Appendix E-3

Model Performance Evaluation for Particulate Matter and Regional Haze of the CAMx 6.40 Modeling System and the VISTAS II 2011 Updated Modeling Platform

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Model Performance Evaluation for Particulate Matter and Regional Haze of the CAMx 6.40 Modeling System and the VISTAS II 2011 Updated Modeling Platform for Task 8.0

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Contents

TABLES

FIGURES

Abbreviations/Acronym List

Alpine	Alpine Geophysics, LLC
AQS	Air Quality Subsystem
CAMx	Comprehensive Air quality Model with eXtensions
CASTNET	Clean Air Status and Trends Network
CM	Coarse Mass
CSN	Chemical Speciation Network
DJF	December, January, and February (i.e., Winter)
EC	Elemental carbon
ERG	Eastern Research Group, Inc.
EGU	Electric Generating Unit
EPA	United States Environmental Protection Agency
FCRS	Crustal fraction of PM
FPRM	Fine other primary (diameter $\leq$ 2.5µm)
FRM	Federal Reference Method
IMPROVE	Interagency Monitoring of Protected Visual Environments
JJA	June, July, and August (i.e., Summer)
km	Kilometer
MAM	March, April, and May (i.e., Spring)
MB	Mean Bias
ME	Mean Error
MFB	Mean Fractional Bias
MFE	Mean Fractional Error
MPE	Model Performance Evaluation
N	Number of observations
NACL	Sodium chloride
NH_4^+	Ammonium Ion
NMB	Normalized Mean Bias
NME	Normalized Mean Error
NO_3^-	Nitrate
O_3	Ozone
OC	Organic carbon
OM	Organic matter
OMC	Organic mass carbon
OSAT	Ozone Source Apportionment Technology
PEC	Primary elemental carbon
PM	Particulate matter
$PM_{2.5}$	Fine particle; primary particulate matter less than or equal to 2.5 microns in aerodynamic diameter
PNH4	Particulate ammonium
PNO3	Particulate nitrate
PSAT	Particulate Source Apportionment Technology
PSO4	Particulate sulfate
r	Pearson correlation coefficient
R	Programming software language called *R*

RADM-AQ	Regional Acid Deposition Model – aqueous chemistry
RHR	Regional Haze Rule
RMSE	Root Mean Squared Error
SESARM	Southeastern States Air Resource Managers, Inc.
SIPS	State Implementation Plans
SMAT-CE	Software for Model Attainment Test – Community Edition
SO_4^{2-}	Sulfate
SOA	Secondary organic aerosol
SOAP	Secondary organic aerosol partitioning
SON	September, October, and November (i.e., Fall)
VISTAS	Visibility Improvement – State and Tribal Association of the Southeast

1.0 INTRODUCTION

Southeastern States Air Resource Managers, Inc. (SESARM) has been designated by the United States Environmental Protection Agency (EPA) as the entity responsible for coordinating regional haze evaluations for the ten Southeastern states of Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, Tennessee, Virginia, and West Virginia. The Eastern Band of Cherokee Indians and the Knox County, Tennessee local air pollution control agency are also participating agencies. These parties are collaborating through the Regional Planning Organization known as Visibility Improvement - State and Tribal Association of the Southeast (VISTAS) in the technical analyses and planning activities associated with visibility and related regional air quality issues. VISTAS analyses will support the VISTAS states in their responsibility to develop, adopt, and implement their State Implementation Plans (SIPs) for regional haze.

The state and local air pollution control agencies in the Southeast are mandated to protect human health and the environment from the impacts of air pollutants. They are responsible for air quality planning and management efforts including the evaluation, development, adoption, and implementation of strategies controlling and managing all criteria air pollutants including fine particles and ozone as well as regional haze. This project will focus on regional haze and regional haze precursor emissions. Control of regional haze precursor emissions will have the additional benefit of reducing criteria pollutants as well.

