Attainment Demonstration for the 2012 $PM_{2.5}$ National Ambient Air Quality Standard for Cleveland, Ohio

Technical Support Document

Lake Michigan Air Directors Consortium
August 22, 2016

Table of Contents

List of List of Figures

List of Figures (continued)

List of Figures (continued)

List of Tables

EXECUTIVE SUMMARY

On December 18, 2014, the U.S. Environmental Protection Agency (U.S. EPA) established final air quality designations for the 2012 $PM_{2.5}$ National Ambient Air Quality Standard (NAAQS), identifying as ‘‘nonattainment’’ those areas that were violating the NAAQS based on air quality monitoring data from 2011 to 2013, or those areas that were considered to be contributing to a violation of the NAAQS in a nearby area. In this action, U.S. EPA designated the Cleveland area, including all of Cuyahoga and Lorain counties in Ohio, as a “moderate” $PM_{2.5}$ nonattainment area with an attainment deadline of 2021. The nonattainment area designation triggered the requirement for the State of Ohio to develop and submit to U.S. EPA a State Implementation Plan (SIP), due on October 15, 2016, which identifies emissions reduction strategies sufficient to achieve the NAAQS by the attainment date.

The Lake Michigan Air Directors Consortium (LADCO), in cooperation with Ohio EPA, developed air quality analyses to support the development of Ohio’s attainment SIP for $PM_{2.5}$. The analyses include preparation of regional emissions inventories and meteorological data, evaluation and application of regional chemical transport models, and collection and analysis of ambient monitoring data. The technical analyses described in this report are conducted in a manner that is consistent with U.S. EPA’s guidance (U.S. EPA, 2016B).

Monitoring data are analyzed to produce a conceptual understanding of the air quality problems. Key findings of the analyses include:

- Current monitoring data (2013-2015) show 2 monitoring sites in the Cleveland area that violate the annual $PM_{2.5}$ standard of 12.0 $\mu g/m^3$. A third monitoring site in the area has a 3-year average annual $PM_{2.5}$ concentration that exceeds the NAAQS but did not have a sufficient number of samples in 2013-2015 to compute a valid $PM_{2.5}$ design value. Nonattainment sites are characterized by an elevated regional background (about 10 $\mu g/m^3$) and a local (urban) increment (about 2 – 3 $\mu g/m^3$).

- Historical $PM_{2.5}$ data show a significant downward trend since deployment of the $PM_{2.5}$ monitoring network in 1999.

- On an annual average basis, $PM_{2.5}$ chemical composition consists mostly of sulfate, nitrate, and organic carbon in similar proportions.

Future year strategy modeling was conducted to determine whether existing (“on the books”) controls would be sufficient to provide for attainment of the 2012 $PM_{2.5}$ NAAQS and if not, then what additional emission reductions would be necessary for attainment.

An air quality modeling platform is established to evaluate the adequacy of current and potential identified emissions reduction strategies to demonstrate attainment of the 2012 $PM_{2.5}$ NAAQS by the 2021 attainment deadline established by U.S. EPA.

LADCO conducted “base year” modeling for 2011 for the purpose of evaluating the model’s performance against measured air quality data. Model performance of speciated and total $PM_{2.5}$ was found to be improvement over previous modeling efforts and meets the standard for SIP modeling. Hence, LADCO is confident in the modeling platform and its application in examining control strategies.

Based on the modeling and other supplemental analyses, the following conclusions can be made:

- Existing controls are expected to produce significant improvement in $PM_{2.5}$ concentrations between 2011 and 2021.

- Modeling demonstrates that all monitoring sites in Cleveland are expected to meet the 2012 $PM_{2.5}$ air quality standard by the applicable attainment date, 2021.

- Modeled impacts from NH_3 and VOC point sources within the Cleveland NAA potentially subject to NNSR are found to be insignificant for annual $PM_{2.5}$.

- Modeled reductions of all anthropogenic sources of NH_3 and VOC within the Cleveland NAA are found to be insignificant for annual $PM_{2.5}$.

1.0 Introduction

On December 14, 2012, the United States Environmental Protection Agency (U.S. EPA) promulgated a revised primary annual National Ambient Air Quality Standard (NAAQS) for fine particulate matter ($PM_{2.5}$). In that action, the U.S. EPA revised the primary annual $PM_{2.5}$ standard, strengthening it from 15.0 micrograms per cubic meter (µg/m 3) to 12.0 µg/m 3. Subsequently, on December 18, 2014, U.S. EPA established air quality designations for the 2012 $PM_{2.5}$ NAAQS, identifying as ‘‘nonattainment’’ those areas that were violating the NAAQS based on air quality monitoring data from 2011 to 2013, or those areas that were considered to be contributing to a violation of the NAAQS in a nearby area. Based on 2011 to 2013 monitoring data, U.S. EPA designated the Cleveland area, including all of Cuyahoga and Lorain counties in Ohio, as a “moderate” $PM_{2.5}$ nonattainment area with an attainment deadline of 2021. The Cleveland nonattainment area for the 2012 $PM_{2.5}$ NAAQS is shown in Figure 1.1. The nonattainment area designation triggered the requirement for the State of Ohio to develop and submit to U.S. EPA a State Implementation Plan (SIP), due on October 15, 2016, that identifies and demonstrates emissions reduction strategies sufficient to achieve the NAAQS by the attainment date.

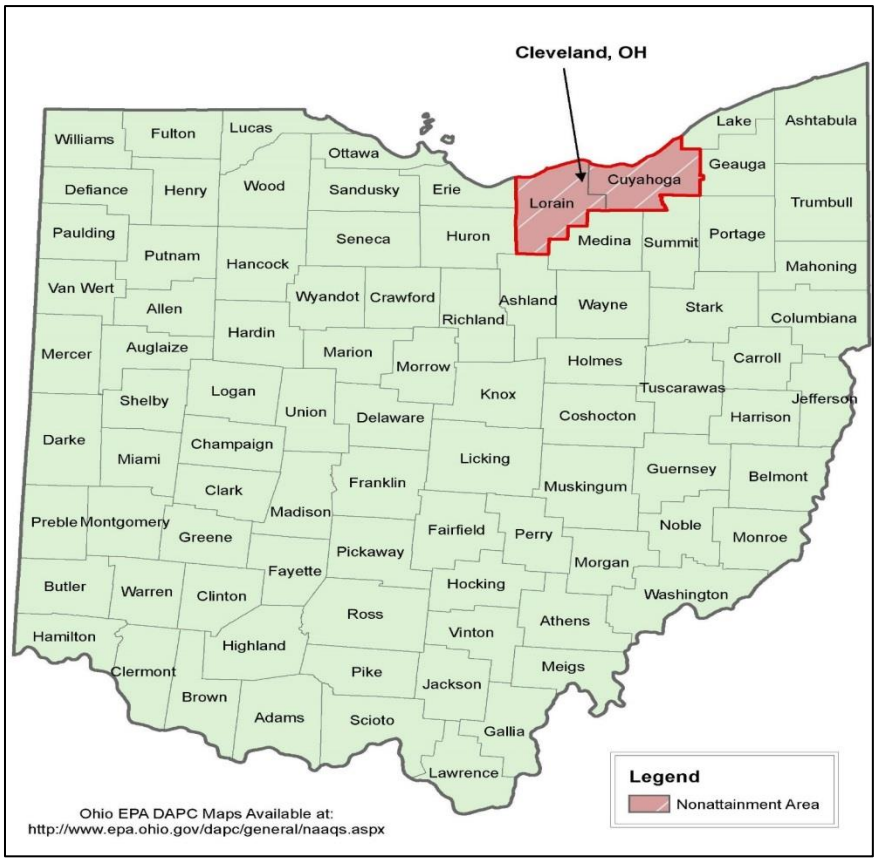

Figure 1.1 – The Cleveland Nonattainment Area for the 2012 $PM_{2.5}$ National Ambient Air Quality Standard

In 1989, the States of Illinois, Indiana, Michigan, and Wisconsin signed a Memorandum of Agreement (MOA) to establish the Lake Michigan Air Directors Consortium (LADCO). The main purposes of LADCO are to provide technical assessments for and assistance to its member states, and to provide a forum for its member states to discuss regional air quality issues. Ohio joined LADCO in 2004 and Minnesota joined in 2012. LADCO consists of a Board of Directors (i.e., the State Air Directors), a technical staff, and various workgroups.

This Technical Support Document summarizes the air quality analyses conducted by LADCO to support the development of Ohio's SIP for $PM_{2.5}$ for the Cleveland nonattainment area. The analyses included preparation of emissions inventories for the base year (2011) and the projected year of attainment (2021), evaluation and application of the meteorological and photochemical transport models, and analysis of ambient monitoring data.

This Introduction provides an overview of regulatory requirements and background information. Section 2 reviews the ambient monitoring data and presents a conceptual model of $PM_{2.5}$ in Cleveland and the Midwest. Section 3 discusses the development of the emissions inventory used for modeling the base year (2011) and the projected year of attainment (2021). The 2011 base case model performance evaluation and the modeled attainment demonstration for $PM_{2.5}$ is presented in Section 4, along with relevant data analyses considered as part of the weight-of-evidence determination. Modeling sensitivity analyses addressing requirements for attainment planning purposes and Nonattainment Area New Source Review (NNSR) are also included in Section 4. Finally, key study findings are reviewed and summarized in Section 5.

SIP Requirements

On December 18, 2014, the U.S. EPA issued final area designations for the 2012 annual NAAQS for $PM_{2.5}$. U.S. EPA had previously strengthened the annual $PM_{2.5}$ standard to 12.0 micrograms per cubic meter (µg/m3) in 2012. The effective date of the final area designations was April 15, 2015. States are required to submit attainment plans to U.S. EPA within 18 months from the effective date of designations, October 15, 2016. In accordance with CAA section 188(c), moderate nonattainment areas are required to attain the NAAQS as expeditiously as practicable, but no later than the end of the sixth calendar year after the designation (2021).

Technical Work: Overview

For the Cleveland $PM_{2.5}$ attainment demonstration, LADCO worked closely with the Ohio EPA and U.S. EPA Region 5 to develop the technical analyses described in this report. An overview of the technical work is provided below.

Air Quality Analyses: A "conceptual model" model presents a qualitative description of the region's $PM_{2.5}$ air quality problems, which relies on an analysis of ambient air quality data. Air quality data analyses are examined to develop a conceptual model for the Cleveland area describing $PM_{2.5}$ air quality and also to provide information for evaluating the performance of the air quality model. The data analyses are an integral part of the overall technical support given uncertainties in emissions inventories and modeling.

Air Quality Modeling: The modeling methodology for the Cleveland $PM_{2.5}$ modeling platform adhered to U.S. EPA's guidance document: "Draft Modeling Guidance for Demonstrating Attainment of Air Quality Goals for Ozone, $PM_{2.5}$, and Regional Haze" (U.S. EPA, 2014B). U.S. EPA's modeling guidance details several prerequisites for a model to be used to support an attainment demonstration:

- It should have received a scientific peer review.
- It should be appropriate for the specific application on a theoretical basis.
- It should be used with databases that are available and adequate to support its application.
- It should be shown to have performed well in past modeling applications.

The models used in this attainment demonstration meet all of the prerequisites stated in U.S. EPA's draft modeling guidance. Below is a brief summary of each of the model components and a description of how each component fits into the Cleveland $PM_{2.5}$ attainment demonstration modeling.

WRF: The Weather Research and Forecasting (WRF) model was developed collaboratively by the National Center for Atmospheric Research's (NCAR), the National Oceanic and Atmospheric Administration (NOAA), the Department of Defense's Air Force Weather Agency (AFWA) and Naval Research Laboratory (NRL), the Center for Analysis and Prediction of Storms (CAPS) at the University of Oklahoma, and the Federal Aviation Administration (FAA), with the participation of university scientists. WRF is a prognostic meteorological model routinely used by U.S. EPA and others for urban- and regional-scale photochemical modeling of $PM_{2.5}$, ozone, and regional haze (U.S. EPA, 2014A).

SMOKE: The Sparse Matrix Operator Kernel Emissions (SMOKE) modeling system is an emissions modeling system that generates hourly gridded, speciated emission inputs of mobile, nonroad, area, point, fire and biogenic emission sources for photochemical grid models. Its purpose is to provide an efficient tool for converting emissions inventory data into the formatted emission files required by an air quality simulation model. For mobile sources, SMOKE actually simulates emissions rates based on input mobile-source activity data, using emission factors and outputs from U.S. EPA's MOVES mobile-source emissions model.

SMOKE generated base year emissions (2011) and future year (2021) inventories are based on U.S. EPA's modeling platforms, as described in U.S.

EPA's "Notice of Availability of the Environmental Protection Agency's Updated Ozone Transport Modeling Data for the 2008 Ozone National Ambient Air Quality Standard (NAAQS)" (U.S. EPA, 2015A). States provided point source and area source emissions data, and MOVES input files and mobile source activity data to U.S. EPA's 2011 National Emissions Inventory (NEI) database. U.S. EPA prepared emissions data for other categories not provided by the states, including nonroad sources, ammonia, fires, and biogenics. LADCO developed a future year inventory for 2021 based on U.S. EPA's 2017 and 2025 modeling inventories to support the attainment demonstration modeling. LADCO and its contractors developed improved emissions data for its member states for on-road and electrical generating stations.

ERTAC: The Eastern Regional Technical Advisory Committee (ERTAC) is a collaborative effort to improve emission inventories among the Northeastern, Mid-Atlantic, Southeastern, and Lake Michigan area states; other member states; industry representatives; and multi-jurisdictional planning organization (MJO) representatives. ERTAC developed the Electrical Generation Unit (EGU) Forecast Tool for states to use for SIP planning. The tool uses base year reported EGU data obtained from U.S. EPA's Clean Air Markets Division (CAMD) and applies growth rates by region and fuel type provided by the U.S. Energy Information Administration (EIA) to estimate future emissions. The ERTAC EGU Forecast Tool is open-source and has been provided to U.S. EPA.

CAMx: The Comprehensive Air quality Model with extensions (CAMx) is a photochemical grid model that is designed for simulating atmospheric transport and chemical transformation of air pollution over urban to regional scales. CAMx is a state-of-the-science open-source air quality model that is computationally efficient with an extensive history of regulatory applications. The selection of CAMx as the primary transport model is based on several factors including performance, operational considerations (e.g., ease of application and resource requirements), technical support and documentation, model extensions (e.g., process analysis, source apportionment, and plume-in-grid), and model science.

2.0 Ambient Air Quality Data

An extensive network of air quality monitors in the region provides data for $PM_{2.5}$ total mass and individual chemical species. These data are used to determine attainment/nonattainment designations, support the CAMx model performance evaluation, and provide air quality information to the public.

Analyses of the data are conducted to produce a conceptual model, which is a qualitative summary of the physical, chemical, and meteorological processes that control the formation and distribution of pollutants in a given region. This section reviews the relevant data analyses and describes our understanding of $PM_{2.5}$ air quality in Ohio and in the region.

Two monitoring networks were operating in the Cleveland NAA during the 2011 modeling period:

- $PM_{2.5}$ mass is collected at 7 Federal Reference Method (FRM) monitoring sites in the Cleveland NAA as depicted in Figure 2.1.
- Speciated $PM_{2.5}$ concentrations are measured at 2 Chemical Speciation Network (CSN) monitoring site, highlighted in Figure 2.1.

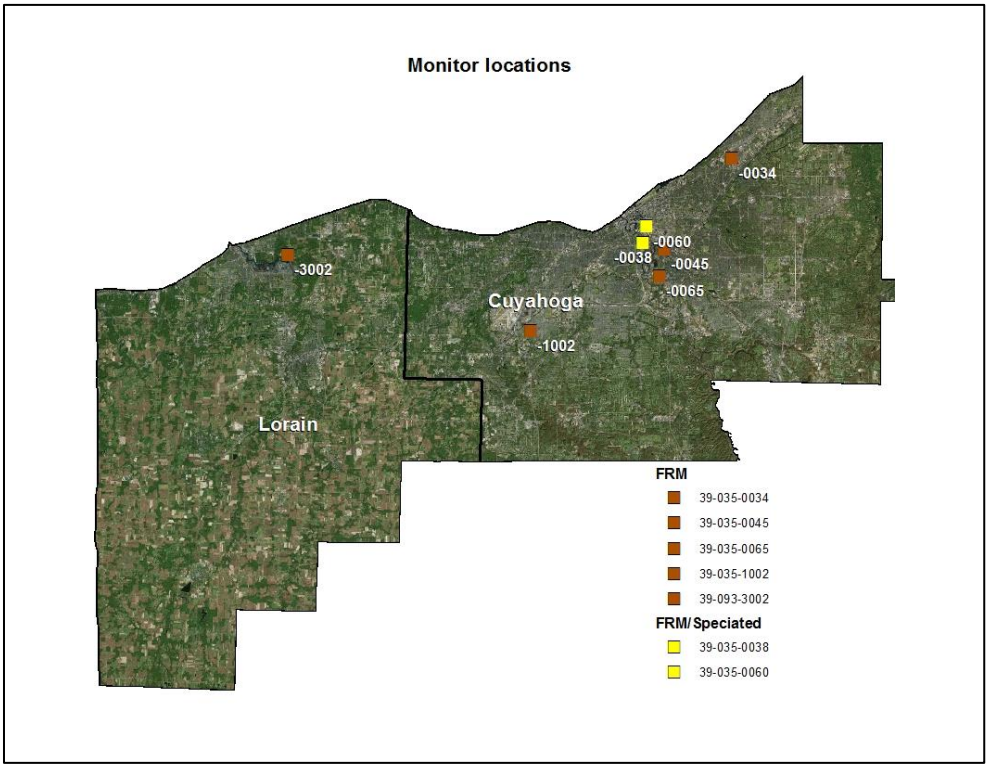

Figure 2.1. Locations of FRM $PM_{2.5}$ Mass and CSN Monitoring Sites in the Cleveland NAA

Table 2.1 summarizes the annual $PM_{2.5}$ concentrations measured at the 7 FRM monitoring sites in the Cleveland NAA from 2010 through 2015. Also included in the table are the computed $PM_{2.5}$ design values for each FRM site for the 3-year periods from 2010-12 through 2013-15. In the most recent 3-year period, there are 2 sites in violation of the annual $PM_{2.5}$ standard of 12.0 µg/m ^{3}. A third monitoring site in the area has a 3-year average annual $PM_{2.5}$ concentration that exceeds the NAAQS but did not have a sufficient number of samples in 2013-2015 to compute a valid $PM_{2.5}$ design value.

Table 2.1. Annual Average $PM_{2.5}$ and Design Values (µg/m^3)
Measured at FRM Monitoring Sites in the Cleveland NAA.

Site	County	Design value[1]						Annual $PM_{2.5}$ NAAQS DV[2]			
		2010	2011	2012	2013	2014	2015	10-12	11-13	12-14	13-15
39-035-0034	Cuyahoga	10.9	10.0	9.3	9.5	9.6	9.2	10.1	9.6	9.5	9.4
39-035-0038		14.0	12.6	12.3	12.2	12.3	11.8	13.0	12.4	12.3	12.1
39-035-0045		13.3	11.9	11.4	11.2	11.4	11.0	12.2	11.5	11.3	11.2
39-035-0060		13.7	12.5	12.8	12.2	12.1	12.0	13.0	12.5	12.4	12.1
39-035-0065		13.2	12.6	12.3	11.4	12.5	13.3	12.7	12.1	12.0	12.4
39-035-1002		11.3	10.4	9.7	9.2	9.7	9.1	10.5	9.7	9.5	9.3
39-093-3002	Lorain	10.4	9.4	9.5	8.8	9.1	8.2	9.8	9.2	9.1	8.7

1 Highlighted cells indicate less than 75% capture for at least one quarter.
2 Monitor 39-035-0060 does not meet eligible site criteria for NAAQS DV designation.

Current Conditions

Maps of annual and 24-hour $PM_{2.5}$ design values for the 3-year period 2013-2015 are shown for Ohio in Figures 2.2 and 2.3, respectively. Red dots represent sites with design values above the annual standard. Currently, there are 2 sites in violation of the annual $PM_{2.5}$ standard in Ohio, both of which are in the Cleveland nonattainment area. No sites exceed the daily standard.

Spatial, Temporal, and Chemical Variability

$PM_{2.5}$ concentrations vary spatially, temporally, and chemically in the region. $PM_{2.5}$ exhibits a distinct and consistent spatial pattern on an annual basis, as shown in Figure 2.4. Across the Midwest annual concentrations follow a gradient from low values (5-6 µg/m^3) in northern and western areas (Minnesota and northern Wisconsin) to high values (11-12 µg/m^3) in Ohio and along the Ohio River. In addition, concentrations in urban areas are higher than in upwind rural areas, indicating that local urban sources add a significant increment of 1-3 µg/m^3 to the regional background of 6-10 µg/m^3, as shown in Figure 2.5.

Time series based on federal reference method (FRM) $PM_{2.5}$ mass data show a consistent downward trend across the Midwest and in the nonattainment area monitors in Cleveland, as shown in Figures 2.6 and 2.7, respectively. The similarity of these trends is due in large part to the regional nature of $PM_{2.5}$ and the effectiveness of regional controls for SO_2 and NO_X put in place in the last 15 years.

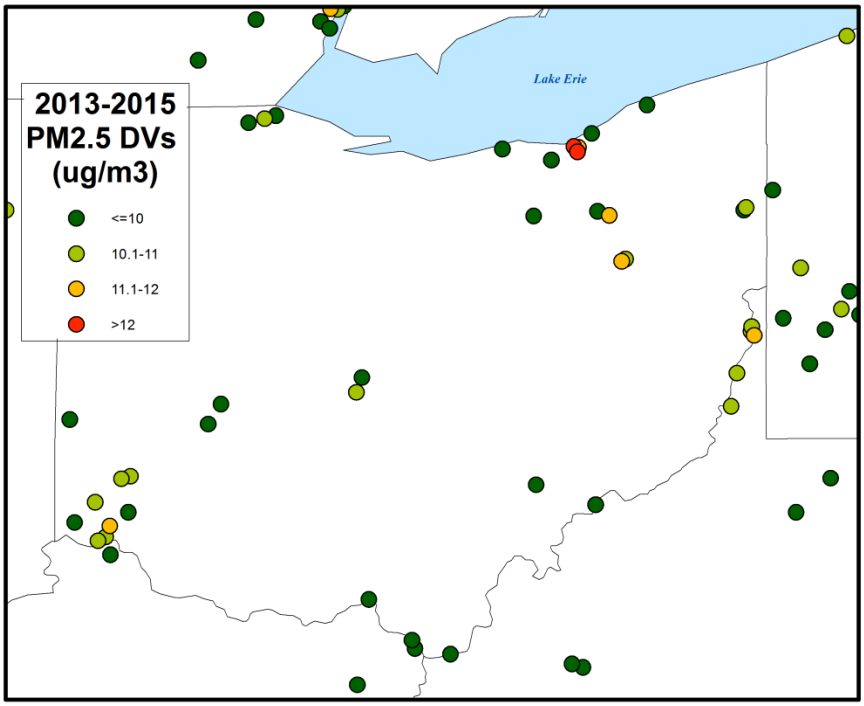

Figure 2.2. 2015 $PM_{2.5}$ Design Values for the Annual NAAQS

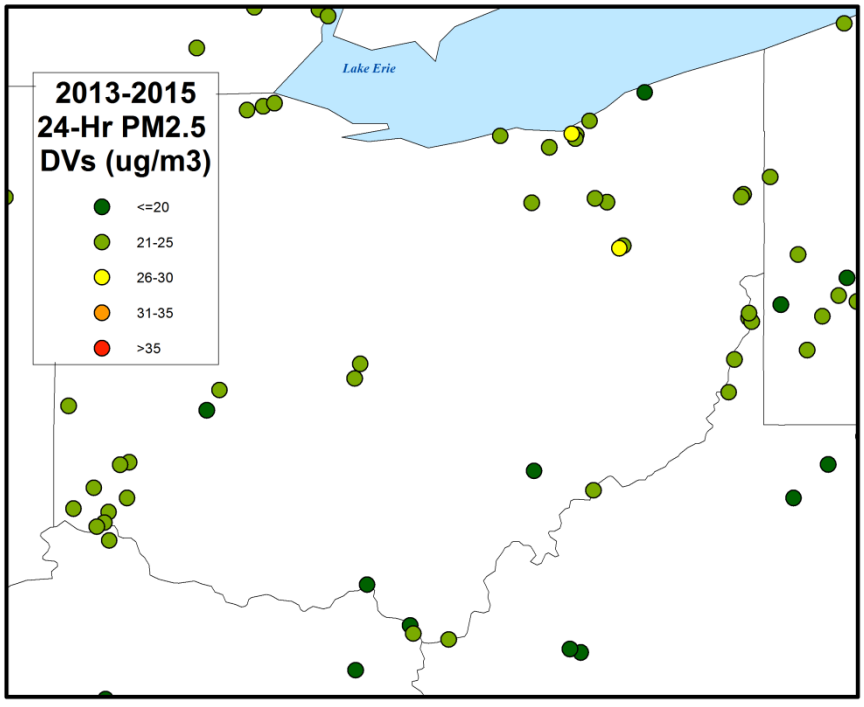

Figure 2.3. 2015 $PM_{2.5}$ Design Values for the 24-hour NAAQS

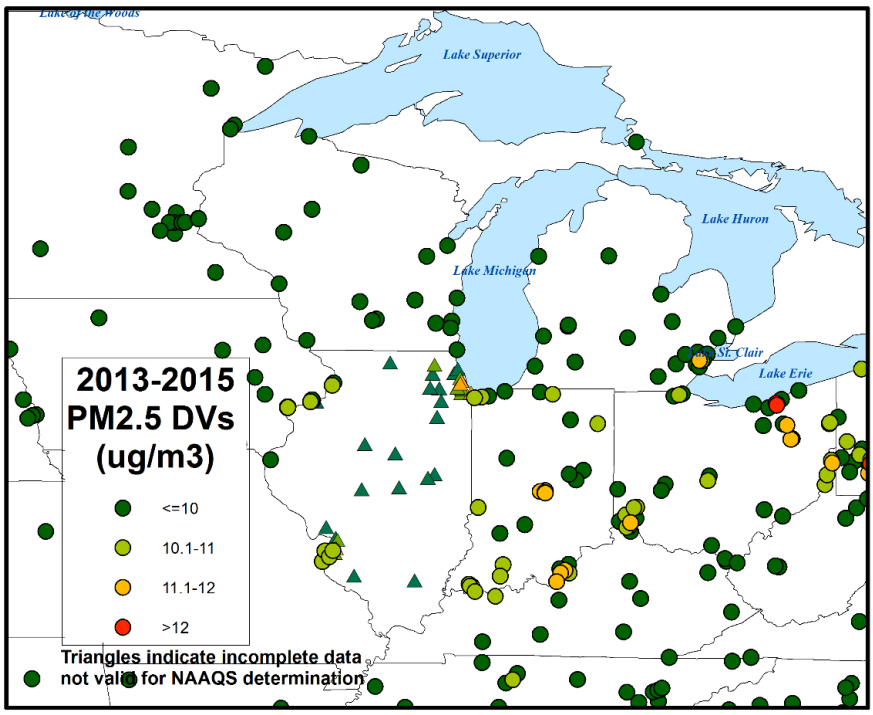

Figure 2.4. Spatial Gradient in $PM_{2.5}$ Across the LADCO States

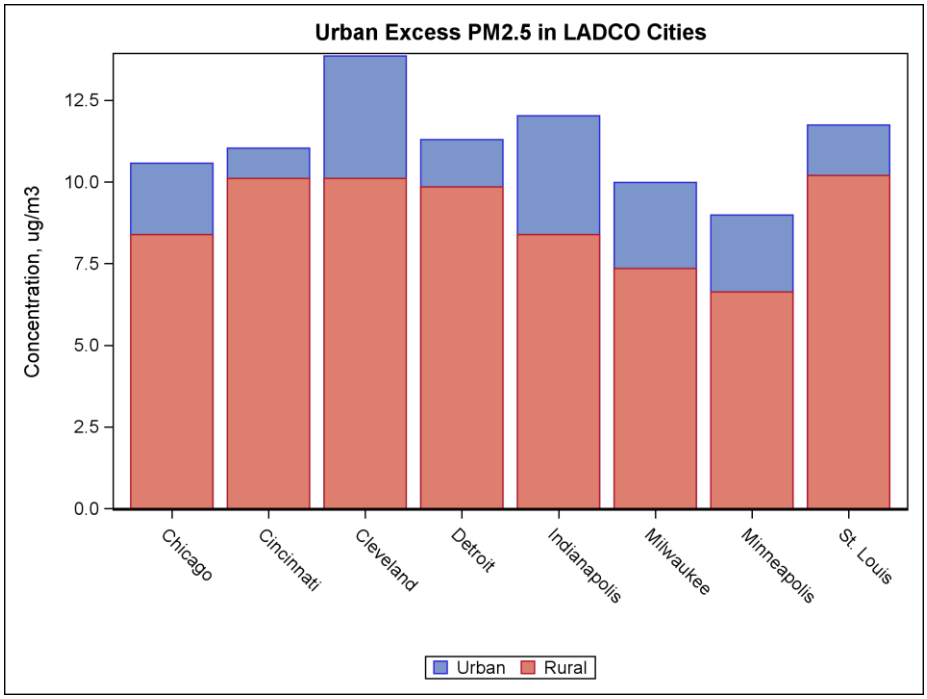

Figure 2.5. Regional (red) v. Local Components (blue) of Annual Average $PM_{2.5}$ Concentrations.

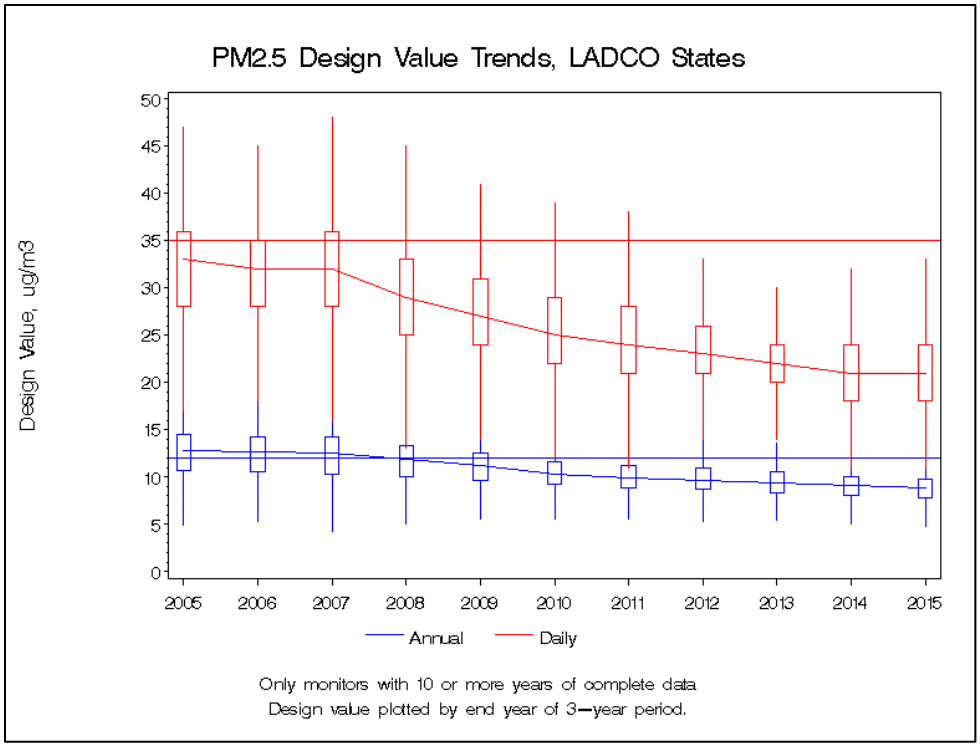

Figure 2.6. Regional Design Value Trends, Annual and 24-Hour

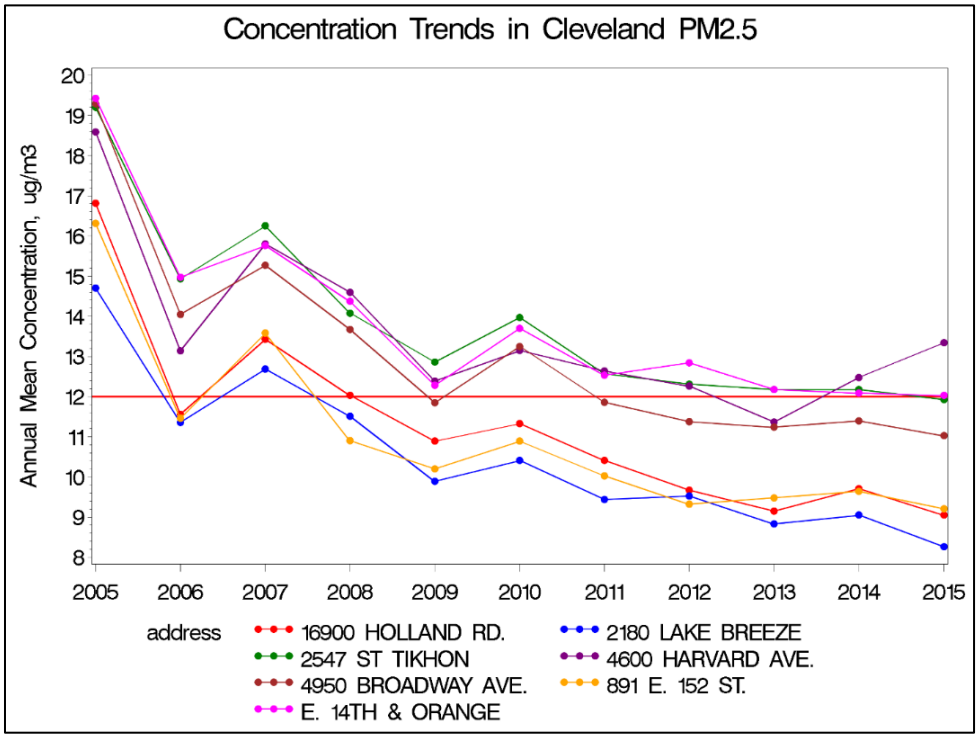

Figure 2.7. Concentration Trends at Monitors in the Nonattainment Area

Seasonal data shown in Figure 2.8 indicates that concentrations of $PM_{2.5}$ in Cleveland are typically highest in the winter and summer, with lower concentrations in the spring and fall. The mean quarterly concentration (red box) is most indicative of this behavior. Because the maximum concentration (blue box) for each quarter is, by definition, an extreme statistic, it exhibits much more variability from quarter to quarter and is a less useful indicator. Seasonal patterns are driven partly by changes in emissions, such as changing electrical demand, and partly by the influence of meteorology on $PM_{2.5}$. Ammonium nitrate, which makes up about a third of PM mass on an annual basis, is highly volatile and only present in significant amounts during the colder temperatures of winter. Many sources of both anthropogenic and biogenic organic carbon are temperature sensitive, but unlike nitrate, these organic species are emitted at higher rates during warmer temperatures.

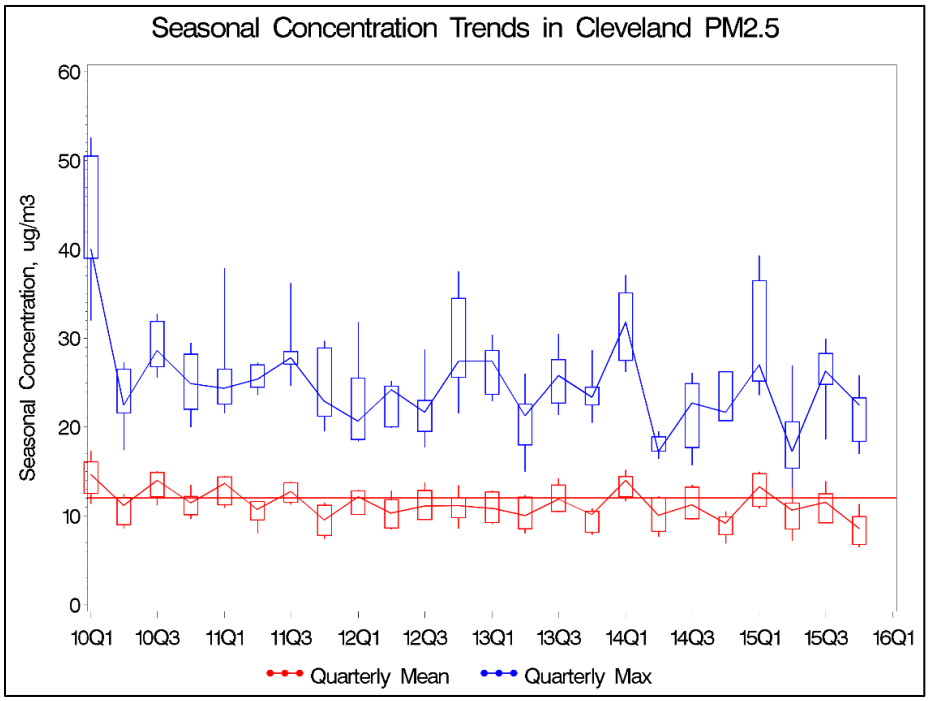

Figure 2.8. Seasonal Variation in Cleveland $PM_{2.5}$ from 2010 to 2015 (Q1 = Winter, Q3 = Summer).

Seasonal patterns at each of the Cleveland monitors are shown in Figure 2.9. The twice-yearly peaks in winter and summer are clear in most years. The data for 2012 are more disorganized for some monitors, but subsequent years return to the typical pattern.

