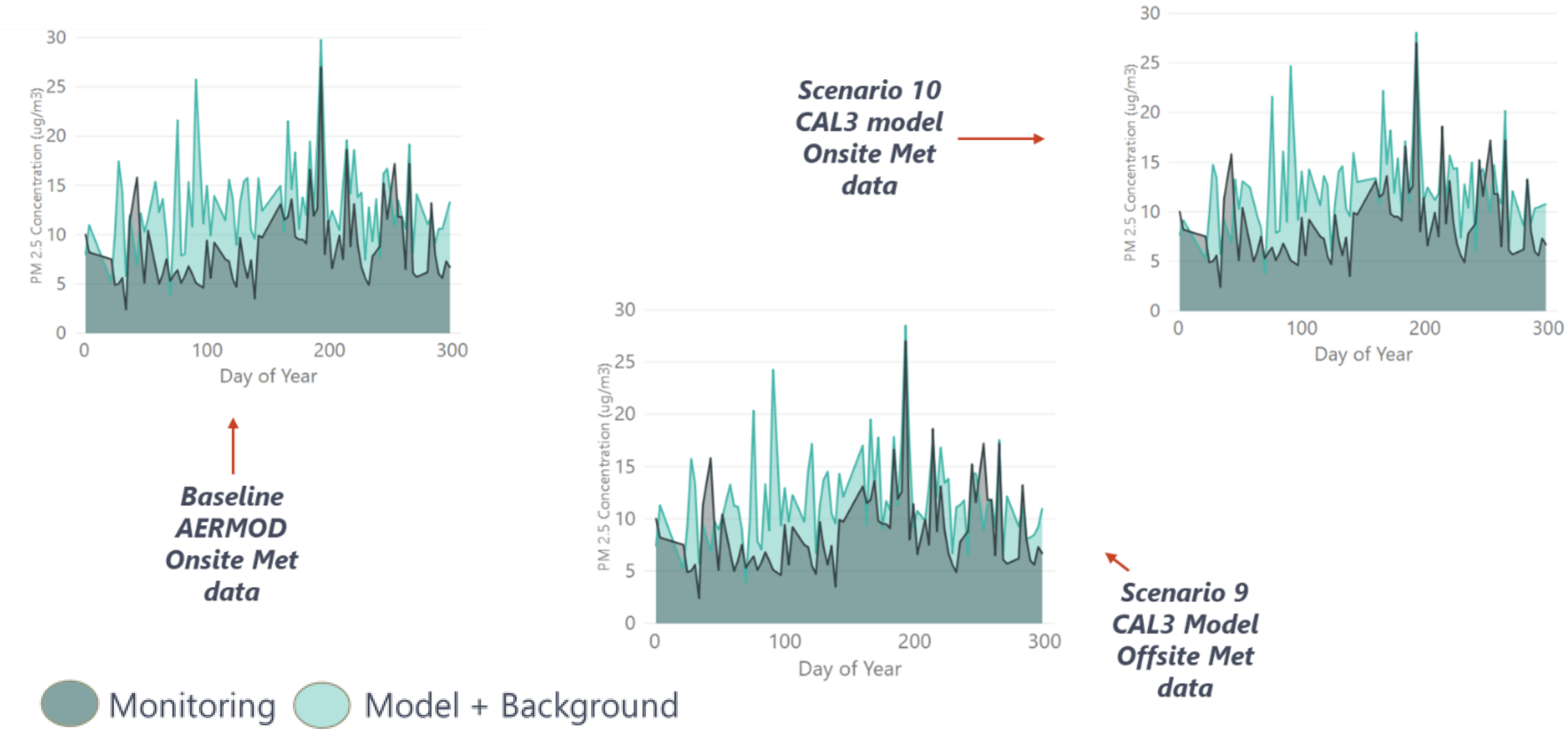


Figure C8. Effect of Land Use Type for Houston.

MODEL CHOICE: CAL3QHCR, MET DATA

Two different scenarios were performed using CAL3QHCR with onsite (Scenario 10) and offsite (Scenario 9) meteorology data. The results shown in Figure C9 and Figure C10 for Fort Worth and Houston sites, respectively, are found to be lower compared to that of AERMOD for both sets of meteorological data.