The 1999 Regional Haze Rule (RHR) identified 18 Class I Federal areas (national parks greater than 6,000 acres and wilderness areas greater than 5,000 acres) in the VISTAS region. The 1999 RHR required states to define long-term strategies to improve visibility in Federal Class I national parks and wilderness areas. States were required to establish baseline visibility conditions for the period 2000-2004, natural visibility conditions in the absence of anthropogenic influences, and an expected rate of progress to reduce emissions and incrementally improve visibility to natural conditions by 2064. The original RHR required states to improve visibility on the 20% most impaired days and protect visibility on the 20% least impaired days.[1] The RHR

[1] RHR summary data is available at: http://vista.cira.colostate.edu/Improve/rhr-summary-data/

requires states to evaluate progress toward visibility improvement goals every five years and submit revised SIPs every ten years.

To demonstrate progress toward the improvement goals, the SESARM partners modeled visibility and air quality conditions for a base year of 2011 and future year of 2028. The SESARM VISTAS II Regional Haze modeling analysis was performed by the contractor team Eastern Research Group, Inc. (ERG) and Alpine Geophysics, LLC (Alpine). The preparation and modeling were conducted over several contract tasks, including emission inventory development, ambient data collection, CAMx modeling, and model performance evaluation of the base year. The VISTAS II modeling included particulate matter simulations and source apportionment studies using the 12-kilometer (km) grid based on EPA's 2011/2028el modeling platform and preliminary source contribution assessment,[2] updated to include a 12km subdomain over the VISTAS region and augmented with revisions to electric generating unit (EGU) and non-EGU point source projections. The air quality modeling was conducted using Comprehensive Air quality Model with extensions (CAMx). A detailed description of the modeling platform can be found in the Task 6 modeling report.

Under Task 8 of the Regional Haze Modeling for Southeastern VISTAS II Regional Haze Analysis Project, a thorough model performance evaluation (MPE) was conducted for particulate matter less than or equal to 2.5 microns in aerodynamic diameter ($PM_{2.5}$) species components and light extinction to examine the ability of the CAMx v6.40 modeling system to simulate 2011 measured concentrations. This report documents the MPE for that base year CAMx modeling.

The VISTAS II modeling for 2011 is based on the EPA modeling conducted for Regional Haze Analysis, sometimes referred to as the "2011el" modeling. Updates to the EPA platform in the VISTAS II modeling include updating the version of CAMx from version 6.32 to 6.40. Many updates to the CAMx model were implemented between the 6.32 and 6.40 release. According to the CAMx 6.40 release notes, the significant changes included:

2 EPA. 2017. Documentation for the EPA's Preliminary 2028 Regional Haze Modeling. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards. October. Available at: https://www3.epa.gov/ttn/scram/reports/2028_Regional_Haze_Modeling-TSD.pdf.

1. Updates to the chemistry to include a condensed halogen mechanism for ocean-borne inorganic reactive iodine, hydrolysis of isoprene-derived organic nitrate and SO_2 oxidation on primary crustal fine PM. This update includes the changes to the Ozone and Particulate Source Apportionment Technology (OSAT/PSAT) algorithms;
2. Inclusion of in-line inorganic iodine emissions to support halogen chemical mechanisms;
3. A major revision to the Secondary organic aerosol partitioning (SOAP) and secondary organic aerosol (SOA) chemistry algorithm;
4. Updates to the Regional Acid Deposition Model aqueous chemistry (RADM-AQ) algorithm; and
5. A major revision to the wet deposition algorithm to identify assumptions or processes that were unintentionally or otherwise unreasonably limiting gas and PM update into precipitation. The wet deposition algorithm was simplified and improved in several ways, resulting in the increased scavenging of gases and PM.

In addition to the model version, the CAMx 6.32 and 6.40 simulations contained differences from the EPA modeling platform that had been made subsequent to the 2011el/2028el model release. In the most current 2023en simulation, EPA developed new photolysis rates and ozone column data. These updates were included in the updated modeling platform and resulting CAMx 6.40 simulation and were used in the VISTAS II 2011el simulations.

Another configuration difference is how the boundary conditions were mapped for speciation from the two versions of the model. EPA and the VISTAS CAMx 6.32 and 6.40 simulations all used the same boundary condition files. However, when CAMx was updated from 6.32 to 6.40 the species in the SOA scheme changed. The SOA5, SOA6, and SOA7 were removed and SOA3 and SOA4 were redefined. However, neither EPA nor this study remapped the boundary conditions to account for this change. EPA examined the regional haze summary data for all Class I areas and found the total organic carbon (OC) species (not just SOA) accounted for 1-5% of the boundary condition impairment at the Southeastern Class I areas.[3] This is a small impact on regional haze and the impact of SOA on regional haze is even smaller.