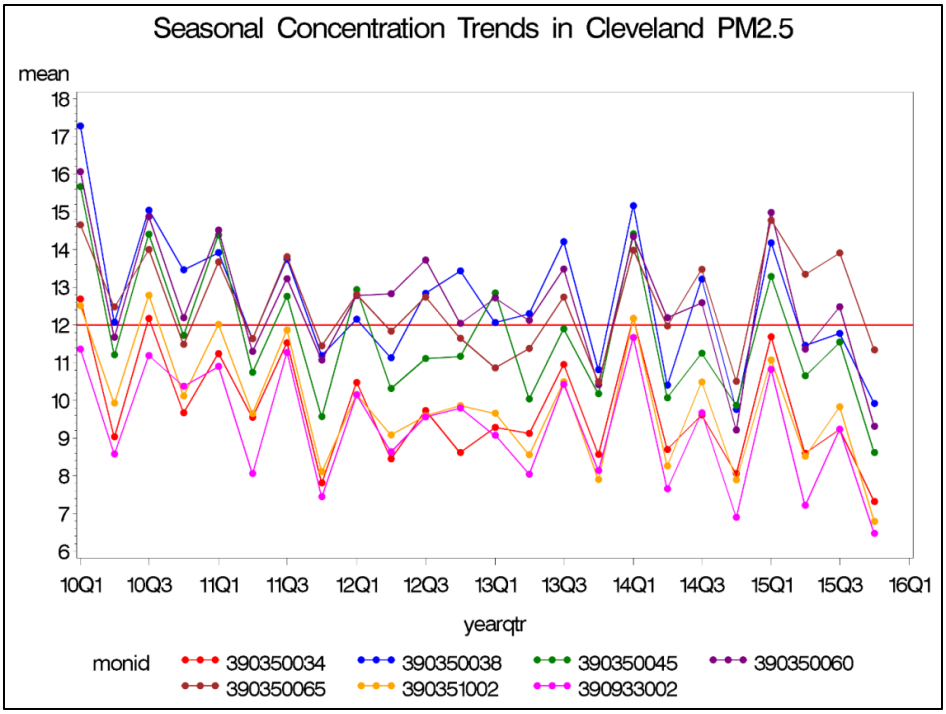

Figure 2.9. Seasonal Concentration Trends in $PM_{2.5}$ at Monitors in the Cleveland Nonattainment Area

In the Midwest, $PM_{2.5}$ is made up of mostly ammonium sulfate, ammonium nitrate, and organic carbon in approximately equal proportions on an annual average basis. Elemental carbon and crustal matter otherwise referred to as soil, contribute less than 5% each. Figure 2.10 shows the trends in these major components and the contributions of each to $PM_{2.5}$ total mass in Ohio. It is apparent that Ohio $PM_{2.5}$ used to be dominated by sulfate, but over time the proportion of sulfate has decreased and in 2015 it was actually slightly less than organic carbon. Over the same period, organic carbon and ammonium nitrate concentrations have also declined, although somewhat less than sulfate. Elemental carbon and soil are unchanged.

The three major components of $PM_{2.5}$ vary spatially and exhibit notable urban and rural differences, as shown in Figure 2.11. Of the urban areas examined, Cleveland stands out by having higher local (urban) contributions to EC and soil. These are indicators of local source impacts. Sources of EC are usually combustion processes, which can include mobile sources (especially diesel) and industrial fuel use. The soil fraction of $PM_{2.5}$ is generally from mechanical processes, road dust, and construction.

The major components of $PM_{2.5}$ also vary seasonally, as shown in Figure 2.12. These patterns account for much of the annual variability in $PM_{2.5}$ mass, as noted above. In Cleveland, ammonium sulfate peaks in the summer and winter. Sulfate is generally considered a regional pollutant; concentrations are similar in rural and urban areas and highly correlated over large distances. Cleveland has a somewhat larger local

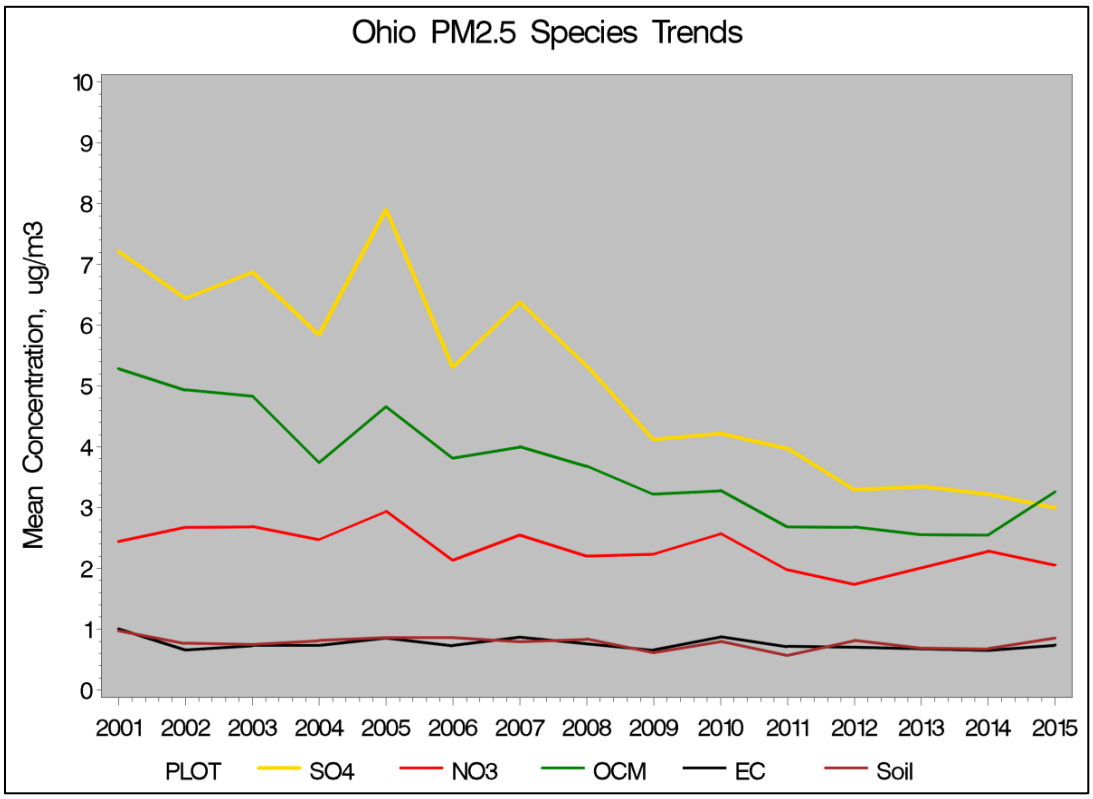

Figure 2.10. Trends in Ohio $PM_{2.5}$ Components

contribution to sulfate than most Midwestern cities. The sulfate is formed when sulfuric acid (an oxidation product of sulfur dioxide) and ammonia react in the atmosphere, especially in cloud droplets. Coal combustion is the primary source of sulfur dioxide; ammonia is emitted primarily from animal husbandry operations and fertilizer use.

Ammonium nitrate has almost the opposite spatial and seasonal pattern, with the highest concentrations occurring in the winter. Nitrate can also have both regional and local sources, because urban concentrations are higher than rural upwind concentrations. As shown in Figure 2.12, in Cleveland most nitrate seems to be regional. Ammonium nitrate forms when nitric acid reacts with ammonia, a process that is enhanced when temperatures are low and humidity is high. Nitric acid is a product of the oxidation of nitric oxide, a pollutant that is emitted by combustion processes. Organic carbon is more consistent from season to season and city to city, although concentrations are generally slightly higher in the summer. Organic carbon has both regional and local components. Particulate organic carbon can be emitted directly from cars and other fuel combustion sources or formed in a secondary process as volatile organic gases react and condense. In rural areas, summer organic carbon has significant contributions from biogenic sources.

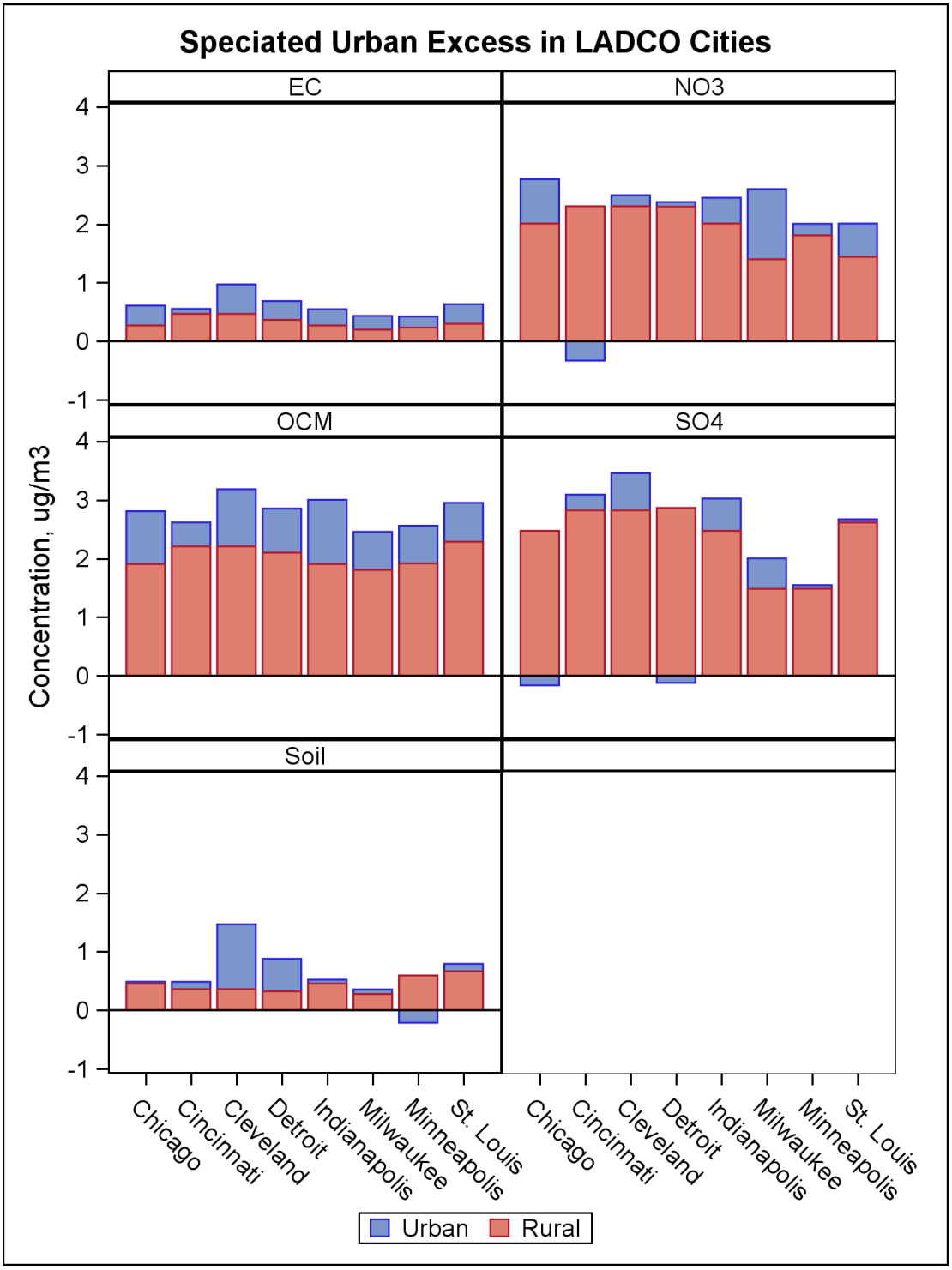

Figure 2.11. Urban/Rural Differences in $PM_{2.5}$ Components in Major Midwest Cities

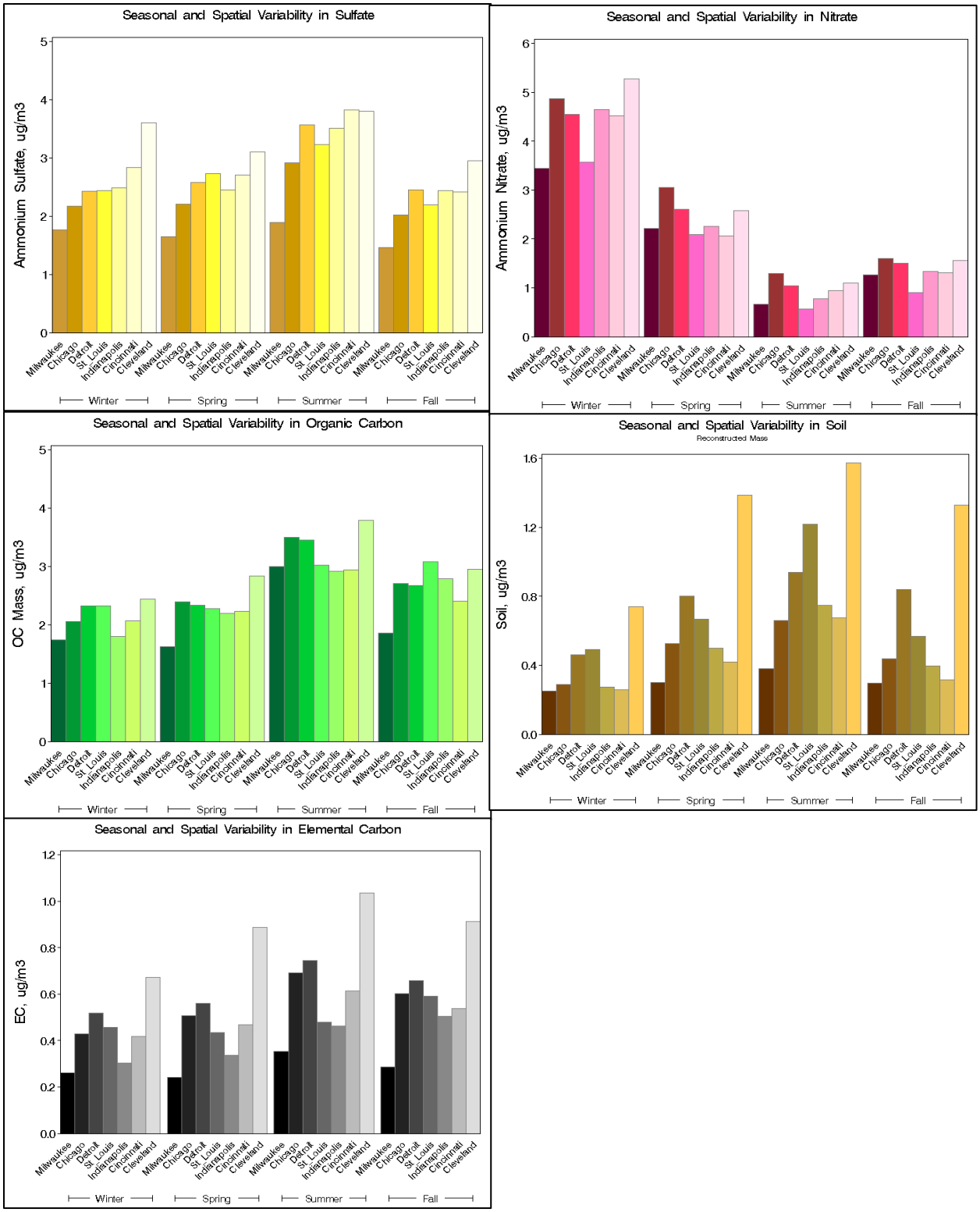

Figure 2.12. Seasonal and Spatial Variability of Major $PM_{2.5}$ Components in Midwest Cities

Precursor Sensitivity

Data from the Midwest ammonia monitoring network are analyzed with thermodynamic equilibrium models to assess the effect of changes in precursor gas concentrations on $PM_{2.5}$ concentrations (Blanchard, 2005b). These analyses indicate that particle formation responds in varying degrees to reductions in sulfate, nitric acid, and ammonia. Figure 2.13 shows $PM_{2.5}$ concentrations as a function of sulfate, nitric acid (HNO3), and ammonia (NH3).

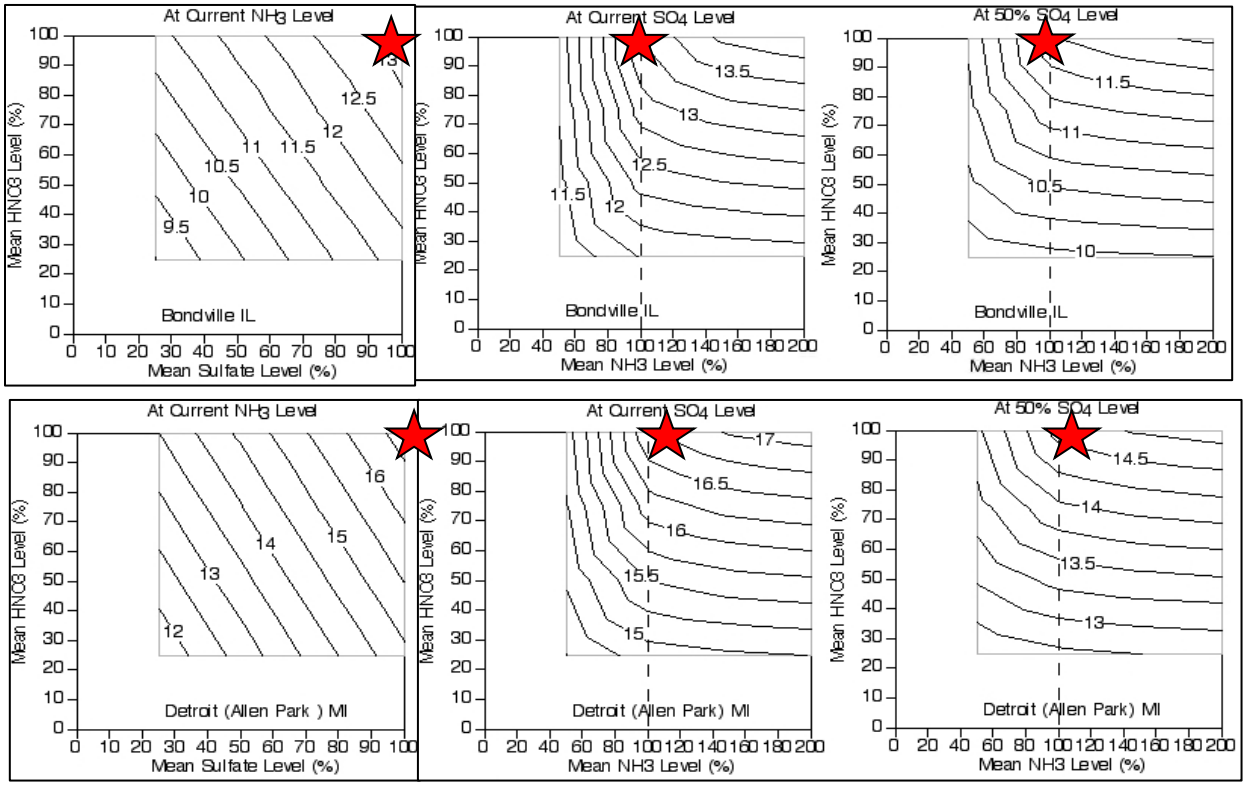

Figure 2.13. Predicted mean PM fine mass concentrations at Bondville, IL (top) and Detroit (Allen Park), MI (bottom) as functions of changes in sulfate, nitric acid (HNO3), and ammonia (NH3) Note: starting at the baseline values (represented by the red star), either moving downward (reductions in nitric acid) or moving leftward (reductions in sulfate or ammonia) results in lower $PM_{2.5}$ values

Several key findings should be noted:

- $PM_{2.5}$ mass is sensitive to reductions in sulfate at all times of the year and all parts of the region. Even though sulfate reductions cause more ammonia to be available to form ammonium nitrate (PM nitrate increases slightly when sulfate is reduced), this increase is generally offset by the sulfate reductions, such that $PM_{2.5}$ mass decreases.

- $PM_{2.5}$ mass is also sensitive to reductions in nitric acid and ammonia. The greatest $PM_{2.5}$ decrease in response to nitric acid reductions occurs during the winter, when nitrate is a significant fraction of $PM_{2.5}$.

- Under conditions with lower sulfate levels (i.e., proxy of future year conditions), $PM_{2.5}$ is more sensitive to reductions in nitric acid compared to reductions in ammonia.

- Ammonia becomes more limiting as one moves from west to east across the region.

Meteorology

$PM_{2.5}$ concentrations are not as strongly influenced by meteorology as ozone, but the two pollutants share some similar meteorological dependencies. In the summer, conditions that are conducive to ozone (hot temperatures, stagnant air masses, and low wind speeds due to stationary high pressure systems) also frequently give rise to high $PM_{2.5}$. In the case of PM, the reason is two-fold: (1) stagnation and limited mixing under these conditions cause $PM_{2.5}$ to build up, usually over several days, and (2) these conditions generally promote higher conversion of important precursors (SO_2 to SO_4) and higher emissions of some precursors, especially biogenic carbon. Wind direction is another strong determinant of $PM_{2.5}$; air transported from polluted source regions has higher concentrations.

Unlike ozone, $PM_{2.5}$ has occasional winter episodes. Conditions are similar to those for summer episodes, in that stationary high pressure and seasonally warm temperatures are usually factors. Winter episodes are also fueled by high humidity and low mixing heights.

$PM_{2.5}$ chemical species show noticeable transport influences. Trajectory analyses have demonstrated that high PM sulfate is associated with air masses that traveled through the sulfate-rich Ohio River Valley (Poirot, et al., 2002; Kenski, 2004). Likewise, high PM-nitrate is associated with air masses that traveled through the ammonia-rich Midwest. Figure 2.14 shows results from an ensemble trajectory analysis of 17 rural eastern IMPROVE sites.

When these results are considered together with analyses of precursor sensitivity, shown previously in Figure 2.13, one possible conclusion is that regional ammonia control in the Midwest could be effective at reducing nitrate concentrations. LADCO conducted a sensitivity analysis of the effectiveness of precursor emissions reductions and concluded that local ammonia emissions reductions (i.e., within the Cleveland NAA) are not effective at reducing $PM_{2.5}$ concentrations (see Section 4). The thermodynamic equilibrium modeling shows that regional ammonia reductions would reduce PM

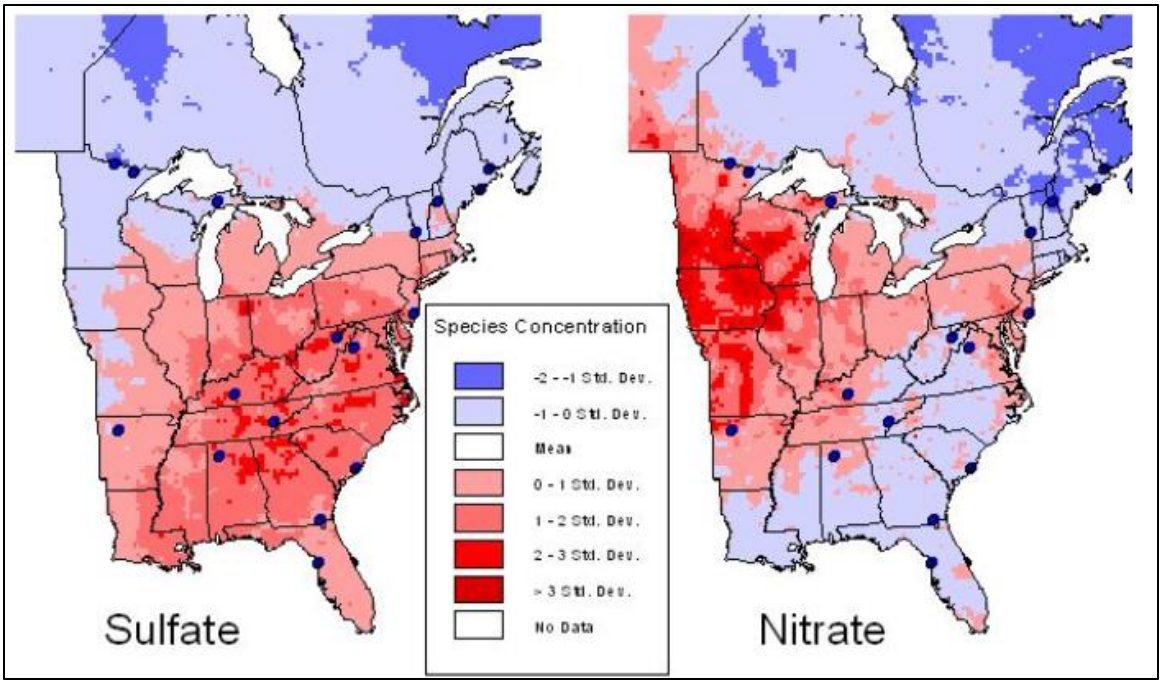

Figure 2.14. Sulfate and nitrate source regions based on ensemble trajectory analysis

concentrations in the Midwest, but that nitric acid reductions are more effective when the probable reductions in future sulfate levels are considered.

Source Culpability

Three source apportionment studies were performed using speciated $PM_{2.5}$ monitoring data and statistical analysis methods (Hopke, 2005; STI, 2006; STI, 2008). Figure 2.15 summarizes the source contributions from these studies. The studies show that a large portion of $PM_{2.5}$ mass consists of secondary, regional impacts, which cannot be attributed to individual facilities or sources (e.g., secondary sulfate, secondary nitrate, and secondary organic aerosols). Regional- or national-scale control programs may be the most effective way to deal with these impacts.

The studies also show that a smaller, yet significant portion of $PM_{2.5}$ mass is due to emissions from nearby (local) sources. Local (urban) excesses occur in many urban areas for organic and elemental carbon, crustal matter, and, in some cases, sulfate. The statistical analysis methods help to identify local sources and quantify their impacts. This information is valuable to states wishing to develop control programs to address local impacts.

The carbon sources are not easily identified in complex urban environments. LADCO's Urban Organics Study (STI, 2006) identified four major sources of organic carbon: mobile sources, burning, industrial sources, and secondary organic aerosols. A more recent study by Rutter et al (2014) found that 29% of total organic carbon in Cleveland

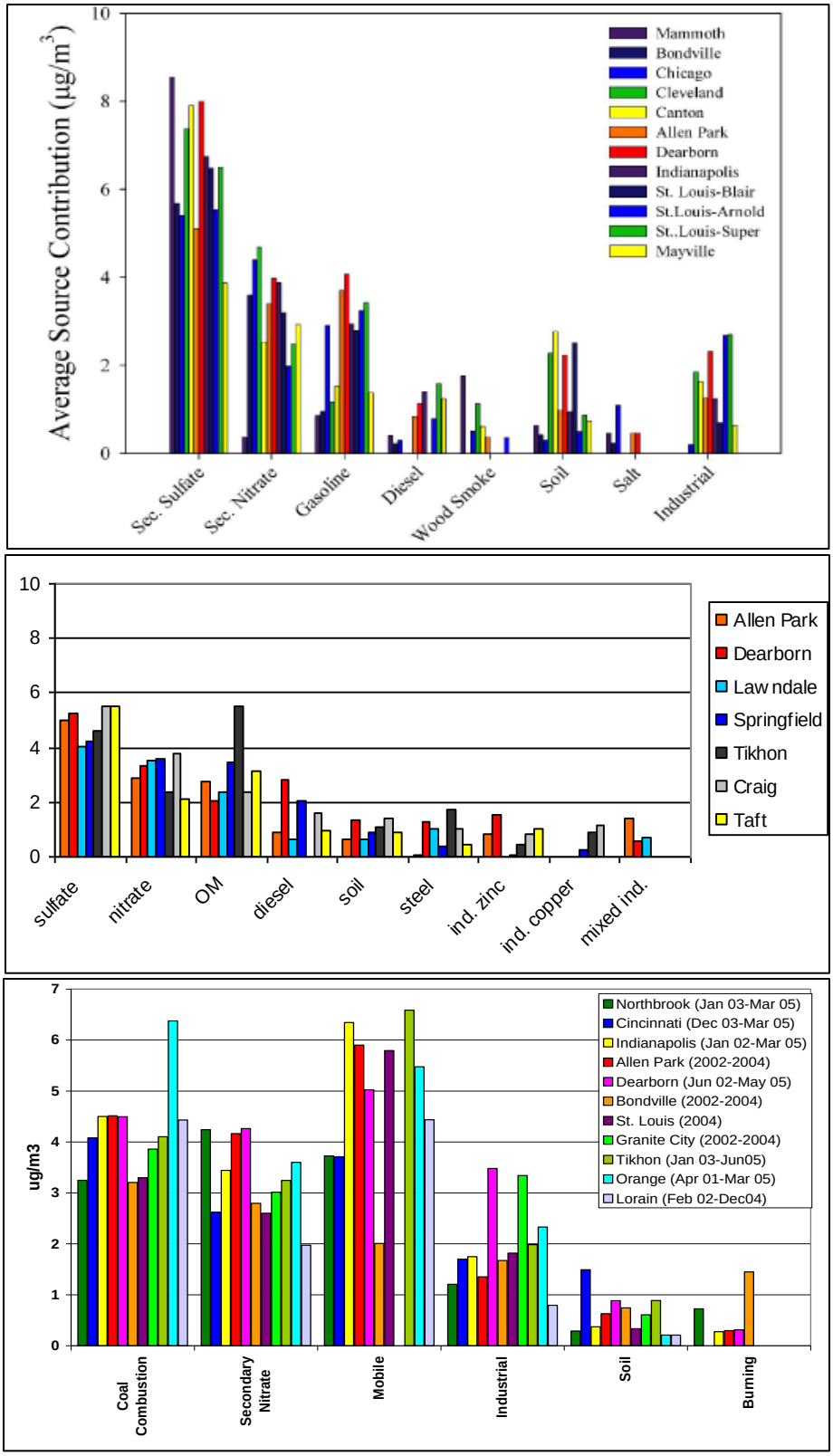

Figure 2.15. Major Source Contributions in the Midwest Based on Hopke 2005 (top), STI 2006 (middle), and STI 2008 (bottom).

was from secondary sources (mostly in the summer), and that as much as half was from anthropogenic sources.

Emissions Trends

Trends in ambient $PM_{2.5}$ track reductions in $PM_{2.5}$ precursor emissions closely, as shown in Figure 2.16. The largest emission reductions have been in SO_2, followed by NO_X and VOC. Primary emissions are a small fraction of the inventory.

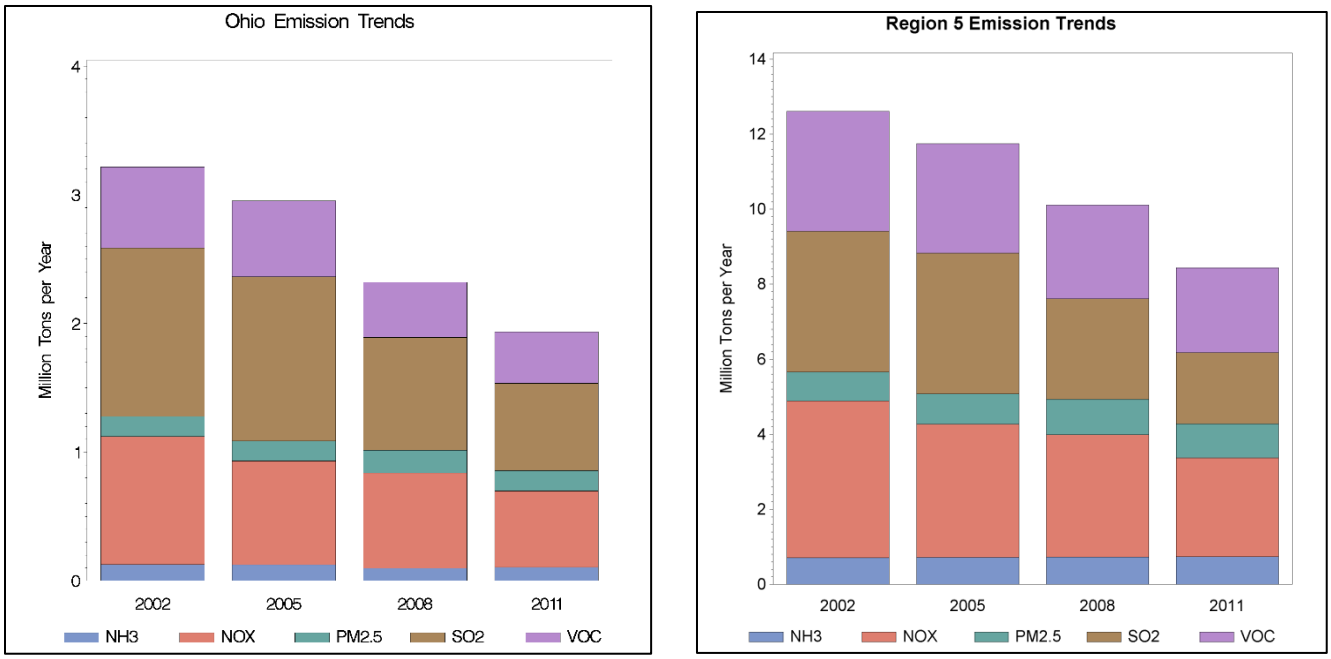

Figure 2.16. Emission Trends for Ohio (left) and Region 5 (right).
(from U.S. EPA's National Emissions Inventory (NEI) (https://www.epa.gov/air-emissions-inventories/national-emissions-inventory).

Conceptual Model

Using both the $PM_{2.5}$ mass and speciation measurements from the CSN and FRM monitoring networks in Cleveland and in the Midwest, a Conceptual Model of the sources and causes of elevated $PM_{2.5}$ concentrations in the Cleveland NAA is summarized below.

Currently, there are 2 sites in violation of the annual $PM_{2.5}$ standard in Ohio, both of which are in the Cleveland nonattainment area. No sites exceed the daily standard.

On an annual basis across the Midwest, $PM_{2.5}$ concentrations follow a gradient from low values in northern and western areas (Minnesota and northern Wisconsin) to high values (11-12 $\mu g/m^3$) in Ohio and along the Ohio River.

$PM_{2.5}$ mass data show a consistent downward trend across the Midwest and in the nonattainment area monitors in Cleveland. These trends are consistent with the downward trends in regional and local emissions, most notably emissions reductions of SO_2, NO_X, and VOC.

Seasonally, concentrations of $PM_{2.5}$ in Cleveland are typically highest in the winter and summer, with lower concentrations in the spring and fall. Seasonal patterns are driven partly by changes in emissions (for example, from changing electrical demand) and partly by the influence of meteorology on $PM_{2.5}$ (for example, ammonium nitrate is present in significant amounts during the colder winter months).

Chemically, $PM_{2.5}$ is made up of mostly ammonium sulfate, ammonium nitrate, and organic carbon in approximately equal proportions on an annual average basis. Elemental carbon and crustal matter (also referred to as soil) contribute less than 5% each.

Spatially, $PM_{2.5}$ concentrations in urban areas are higher than in upwind rural areas, indicating that local urban sources add a significant increment of 1-3 $\mu g/m^3$ to the regional background of 6-10 $\mu g/m^3$. The components of $PM_{2.5}$ also vary spatially and exhibit notable urban and rural differences. Urban areas, including Cleveland, have higher local contributions to EC and soil. Sources of EC are usually combustion processes (for example, mobile sources - especially diesel, and industrial fuel use), and the soil fraction of $PM_{2.5}$ is generally from mechanical processes, road dust, and construction.

The major components of $PM_{2.5}$ vary seasonally. In Cleveland, ammonium sulfate peaks in the summer and winter. Sulfate is formed when sulfuric acid (an oxidation product of sulfur dioxide) and ammonia react in the atmosphere, especially in cloud droplets. Coal combustion is the primary source of sulfur dioxide, whereas ammonia is emitted primarily from animal husbandry operations and fertilizer use. Ammonium nitrate peaks in the winter. Ammonium nitrate forms when nitric acid reacts with ammonia, a process that is enhanced when temperatures are low and humidity is high. Nitric acid is a product of the oxidation of nitric oxide, a pollutant that is emitted by combustion processes. Organic carbon concentrations are generally slightly higher in the summer than in other season. Particulate organic carbon can be emitted directly from cars and other fuel combustion sources or formed in a secondary process as volatile organic gases react and condense. In rural areas, summer organic carbon has significant contributions from biogenic sources.

$PM_{2.5}$ mass is sensitive to reductions in sulfate at all times of the year and all parts of the region. Even though sulfate reductions cause more ammonia to be available to

form ammonium nitrate (PM nitrate increases slightly when sulfate is reduced), this increase is generally offset by the sulfate reductions, such that $PM_{2.5}$ mass decreases.

$PM_{2.5}$ mass is also sensitive to reductions in nitric acid and ammonia. The greatest $PM_{2.5}$ decrease in response to nitric acid reductions occurs during the winter, when nitrate is a significant fraction of $PM_{2.5}$. Under conditions with lower sulfate levels (i.e., proxy of future year conditions), $PM_{2.5}$ is more sensitive to reductions in nitric acid compared to reductions in ammonia. Ammonia becomes more limiting as one moves from west to east across the region.

$PM_{2.5}$ chemical species show noticeable transport influences. High PM sulfate is associated with air masses that traveled through the sulfate-rich Ohio River Valley. High PM-nitrate is associated with air masses that traveled through the ammonia-rich Midwest.

A large portion of $PM_{2.5}$ mass consists of secondary, regional impacts, which cannot be attributed to individual facilities or sources (e.g., secondary sulfate, secondary nitrate, and secondary organic aerosols). A smaller, yet significant portion of $PM_{2.5}$ mass is due to emissions from nearby (local) sources. Local (urban) excesses occur in many urban areas for organic and elemental carbon, crustal matter, and, in some cases, sulfate.

3.0 Emissions Inventory Development

U.S. EPA's Modeling Platform

LADCO utilized emissions inventories compiled by U.S. EPA for the years 2011, 2017, and 2025 as the starting point for the modeling inventories used in this analysis. U.S. EPA's 2011 emission inventory (Version 2011EH) is based on the 2011 National Emissions Inventory, version 2 (2011NEIv2). The inventory uses hourly 2011 continuous emissions monitoring system (CEMS) data for electrical generation units (EGUs) emissions, hourly on-road mobile emissions, and 2011 day-specific wild and prescribed fire data. Emissions include all criteria pollutants and precursors (CAPs), and a few hazardous air pollutants (HAPs). See U.S. EPA's Technical Support Document (U.S. EPA, 2015A) for a thorough description of the methodology used to develop the 2011EH emissions inventory. Regional on-road mobile sources are updated as described in more detail later in this section.

U.S. EPA projected future emission inventories for the years 2017 and 2025 based on the 2011 baseline inventory. The future year scenarios incorporate current "on-the-books" regulations, but do not include emissions reduction measures that may be needed to attain the current NAAQS. See U.S. EPA (2015A) for a thorough description of the methodology used to project future emissions. For most emissions categories, LADCO developed the 2021 future year emissions inventory by interpolating between U.S. EPA's 2017 and 2025 inventories. The interpolation was done for each model species at each model cell for every model hour. However, LADCO developed updated EGU and regional on-road emissions for 2021 as described in more detail later in this section.