Baseline AERMOD Onsite Met data

Scenario 10 CAL3 model Onsite Met data

Scenario 9 CAL3 Model Offsite Met data

Figure C9. AERMOD and CAL3QHCR Results – Fort Worth.

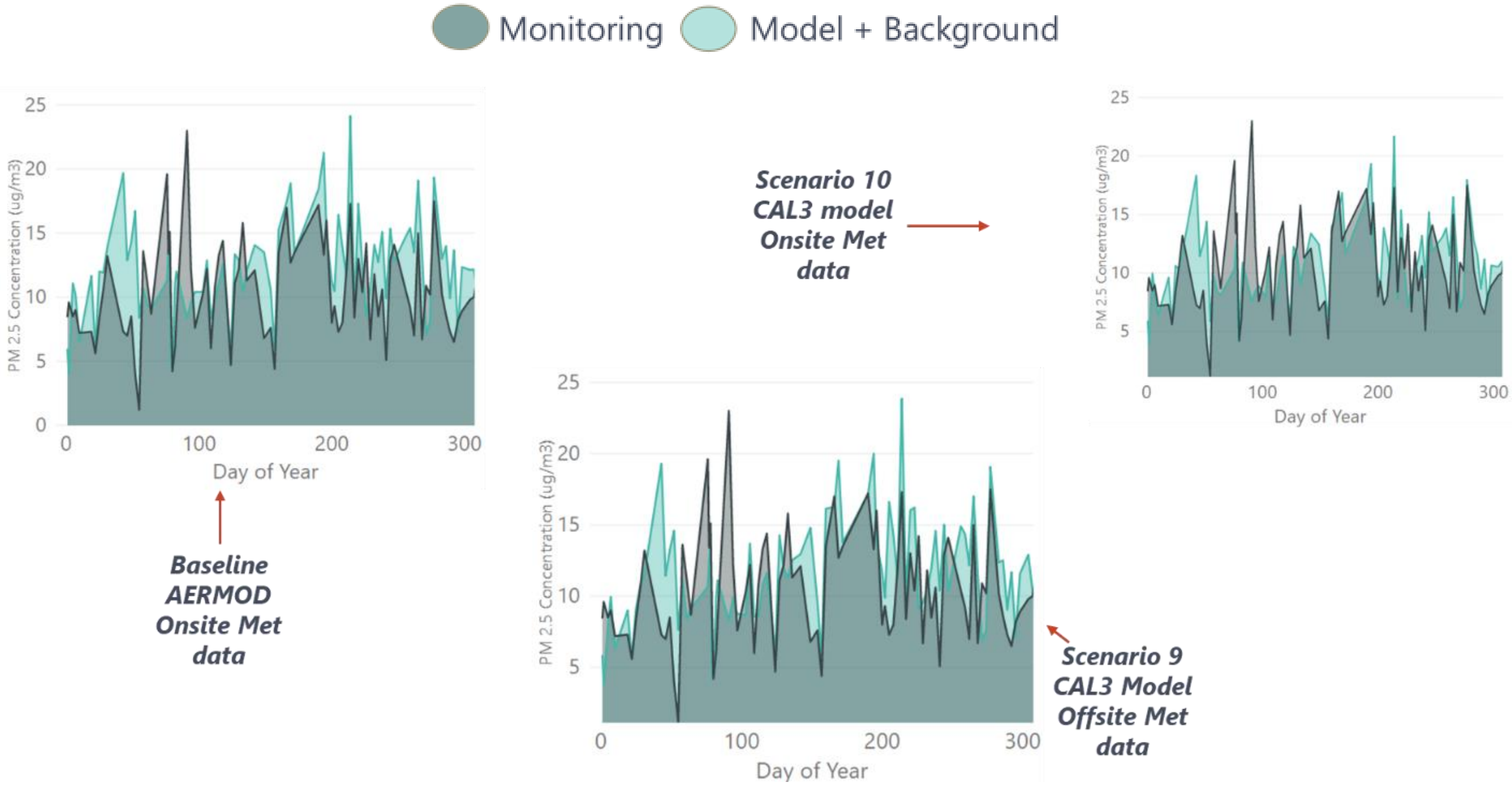


Figure C10. AERMOD and CAL3QHCR Results – Houston.