[3] Brian Timin, EPA Office of Air Quality Planning and Standards (OAQPS) personal communication October 11, 2018.

Figure 1-1 presents the Interagency Monitoring of Protected Visual Environments (IMPROVE) monitor locations in the VISTAS 12-km domain.

Figure 1-1. IMPROVE Monitor Locations and the VISTAS 12km Domain.

2.0 MODEL PERFORMANCE EVALUATION

In order to estimate the ability of CAMx to replicate the 2011 base year concentrations of particulate matter and light extinction, an operational model performance evaluation was conducted following the approach outlined in the modeling protocol. For this evaluation, mean bias and normalized mean bias, mean error and normalized mean error, and Pearson's correlation coefficient were used and directly compared to EPA's results[4] using these same statistics and observed concentrations. In addition, mean fractional bias (MFB) and mean fractional error (MFE) were calculated.

Mean bias (MB) is the average difference between predicted (P) and observed (O) concentrations for a given number of samples (n):

$$MB(\mu g\, m^{-3}\ or\ Mm^{-1}) = \frac{1}{n}\sum_{i=1}^{n}(P_i - O_i)$$

Mean error (ME) is the average absolute value of the difference between predicted and observed concentrations for a given number of samples:

$$ME(\mu g\, m^{-3}\ or\ Mm^{-1}) = \frac{1}{n}\sum_{i=1}^{n}|P_i - O_i|$$

Normalized mean bias (NMB) is the sum of the difference between predicted and observed values divided by the sum of the observed values:

$$NMB(\%) = \frac{\sum_1^n (P - O)}{\sum_1^n (O)} * 100$$

Normalized mean error (NME) is the sum of the absolute value of the difference between predicted and observed values divided by the sum of the observed values:

$$NME(\%) = \frac{\sum_1^n |P - O|}{\sum_1^n (O)} * 100$$

4 https://www3.epa.gov/ttn/scram/reports/2028_Regional_Haze_Modeling-TSD.pdf.

Pearson's correlation coefficient (r) is defined as:

$$r = \frac{\sum_{i=1}^{n}(P_i - \overline{P})(O_i - \overline{O})}{\sqrt{\sum_{i=1}^{n}(P_i - \overline{P})^2}\sqrt{\sum_{i=1}^{n}(O_i - \overline{O})^2}}$$

Mean Fractional Bias (MFB) is defined as:

$$MFB(\%) = \frac{2}{N}\sum_{1}^{N}\left(\frac{P - O}{P + O}\right) \times 100$$

Mean Fractional Error (MFE) is defined as:

$$MFE(\%) = \frac{2}{N}\sum_{1}^{N}\left(\frac{|P - O|}{P + O}\right) \times 100$$

Model predictions of PM species were paired in space and time with observational data from the IMPROVE, Chemical Speciation Network (CSN), and the Clean Air Status and Trends Network (CASTNET) monitoring sites. These results are organized by network and season (winter (DJF), spring (MAM), summer (JJA), and fall (SON)), for receptors located within the ten VISTAS states and outside of the region.

Recommended benchmarks for photochemical model performance statistics (Boylan, 2006; Emery, 2017) will be used to assess the applicability of this modeled simulation for regulatory purposes. The goal and criteria values noted in Table 2-1 below will be used for this study.

Table 2-1. Fine Particulate Matter Performance Goals and Criteria

	NMB		NME	
Species	**Goal**	**Criteria**	**Goal**	**Criteria**
24-hr $PM_{2.5}$ and Sulfate	<± 10%	<± 30%	< 35%	< 50%
24-hr Nitrate	<± 10%	<± 65%	< 65%	< 115%
24-hr OC	<± 15%	<± 50%	< 45%	< 65%
24-hr EC	<± 20%	<± 40%	< 50%	< 75%

Appendix A presents the MPE statistics in tabular formats for the CASTNET (Appendix A-1), CSN (Appendix A-2), and IMPROVE (Appendix A-3) datasets.