On-Road Motor Vehicles

For the on-road category, LADCO worked with its member states plus Iowa, Missouri, and Kentucky, to derive improved inputs for running the MOVES emissions model for both 2011 and 2021. In March 2014, LADCO contracted with Ramboll-Environ to evaluate and develop 2011 base year and several future year on-road mobile emissions inventories using U.S. EPA's MOVES emissions model. As part of this contractual effort, Ramboll-Environ quality assured the MOVES inputs used by U.S. EPA in developing the NEIv2 inventory. This quality assurance effort identified some problems in the MOVES inputs in NEIv2 (Ramboll-Environ, 2014). For example, Ramboll-Environ reviewed vehicle population data used in the NEIv2 and discovered that the vehicle population data in Ohio differed markedly from that for other Midwestern states, and warranted further review from the State of Ohio (see Figure 3.1). This is just one example of issues identified by Ramboll-Environ in U.S. EPA's NEIv2 on-road inventory.

Based on these findings, LADCO worked with its member states and 3 adjacent states (IA, KY, and MO) to review and update key MOVES inputs, including vehicle population, vehicle miles travelled (VMT), speed, and vehicle inspection and maintenance characteristics. After extensive review, Ramboll-Environ completed the final MOVES

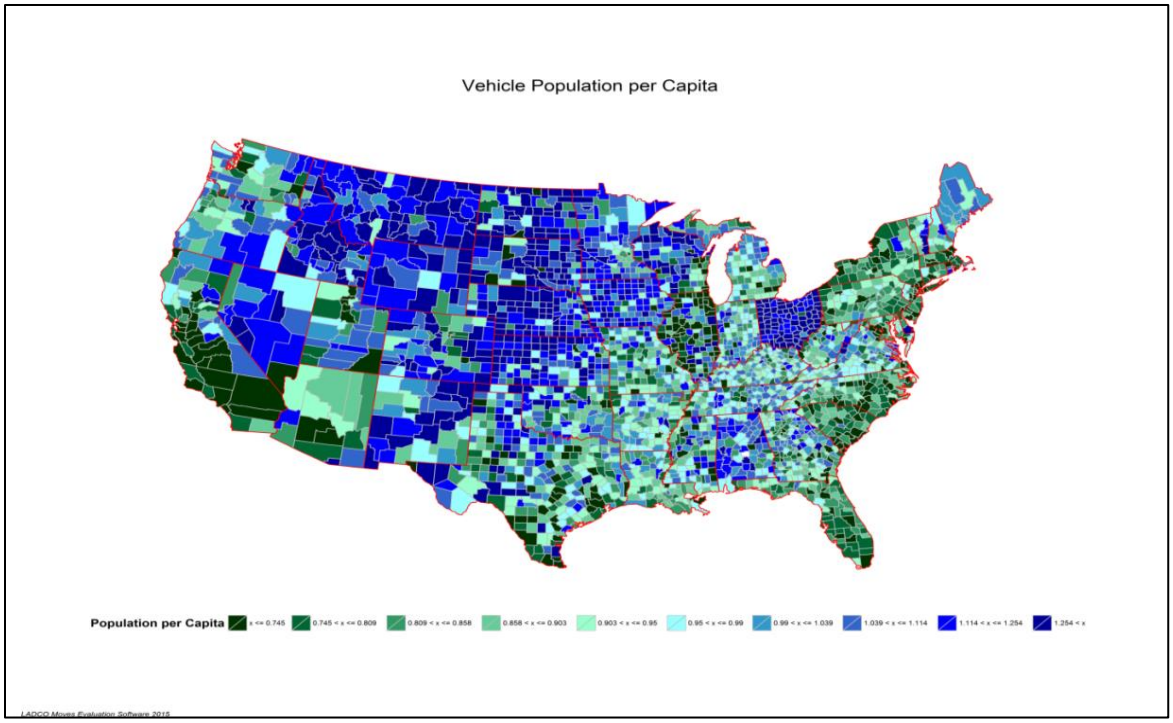

Figure 3.1. Vehicle Population Per Capita Used in the 2011 NEIv2. (Ramboll-Environ, 2014)

(Version MOVES2014) and provided model-ready inputs to LADCO for 2011 and several projection years, including 2021. Figure 3.2 compares on-road mobile source emissions between U.S. EPA's 2011 NEI and the updated results prepared for LADCO by Ramboll-Environ.

Electric Generating Units

LADCO used the ERTAC EGU projection tool (version 2.4L1) to develop future year estimates for 2021 EGU emissions. As mentioned previously, ERTAC is a collaborative effort to improve emission inventories among the Northeastern, Mid-Atlantic, Southeastern, and Lake Michigan area states. The ERTAC effort involves state regulators in the eastern half of the country, industry representatives, and staff from several of the multi-jurisdictional planning organization (MJO).

The ERTAC EGU Forecast Tool is used to project hourly EGU emissions for 2021. The tool uses base year hourly data from U.S. EPA - Clean Air Markets Division (CAMD) data, and fuel specific growth rates from the Annual Energy Outlook (AEO) forecast prepared annually by the U.S. Energy Information Administration (EIA) to estimate future emissions.

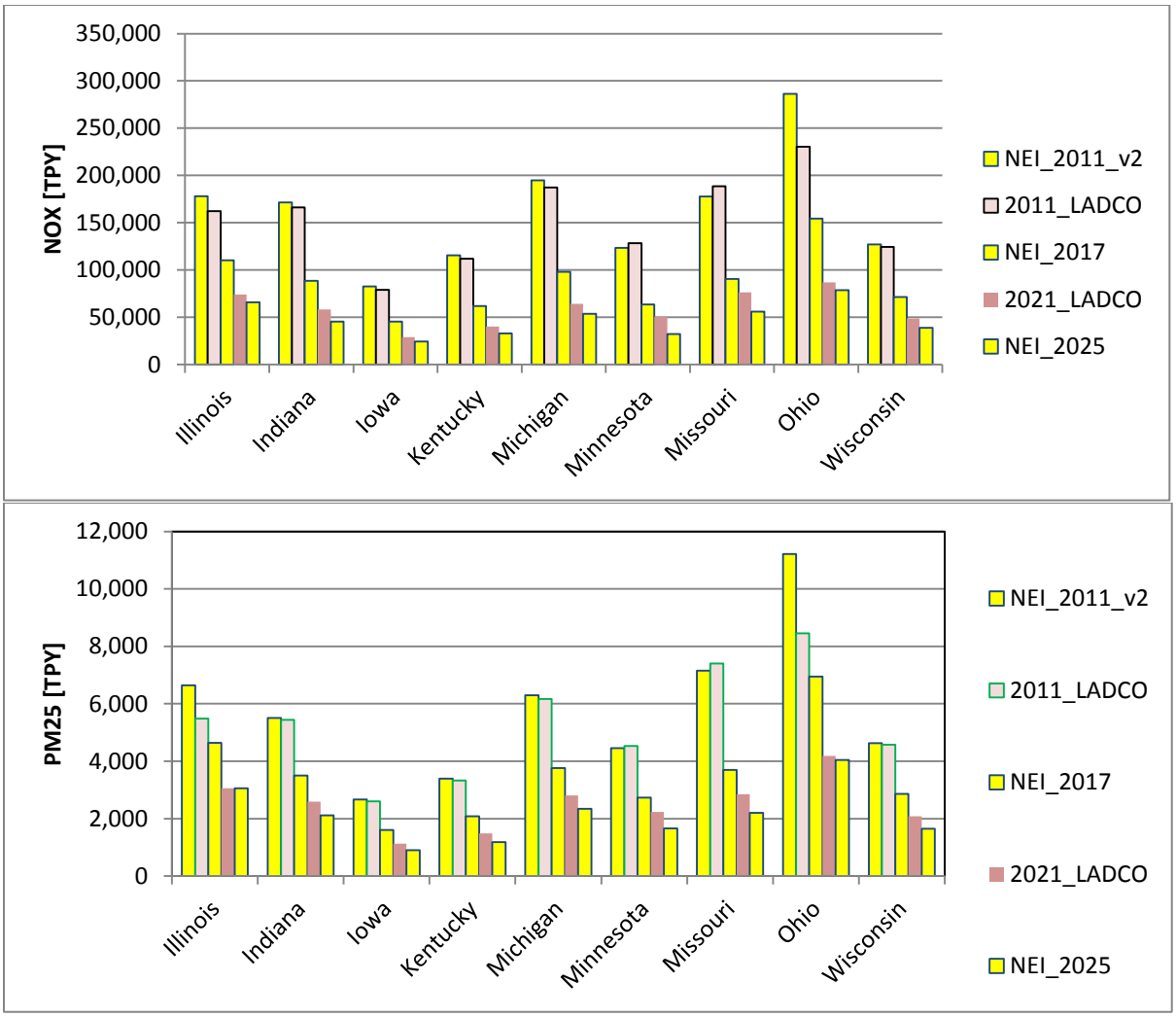

Figure 3.2. Comparison of Mobile Source Emissions for NO_X (top) and $PM_{2.5}$ (bottom) Between NEI and Updates Provided by Ramboll-Environ

The input files used by the tool are described below with links to the files used for the runs. Links to summary output files are also provided below. The enhanced summary files provide NO_X and SO_2 criteria pollutant data for annual and ozone season time periods.

- Base Year CAMD input file: is an improved version of the 2011 base year hourly CAMD CEM data. The data has anomalous data removed, including Non-EGU units and any U.S. EPA substituted data where CEM operation was questionable.

- Unit Availability File (UAF): is a table of base year unit-specific information derived from CAMD NEEDS database, state input, EIA Form 860, and NERC

data. States provide additional information on planned new units, unit retirements, fuel switches, and other changes on a frequent basis.

- Control File: is a table of future unit-specific changes that affect a unit's emissions. State air agency staff has provided this information.

- Season Control File: a table of future year unit-specific emission factors. These data are provided by state air agency staff and are especially helpful in characterizing future year emission rates from seasonal control devices.

- Growth File: a table of growth factors developed from the EIA - AEO and NERC estimates and other information.

- Input Variables File: a table of variables used in the modeling run.

- State File: a table of state level emissions caps or budgets applicable in future years.

- Group File: a table of emissions caps or budgets applicable to multiple states in future years.

- Non-CAMD Hourly File: this file provides updates to the CAMD hourly 2011 base year data to correct hourly reported values.

Additional information on the ERTAC EGU Forecast Tool (version 2.4) can be found at: http://www.marama.org/images/stories/documents/CONUS2.4/Documentation%20of%20ERTAC%20EGU%20CONUS%202.4-%20Final.docx

Additional background information on the ERTAC EGU model can be found at. www.ertac.us/index_egu.html and http://www.marama.org/2013-ertac-egu-forecasting-tool-documentation

For this study, LADCO sought updated information from states and stakeholders on recent EGU unit shutdowns and controls. This effort was initiated in February 2016. LADCO executed the ERTAC EGU Forecast Tool incorporating the most recent updates and EIA's most recent AEO projection for 2015. EIA's 2015 outlook included a "High Oil and Gas Reference" projection that was incorporated in the modeled attainment demonstration. Figure 3.3 illustrates the 2015 AEO forecast by fuel type, including the "High Oil and Gas" forecast used in this analysis. LADCO compared actual coal and natural gas utilization to AEO's 2015 reference case and EIA's "High Oil and Gas Resource" (see Figure 3.3) and found that the AEO2015 reference case forecasts much higher coal use and much lower natural gas use than were actually occurring. LADCO concluded that the "High Oil and Gas Resource" scenario reflected a much more realistic forecast from which to base its 2021 projection of EGU NO_X and SO_2 emissions.

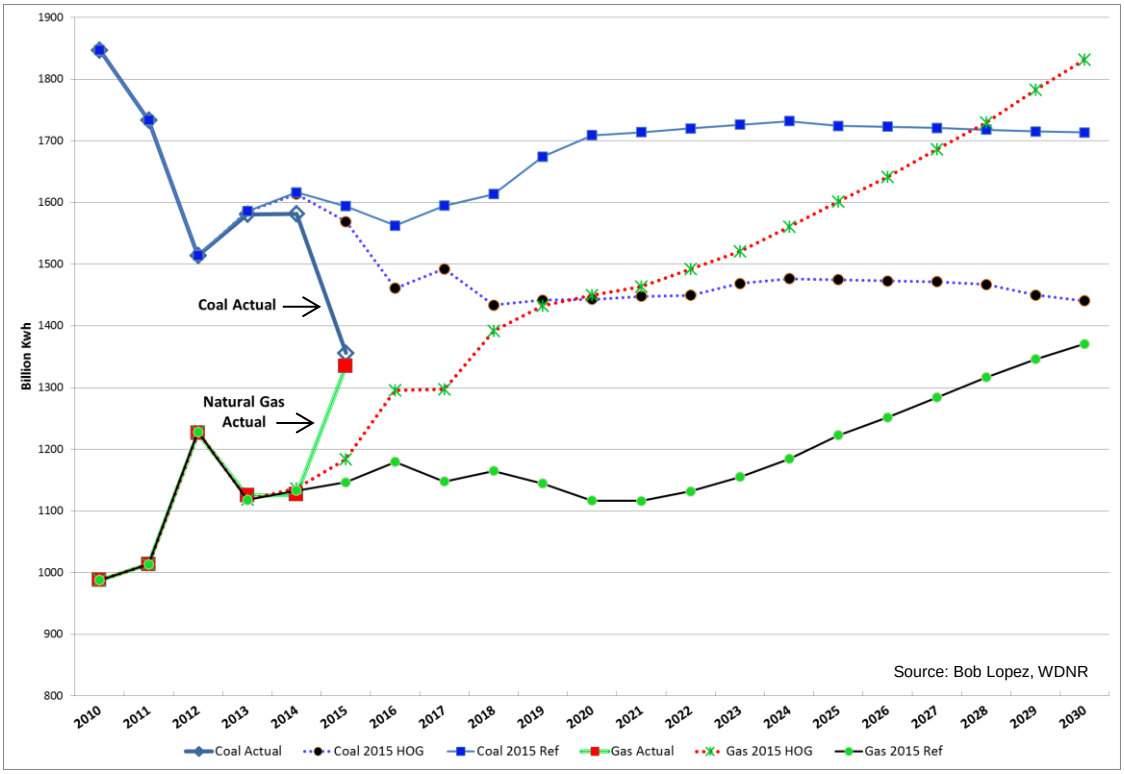

Figure 3.3. 2015 EIA Annual Energy Outlook –
National Forecast of Power Generation for Coal and Natural Gas.

It should be noted that the 2021 emissions for EGU's projected by the ERTAC EGU Forecast Tool reflect enforceable "on-the-books" control measures, fuel switches and unit shutdowns. The model does not forecast unit shutdowns or fuel switches or incorporate assumptions about pending regulatory actions such as the Clean Power Plan (CPP), the Cross-State Air Pollution Rule (CSAPR) Update proposed by U.S. EPA in 2015, or the Mercury and Air Toxics (MATS) rule. These regulatory programs are expected to reduce emissions from Midwestern EGU's but their impacts are as yet uncertain. LADCO made no attempt to quantify these future reductions and considers the 2021 emissions projections for EGU's to be conservative because future emissions are likely to be less than the emissions used in this analysis.

Control Measures

U.S. EPA has adopted a number of national rules over the past few years that require or will require emission reductions from sources of both direct $PM_{2.5}$ and $PM_{2.5}$ precursors, especially of SO_2 and NOx. Emissions standards established for mobile sources have been phased in over recent years but fleet turnover will ensure continued emissions reductions for many years. For Ohio, these rules will provide emissions reductions

between 2011 (base year) and 2021 (attainment year). The national rules that will help States meet their attainment dates include, but are not limited to:

- Tier 2 Light-Duty Vehicle Rule
- Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements
- Clean Air Non-Road Diesel Rule
- Tier 3 Tailpipe and Evaporative Emission and Vehicle Fuel Standards
- Control of Hazardous Air Pollutants from Mobile Sources
- NOx Emission Standard for New Commercial Aircraft Engines
- Control of Emissions for Non-Road Spark Ignition Engines and Equipment
- Emissions Standards for Locomotives and Marine Compression-Ignition Engines
- C3 Oceangoing Vessels Rule
- Area Source Boilers, Major Source Boilers and Commercial/Industrial Solid Waste Incinerators (CISWI) NESHAPs
- Reciprocating Internal Combustion Engines (RICE) NESHAPs
- Mercury and Air Toxics Standards (MATS) (Note that this attainment demonstration includes reductions from MATS as implemented by early 2016 when modeling was initiated. Further emissions reductions are expected from MATS that have not been accounted for in this analysis.)
- Regional Haze Regulations and Guidelines for Best Available Retrofit Technology (BART)
- Clean Air Interstate Rule (CAIR) and Cross State Air Pollution Rule (CSAPR) (Note that U.S. EPA proposed an update to CSAPR in 2015 that, once finalized, will bring even greater reductions in NOx emissions. This attainment demonstration does not rely on the additional emissions to be provided by the CSAPR Update Rule.)
- NSPS for Residential Wood Heaters

In addition to the Federal “on-the-books” control measures listed above, Ohio has adopted a number of state rules over in recent years that require or will require emission

reductions from sources of both direct $PM_{2.5}$ and $PM_{2.5}$ precursors, especially SO_2 and NOx. For Ohio, these rules will provide emissions reductions between 2011 (base year) and 2021 (attainment year). The State rules that will help the Cleveland area meet the attainment date include, but are not limited to:

- Existing Ohio PM RACM/RACT
- Sulfur Dioxide Regulations
- VOC Regulations
- Motor vehicle inspection and maintenance (I/M) program
- Permits-to-install new sources and permit-to-install and operate program

Emissions Summary

Projected NO_X, $PM_{2.5}$, and SO_2 emissions for 2021 are compared to 2011 base year emissions for all emissions categories in Figures 3.4, 3.5, and 3.6, respectively. Emissions of $PM_{2.5}$, NO_X, and SO_2 are expected to decrease significantly in Ohio and regionally between 2011 and 2021 due to “on-the-books” control measures.

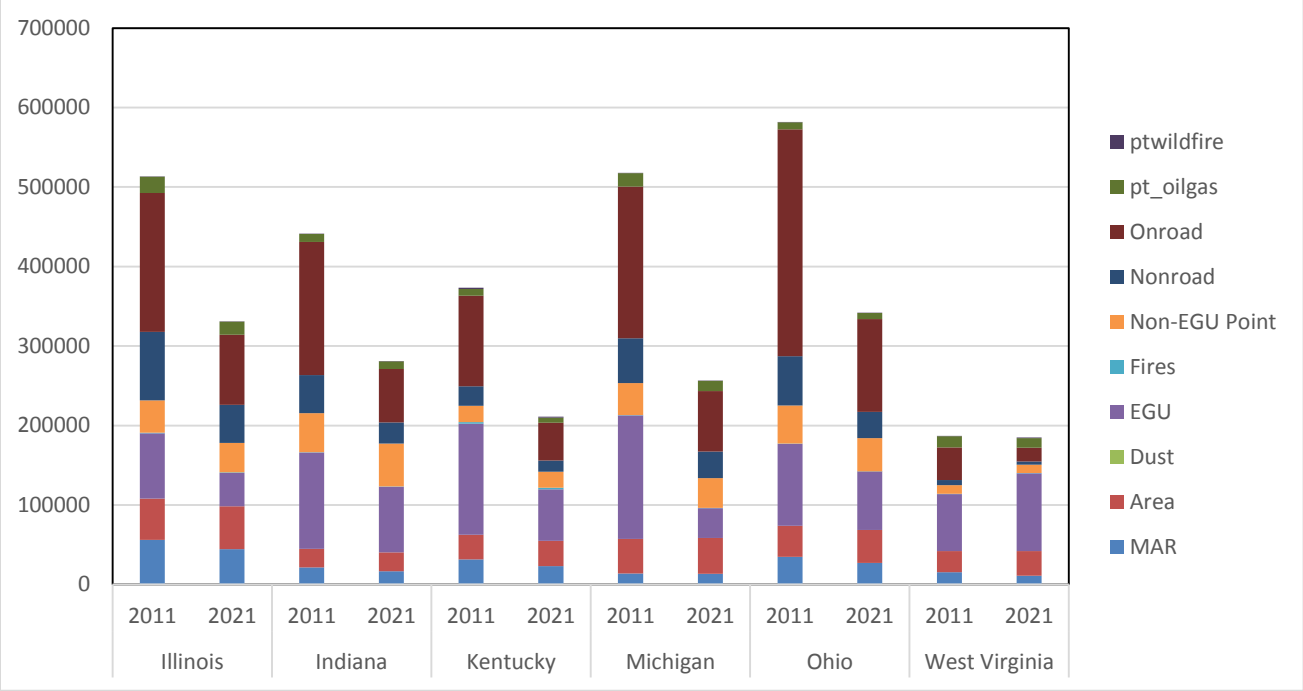

Figure 3.4. Base Year (2011) and Future Year (2021) NO_X Emissions (tons per year).

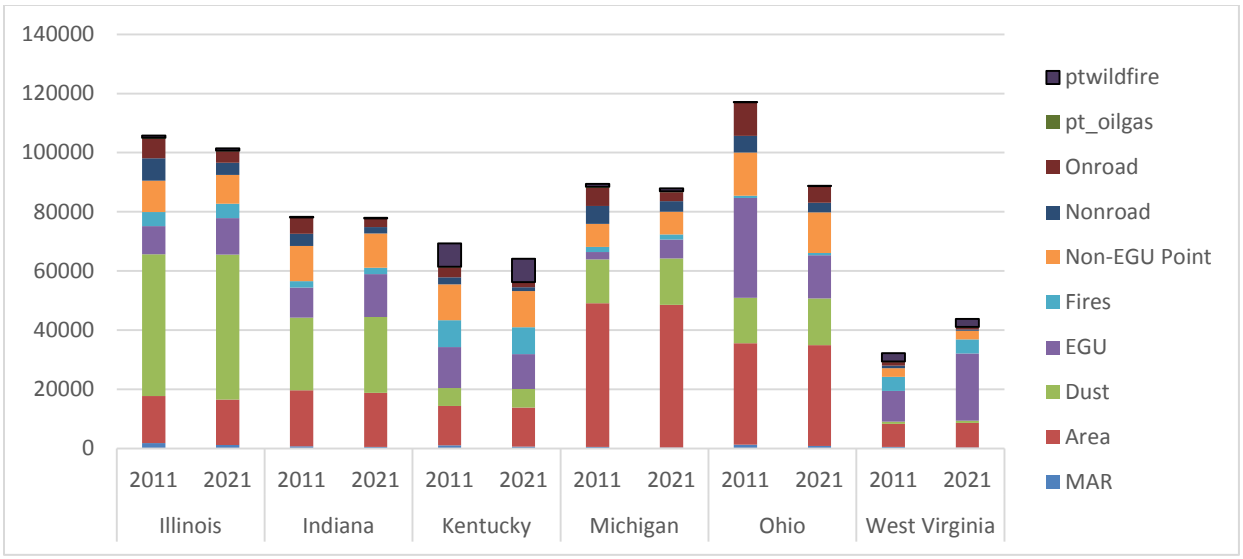

Figure 3.5. Base Year (2011) and Future Year (2021) $PM_{2.5}$ Emissions (tons per year)

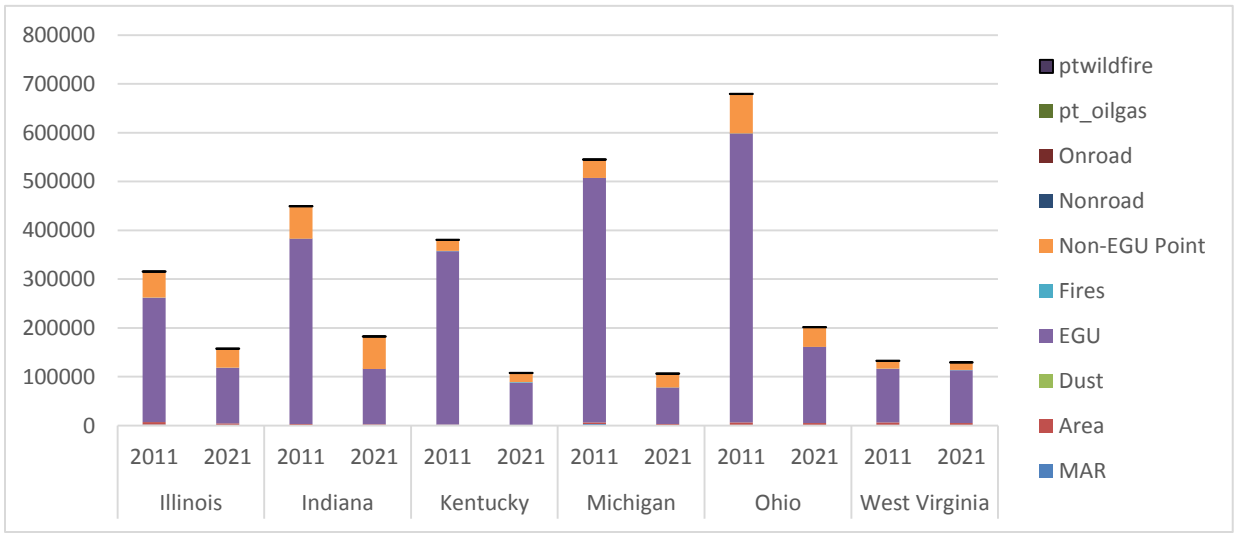

Figure 3.6. Base Year (2011) and Future Year (2021) SO_2 Emissions (tons per year)

This technical analysis relies heavily on emissions and other model inputs prepared by U.S. EPA. U.S. EPA rigorously quality assures their emission inventories (U.S. EPA, 2015). In addition, LADCO conducts rigorous quality assurance procedures to ensure high data quality. LADCO's emissions modeling quality assurance procedures include reviewing emissions model output files for errors and warnings, comparing emissions between processing steps, checking that speciation, temporal, and spatial allocation factors are applied correctly, and reviewing the air quality model emissions inputs and stack parameters.

4.0 Air Quality Modeling

This section reviews the development and evaluation of the modeling system used for the Cleveland $PM_{2.5}$ attainment demonstration. The modeling analyses were conducted in accordance with U.S. EPA's modeling guidelines (EPA, 2014B). Application of the modeling system is described in the following sections.

Selection of Base Year

The calendar year 2011 was selected as the base year for the Cleveland $PM_{2.5}$ modeling, based on the following considerations:

- The 2011 base year is representative of the observed baseline design value (2011-2013) that U.S. EPA used to establish the final air quality designations for the Cleveland area for the 2012 $PM_{2.5}$ NAAQS.

- There are extensive air quality, meteorological, and emissions databases that have been developed for 2011 by U.S. EPA, and others, for regulatory purposes (U.S. EPA, 2015A).

- 2011 appears to be a fairly typical year in terms of meteorology based on available information.

Modeling System

The modeling platform consists of emissions and transport models that reflect the spatial and temporal characteristics of the study region. A summary of the models used in the 2011 modeling platform are shown in Table 4.1.

Table 4.1. 2011 Modeling Platform Components

Model	Type	Managing Organization
WRF	Meteorology	EPA OAQPS
GEOS-CHEM	Global Chemical Transport	EPA OAQPS
SMOKE	Emissions	EPA OAQPS / LADCO
CAMx	Regional Photochemical	LADCO

Meteorological Inputs

Meteorological modeling is an integral part of the modeling platform providing inputs for the emissions and photochemical models. $PM_{2.5}$ modeling requires a full year of meteorological inputs covering January 1 through December 31 not including model spin-up. Meteorological modeling for the 2011 modeling platform was performed with

the Weather Research and Forecast (WRF-ARW V3.4) model operated by U.S. EPA OAQPS. Sea surface temperatures were initialized with a 1 km data set from the Group for High Resolution Sea Surface Temperatures (GHRSST) (Stammer et al., 2003). The 12km WRF modeling domain is shown Figure 4.1. More details concerning the modeling configuration and processing are provided in U.S. EPA's Technical Support Document (U.S. EPA, 2014A).

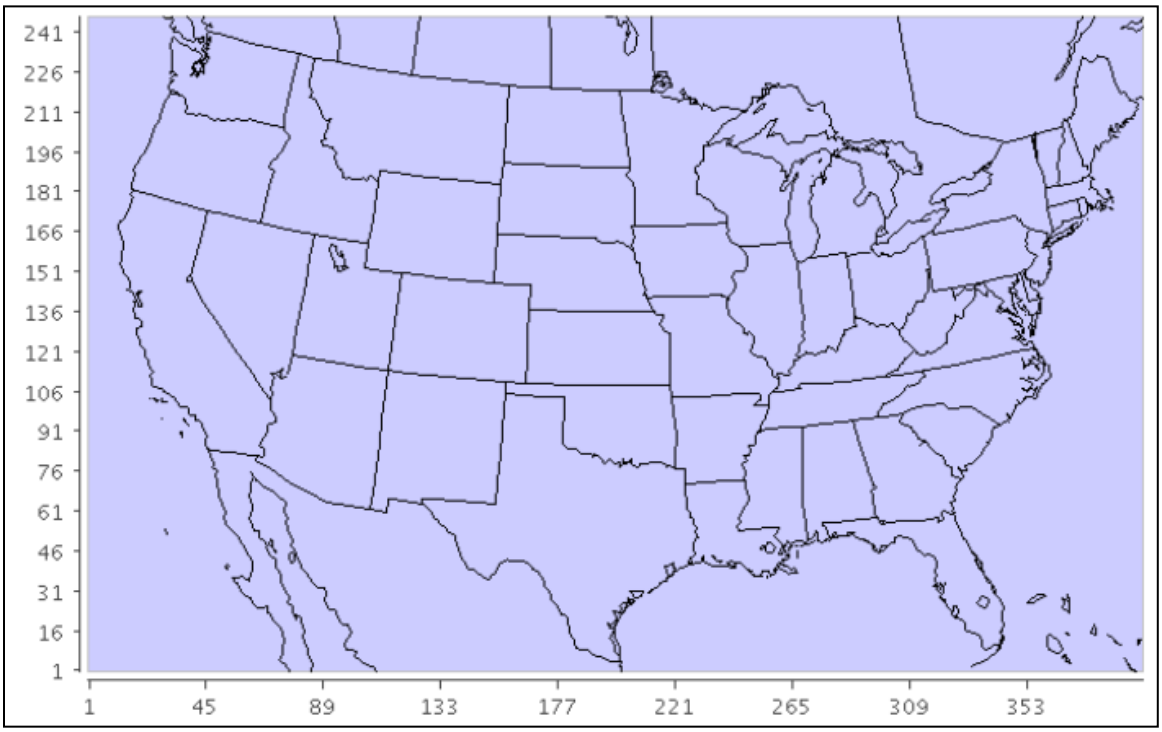

Figure 4.1. Map of WRF Model Domain (U.S. EPA, 2014A)

The 2011 WRF meteorological data has been extensively evaluated on a national scale by U.S. EPA - OAQPS as described in U.S. EPA's Technical Support Document (U.S. EPA, 2014A). Regarding the performance of the WRF meteorological model, U.S. EPA found that, overall, model performance was deemed adequate and an improvement compared with previous meteorological modeling efforts.

Model Configuration

Photochemical modeling of criteria air pollutants is performed with the Comprehensive Air Quality Model with Extensions (CAMx V6.11[1]). CAMx is a commonly used for attainment demonstrations (U.S. EPA, 2014B). CAMx has been peer reviewed (Baker and Scheff, 2007; Vizuete et al., 2011) and has performed well in previous applications (Simon et al., 2012).

[1] Available at http://www.camx.com/home.aspx

CAMx is applied following standard procedures recommended by Ramboll-Environ (2015) and U.S. EPA (2014B). Table 4.2 describes the CAMx modeling configuration.

Table 4.2. CAMx Modeling Configuration

Module	Option
Chemistry Solver	Euler-Backward Iterative
Horizontal Advection Solver	Piecewise Parabolic Method (Colella and Woodward, 1984)
Vertical Diffusion	K-theory
Dry Deposition	Zhang et al. (2003)
Particle Size Distribution	Two-Mode Coarse/Fine (CF)
Chemical Mechanism	CB6r2 (Yarwood et al., 2012)

Grid Projection and Domain

The 12 km photochemical modeling domain adopted for the 2011 modeling platform is referred to as 12US2 by U.S. EPA and shown in Figure 4.2. There are 25 vertical layers with irregular spacing finer near the ground and coarser near the top.

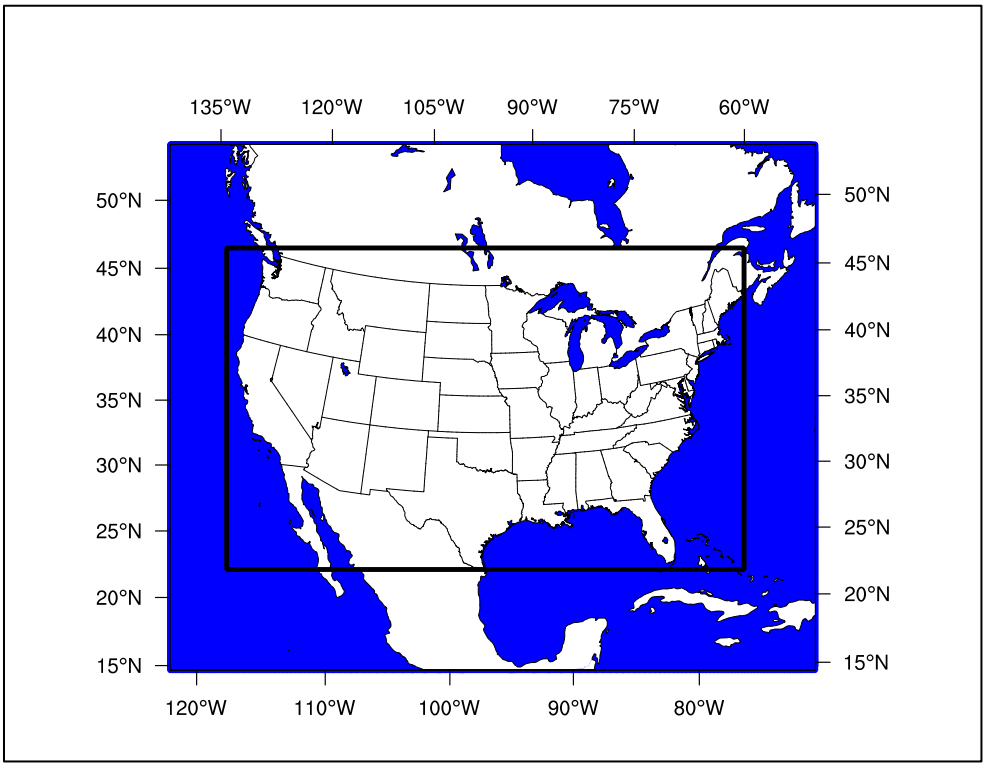

Figure 4.2**.** Photochemical Modeling Domain (shown in black).

Photolysis Rates

2011 clear sky photolysis rates and ozone columns are from the U.S. EPA as part of their 2011 modeling platform.

Initial and Boundary Conditions

Initial and boundary conditions are derived from a 2011 global simulation. GEOS-CHEM v8-03-02 is run with 2 x 2.5 degree resolution and up to 38 vertical layers. Global emissions are based EDGAR with U.S. EPA regional improvements for U.S., Canada, Europe, Mexico, and Asia. See Henderson et al. (2014) for a complete description of the methodology and model evaluation.

Performance Evaluation

The base case modeling is evaluated to assess the model's ability to reproduce the observed concentrations. The model performance evaluation examines the platform's ability to replicate the magnitude, spatial, and temporal pattern of measured concentrations. This exercise was intended to assess whether, and to what degree, confidence in the model is warranted.

Model performance is assessed by comparing paired modeled and monitored concentrations. Graphical (e.g., spatial plots) and statistical analyses are presented. No rigid acceptance/rejection criteria are used for this study. The model performance results presented here describe how well the model replicates observed $PM_{2.5}$ concentrations and $PM_{2.5}$ precursors.

LADCO conducted a performance evaluation of the 2011 modeling platform using ambient monitoring data from the Air Quality System (AQS). The AQS comprises a national database of ambient air pollution including criteria pollutants and speciated particulates. A variety of statistics including mean observed, mean modeled, mean bias, mean error, mean fractional bias, mean fractional error, and correlation coefficient are calculated at each monitor site.

Maps of average observed and predicted $PM_{2.5}$ are shown in Figures 4.3 and 4.4, respectively. Comparing the two figures, the model performs well in reproducing the locations and magnitudes of elevated $PM_{2.5}$ concentrations (shown in red on the two figures), especially in the Midwest and Northeast. The model under-predicts total $PM_{2.5}$ in the Southeast and in California.