2.1 Graphical Presentations

In addition to statistical summaries, graphical displays of data allow for a fuller characterization of model performance. Therefore, plots play a key role in any model performance evaluation. Below are examples of the types of plots that are used in this evaluation.

- **Scatter plots** (Figure 2-1) present the time and space ordered pairs with observations on the x-axis and the model predicted concentrations on y-axis. These plots are useful for indicating trends of either over, or under prediction across the range of values. Scatter plots have been prepared for $PM_{2.5}$ species by network, pollutant, and month (Appendix B) and for SO_4, NO_3, EC, OC, OM, NACL, $PM_{2.5}$, PMC, and soils on the 20% clearest and 20% most anthropogenically impaired days at each Class I area in the VISTAS 12 domain (Appendix C).

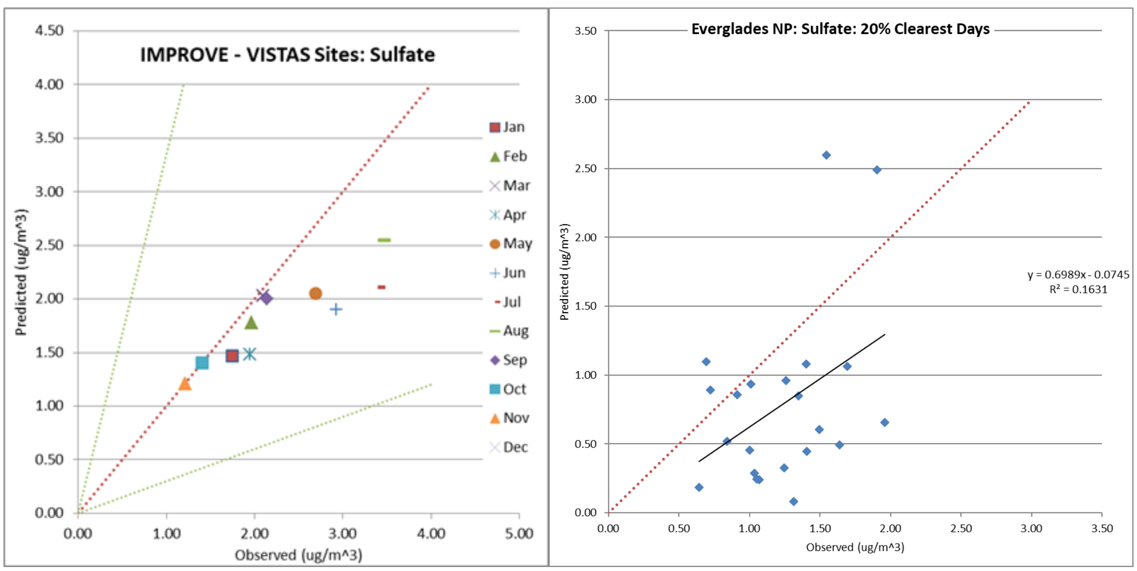


Figure 2-1. Example Scatter Plot of Average 2011 Monthly Sulfate Concentration at IMPROVE Sites in VISTAS States (left) and 20% Clearest Days at Everglades National Park (right).

- **Box plots** (Figure 2-2) can be for a useful tool for evaluating model performance evaluation. These types of plots show the distribution of observations, model estimates, or performance metrics. In this report box plots in this evaluation are grouped by monthly observed and modeled concentrations by species, network, and region. Our box plots show several quantities: the 25% to 75% percentiles are represented by the lower and upper extent of the box, the median values by the line across the box, and outliers as points outside the box. The monthly box plots presented can be used to quickly visualize model performance across the entire year, highlighting the seasonal change in model performance.