The performance evaluation uses statistical metrics to evaluate how well the model reproduces $PM_{2.5}$ measurements. Model "error" is an absolute measure of the deviation or difference between modeled concentrations and observed values, while bias shows the direction of deviation (i.e., whether the model under- or over-predicts measured values). Simon & Baker (2012) present a thorough discussion and summary of regional

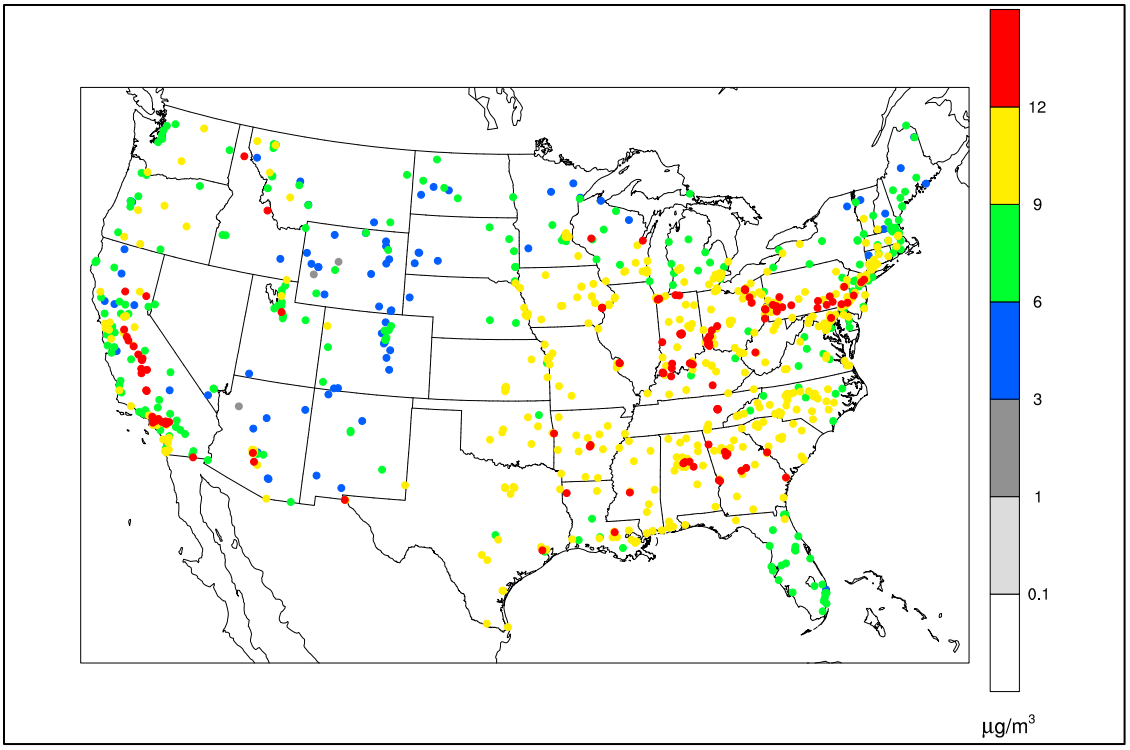

Figure 4.3. 2011 Mean Monitored Daily $PM_{2.5}$ (µg/m^3).

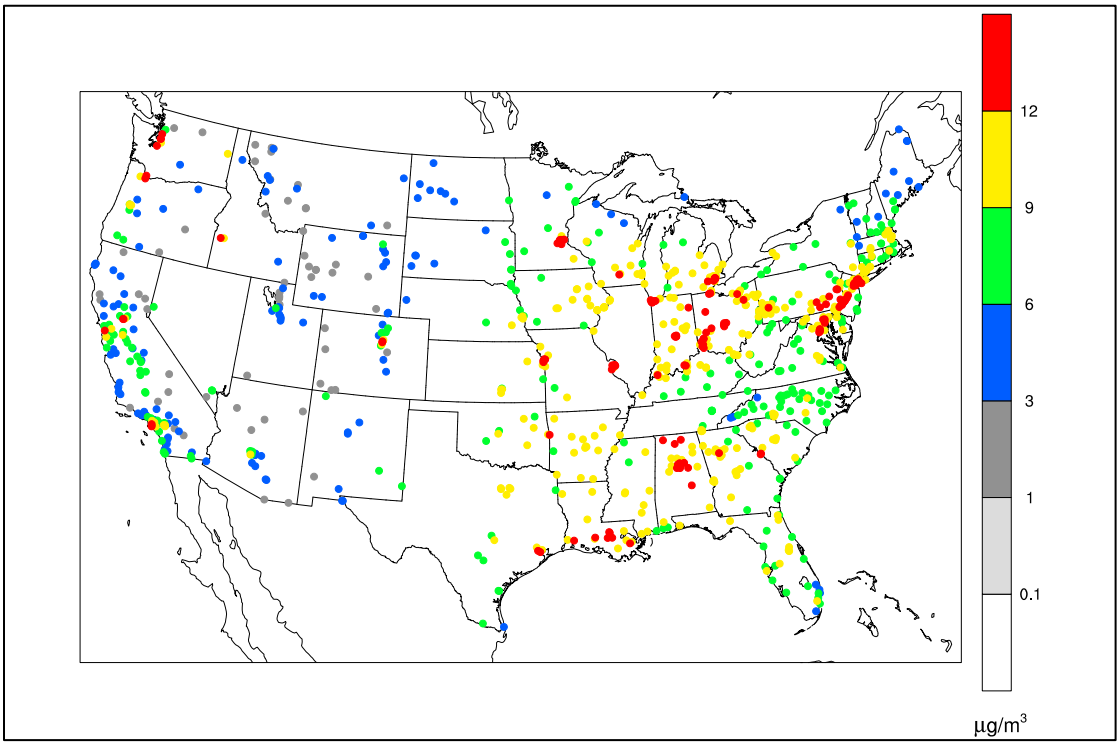

Figure 4.4. 2011 Mean CAMx Predicted Daily $PM_{2.5}$ (µg/m^3) Corresponding with Observed Days.

PM modeling performance statistics. Figures 4.5 and 4.6 depict the spatial distribution of the model's bias. For much of the country, the model generally under predicts $PM_{2.5}$, with negative bias values in most areas less than 3 µg/m 3 (or 30%). In Ohio and much of the Midwest, the model generally over predicts $PM_{2.5}$, with positive bias values generally less than 3 µg/m^3 (10-30%). For the LADCO states, the mean error is generally less than 9 µg/m^3, as shown in Figure 4.7. The fractional mean error is less than 60% for the LADCO states with one exception in a Michigan lakeside monitor, as shown in Figure 4.8. The modeled $PM_{2.5}$ is well correlated with observations (Figure 4.9), which shows that daily increases and decreases predicted by the model track the observations well.

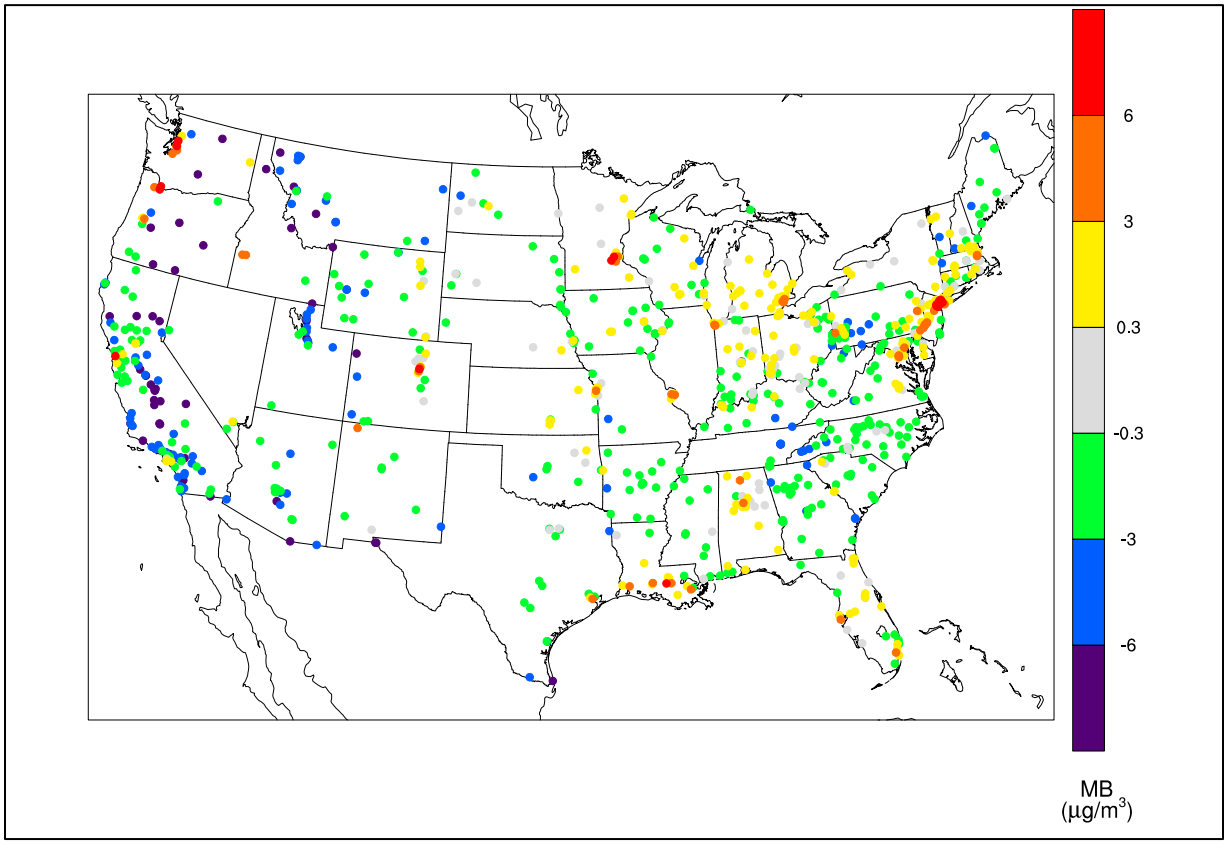

Figure 4.5. 2011 Mean Bias of $PM_{2.5}$ Baseline Modeling

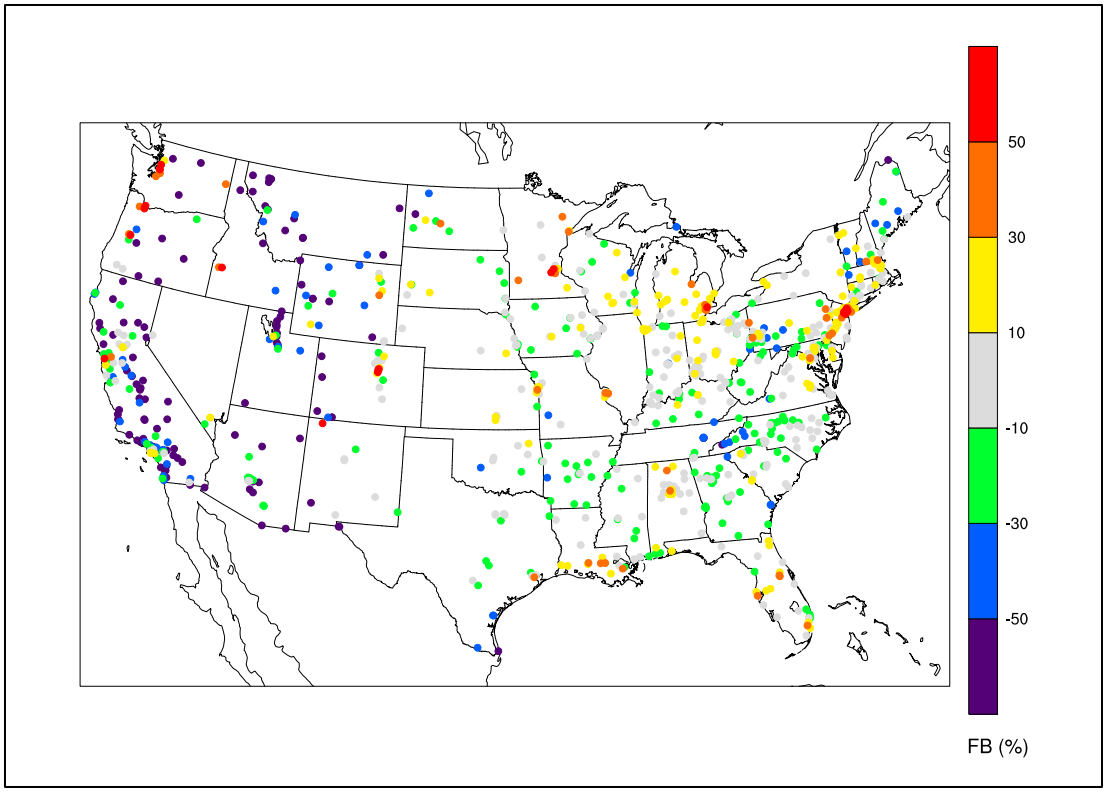

Figure 4.6. 2011 Mean Fractional Bias of $PM_{2.5}$ Baseline Modeling.

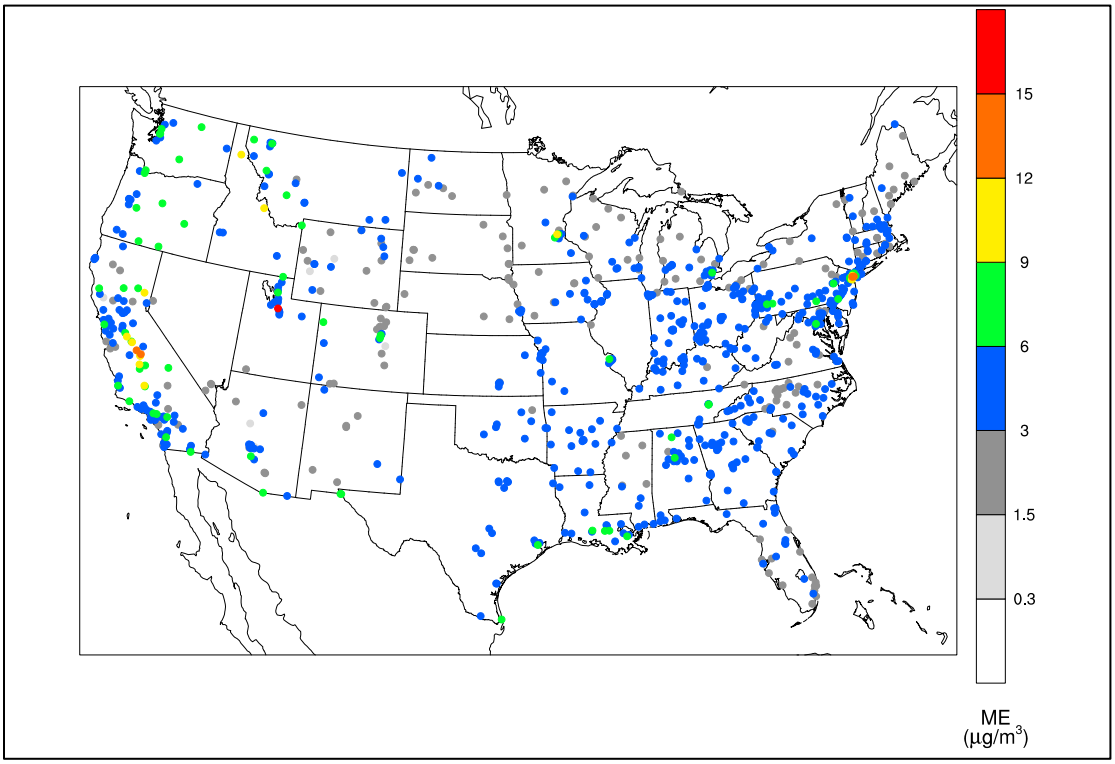

Figure 4.7. 2011 Mean Error of $PM_{2.5}$ Baseline Modeling.

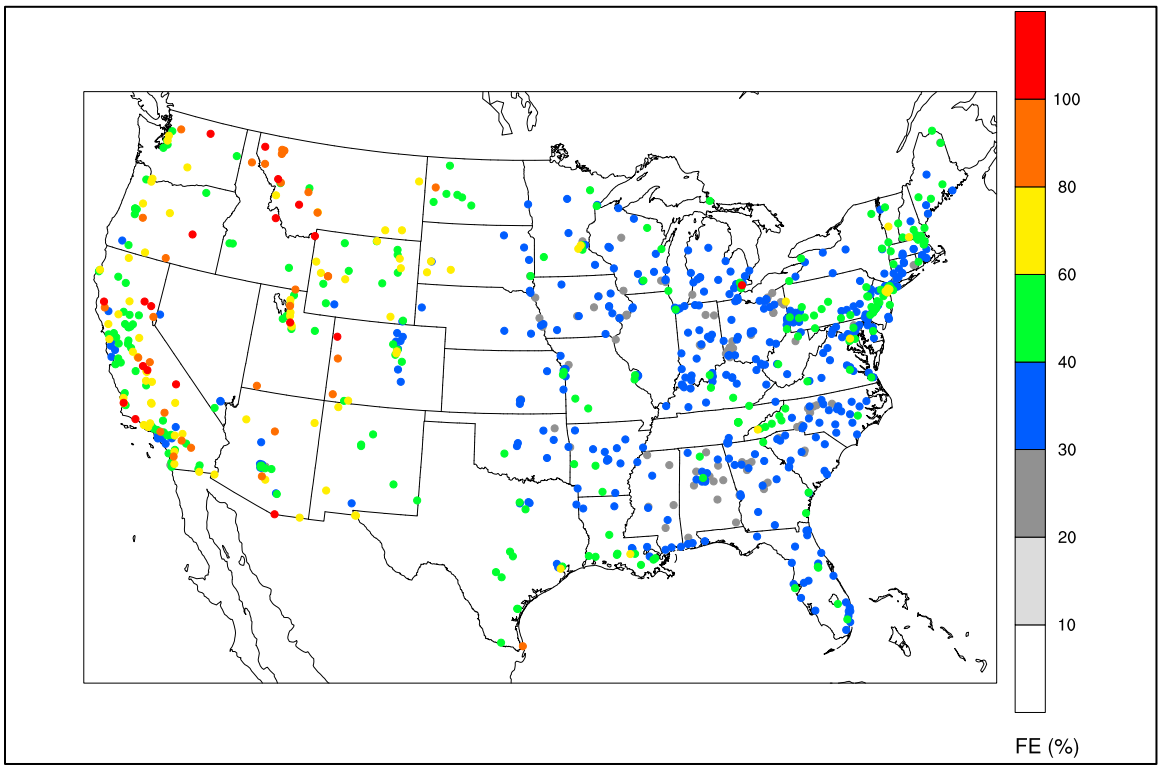

Figure 4.8. 2011 Mean Fractional Error of $PM_{2.5}$ Baseline Modeling.

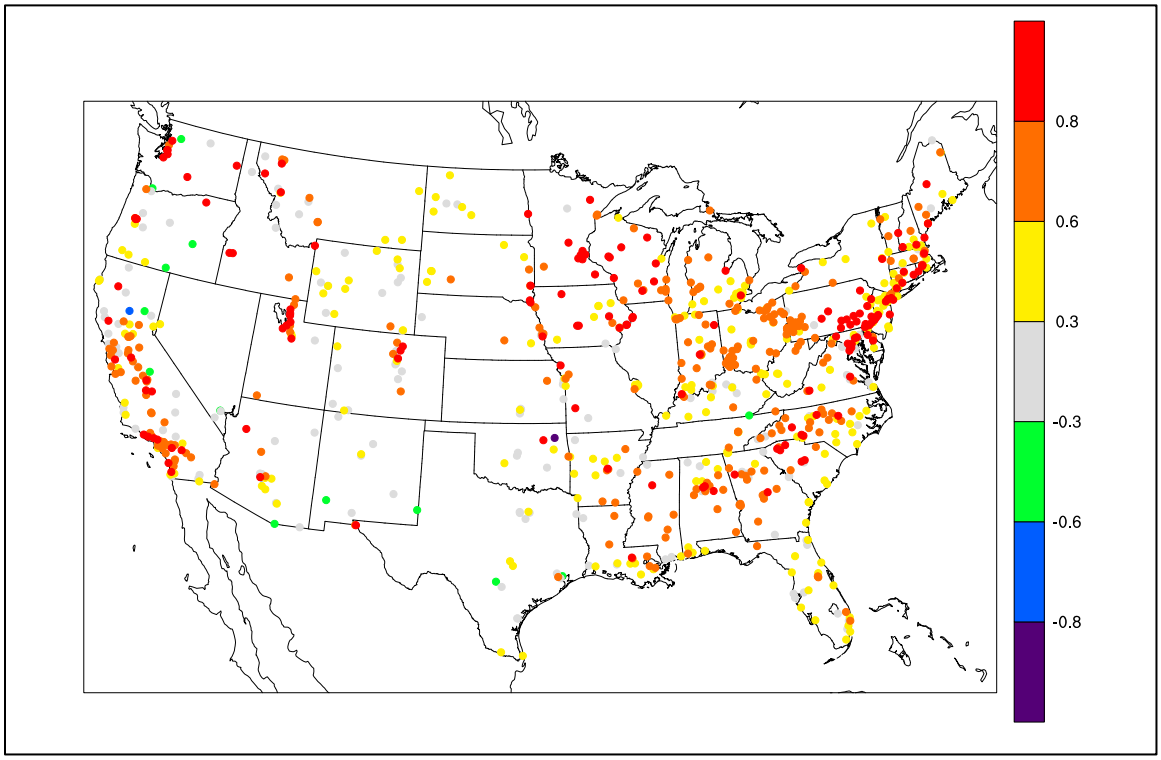

Figure 4.9. 2011 Pearson Correlation Coefficient of $PM_{2.5}$ Baseline Modeling.

$PM_{2.5}$ is evaluated on a component basis. The evaluation considers the individual performance of elemental carbon (EC), organic carbon (OC), total carbon (TC), particulate nitrate, particulate sulfate, and particulate ammonium. Model species are converted to be consistent with measurements. Modeled OC is estimated with a weighted sum of modeled aerosols, as shown in Equation 1.

$$Modeled\ OC = \frac{POA}{1.57} + \frac{SOA1 + SOA2}{2} + \frac{SOA3 + SOA4}{1.6} + \frac{SOA5 + SOA6}{1.4} + \frac{SOA7 + SOPA + SOPB}{2.1}$$ Equation 1

Speciated $PM_{2.5}$ model performance maps are shown in Appendix A.

One easy way to summarize $PM_{2.5}$ model performance and compare it to the performance goals is through the use of box plots. Box plots summarizing fractional error and bias aggregated by month are shown in Figures 4.10 and 4.11 for the continental U.S. and Ohio, respectively. Model performance is generally good for $PM_{2.5}$ and most components with data points clustered near zero bias and less than 60% error. Ohio model performance is similar to national model performance, although particulate nitrates have better performance for Ohio than nationally. There is a significant under-prediction of ammonium particles, which is consistent with past modeling studies (Simon & Baker, 2012).

Time series of speciated $PM_{2.5}$ are shown in Figures 4.12 and 4.13 for two sites in Cleveland. Except for ammonium, the modeled values for most species are of similar magnitudes as the measured values and follow temporal variations reasonably well.

No rigid acceptance or rejection criteria have been established for model performance. The performance of the 2011 modeling platform is an improvement over past modeling studies (Simon & Baker 2012) and meets the high standard for SIP quality modeling.

Quality Assurance

The modeling platform is quality assured by comparing LADCO's CAMx model results with U.S. EPA results (U.S. EPA, 2016A) while using the same inputs. LADCO ran the U.S. EPA 2017 and 2025 modeling platforms provided by U.S. EPA. For this comparison, LADCO used U.S. EPA's emissions inventory, which includes IPM for EGU emissions and the NEI version of national on-road emissions. Table 4.3 compares LADCO's and U.S. EPA's projected $PM_{2.5}$ design values for 2017 and 2025 for monitors located in Ohio. LADCO's projected $PM_{2.5}$ design values are comparable to U.S. EPA's projected design values, and are within 2% at all locations.

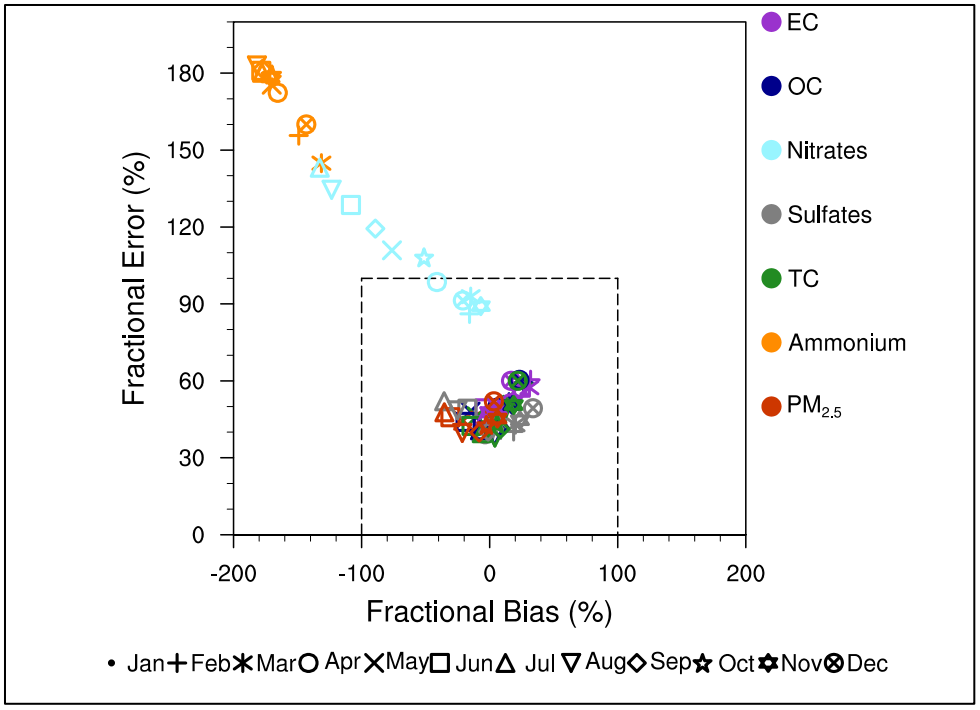

Figure 4.10. Speciated $PM_{2.5}$ Model Performance for the Continental U.S.

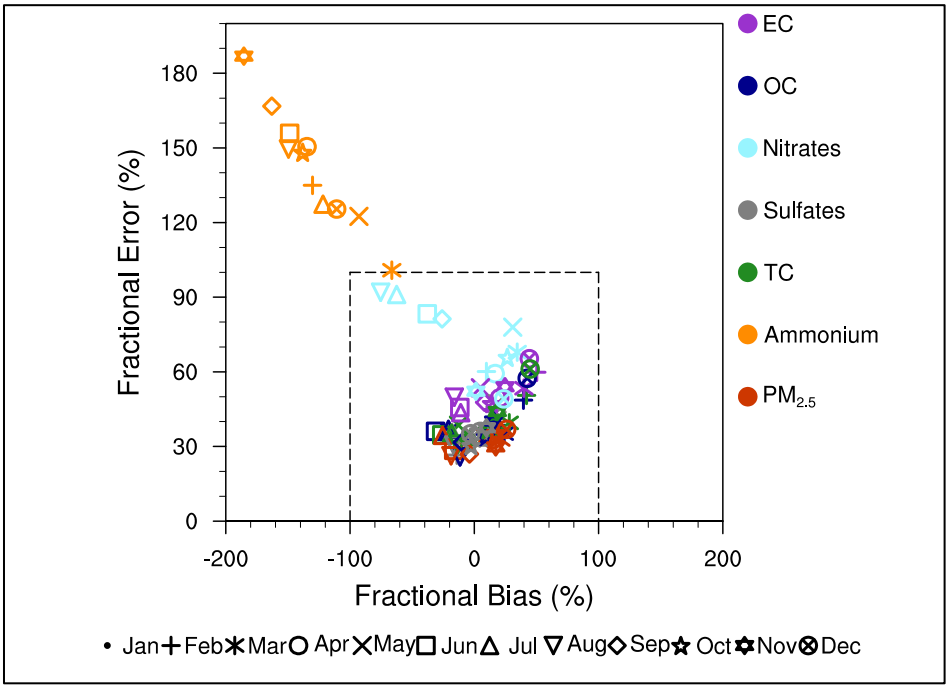

Figure 4.11. Speciated $PM_{2.5}$ model performance for Ohio.

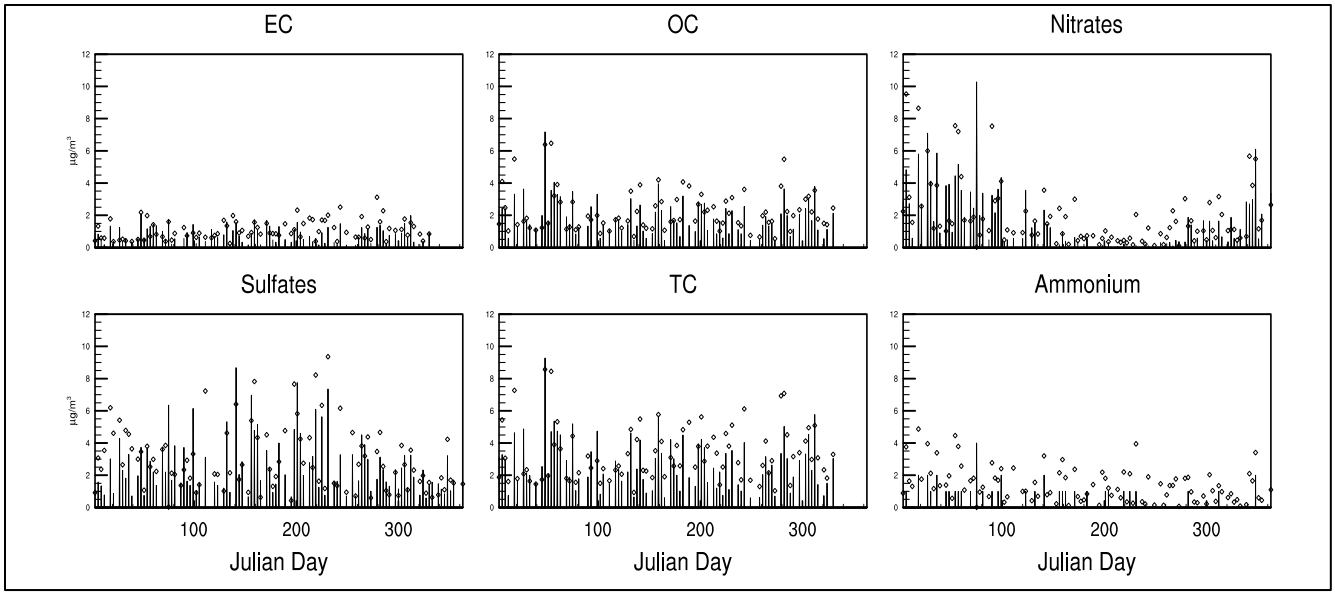

Figure 4.12. Speciated $PM_{2.5}$ Showing Monitoring (diamond) and Modeling (lines) in Cleveland (AQS site ID 390350038).

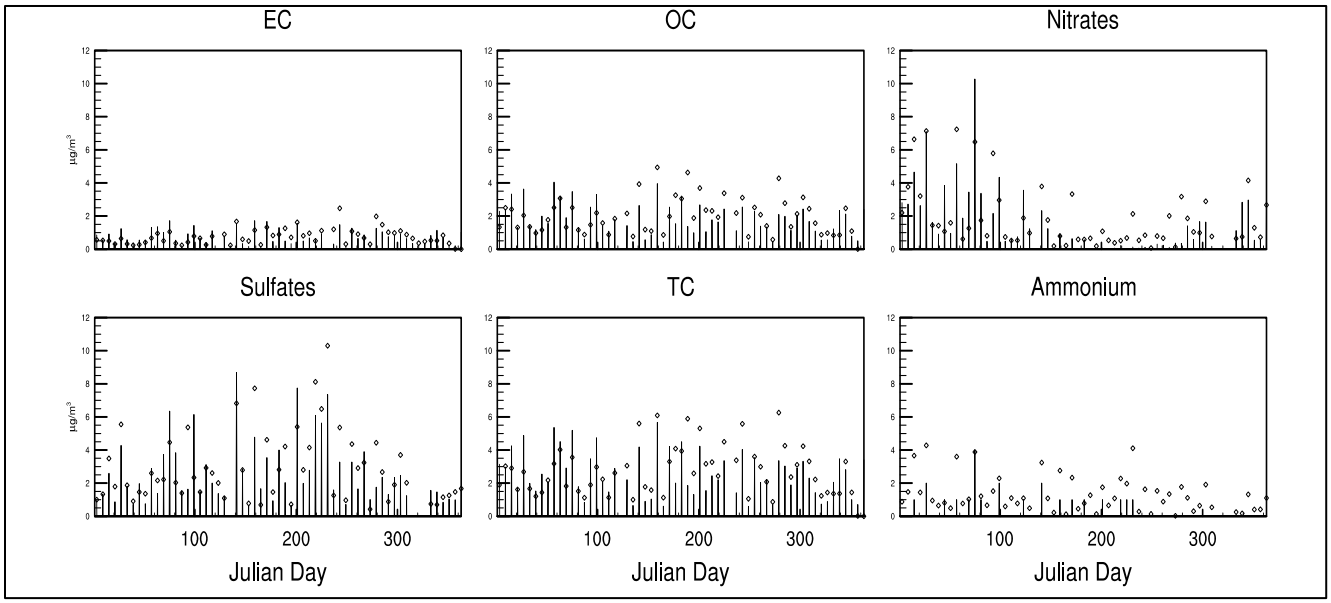

Figure 4.13. Speciated $PM_{2.5}$ Showing Monitoring (diamond) and Modeling (lines) in Cleveland (AQS site ID 390350060).

Table 4.3. Comparison of LADCO's and U.S. EPA's Projected $PM_{2.5}$ Design Values of for 2017 and 2025 Using U.S. EPA's Modeling Platform.

Site #	State	County	EPA 2017	LADCO 2017	EPA 2025	LADCO 2025
390090003	Ohio	Athens	6.87	6.79	6.63	6.55
390170003	Ohio	Butler	10.12	10	9.64	9.51
390170016	Ohio	Butler	9.74	9.63	9.31	9.19
390230005	Ohio	Clark	9.53	9.43	9.07	8.96
390250022	Ohio	Clermont	8.84	8.76	8.48	8.4
390350034	Ohio	Cuyahoga	8.08	7.93	7.79	7.65
390350038	Ohio	Cuyahoga	10.81	10.61	10.42	10.22
390350045	Ohio	Cuyahoga	9.92	9.74	9.56	9.37
390350060	Ohio	Cuyahoga	10.52	10.33	10.13	9.93
390350065	Ohio	Cuyahoga	10.42	10.23	10.04	9.85
390351002	Ohio	Cuyahoga	8.43	8.28	8.14	7.98
390490024	Ohio	Franklin	9.35	9.21	8.86	8.71
390490025	Ohio	Franklin	9.17	9.03	8.7	8.55
390490081	Ohio	Franklin	8.57	8.44	8.13	7.99
390570005	Ohio	Greene	8.9	8.81	8.48	8.38
390610006	Ohio	Hamilton	9.01	8.91	8.62	8.51
390610014	Ohio	Hamilton	10.57	10.46	10.1	9.99
390610040	Ohio	Hamilton	9.46	9.36	9.06	8.95
390610042	Ohio	Hamilton	10.49	10.34	10.03	9.87
390810017	Ohio	Jefferson	9.66	9.52	9.33	9.17
390811001	Ohio	Jefferson	9.07	8.93	8.76	8.6
390850007	Ohio	Lake	7.76	7.67	7.51	7.42
390870012	Ohio	Lawrence	8.92	8.64	8.68	8.39
390933002	Ohio	Lorain	8.06	7.97	7.75	7.65
390950024	Ohio	Lucas	8.85	8.72	8.43	8.29
390950026	Ohio	Lucas	8.87	8.73	8.43	8.3
390950028	Ohio	Lucas	9.14	9.01	8.72	8.58
390990005	Ohio	Mahoning	9.28	9.09	8.93	8.73
390990014	Ohio	Mahoning	9.3	9.11	8.95	8.75
391130032	Ohio	Montgomery	9.69	9.59	9.2	9.1
391330002	Ohio	Portage	8.25	8.14	7.94	7.83
391351001	Ohio	Preble	8.69	8.62	8.27	8.2
391450013	Ohio	Scioto	8.34	8.21	8.07	7.94
391510017	Ohio	Stark	10.86	10.66	10.42	10.22
391510020	Ohio	Stark	9.7	9.52	9.32	9.13
391530017	Ohio	Summit	9.7	9.58	9.29	9.17
391530023	Ohio	Summit	8.99	8.88	8.62	8.5
391550005	Ohio	Trumbull	8.73	8.61	8.42	8.29
391650007	Ohio	Warren	9.23	9.12	8.82	8.7

Future Year of Interest

As mentioned previously, U.S. EPA issued final area designations for the 2012 annual NAAQS for $PM_{2.5}$ with an effective date of April 15, 2015. States are required to submit attainment plans to U.S. EPA within 18 months from the effective date of designations (October 15, 2016), and moderate nonattainment areas are required to attain the NAAQS no later than the end of the sixth calendar year after the designation (2021). This modeling analysis, therefore, uses 2021 as the projection year to demonstrate attainment of the 2012 $PM_{2.5}$ NAAQS.

Modeled Attainment Test

An attainment demonstration based on air quality modeling is used to determine whether identified emissions reduction measures are sufficient to reduce projected pollutant concentrations to a level that meets the NAAQS by the statutory deadline established by U.S. EPA. This modeled attainment demonstration has been performed consistent with the draft guidance issued by U.S. EPA in 2014 (U.S. EPA, 2014B). As described in the previous section, LADCO has estimated the amount of emission reductions expected by 2021 and has applied the CAMx photochemical model to simulate both base year and future year $PM_{2.5}$ concentrations. In this section, the application of U.S. EPA's "model attainment test" for the Cleveland $PM_{2.5}$ nonattainment area is described.

The model attainment test uses model estimates in a relative sense to estimate future year design values. U.S. EPA's Air Quality Modeling Group has developed the Modeled Attainment Test Software (MATS[2]) for this purpose. The MATS software computes the fractional changes, or relative response factors (RRF), of $PM_{2.5}$ concentrations at each monitor location using results of the model base year and the future year. Meteorological conditions are assumed to be unchanged for the base and projection years. The resulting estimates of future $PM_{2.5}$ design values are then compared to the NAAQS. If the future $PM_{2.5}$ design values are less than the NAAQS, then the analysis suggests that attainment will be reached. It is noted that U.S. EPA is developing new software to replace MATS for performing both the annual and 24-hour $PM_{2.5}$ attainment test. This software is called the Software for the Modeled Attainment Test - Community Edition (SMAT-CE). However, the SMAT-CE software is still being tested by U.S. EPA and has not yet been released to the public. Accordingly, LADCO relied on the MATS software (v2.6.1), which is readily available.

LADCO has used the MATS software according to U.S. EPA's recommended approach (U.S. EPA, 2014B). All modeling results are time shifted to local time to be consistent with monitoring measurements. Table 4.4 summarizes the results of the modeling attainment test for the 2021 future year that includes ERTAC EGU and the updated MOVES emissions prepared by Ramboll-Environ. Projected $PM_{2.5}$ annual design values for 2021 for monitoring sites in Cuyahoga and Lorain counties are compared to the corresponding values in the baseline 2011 period. It should be noted that the modeled

[2] Available at http://www.epa.gov/scram001/modelingapps_mats.htm

Table 4.4. Projected $PM_{2.5}$ Design Values ($\mu g/m^3$) for 2021

Monitor ID	County	2011 Baseline Design Value	2021 Projected Design Value
390350034	Cuyahoga	10.02	8.07
390350038	Cuyahoga	12.82	10.69
390350045	Cuyahoga	11.99	9.84
390350060	Cuyahoga	12.79	10.45
390350065	Cuyahoga	12.49	10.32
390351002	Cuyahoga	10.36	8.41
390933002	Lorain	9.64	8.08

attainment test calculates the 2011 design value differently than the method used for calculating the monitored design values shown previously in Table 2.1 (which are 3-year averages). U.S. EPA's MATS software calculates the baseline 2011 design value by averaging 3 successive 3-year design values centered on 2011 (2009-2011, 2010-2012, 2011-2013). The 2011 design values shown in Table 4.4 are therefore weighted averages using ambient data from 2009-2013 at each location (Abt Associates, 2014).

As shown in Table 4.4, all monitoring locations in the Cleveland $PM_{2.5}$ nonattainment area are projected to meet the level of the 2012 $PM_{2.5}$ NAAQS (12.0 $\mu g/m^3$) by 2021.

Weight of Evidence

U.S. EPA (2014B) recommends accompanying all modeling attainment demonstrations with additional supplemental analysis. Supplemental analysis can be used to support conclusions or provide information contrary to the model test. The following weight of evidence analyses is provided to support the conclusion that the Cleveland area will meet the $PM_{2.5}$ NAAQS by 2021.

- The ERTAC EGU Projection Tool is conservative

The ERTAC EGU Projection Tool is conservative, and by design will overestimate future year EGU emissions. As described previously, the ERTAC tool does not use an economics model to forecast future utilization of generating units beyond the forecasts provided by EIA. Economics models attempt to anticipate responses in this sector to future regulatory mandates (such as the Clean Power Plan, and the CSAPR Update Rule) or anticipated fuel prices (especially future prices of natural gas). As a result, economics models, including U.S. EPA's Integrated Planning Model (IPM), predict future controls, unit shutdowns and fuel conversions that may or may not occur. Figure 4.14 depicts projected EGU utilization (heat input) for coal-fired power plants in Ohio, Indiana, and Michigan that were projected to shut down in 2017 by IPM but are projected by ERTAC to be still be in operation. The ERTAC EGU Projection Tool only incorporates new controls, unit shutdowns and fuel conversions that have been

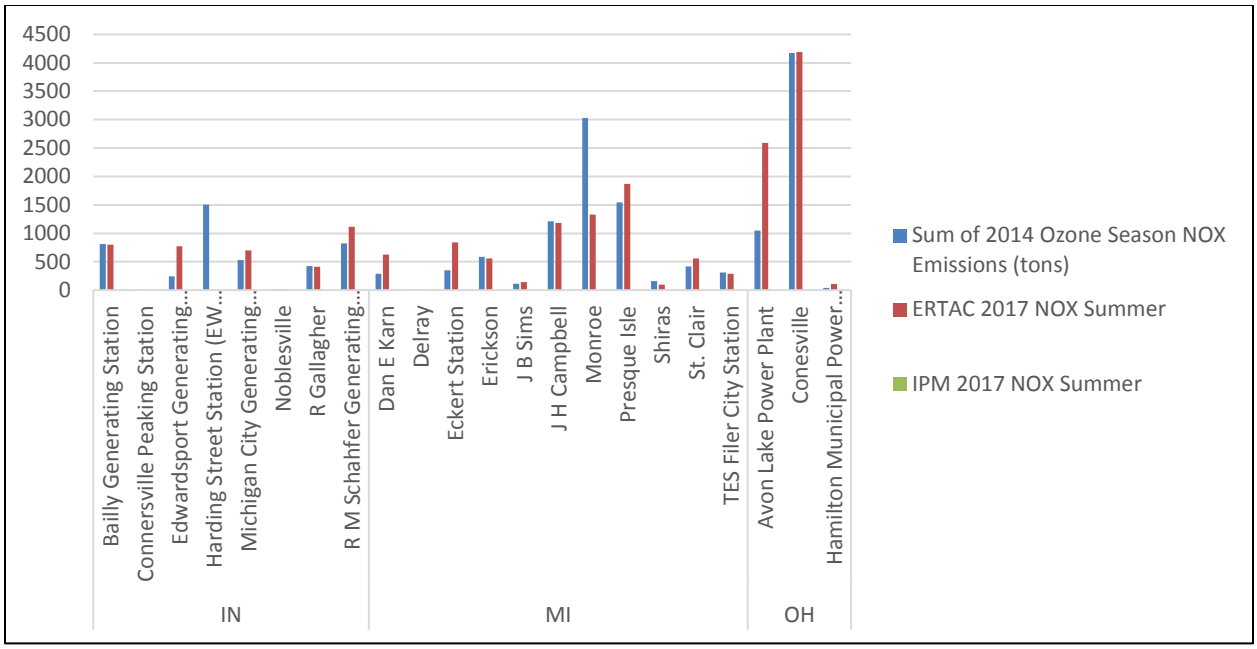

Figure 4.14. Coal Utilization (heat input) Projected by the ERTAC EGU Projection Tool for Power Plants in Ohio, Indiana, and Michigan that IPM Projects to be Shut Down by 2017.

identified by the states based on enforceable commitments made by the utilities, and is therefore more conservative than economics models that are anticipating the effects of future regulatory requirements and fuel prices.

As mentioned above, the ERTAC EGU Projection Tool only incorporates new controls, unit shutdowns and fuel conversions that have been identified by the states based on enforceable commitments made by the utilities. As a result, emissions projections from the ERTAC EGU Projection Tool are consistently higher than those provided by economics-based models, such as IPM. Figure 4.15 illustrates these differences for the year 2017, the most recent year for which emissions projections were available from both models. As shown, SO_2 and NO_X emission projections are consistently higher from ERTAC than from IPM for virtually every state in the region. It follows then the air quality modeling using emissions projected by the ERTAC EGU Projection Tool will be more conservative than modeling based on emissions derived from IPM.

- EIA's forecasts overestimate coal utilization

As mentioned previously, the ERTAC EGU Projection Tool bases projected generation by fuel type on the Annual Energy Outlook (AEO) forecasts provide by EIA. However, EIA's forecasts have historically overestimated the amount of coal expected to be used for generating electricity in future years. Figure 4.16 compares EIA's AEO projections for successive years beginning in 2008. As shown in the figure, EIA has lowered its coal

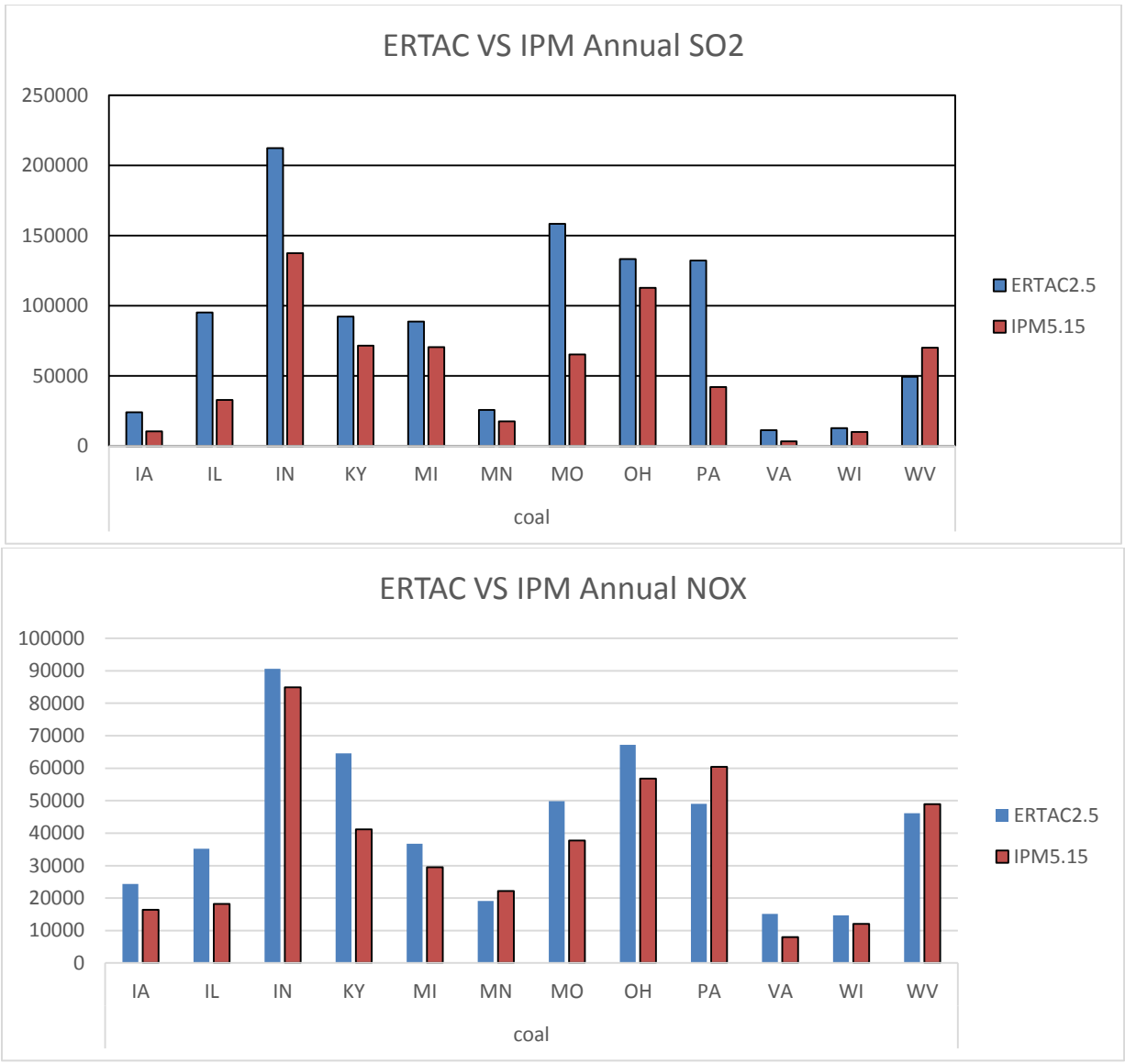

Figure 4.15. Comparison of ERTAC and IPM Emissions (tons per year) in 2017 for SO_2 (top) and NO_X (bottom).

generation forecast each year to account for decreases in coal utilization that actually occurred (shown in solid blue line). Given this inherent bias in EIA's projections, and considering that the EIA's projection used in this analysis does not consider U.S. EPA's Clean Power Plan, it is likely that the current EIA projection of coal-based electric generation will overestimate coal use in future years. Since the ERTAC EGU Projection Tool incorporates the EIA projection, it follows that projected SO_2 and NO_X EGU emissions based on this forecast will be conservative.

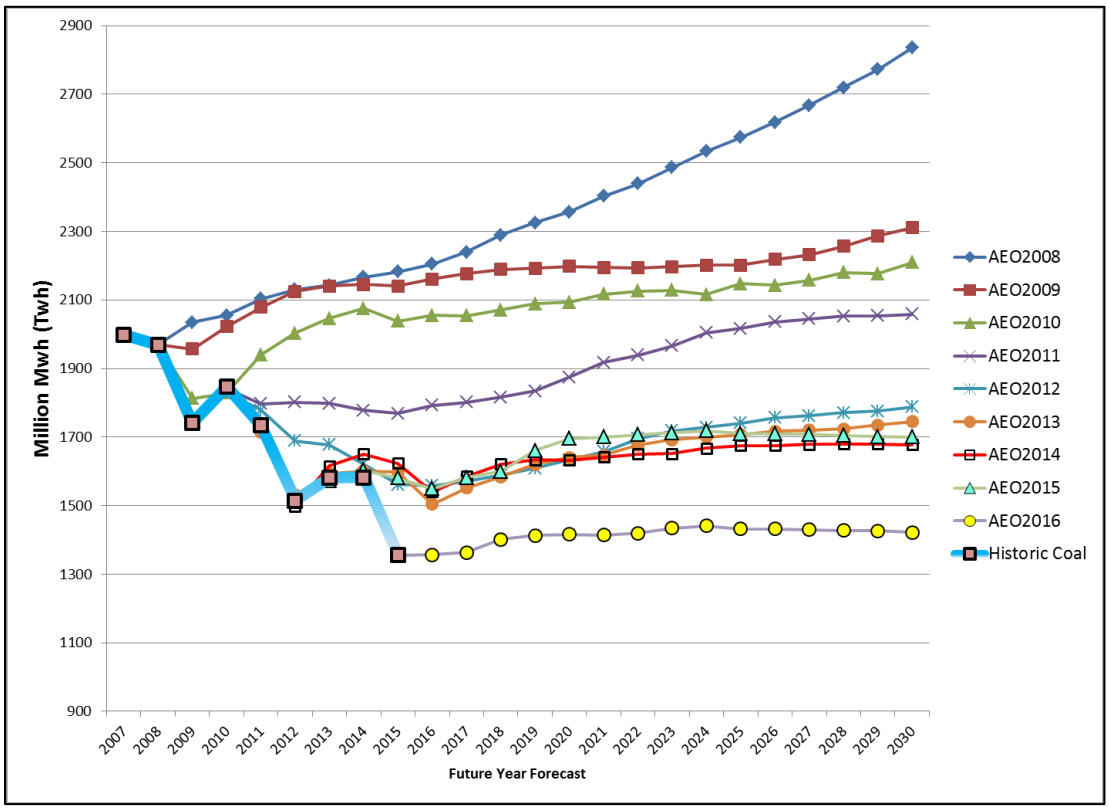

Figure 4.16. Downward Trend in U.S. Coal Net Generation Forecasts from EIA, 2008-2016.

- U.S. EPA's modeling for 2017 showed that Cleveland is expected to attain before 2021

U.S. EPA conducted modeling in 2015 in support of regulatory initiatives regarding the revised ozone NAAQS and interstate transport. (EPA, 2015A) As shown previously in Table 3.3, U.S. EPA's modeling indicates the likelihood that the Cleveland area will attain the $PM_{2.5}$ NAAQS well before the attainment deadline in 2021.

- LADCO's modeling for 2021 shows that Cleveland's design value will be significantly lower than the NAAQS in 2021.

The highest predicted 2021 design value for the area is 10.69 $\mu g/m^3$, nearly 11% lower than the 12.0 $\mu g/m^3$ standard. Current on the books controls are sufficient to achieve greater than the NAAQS for this area.

- Emission reductions needed to attain the SO_2 NAAQS have not been included

Emission reductions that may be needed to attain the SO_2 NAAQS have not been included in this analysis, although several facilities in this area are actively working with

Ohio to implement SO_2 reduction strategies that will occur in early 2017. However, due to the timing of this analysis and the fact these strategies were not yet enforceable commitments, they were not accounted for in the future year modeling.

- Emission reductions from Ohio's Diesel Emissions Reduction Grant (DERG) program were not included.

Ohio EPA in partnership with the Ohio Department of Transportation (ODOT) just completed the 6th round of the Diesel Emissions Reduction Grant (DERG) program. The DERG Program is designed to assist successful applicants with funding to replace older diesel powered mobile source equipment with newer (less polluting) powered equipment. The program targets public agency owned diesel engine fleets and privately owned diesel engine fleets with a public sponsor (public-private partnerships) that will undertake vehicle/equipment replacement, repower, retrofit, or installation of anti-idle equipment for the purpose of PM2.5 (and precursor) emissions reduction. The DERG Program awards up to $15 million (per grant cycle) in Federal Highway Congestion Mitigation and Air Quality (CMAQ) funding for clean diesel projects in Ohio. Ohio has been guaranteed $12 million in 2016, $10 million in 2017 and $10 million in 2018 and anticipates the program to continue beyond 2018.

- Emission reductions from Ohio's Clean Diesel School Bus Retrofit Grant program were not included.

Ohio EPA provides grants through the Ohio's Clean Diesel School Bus Retrofit Grant Program. The program ran from 2006 to early 2016 and provided grants to retrofit existing school buses with devices that reduce emissions, reduce school bus idling and provides assistance funding to Ohio school districts for successful approaches to reducing bus pollution. Projects in counties that have been in nonattainment for the PM2.5 NAAQS, including Cuyahoga and Lorain counties, were given priority. Ohio Clean Diesel School Bus grants totaling more than $8.5 million were awarded across the State during this period to 179 school districts and county developmental disability programs to install emission control equipment on 2,633 school buses, and idle reduction equipment on 1,036 buses.

- Emission reductions from Ohio's Alternative Fuel Vehicle Conversion program were not included.

In June, 2016, The Ohio General Assembly re-assigned $5 million in State funds for a one-time Alternative Fuel Vehicle Conversion grant program to assist commercial fleets in retrofitting or replacing class 7 and 8 diesel vehicles (greater than 26,000 pounds) to run on natural gas or propane. The funds come from an Ohio Facilities Establishment Fund that has been used previously to support advanced energy research and development. Ohio expects to award the entire $5 million before June 20, 2017.

- Emission reductions from Ohio's Stage II removal and low permeable hose requirements were not included.

On April 29, 2013, Ohio submitted a SIP revision request to remove all Stage II controls from gasoline dispensing stations in the Cleveland area ozone counties, which includes Cuyahoga and Lorain counties. Removal of Stage II requires the installation of low permeable hoses to be phased in completely by January 1, 2017. U.S. EPA proposed to approve this SIP revision on June 30, 2016. In Ohio's analysis the following VOC benefits were found:

Cuyahoga County: In 2017, retaining Stage II controls would have increased VOC emissions by 7.14 tons during the ozone season and installation of low permeable hoses would decrease VOC by 9.29 tons during the ozone season. Therefore, a net benefit of 16.43 tons of VOC is realized beginning in 2017.

Lorain County: In 2017, retaining Stage II controls would have increased VOC emissions by 1.84 tons during the ozone season and installation of low permeable hoses would decrease VOC by 2.34 tons during the ozone season. Therefore, a net benefit of 4.18 tons of VOC is realized beginning in 2017.

- Certain shutdowns and restrictions that have (or will) occurred since development of the attainment modeling are not included.

A shutdown and restrictions at two coal burning facilities have occurred, or will occur, since the 2011 base year and were not included in the projected modeling due to timing of commitments. In Lorain County, the Avon Lake Power Plant will be accepting federally enforceable restrictions to address the SO2 NAAQS. Avon Lake will be accepting a pound per hour facility-wide emission limit that models attainment for the 2010 SO2 NAAQS. In addition, one of the coal fired boilers will be accepting a 10% limited use provision (also addresses the major source boiler NESHAP) and the remaining large boilers will be accepting more stringent SO_2 emission limitations. Emissions in 2011 were 32,041 tpy for SO2, 4,659 tpy for NOx and 394 tpy for PM2.5. Projections to 2021 for Avon Lake were 34,870 tpy for SO_2, 5,069 tpy for NOx and 385 tpy for PM2.5. It is expected that there will be substantial reduction in SO2 emissions in the future. Compliance is required by January 13, 2017. In addition, Oberlin College shut down it coal fired boilers in 2014. Emissions in 2011 were 325 tpy for SO2, 38 tpy for NOx and 3 tpy for PM2.5. Projections to 2021 for Oberlin College were 230 tpy for SO_2, 30 tpy for NOx and 3 tpy for PM2.5.

- Ohio's NOx RACT regulations are not included for reductions after 2011.

OAC Chapter 3745-110[2] are performance based NOx regulations for nine counties in the Cleveland area 1997 ozone nonattainment area (including Cuyahoga and Lorain) that became effective in 2007. The rules are not a part of Ohio's SIP and Ohio does not

[2] http://www.epa.ohio.gov/dapc/regs/3745_110.aspx

take credit in any SIP's for projected reductions[3]. The rules set NOx emission limits which must be met, and allow regulated sources to determine the methods by which they will meet the limits.

- Ohio is working to mitigate local impacts from companies near the monitors.

Ohio EPA has been in close communication with significant local point sources in the area of the violating monitors. These monitors are located in the industrialized core of Cleveland, which contains a complex array of emission sources. There are several large industrial sources, including steel plants, in this area. Some of these sources (e.g., ArcelorMittal Steel and Charter Steel) have recently been cited for violations.

Precursor Analysis for Attainment Planning Purposes

The potential impact of applying reasonable available control technologies (RACT), reasonable available control measures (RACM), additional reasonable measures, or other control measures on sources was estimated with across the board reductions in anthropogenic NH_3 or VOC emissions within the nonattainment counties. Implementation of RACT and RACM is expected no later than 4 years after nonattainment designation while implementation of additional reasonable measures is expected between the 4^{th} and 6^{th} year of designation (EPA, 2016B). Therefore Ohio RACT and RACM, if required, would be implemented by December 2018 and additional reasonable measures would be implemented by December 2020. The impact of these potential control measures was modeled with perturbations to the future projection year of 2021 because 2021 is more representative of 2018 and 2020 conditions than the base year 2011.

LADCO examined the degree to which concentrations in the nonattainment area are sensitive to decreases of a precursor by reducing anthropogenic emissions of NH_3 or VOC within the nonattainment counties by 40%. The modeling represents a conservative estimate of the reductions possible through control measures. The results of the 2021 sensitivities analysis for attainment planning purposes are shown in Table 4.5.

The modeled $PM_{2.5}$ impacts from the NH_3 and VOC sensitivity reductions within the nonattainment counties does not exceed the significance level of 0.2 $\mu g/m^3$ selected by Ohio EPA in consultation with U.S. EPA Region 5. Therefore, the potential impact of additional control measures for NH_3 and VOC are found to be insignificant.

[3] Any sources that realized reduction in their actual emissions due to a requirement in these rules would be accounted for in the 2011 inventory.

Table 4.5. Change in 2021 MATS Projected Annual $PM_{2.5}$ Design Values from Attainment Planning Sensitivity Analysis.

Monitor ID	County	NH_3 ($\mu g/m^3$)	VOC ($\mu g/m^3$)
390350034	Cuyahoga	-0.15	0.00
390350038	Cuyahoga	-0.21	-0.01
390350045	Cuyahoga	-0.20	0.00
390350060	Cuyahoga	-0.18	0.00
390350065	Cuyahoga	-0.20	0.00
390351002	Cuyahoga	-0.16	0.00
390933002	Lorain	-0.10	0.00

Precursor Analysis for NNSR Purposes

The impact of potential new major stationary sources within the nonattainment counties is estimated to examine if a particular precursor contributes significantly to levels that exceed the $PM_{2.5}$ standard, meaning that the precursor can be excluded from control requirements for major sources and from NNSR permitting. Emission scenarios considering a high-growth economy and a reasonable extension of typical major sources that are already in the nonattainment counties are analyzed with the modeling platform.

For the insignificance test, U.S. EPA recommends making adjustments to the base year emissions. However, LADCO and Ohio EPA determined adjustment to the attainment year inventory would be more appropriate, accurate, and conservative due to significant changes that have occurred to the base year emissions since 2011. 2021 emissions better represent current emissions within Cuyahoga and Lorain counties due to, for example, shutdown of EGUs and a significant number of conversions to natural gas at coal fired non-EGUs. Changes from potential new major sources are better represented with changes to 2021 emissions than altering the 2011 base case.

Both new sources and an expansion of certain existing sources were added to the 2021 baseline modeling as point sources in grid cells centers designed to release emissions within the ground layer so they are well mixed within a grid cell. The emission rates and locations determined by Ohio EPA for NH_3 and VOC are shown in Figures 4.17 and 4.18, respectively. The emissions rates for existing sources are in addition to those rates already predicted for 2021 based upon growth and control.

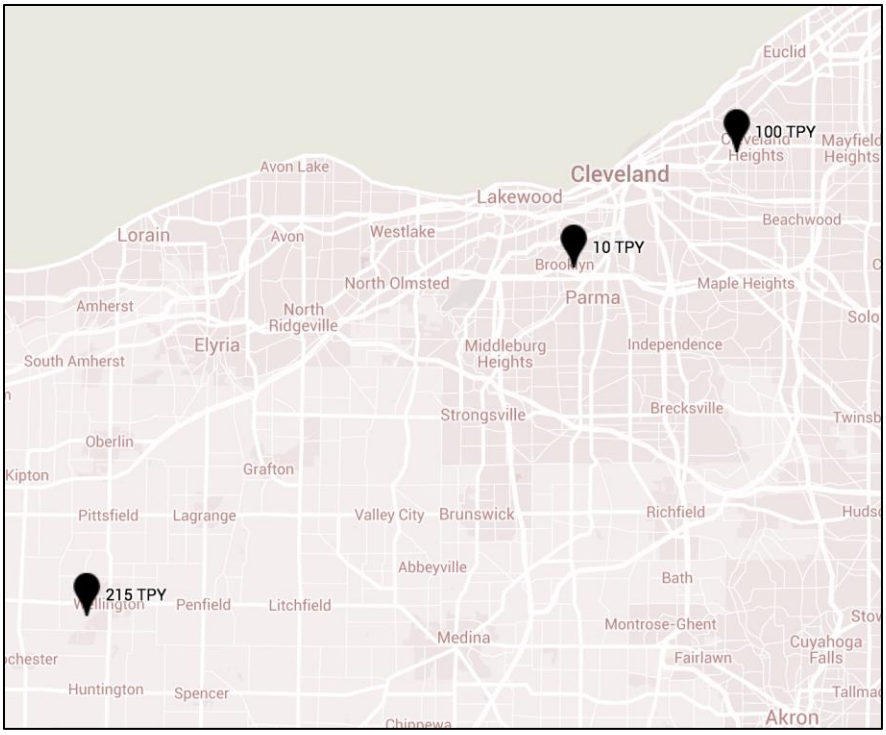

Figure 4.17. Map of NH_3 Point Sources Showing Location and Magnitude of Emissions

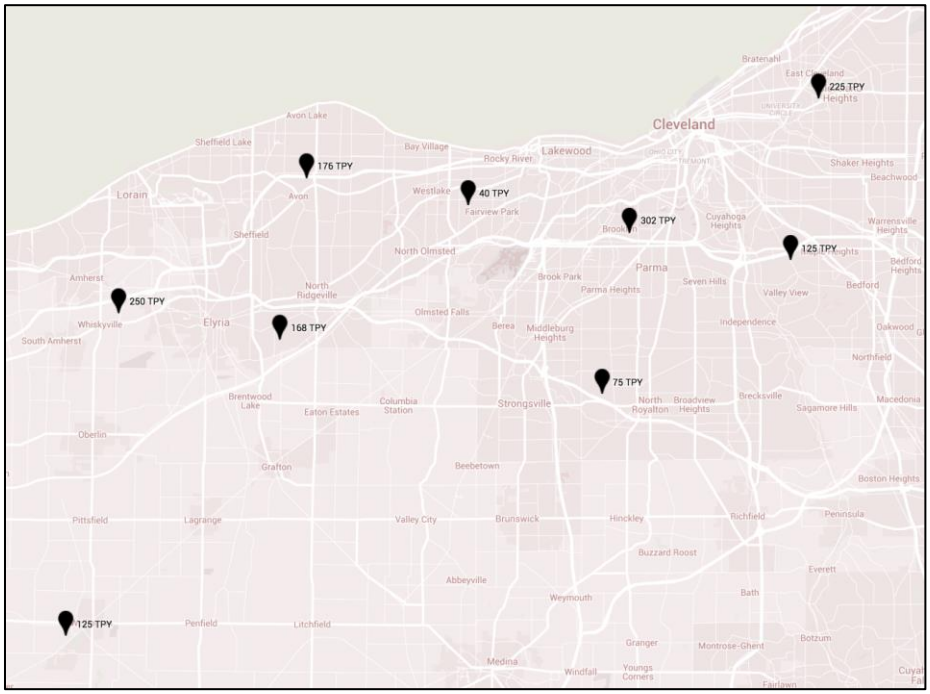

Figure 4.18. Map of VOC Point Sources Showing Location and Magnitude of Emissions

In total, the VOC NNSR sensitivity adds 1486 TPY of VOC and the NH_3 NNSR sensitivity adds 325 TPY of NH_3. Emission rates are assumed to be constant. An average VOC profile of Ohio non-EGU point sources is used for NNSR VOC sources, as shown in Figure 4.19.

The modeled impact of the NNSR sources to monitors in the NAA is shown in Table 4.6. The potential impact of the NNSR sources is also examined for the 2-county NAA using a gradient-adjusted unmonitored area analysis. The expected change in $PM_{2.5}$ concentrations in 2021 resulting from the unmonitored area analysis are shown in Figures 4.20 and 4.21 for NH3 and VOC, respectively.

The peak impacts of the interpolated fused surface analysis for the Ohio NNSR NH_3 and VOC sources are 0.08 and 0.02 µg/m^3, respectively. These peak impacts are less than the significance level of 0.2 ug/m3 Ohio EPA selected in consultation with U.S. EPA Region 5, and are therefore considered to be insignificant.

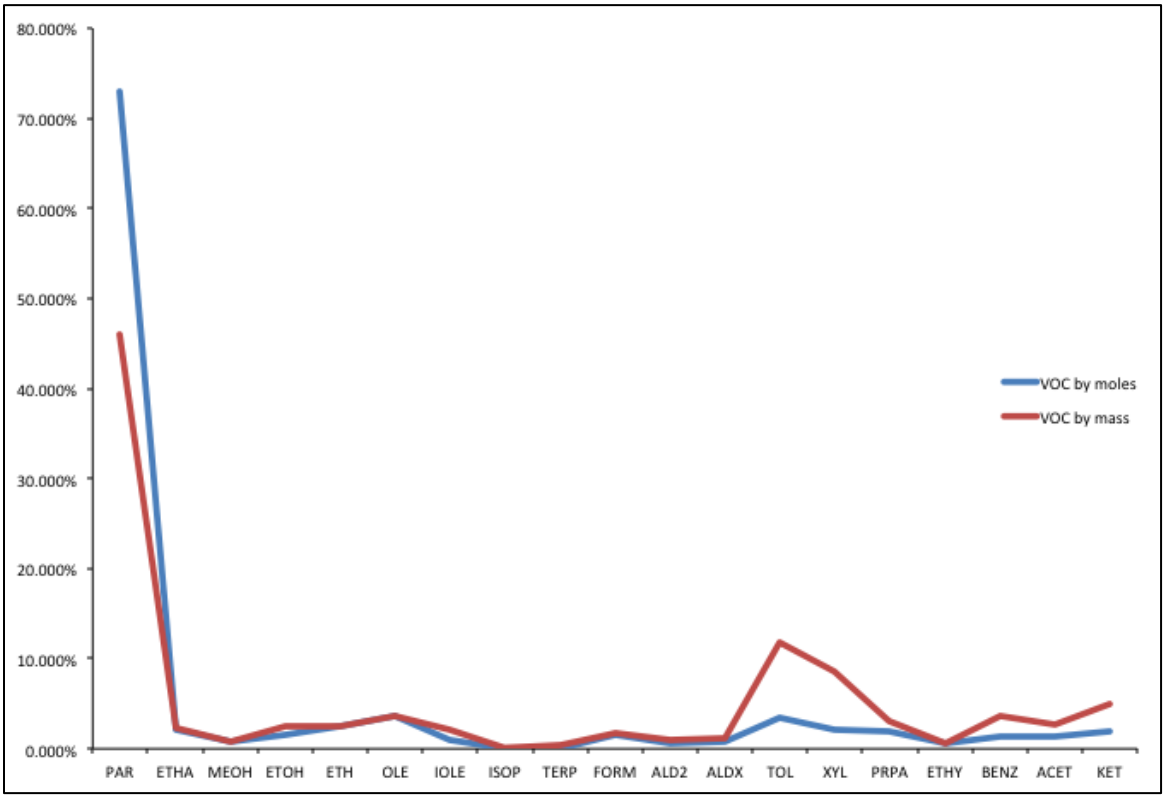

Figure 4.19. VOC Profile Used for VOC NNSR Sensitivities.

Table 4.6. Change in 2021 MATS Projected Annual $PM_{2.5}$ Design Values from Assumed NNSR Sources.

Monitor ID	County	NNSR NH_3 Sources	NNSR VOC Sources
390350034	Cuyahoga	0.04	0.00
390350038	Cuyahoga	0.04	0.00
390350045	Cuyahoga	0.04	0.01
390350060	Cuyahoga	0.03	0.00
390350065	Cuyahoga	0.04	0.00
390351002	Cuyahoga	0.03	0.00
390933002	Lorain	0.03	0.01

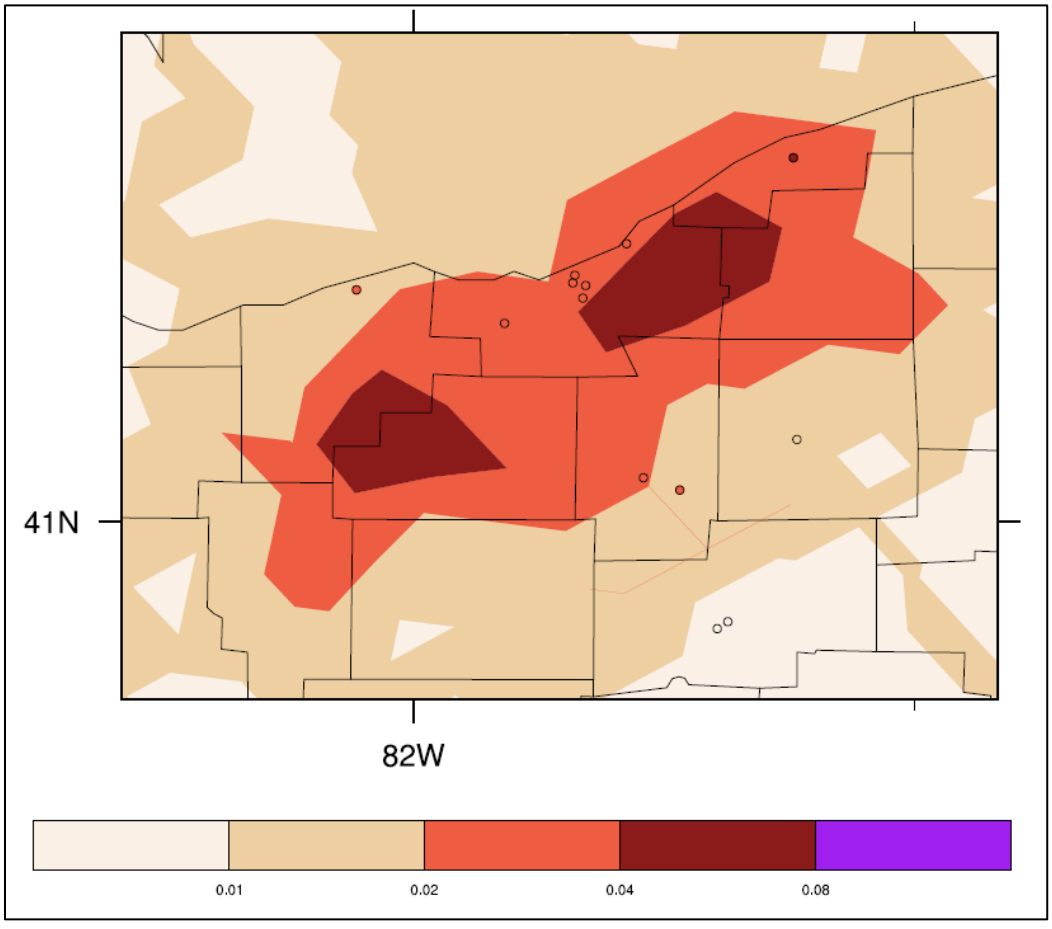

Figure 4.20. Unmonitored Area Analysis Showing the Change in $PM_{2.5}$ Concentrations from Ohio NNSR runs of NH3 Point Sources ($\mu g/m^3$).

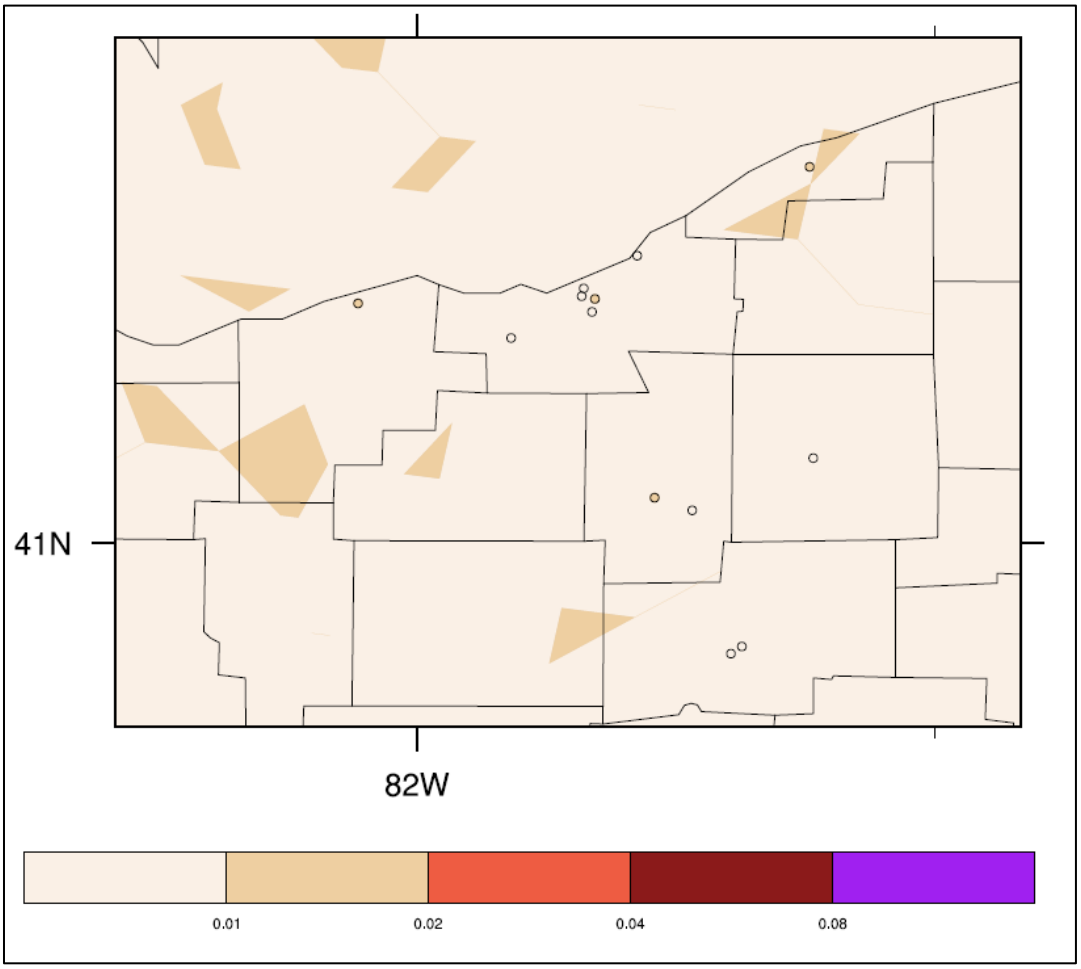

Figure 4.21. Unmonitored Area Analysis Showing the Change in $PM_{2.5}$ Concentrations from Ohio NNSR Runs of VOC Point Sources ($\mu g/m^3$).