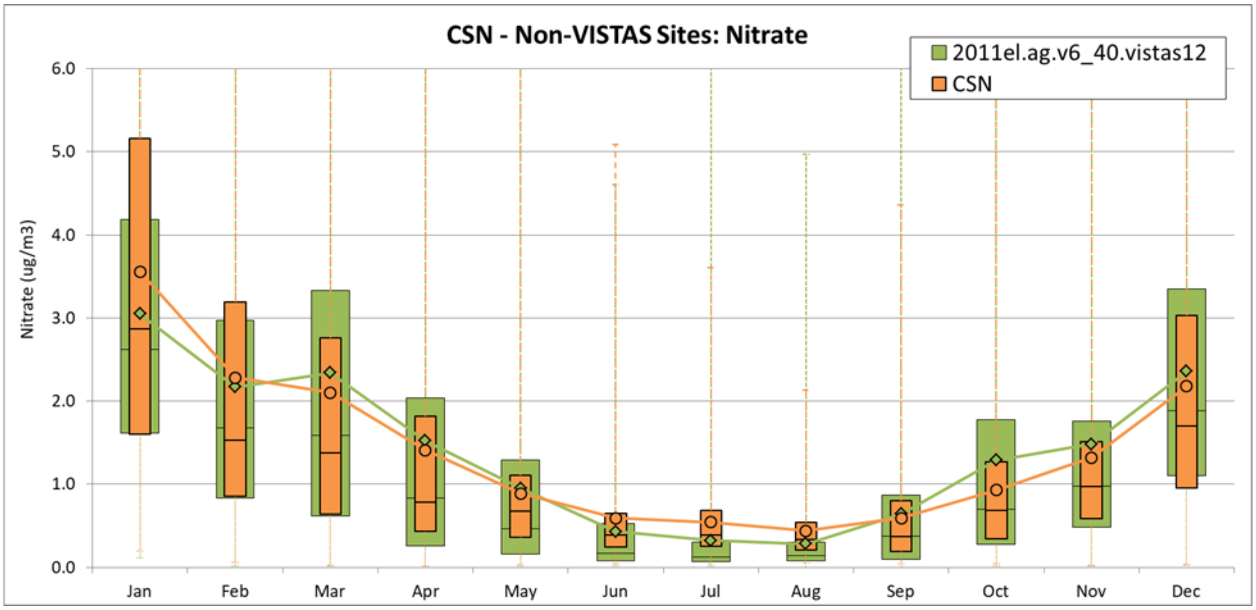


Figure 2-2. Example Box Plot of Monthly Average Nitrate Concentration for Non-VISTAS State CSN Sites.

- **Spatial plots of model performance at monitor locations** (Figure 2-3) provide an overall picture of the geographic patterns in model performance. Any performance metric can be plotted in this manner and we include spatial plots of MB, ME, NMB, and NME. The markers are plotted at the monitor location with the color of the marker keyed to the value of the metric being presented.

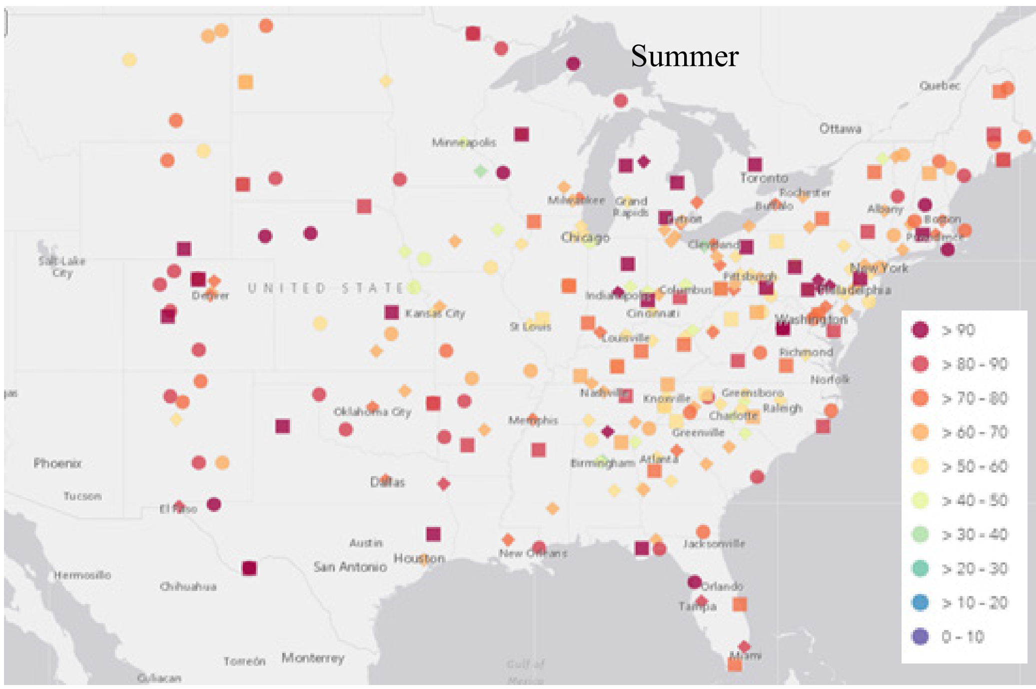


Figure 2-3. Example Spatial Plot of Nitrate NMB by Network for Summer Months (Circle = IMPROVE, Square = CASTNET, Diamond = CSN).

- **The soccer plot** (Figure 2-4) is so named because the dotted lines illustrating performance goals resemble a soccer goal. The error is plotted on the y-axis and the bias plotted on the x-axis. The plot is a convenient way to visualize both bias and error model performance on a single plot. As bias and error approach zero, the points are plotted closer to or within the "goal," represented by the dashed boxes. The size of the goal is developed from historical values of the metric for each variable from comparable modeling studies. Soccer plots have been prepared for $PM_{2.5}$ species by network, pollutant, and month (Appendix D) and by species on the 20% clearest and 20% most anthropogenically impaired days at each Class I area in the VISTAS 12 domain (Appendix C).

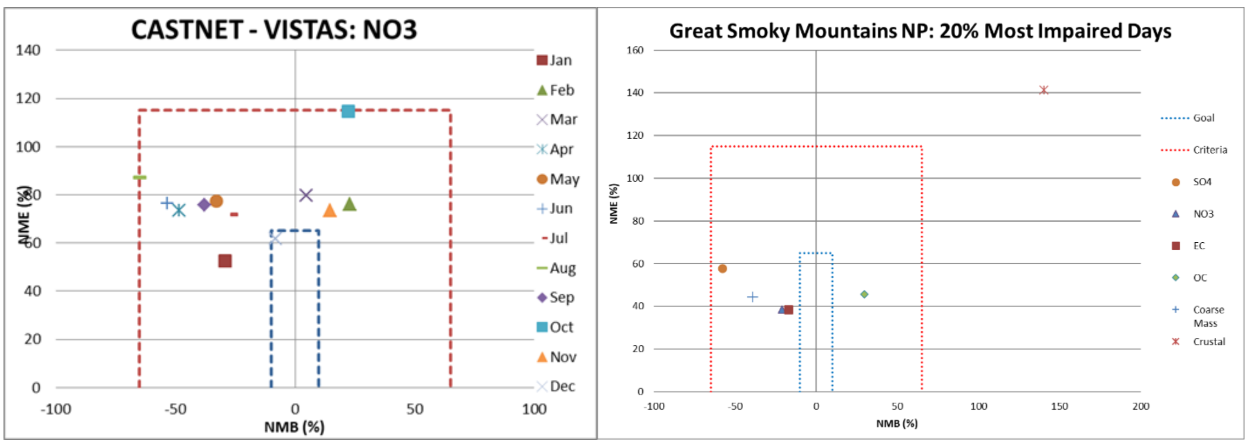


Figure 2-4. Example Soccer Plot of Monthly Nitrate Normalized Mean Bias and Error for CASTNET Sites in VISTAS States (left) and $PM_{2.5}$ Species on the 20% Most Anthropogenically Impaired Days at Great Smoky Mountains National Park (right).

- **The bugle plot** (Figure 2-5), named for the shape formed by the criteria and goal lines. The bugle plots are shaped as such because the goal and criteria lines are adjusted based on the average concentration of the observed species. As the average concentration becomes smaller, the criteria and goal lines become larger to adjust for the model's ability to predict at low concentrations. Bugle plots for the mean fractional bias and mean fractional error have been prepared for $PM_{2.5}$ species by network, pollutant, and month (Appendix E) and by species on the 20% clearest and 20% most anthropogenically impaired days at each Class I area in the VISTAS 12 domain (Appendix C).