5.0 Summary

On December 18, 2014, the U.S. EPA established final air quality designations for the 2012 $PM_{2.5}$ NAAQS, identifying as ‘‘nonattainment’’ those areas that were violating the NAAQS based on air quality monitoring data from 2011 to 2013, or those areas that were considered to be contributing to a violation of the NAAQS in a nearby area. In this action, U.S. EPA designated the Cleveland area, including all of Cuyahoga and Lorain counties in Ohio, as a “moderate” $PM_{2.5}$ nonattainment area with an attainment deadline of 2021. The nonattainment area designation triggered the requirement for the State of Ohio to develop and submit to U.S. EPA a State Implementation Plan (SIP), due on October 15, 2016, that identifies emissions reduction strategies sufficient to achieve the NAAQS by the attainment date.

LADCO, in cooperation with the Ohio EPA, developed air quality analyses to support the development of Ohio’s attainment SIP for $PM_{2.5}$. The analyses includes preparation of regional emissions inventories and meteorological data, evaluation and application of regional chemical transport models, and collection and analysis of ambient monitoring data. The technical analyses described in this report are conducted in a manner that is consistent with U.S. EPA’s guidance (U.S. EPA, 2014B).

Monitoring data are analyzed to produce a conceptual understanding of the air quality problems. Key findings of the analyses include:

- Current monitoring data (2013-2015) show 2 monitoring sites in the Cleveland area that violate the annual $PM_{2.5}$ standard of 12.0 $\mu g/m^3$. Nonattainment sites are characterized by an elevated regional background (about 10 $\mu g/m^3$) and a local (urban) increment (about 2 – 3 $\mu g/m^3$).

- Historical $PM_{2.5}$ data show a significant downward trend since deployment of the $PM_{2.5}$ monitoring network in 1999.

- On an annual average basis, $PM_{2.5}$ chemical composition consists mostly of sulfate, nitrate, and organic carbon in similar proportions. Elemental carbon and crustal components are also important components of $PM_{2.5}$ mass in Cleveland.

Air quality models are applied to evaluate the adequacy of identified emissions reduction strategies to demonstrate attainment of the 2012 $PM_{2.5}$ NAAQS by the 2021 attainment deadline established by U.S. EPA. LADCO conducted “base year” modeling of 2011. Model performance for speciated and total $PM_{2.5}$ was found to be generally acceptable and an improvement over previous modeling efforts, hence the modeling platform is deemed appropriate for use in examining control strategies.

Future year strategy modeling is conducted to determine whether existing “on the books” controls are sufficient to ensure attainment of the 2012 $PM_{2.5}$ NAAQS and if not, then what additional emission reductions would be necessary for attainment. Based on

the modeling and other supplemental analyses, the following general conclusions can be made:

- Existing controls are expected to produce significant improvement in $PM_{2.5}$ concentrations between 2011 and 2021.

- Modeling demonstrates that all monitoring sites in Cleveland are expected to meet the 2012 $PM_{2.5}$ standard by the applicable attainment date, 2021.

- Modeled impacts from NH_3 and VOC point sources within the Cleveland NAA potentially subject to NNSR are found to be insignficant for annual $PM_{2.5}$.

- Modeled reductions of control measures for attainment planning purposes for NH_3 and VOC within the Cleveland NAA are found to be insignificant for annual $PM_{2.5}$.

References

Abt Associates, 2014. Modeled Attainment Test Software: User's Manual. Available at: https://www3.epa.gov/ttn/scram/guidance/guide/MATS_2-6-1_manual.pdf

Baker, K., Scheff, P., 2007. Photochemical Model Performance for $PM_{2.5}$ Sulfate, Nitrate, Ammonium, and Precursor Species SO_2 , HNO_3, and NH_3 at Background Monitor Locations in the Central and Eastern United States. Atmospheric Environment, 41, 6185- 6195.

Blanchard, C.L., Tanenbaum, S., 2005. "Analysis of Data from the Midwest Ammonia Monitoring Project", Draft Final Technical Memorandum, March 31, 2005.

Colella, P., Woodward, P.R., 1984. The Piecewise Parabolic Method (PPM) for Gas-dynamical Simulations. J. Comp. Phys., 54, 174-201.

Ramboll-Environ, 2014. "Task 2 MOVES and SMOKE Input Data Evaluation", Technical Memorandum, February 20, 2014.

Ramboll-Environ, 2015. User's Guide Comprehensive Air Quality Model with Extensions Version 6.2. Available at http://www.camx.com/files/camxusersguide_v6-20.pdf

Henderson, B.H., Akhtar, F., Pye, H.O.T., Napelenok, S.L., Hutzell, W.T., 2014. A Database and Tool for Boundary Conditions for Regional Air Quality Modeling: Description and Evaluation. Geosci. Model Dev., 7, 339–360.

Hopke, P.K., 2005, Analyses of Midwest PM-Related Measurements, Report to LADCO, March 2005.

Kenski, D.M., 2004, Quantifying Transboundary Transport of $PM_{2.5}$: A GIS Analysis, Proc. AWMA 97th Annual Conf., Indianapolis, June 2004.

Poirot, R.L., Wishinski, P.R., Hopke, P.K., Polissar, A.V., 2002. Comparative Application of Multiple Receptor Methods To Identify Aerosol Sources in Northern Vermont, Environ. Sci. Technol., *36*(4), 820-820 .

Rutter, A.P., Snyder, D.C., Stone, E.A., Shelton, B., Deminter, J., Schauer, J.J., 2014. Preliminary assessment of the anthropogenic and biogenic contributions to secondary organic aerosols at the two industrial cities in the upper Midwest, Atmos. Env., 84, 307-313.

Simon, H., Baker, K.R., Phillips, S., 2012. Compilation and Interpretation of Photochemical Model Performance Statistics Published Between 2006 and 2012. Atmospheric Environment, 61, 124-139.

STI, 2006, “Integration of Results for the Upper Midwest Urban Organics Study”, Final Report, STI-903520-2942-FR, Sonoma Technology, Inc. March 31, 2006.

STI, 2008, “Data Analysis and Source Apportionment of $PM_{2.5}$ in Selected Midwestern Cities”, Final Report, STI-907018.03-3264-DRF, Sonoma Technology, Inc., February 2008

Stammer, D., Wentz, F.J., Gentemann, C.L., 2003. Validation of Microwave Sea Surface Temperature Measurements for Climate Purposes. J. Climate, 16, 73-87.

U.S. EPA, 2007. Guidance on the Use of Models and Other Analyses for Demonstrating Attainment of Air Quality Goals for Ozone, $PM_{2.5}$, and Regional Haze. Available at http://www.epa.gov/ttn/scram/guidance/guide/final-03-pm-rh-guidance.pdf

U.S. EPA, 2014A. Meteorological Model Performance for Annual 2011 WRF v3.4 Simulation. Available at http://www.epa.gov/ttn/scram/reports/MET_TSD_2011_final_11-26-14.pdf

U.S. EPA, 2014B. Draft Modeling Guidance for Demonstrating Attainment of Air Quality Goals for Ozone, $PM_{2.5}$, and Regional Haze. Available at http://www.epa.gov/ttn/scram/guidance/guide/Draft_O3-PM-RH_Modeling_Guidance-2014.pdf

U.S. EPA, 2015A. Notice of Availability of the Environmental Protection Agency’s Updated Ozone Transport Modeling Data for the 2008 Ozone National Ambient Air Quality Standard (NAAQS). Available at https://www.epa.gov/airmarkets/noda-epas-updated-ozone-transport-modeling

U.S. EPA, 2015B. Information on the Interstate Transport “Good Neighbor” Provision for the 2008 Ozone National Ambient Air Quality Standards (NAAQS) under Clean Air Act (CAA) Section 110(a)(2)(D)(i)(I). Available at http://www.epa.gov/airtransport/GoodNeighborProvision2008NAAQS.pdf

U.S. EPA, 2016A. Information on the Interstate Transport “Good Neighbor” Provision for the 2012 Fine Particulate Matter National Ambient Quality Standards under Clean Air Act Section 110(a)(2)(D)(i)(I). Available at https://www.epa.gov/sites/production/files/2016-05/documents/good-neighbor-memo_implementation.pdf

U.S. EPA, 2016B. Fine Particulate Matter National Ambient Air Quality Standards: State Implementation. Available at https://www.epa.gov/sites/production/files/2016-07/documents/pm25-naaqs-implementation-final-preamble-rule-signature.pdf

U.S. EPA, 2016C. Guidance on Significant Impact Levels for Ozone and Fine Particles in the Prevention of Significant Deterioration Permitting Program. Available at https://www.epa.gov/sites/production/files/2016-08/documents/pm2_5_sils_and_ozone_draft_guidance.pdf

Vizuete, W., Jeffries, H.E., Tesche, T.W., Olaguer, E.P., Couzo, E., 2011. Issues with Ozone Attainment Methodology for Houston, TX. J. Air Waste Manage. Assoc., 61, 238-253.

Yarwood, G., Gookyoung, H., Carter, W.P.L., Whitten, G.Z., 2012. Environmental Chamber Experiments to Evaluate NO_X Sinks and Recycling in Atmospheric Chemical Mechanisms. Final Report prepared for the Texas Air Quality Research Program, University of Texas, Austin, Texas (AQRP Project 10-042).

Zhang, L., Brook, J.R., Vet, R., 2003. A Revised Parameterization for Gaseous Dry Deposition in Air-Quality Models. Atmos. Chem. Phys., 3, 2067–2082.

Appendix A
Speciated PM2.5 Model Performance

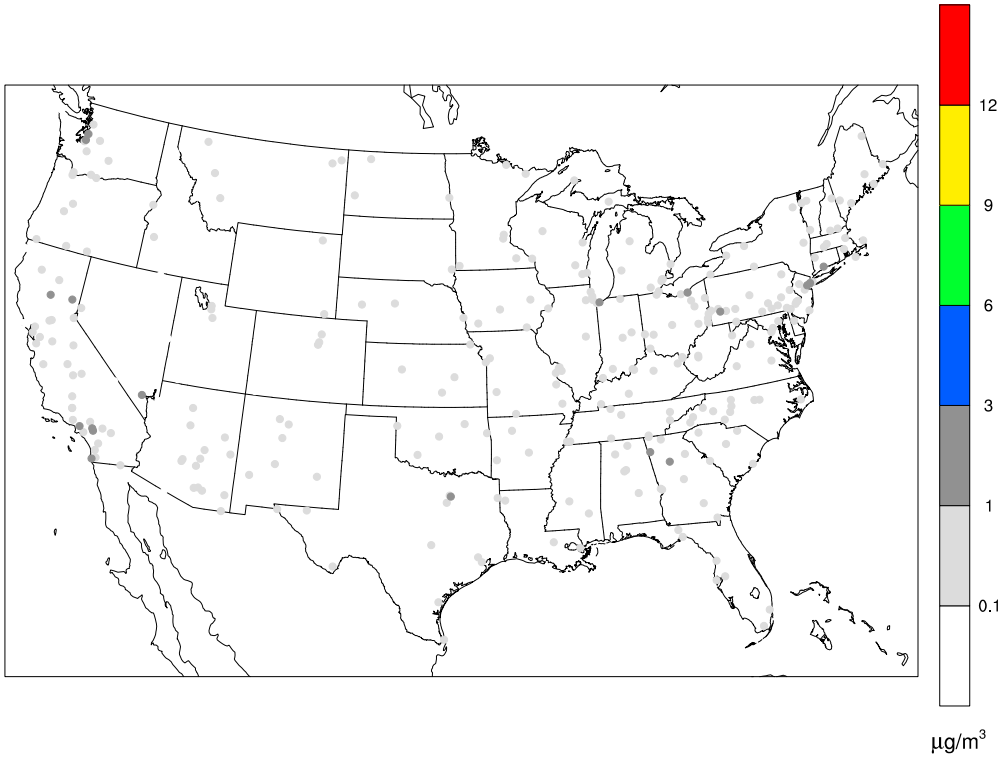

Figure A-1. 2011 mean monitored daily EC.

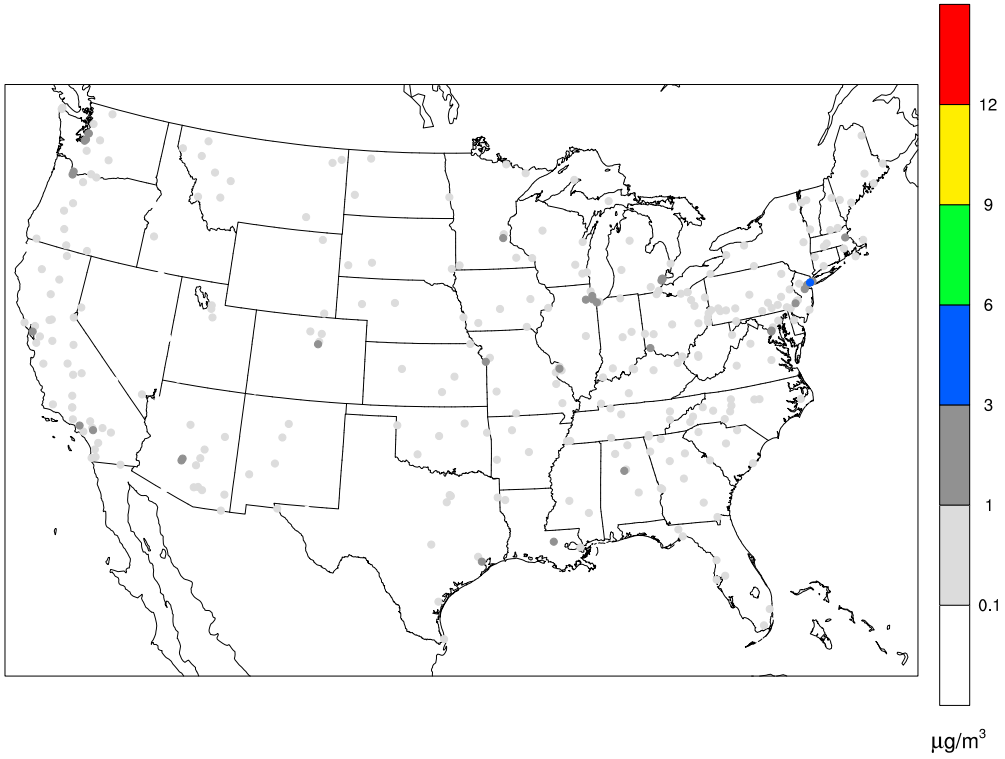

Figure A-2. 2011 mean CAMx modeled daily EC corresponding with observed days.

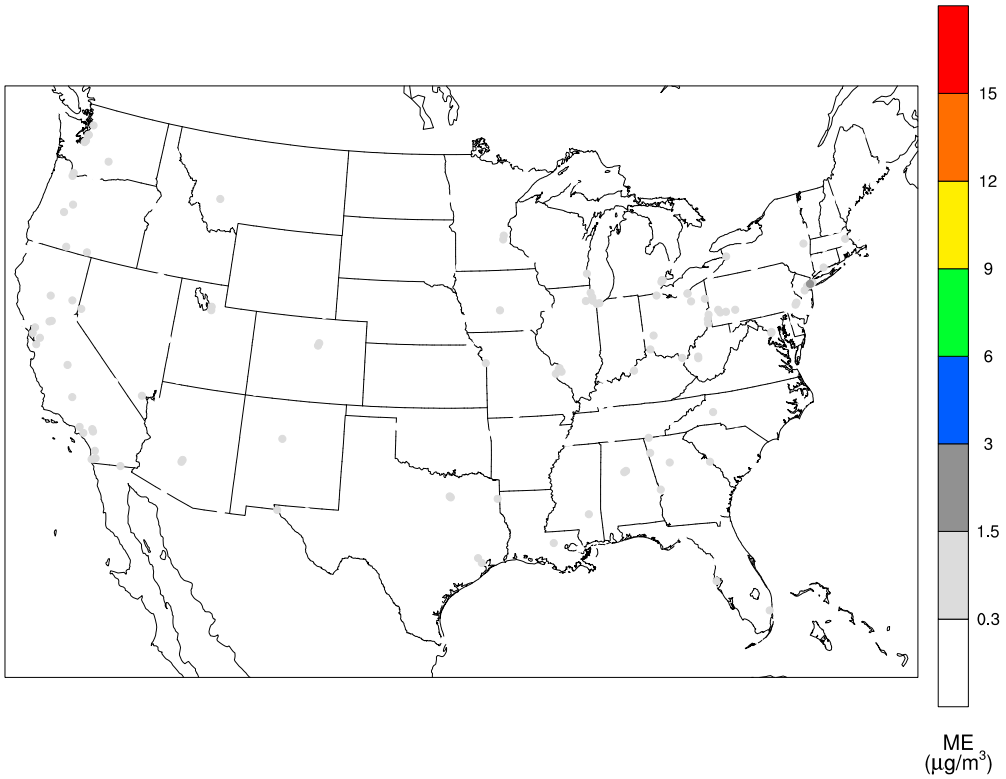

Figure A-3. 2011 mean error of EC baseline modeling.

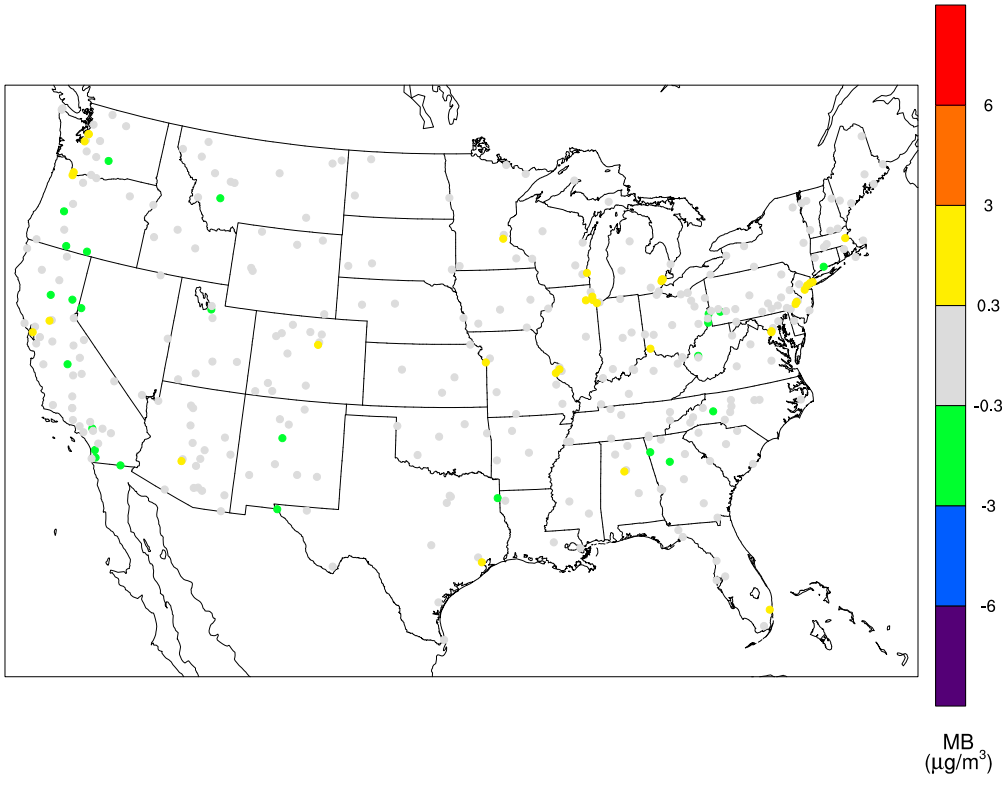

Figure A-4. 2011 mean bias of EC baseline modeling.

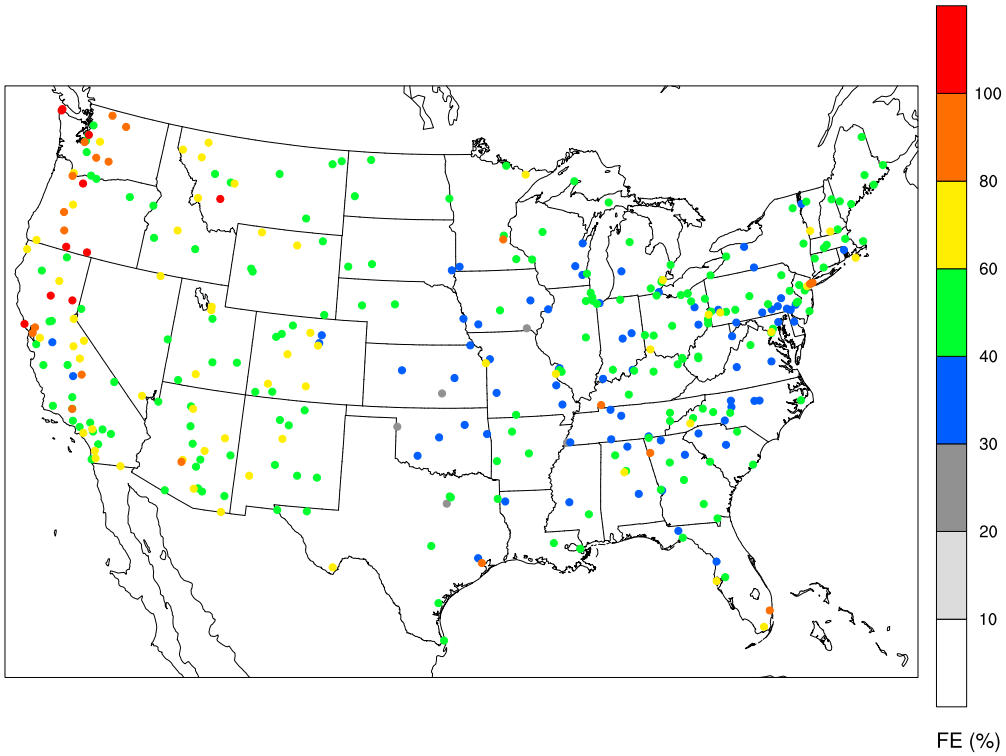

Figure A-5. 2011 mean fractional error of EC baseline modeling.

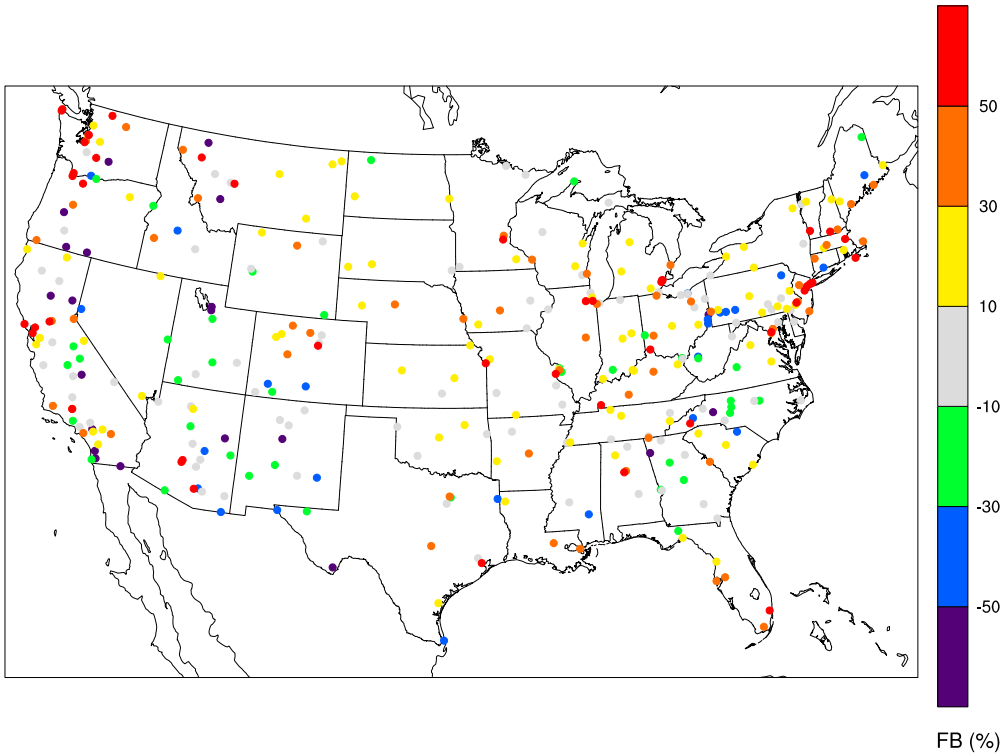

Figure A-6. 2011 mean fractional bias of EC baseline modeling.

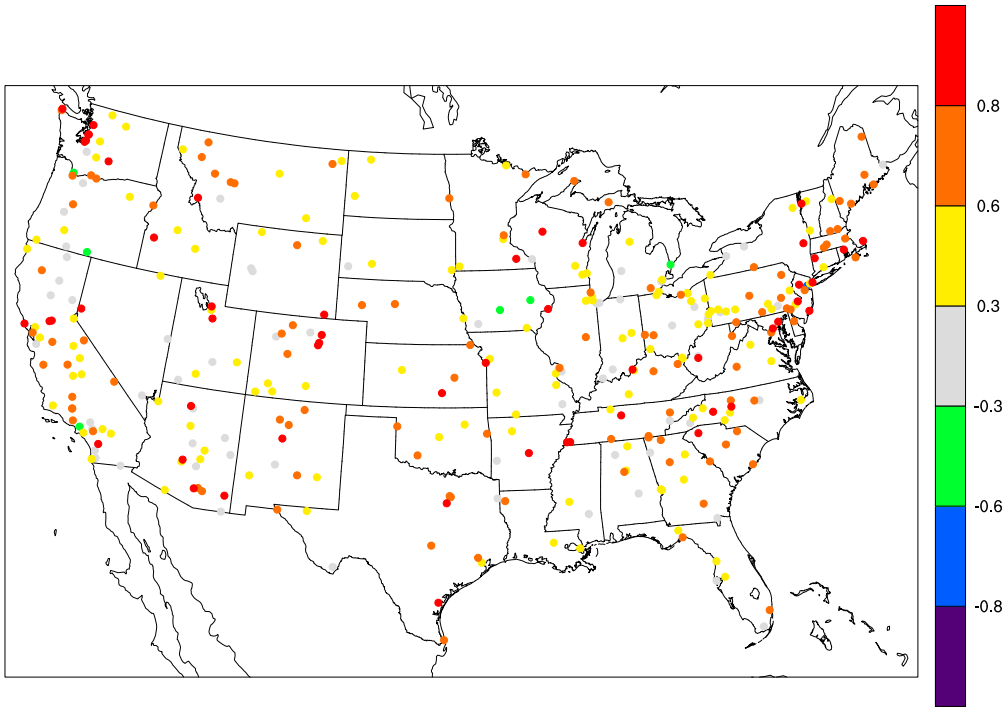

Figure A-7. 2011 Pearson correlation coefficient of EC baseline modeling.

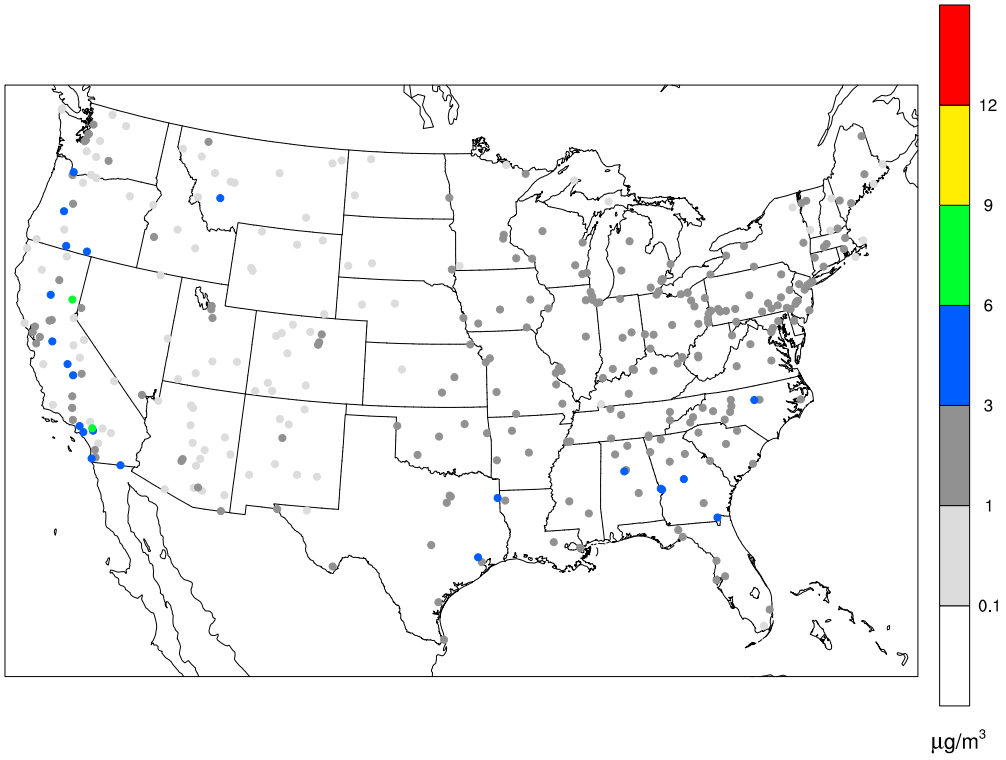

Figure A-8. 2011 mean monitored daily OC.

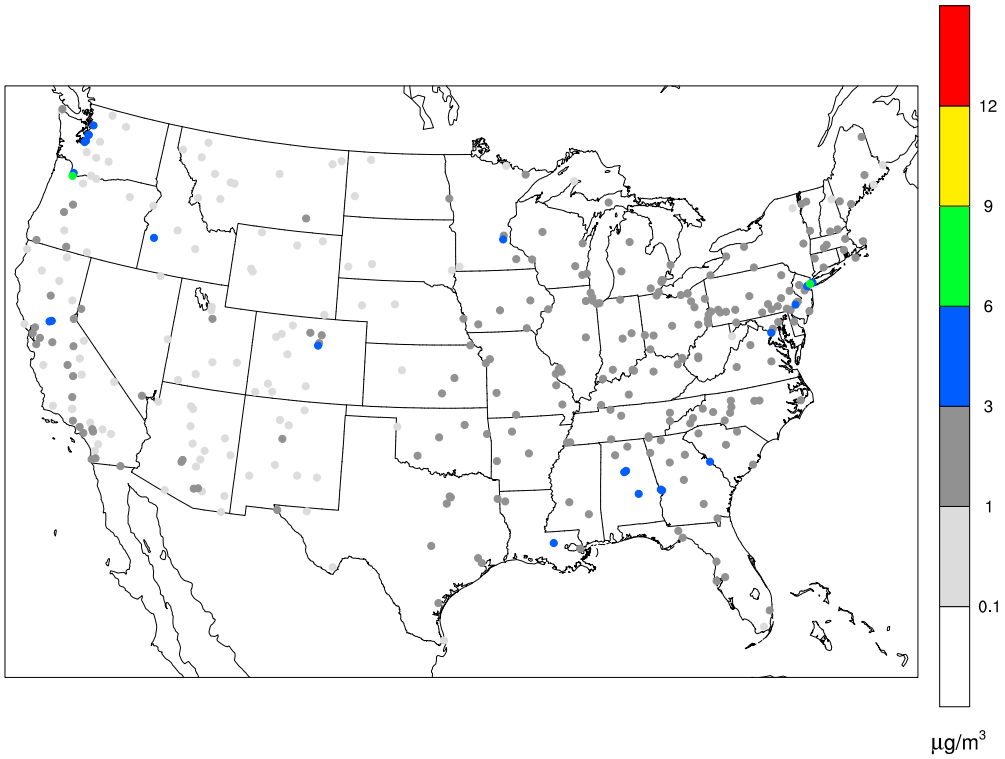

Figure A-9. 2011 mean CAMx modeled daily OC corresponding with observed days.

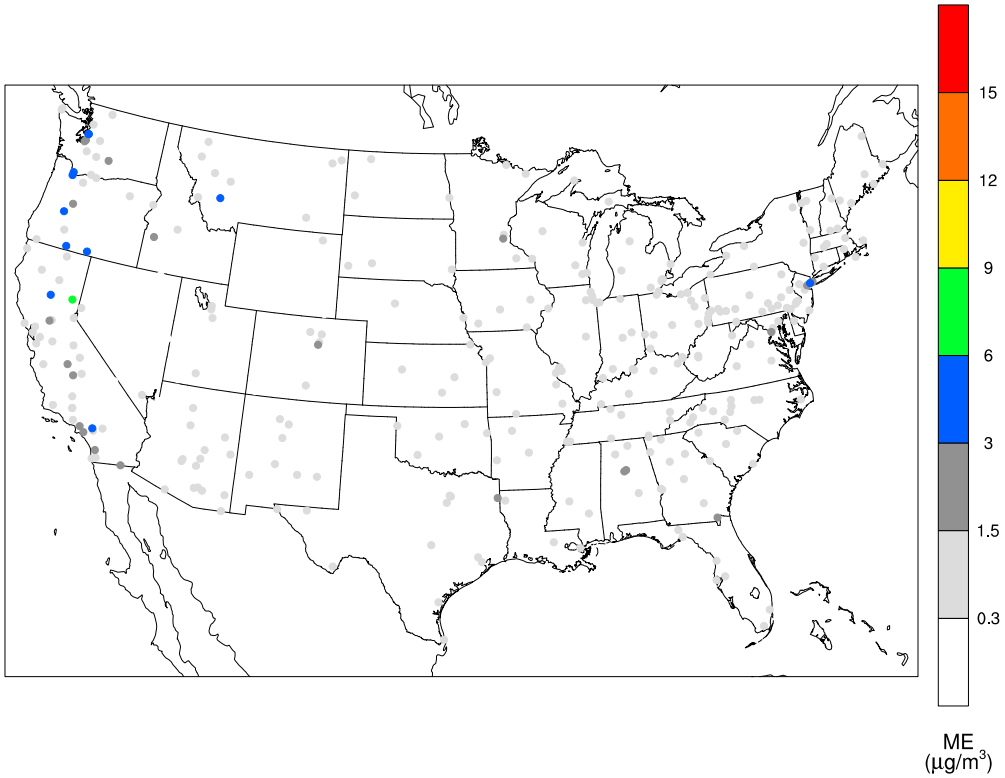

Figure A-10. 2011 mean error of OC baseline modeling.

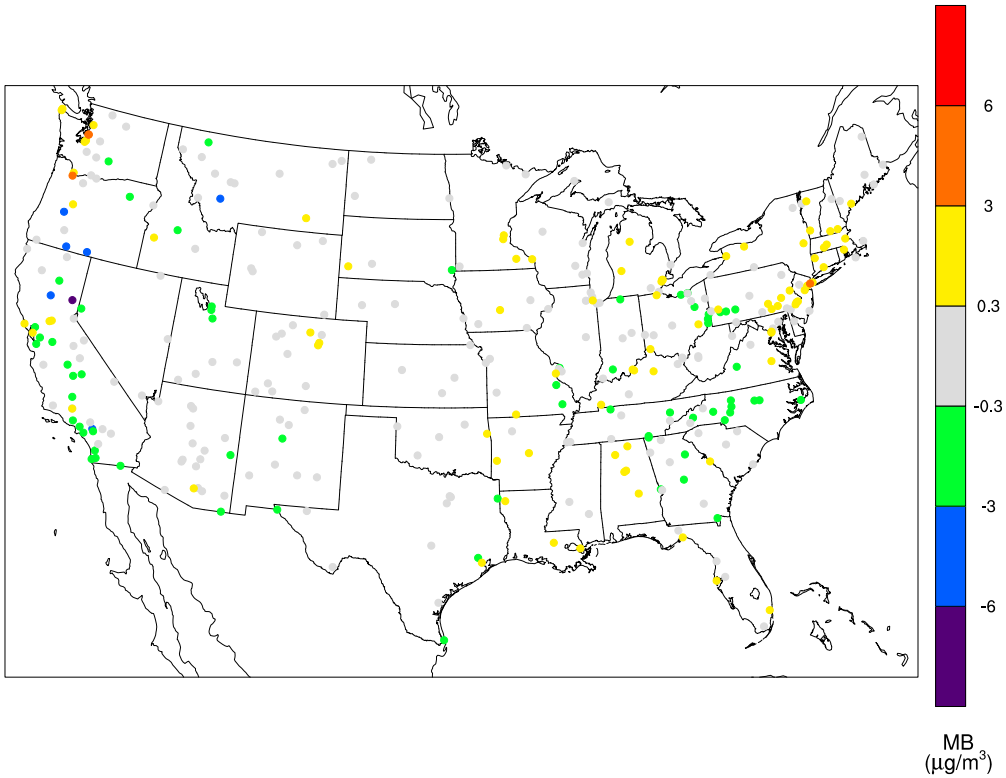

Figure A-11. 2011 mean bias of OC baseline modeling.

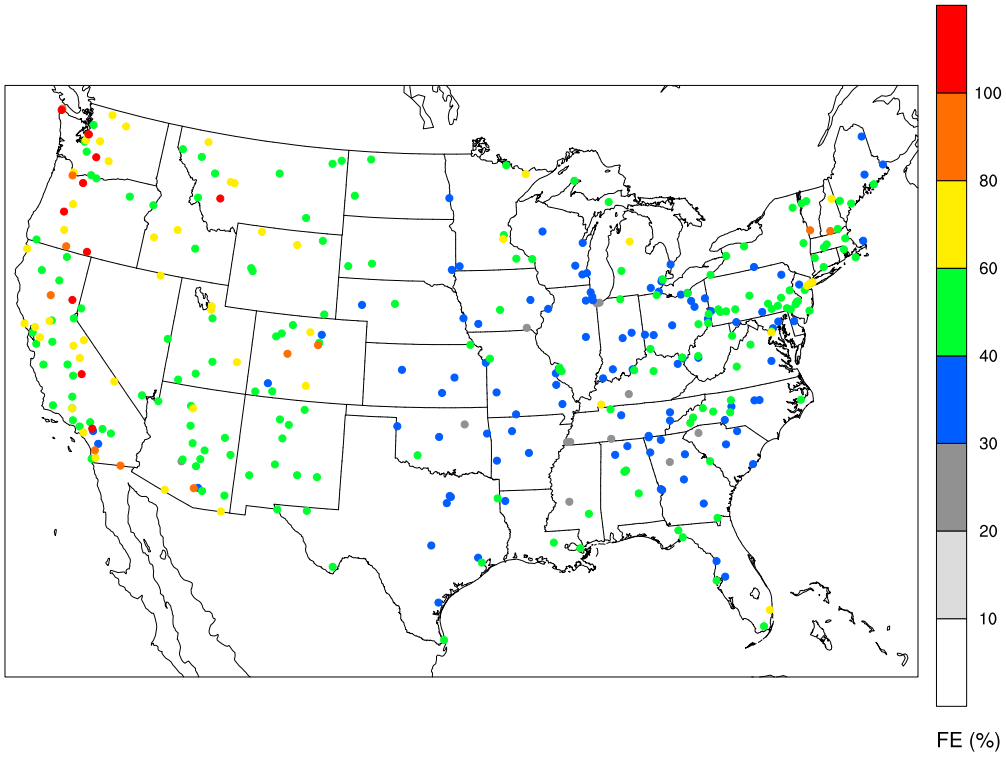

Figure A-12. 2011 mean fractional error of OC baseline modeling.

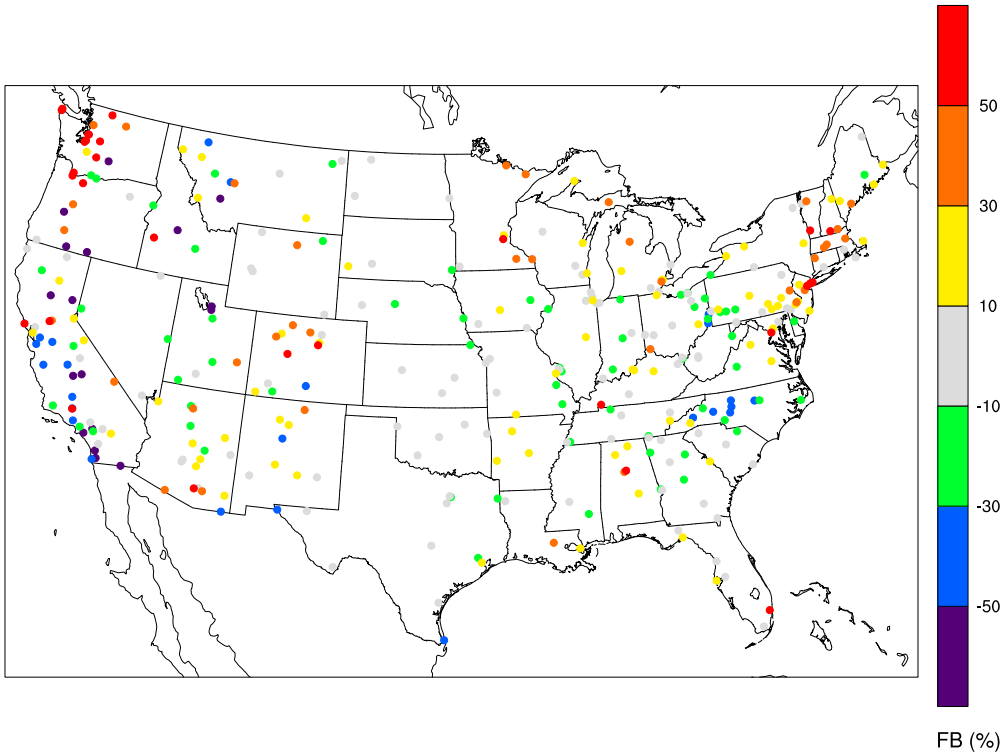

Figure A-13. 2011 mean fractional bias of OC baseline modeling.

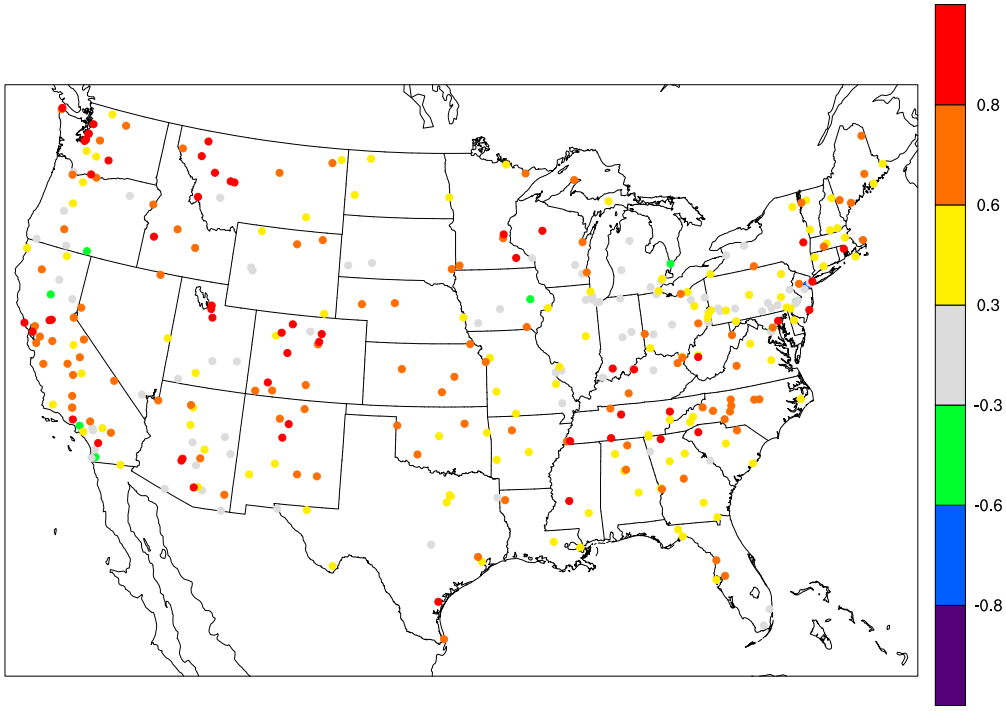

Figure A-14. 2011 Pearson correlation coefficient of OC baseline modeling.

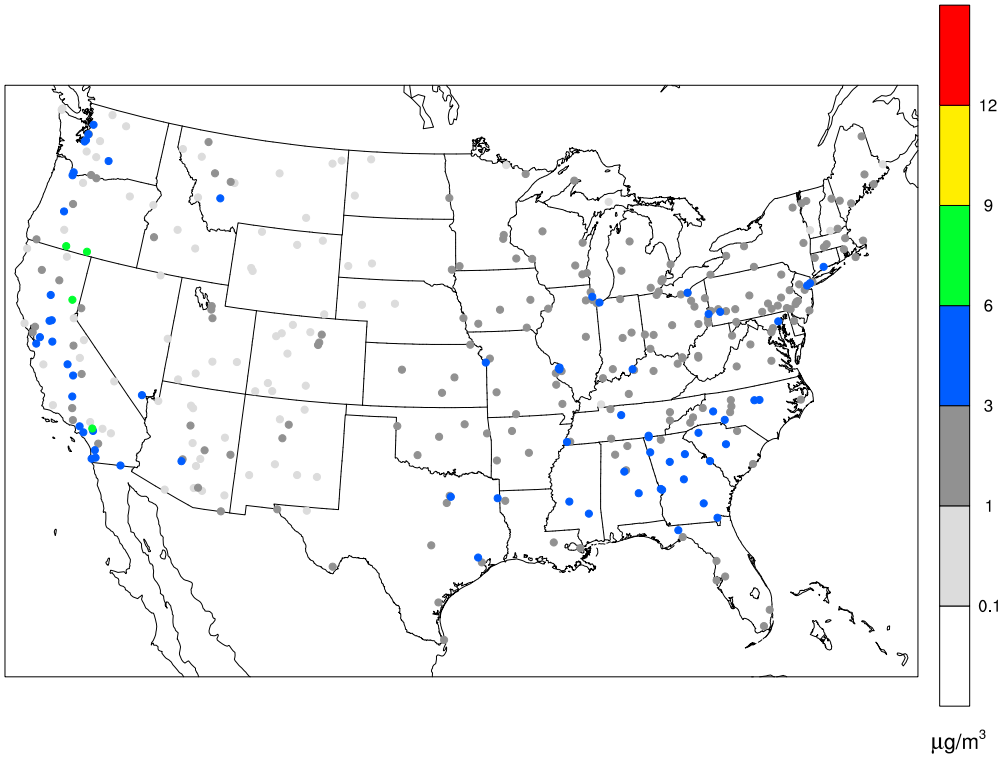

Figure A-15. 2011 mean monitored daily TC.

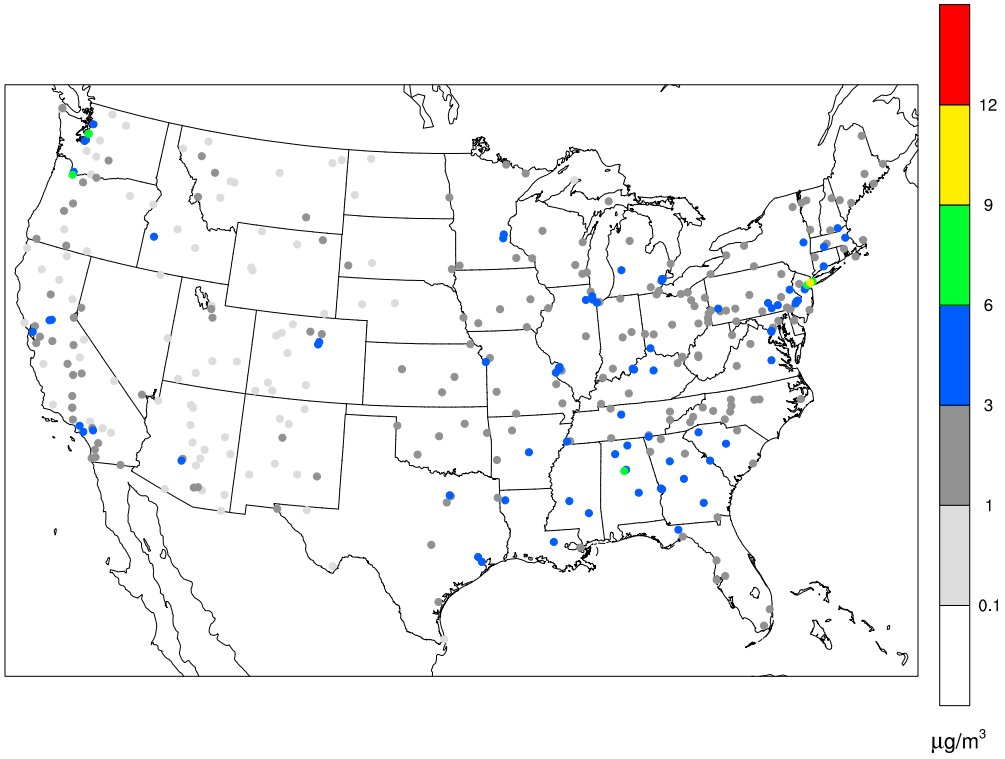

Figure A-16. 2011 mean CAMx modeled daily TC corresponding with observed days.

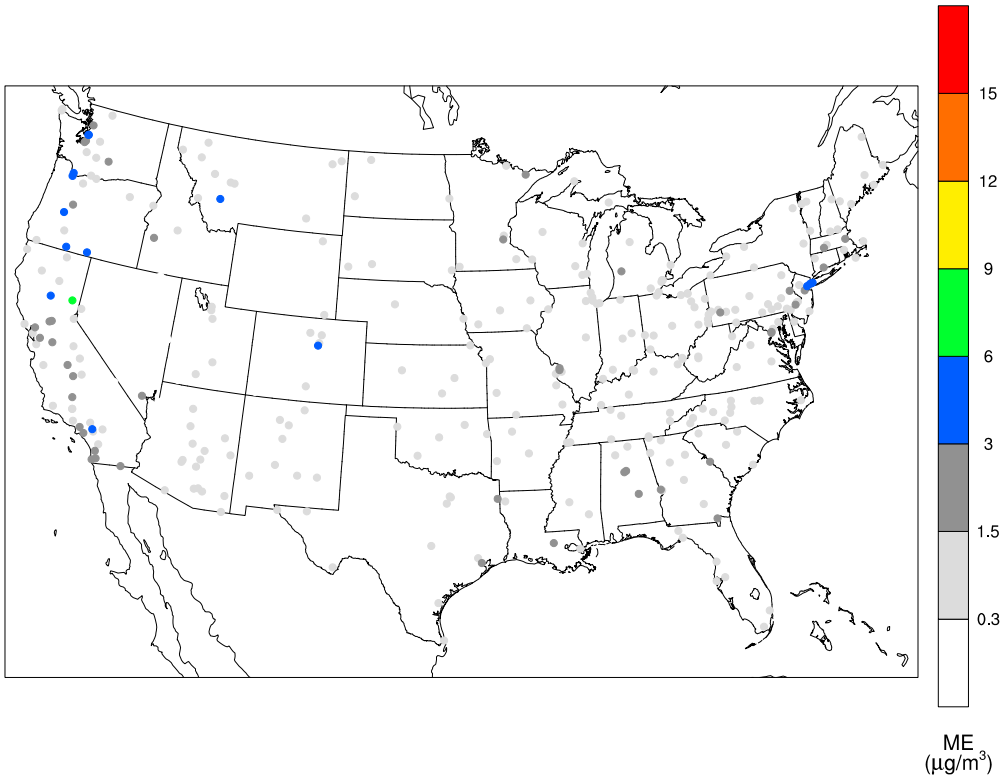

Figure A-17. 2011 mean error of TC baseline modeling.

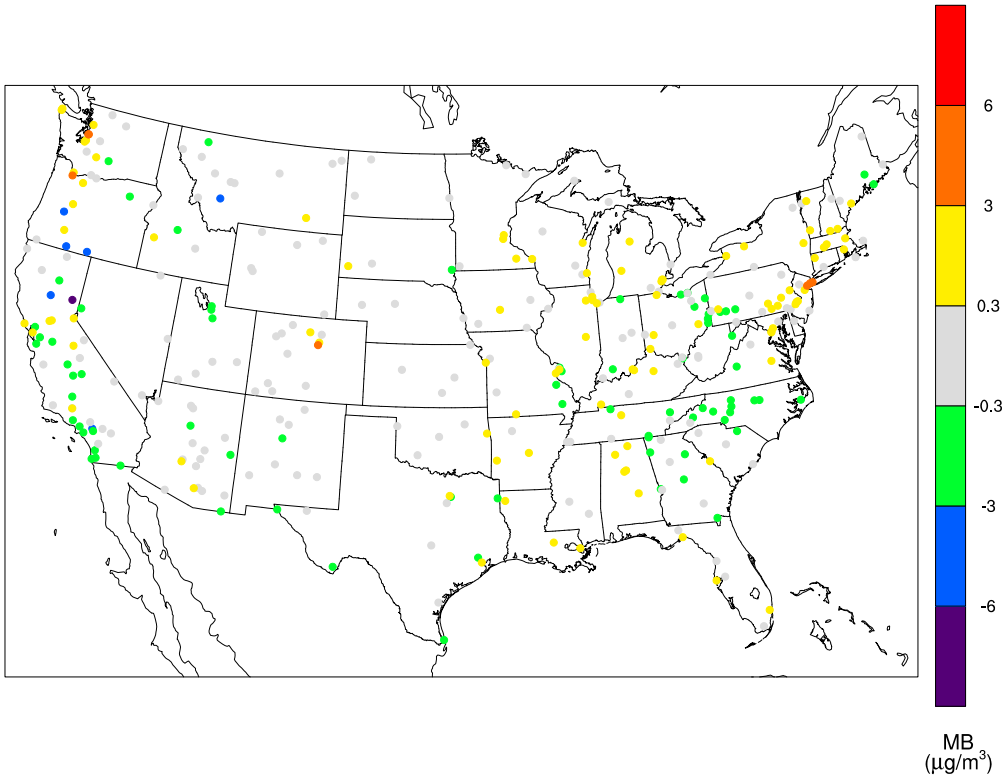

Figure A-18. 2011 mean bias of TC baseline modeling.

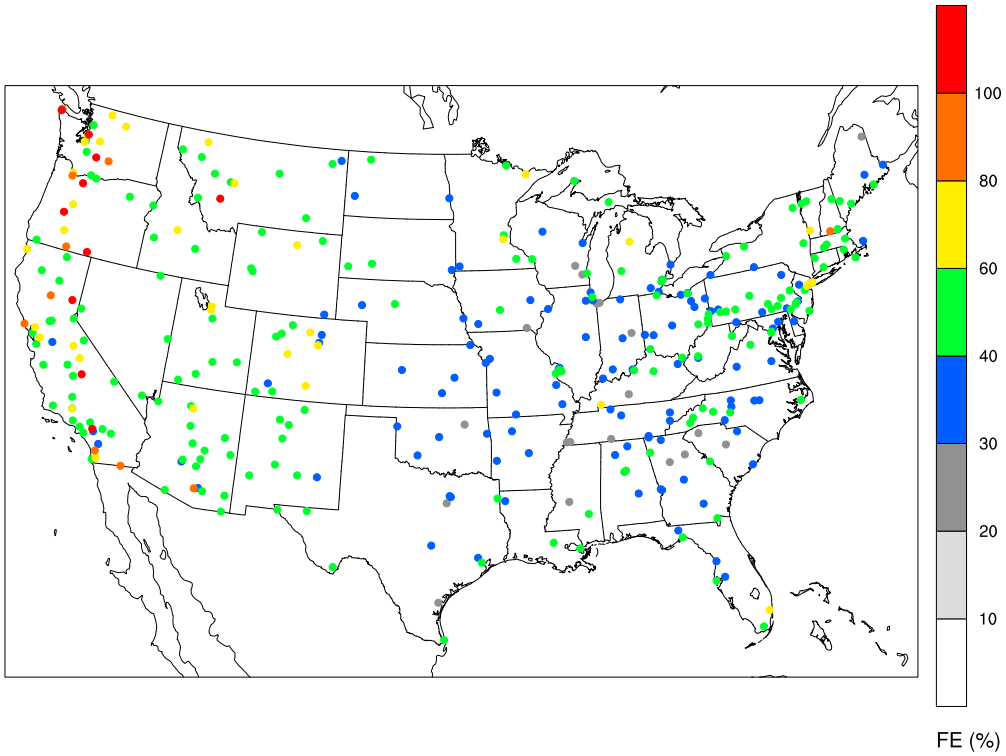

Figure A-19. 2011 mean fractional error of TC baseline modeling.

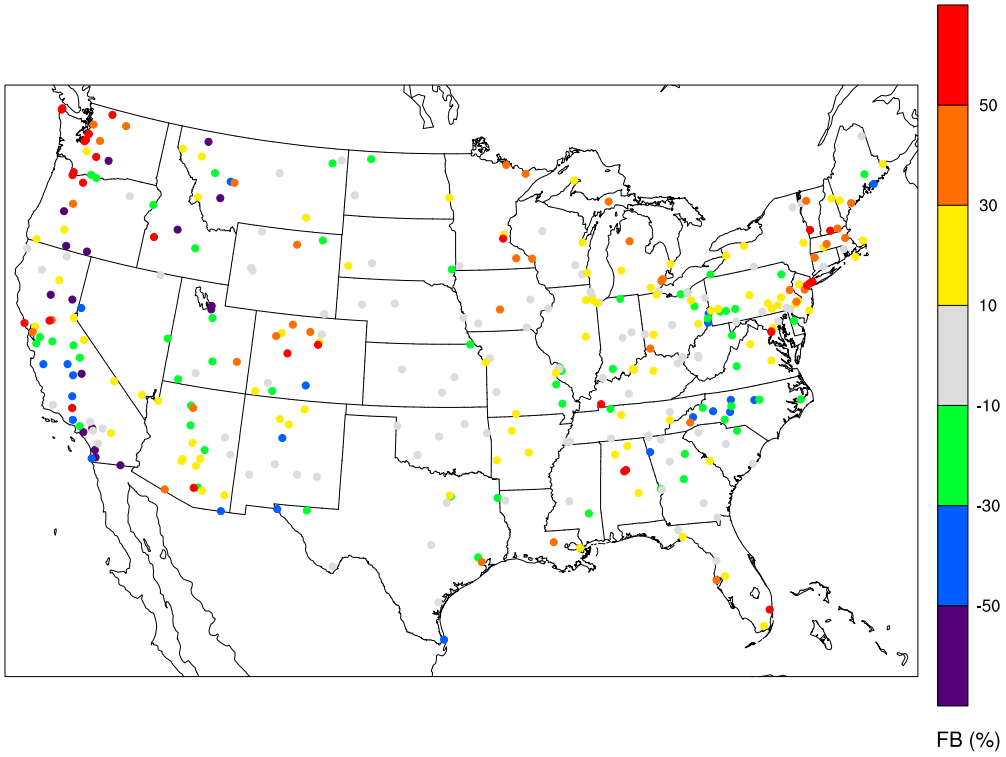

Figure A-20. 2011 mean fractional bias of TC baseline modeling.

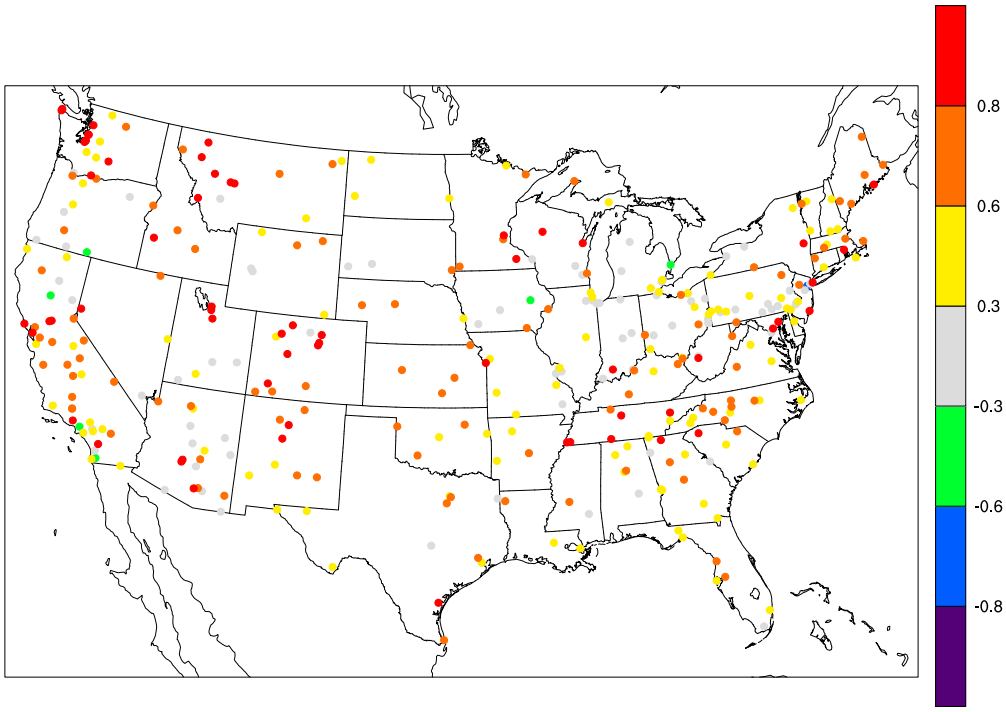

Figure A-21. 2011 Pearson correlation coefficient of TC baseline modeling.

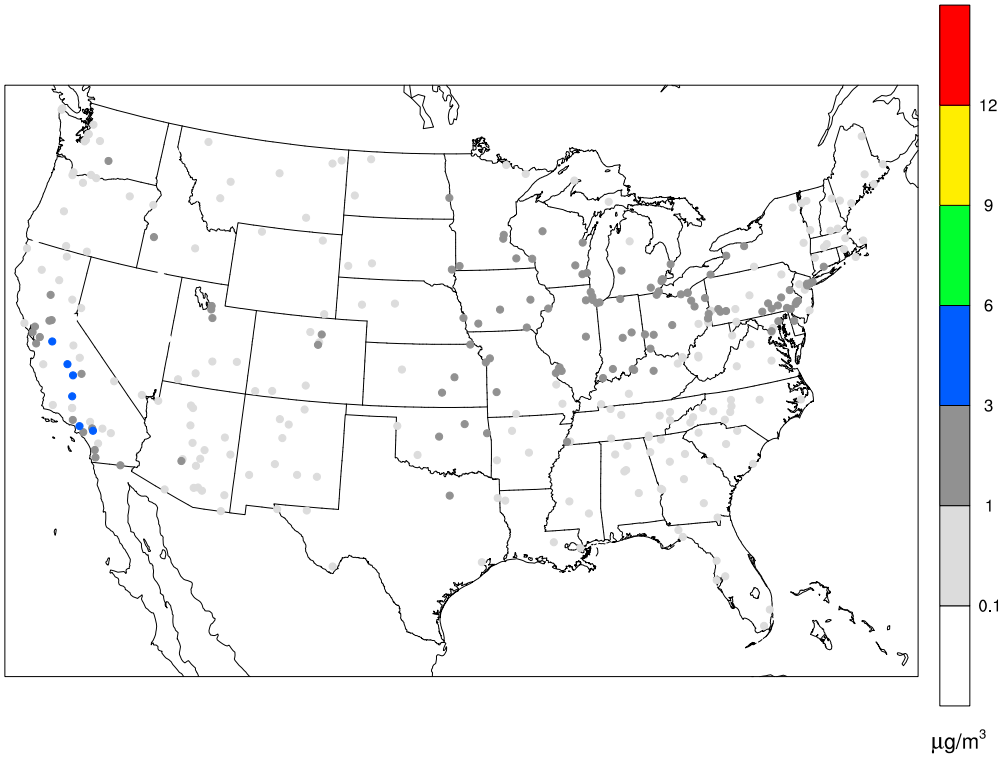

Figure A-22. 2011 mean monitored daily particulate nitrate.

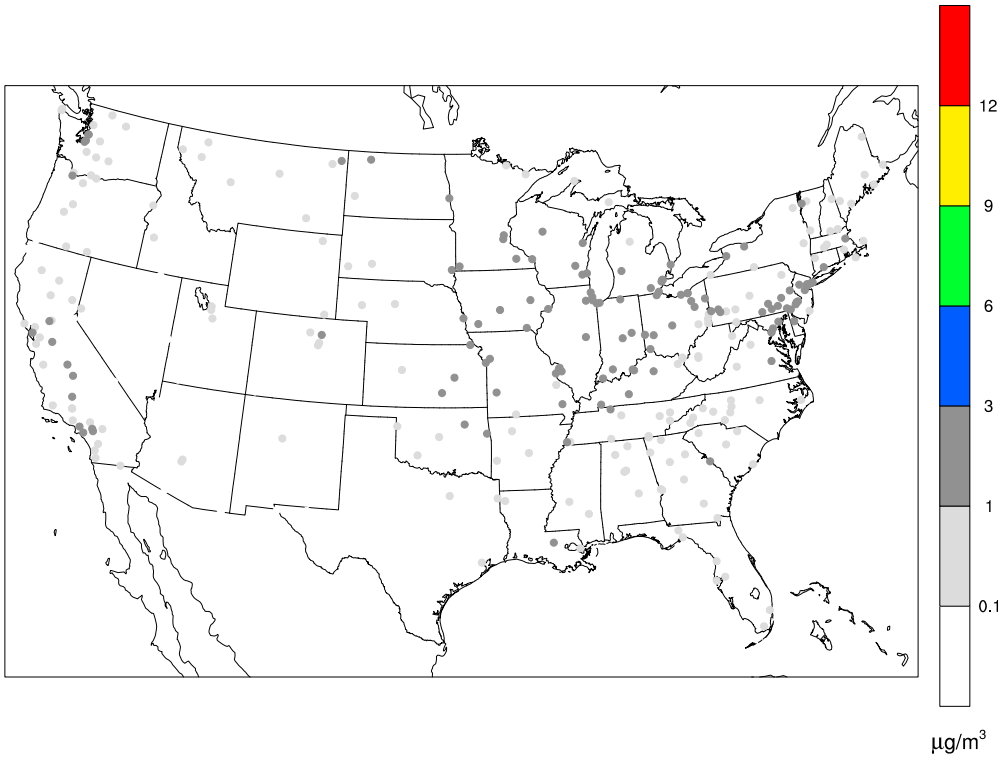

Figure A-23. 2011 mean CAMx modeled daily particulate nitrate corresponding with observed days.

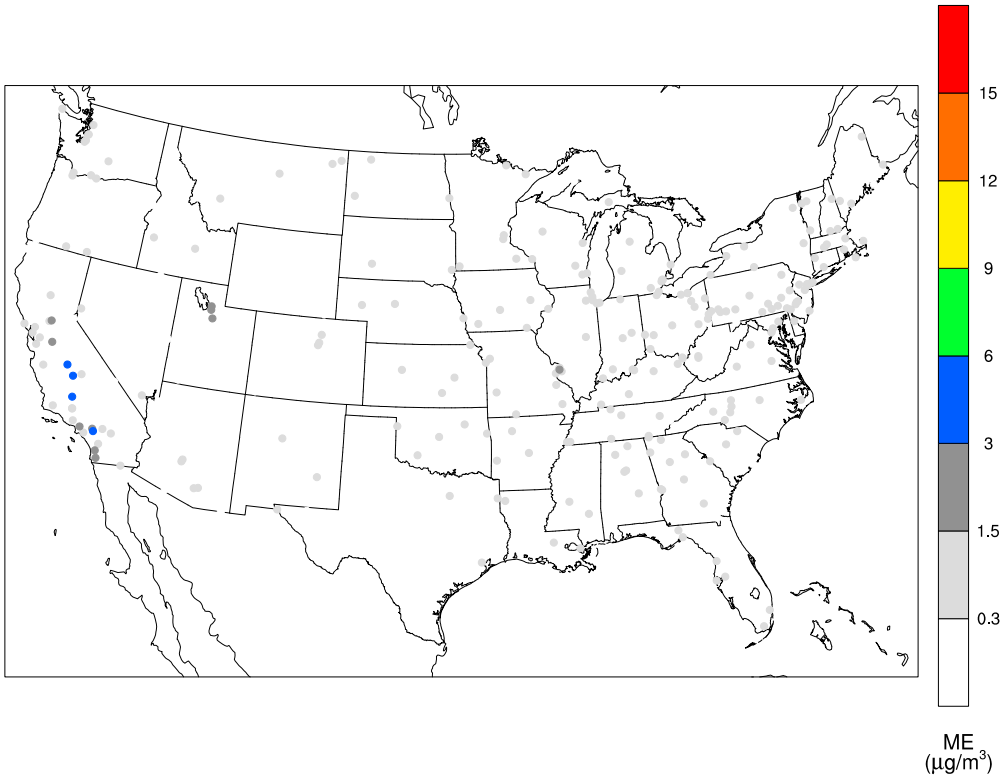

Figure A-24. 2011 mean error of particulate nitrate baseline modeling.

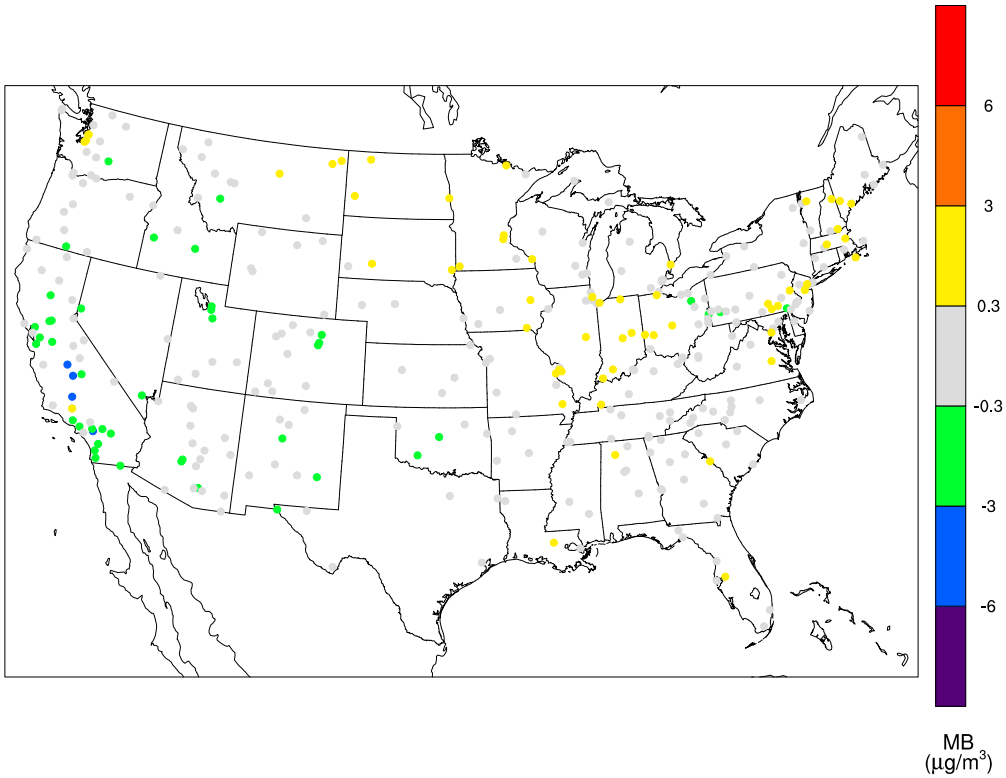

Figure A-25. 2011 mean bias of particulate nitrate baseline modeling.

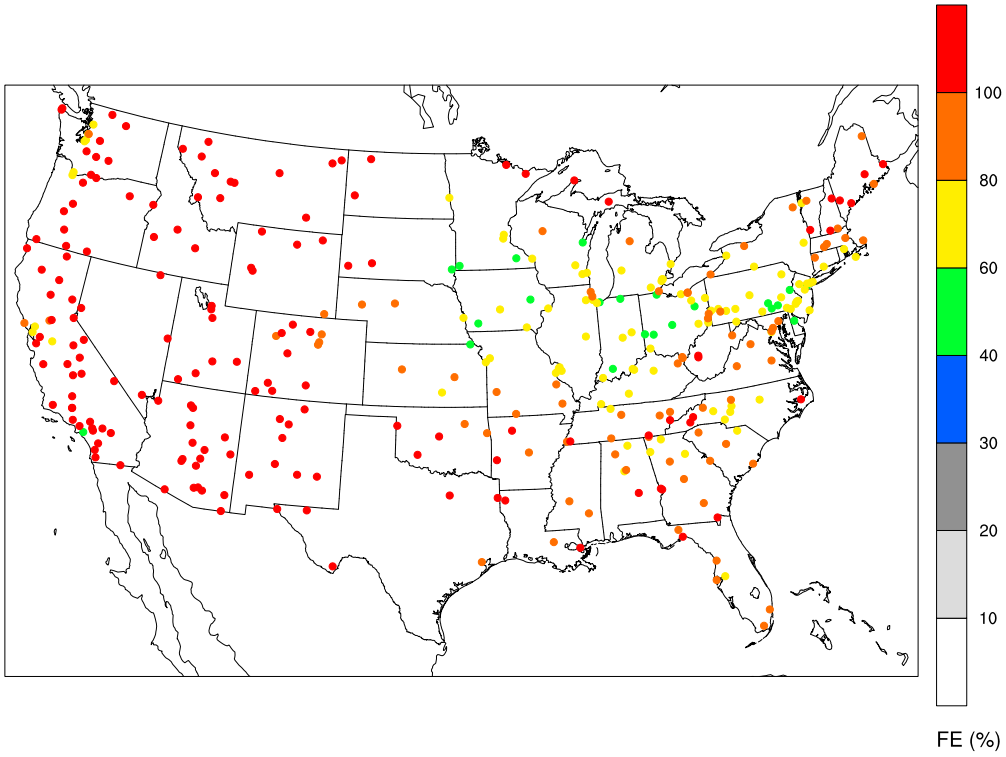

Figure A-26. 2011 mean fractional error of particulate nitrate baseline modeling.

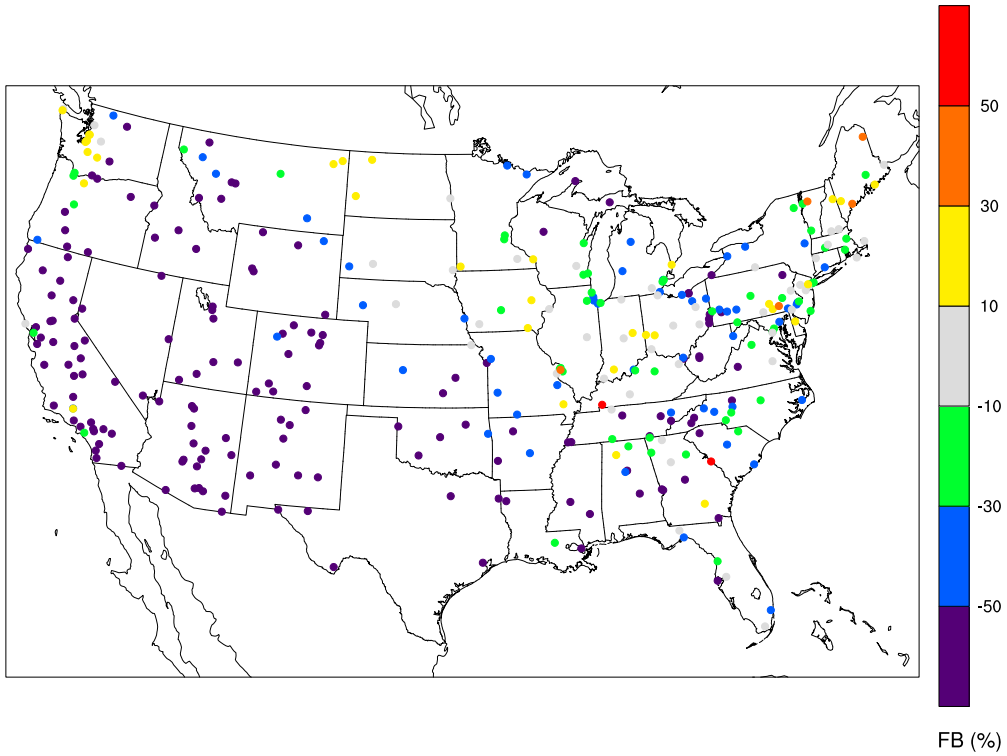

Figure A-27. 2011 mean fractional bias of particulate nitrate baseline modeling.

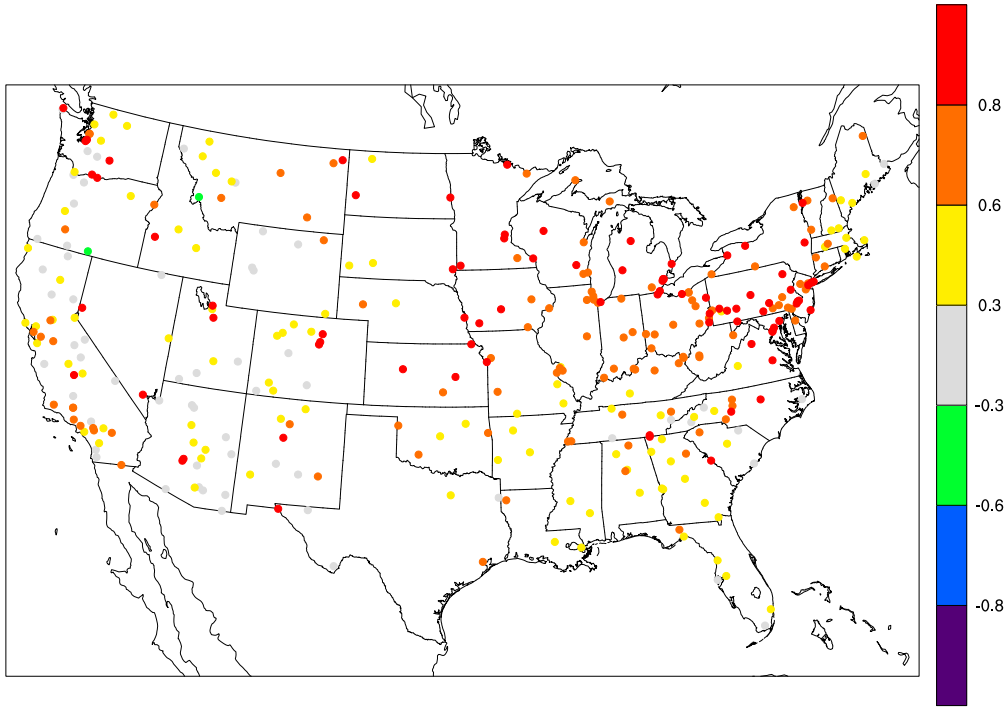

Figure A-28. 2011 Pearson correlation coefficient of particulate nitrate baseline modeling.

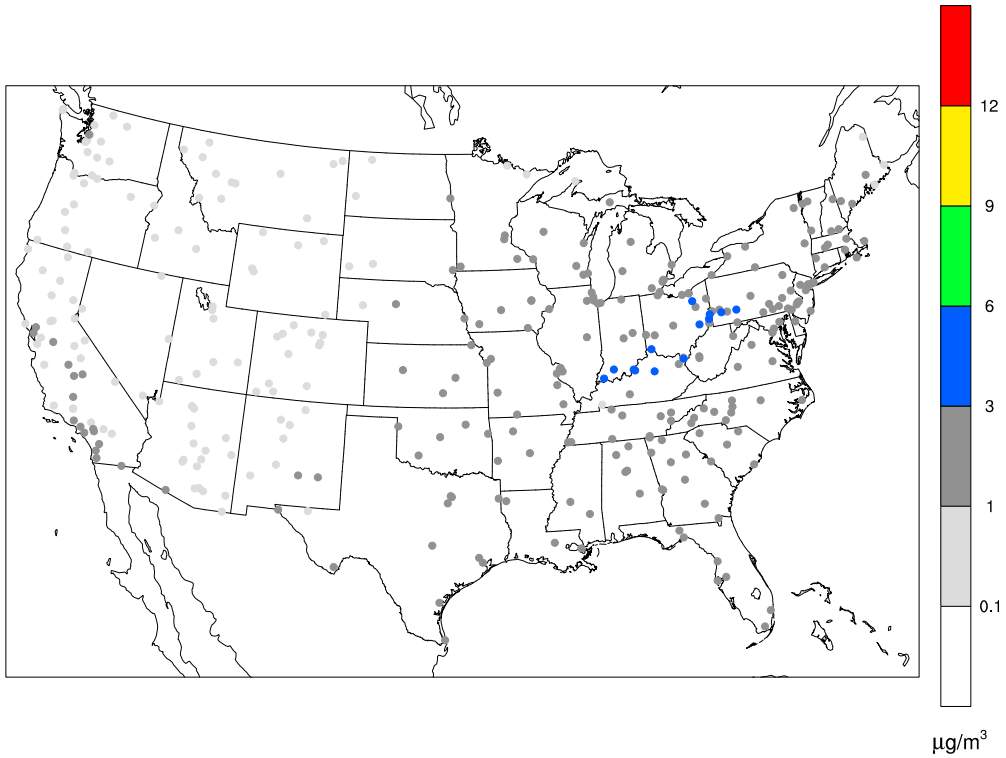

Figure A-29. 2011 mean monitored daily particulate sulfate.

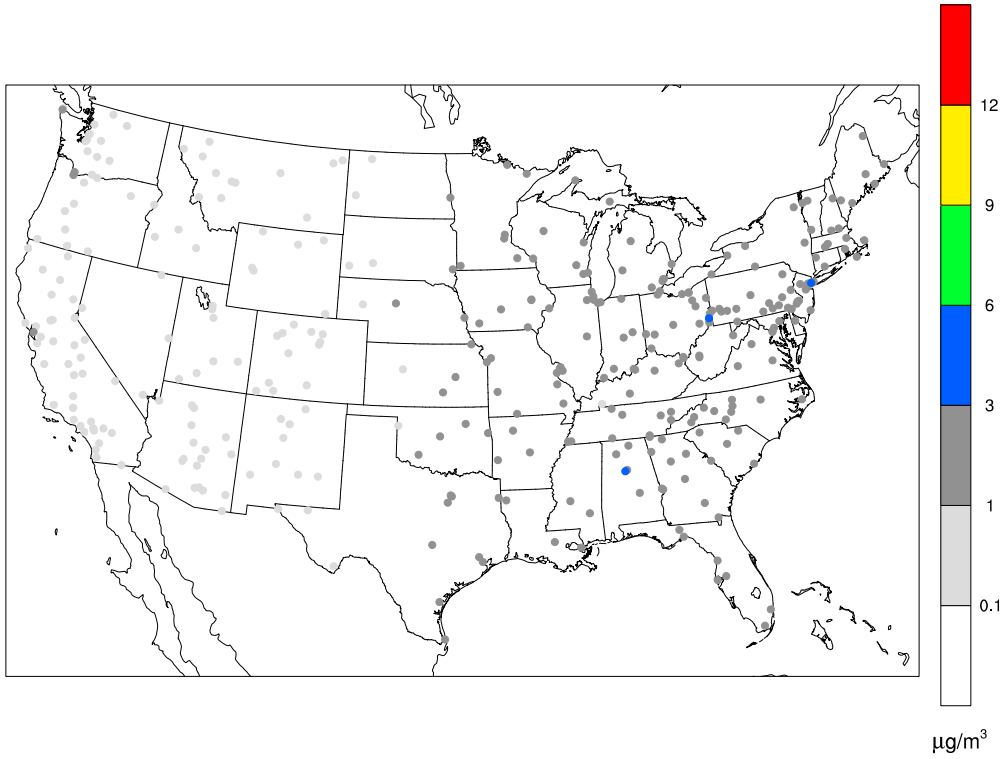

Figure A-30. 2011 mean CAMx modeled daily particulate sulfate corresponding with observed days.

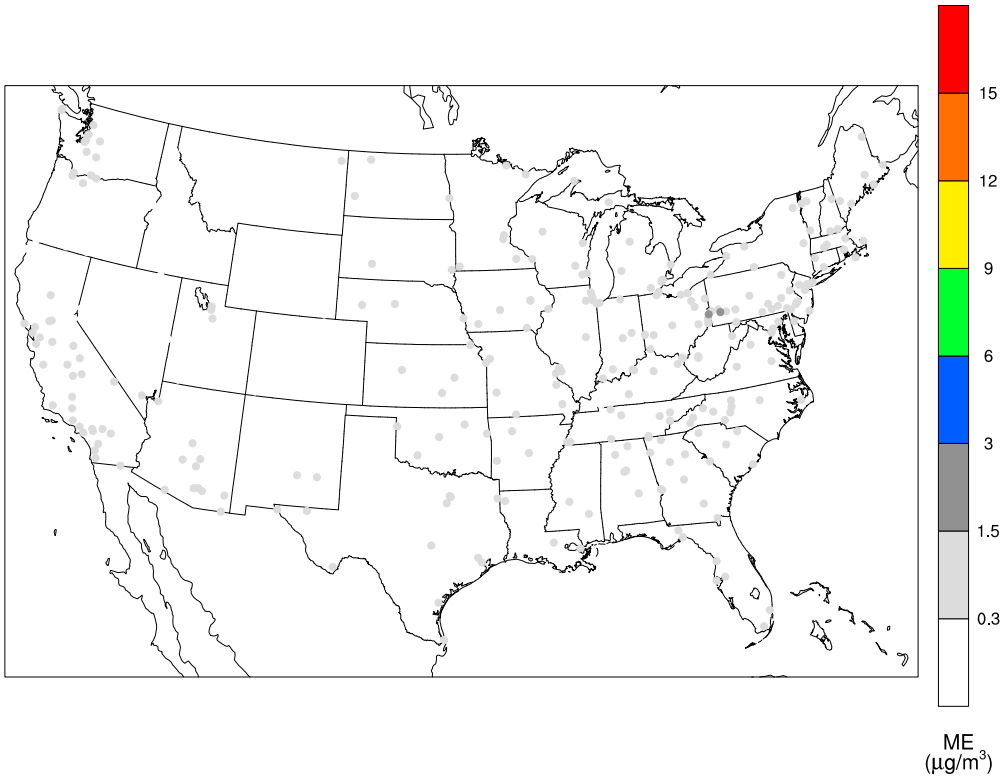

Figure A-31. 2011 mean error of particulate sulfate baseline modeling.

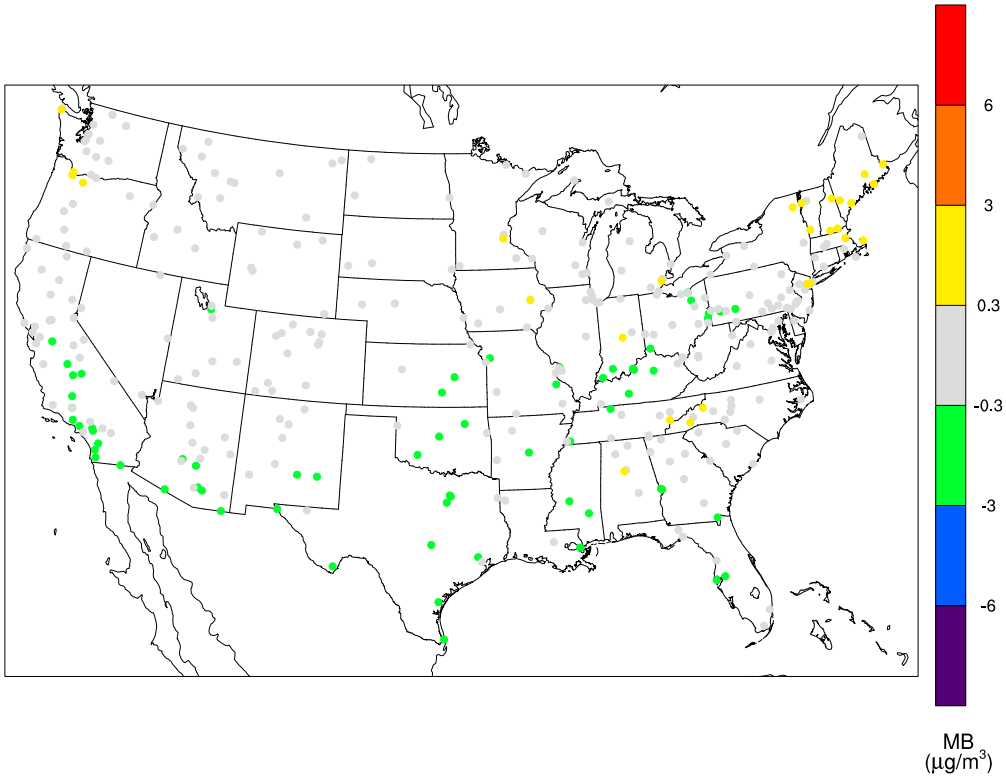

Figure A-32. 2011 mean bias of particulate sulfate baseline modeling.

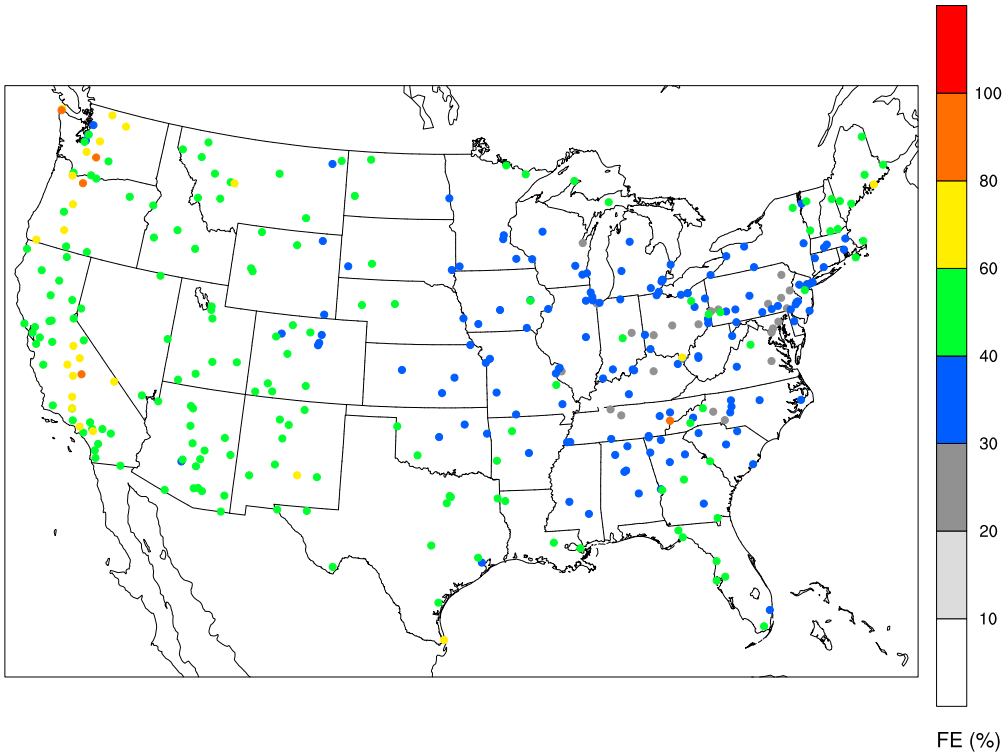

Figure A-33. 2011 mean fractional error of particulate sulfate baseline modeling.

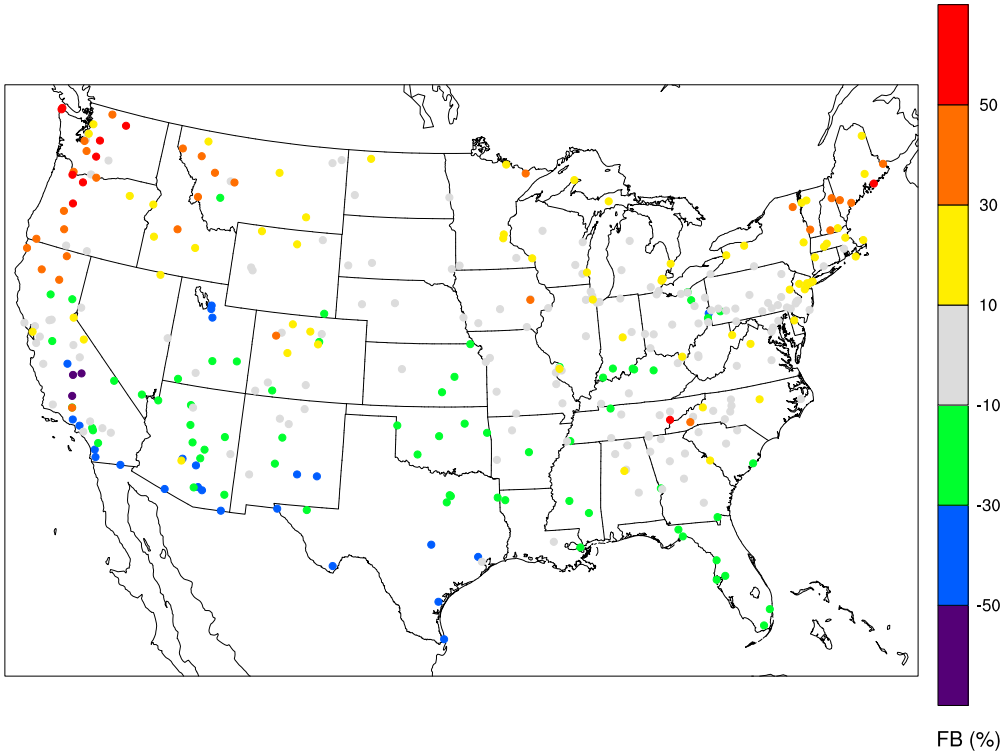

Figure A-34. 2011 mean fractional bias of particulate sulfate baseline modeling.

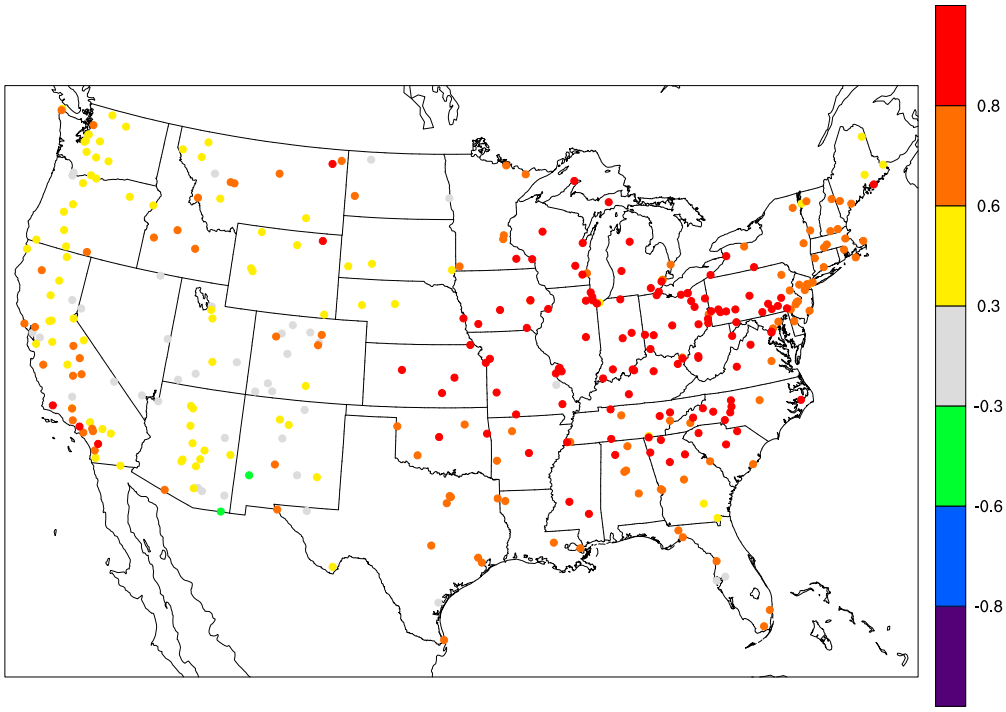

Figure A-35. 2011 Pearson correlation coefficient of particulate sulfate baseline modeling.

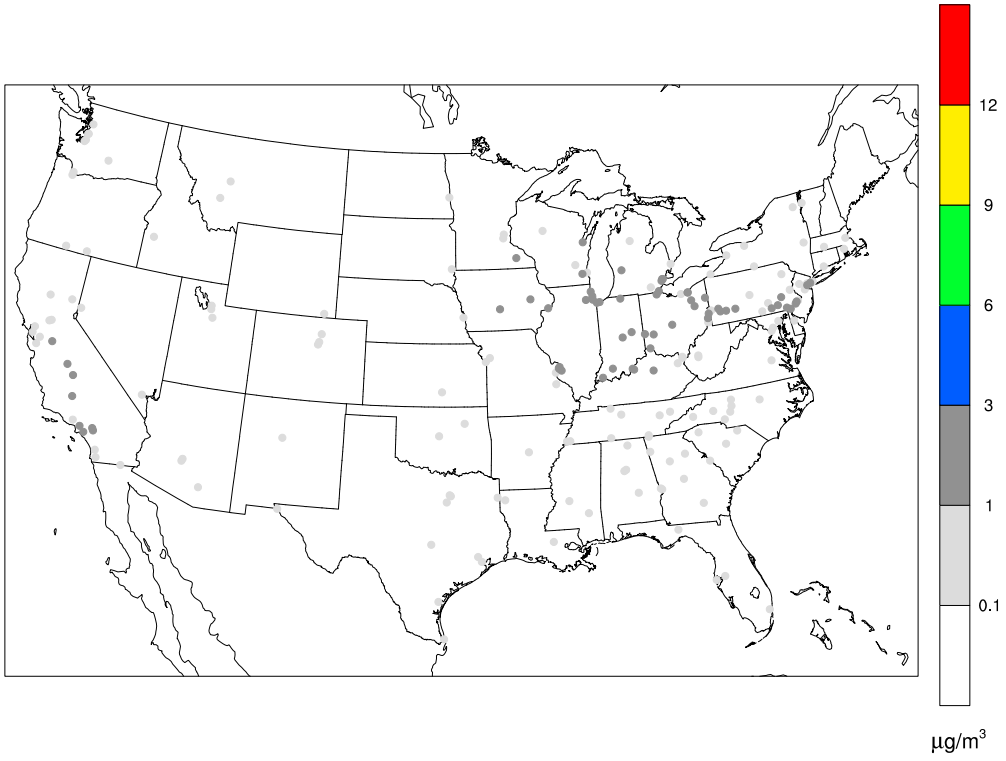

Figure A-36. 2011 mean monitored daily particulate ammonium.

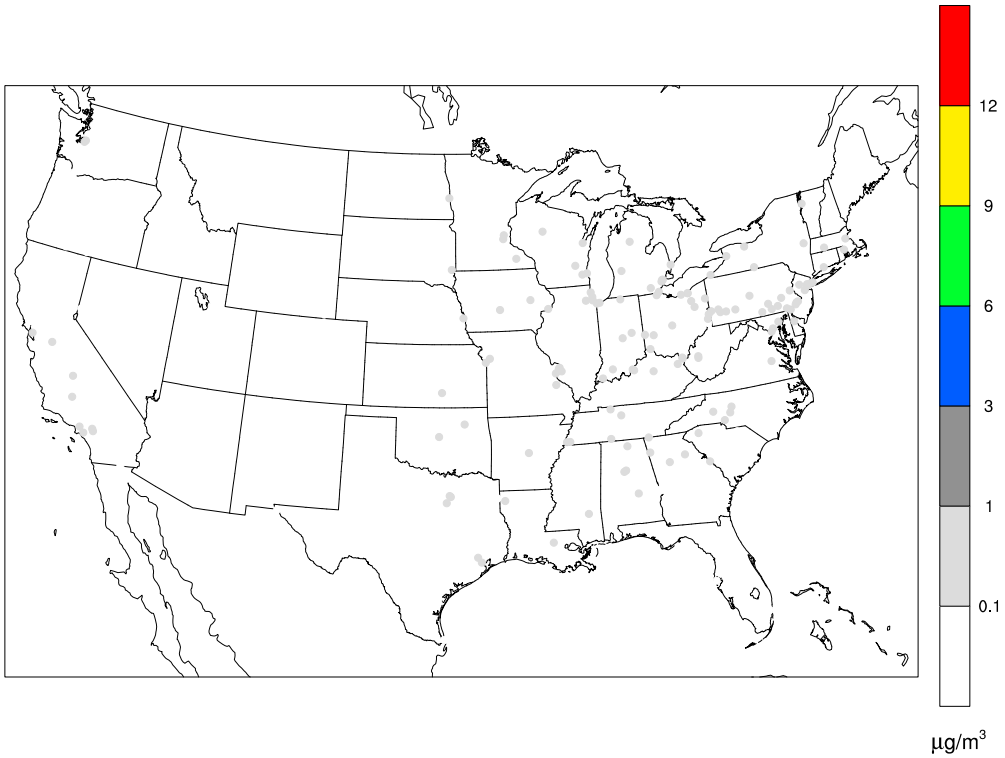

Figure A-37. 2011 mean CAMx modeled daily particulate ammonium corresponding with observed days.

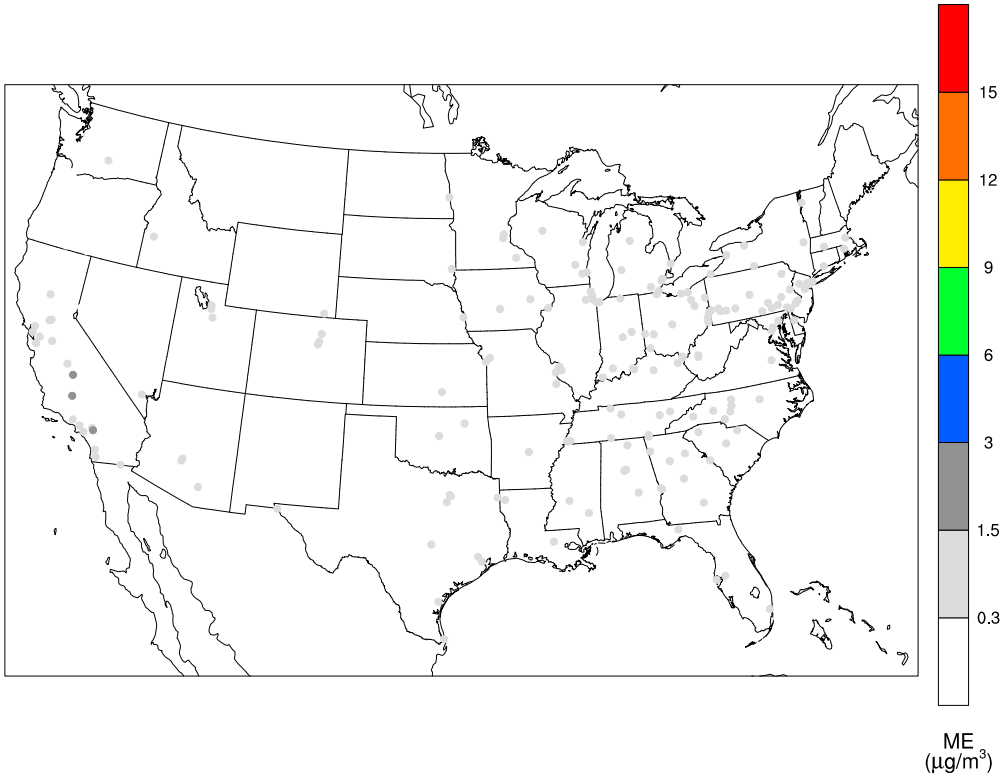

Figure A-38. 2011 mean error of particulate ammonium baseline modeling.

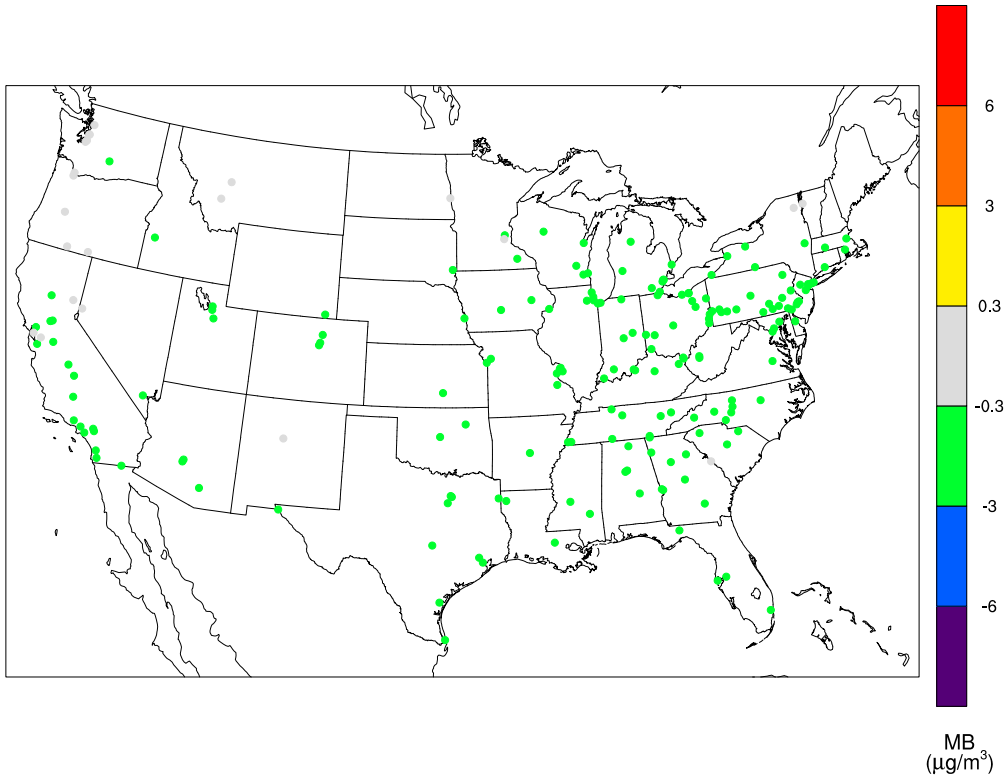

Figure A-39. 2011 mean bias of particulate ammonium baseline modeling.

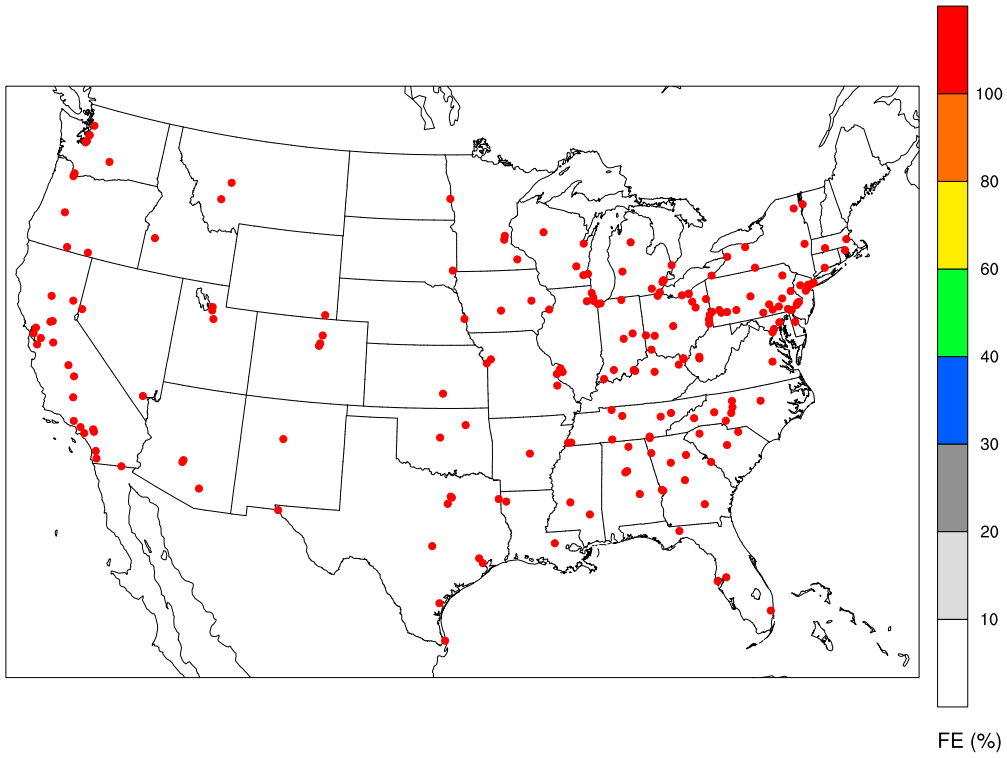

Figure A-40. 2011 mean fractional error of particulate ammonium baseline modeling.

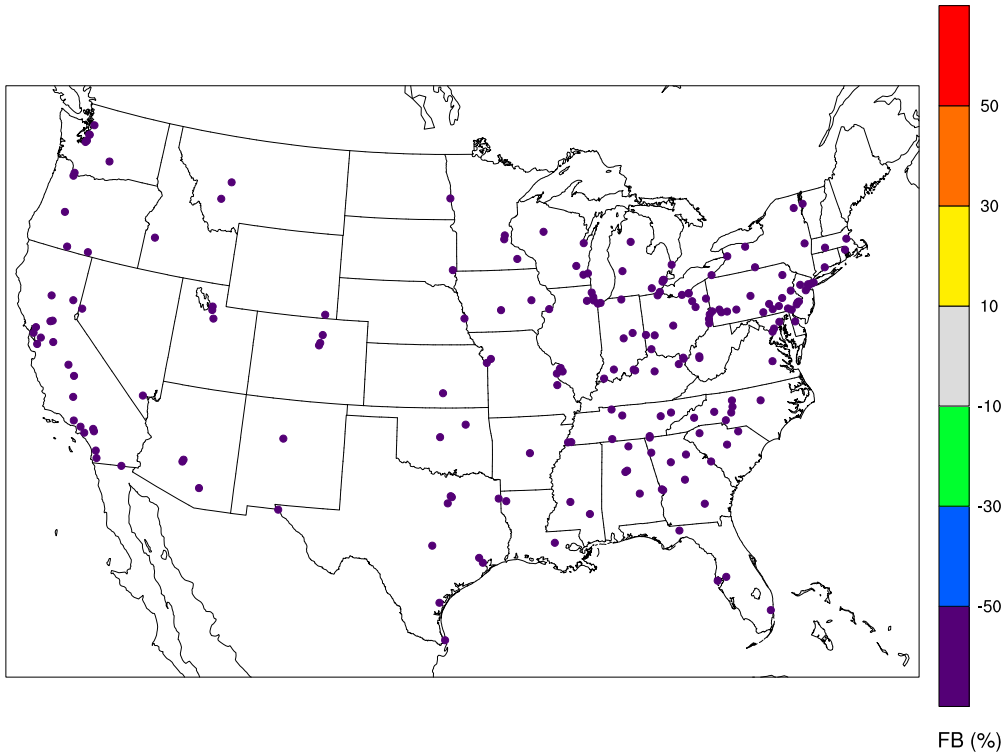

Figure A-41. 2011 mean fractional bias of particulate ammonium baseline modeling.

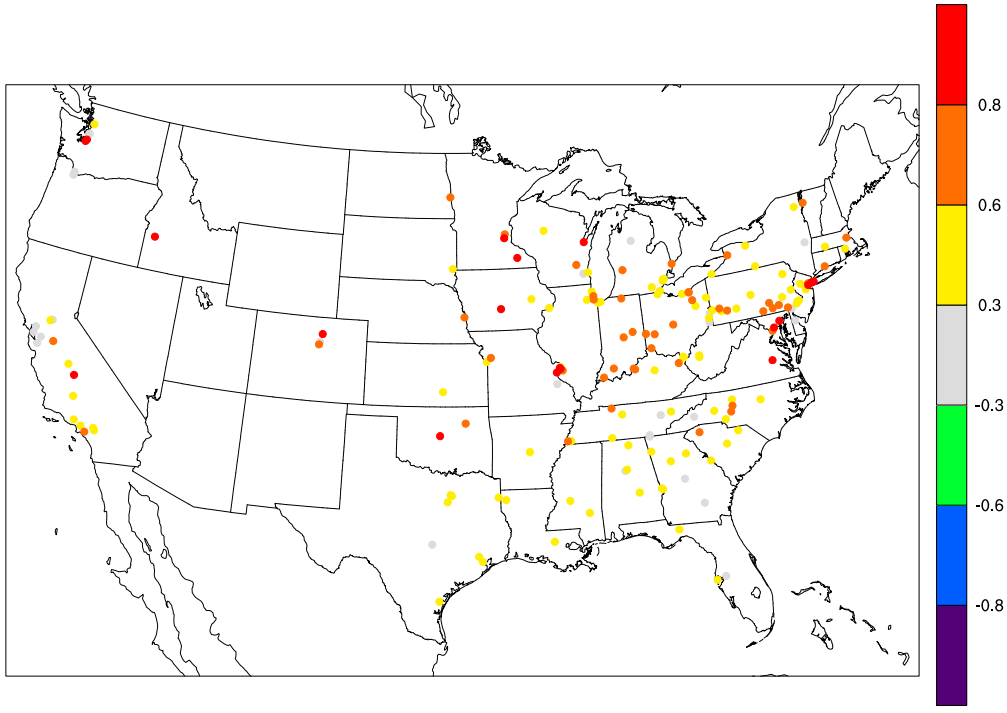

Figure A-42. 2011 Pearson correlation coefficient of particulate ammonium baseline modeling.