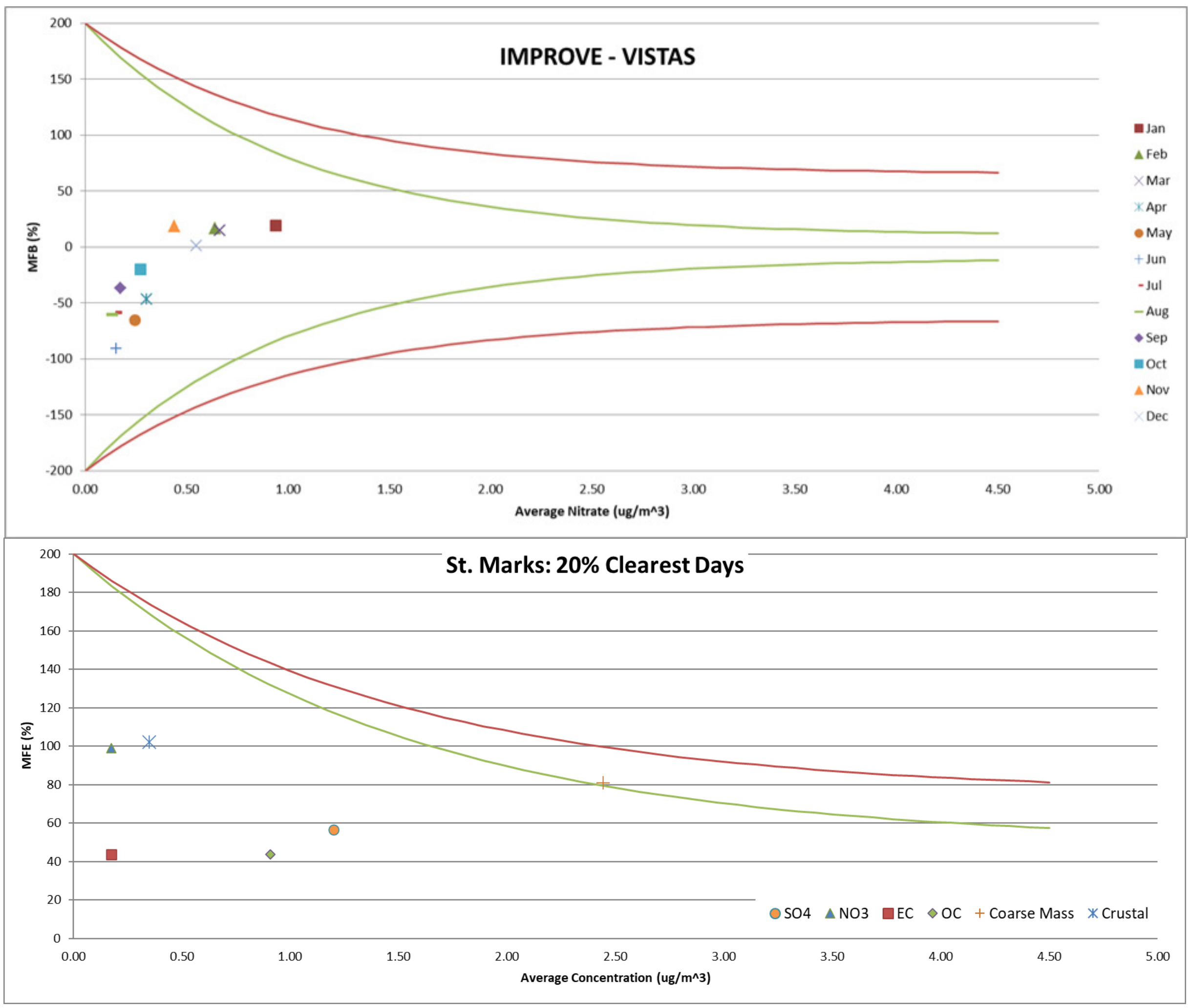


Figure 2-5. Example Bugle Plot of Monthly Mean Fractional Bias as a Function of Modeled Concentration at IMPROVE Sites in VISTAS States (top) and Mean Fractional Error for PM2.5 Species on the 20% Clearest Days at Saint Marks (bottom).

- **Mass daily stacked bar charts** (Figure 2-6) compare 2011 observations to 2011 model values by $PM_{2.5}$ species mass concentration. Mass daily stacked bar charts have been prepared for the 20% clearest and 20% most anthropogenically impaired days at each Class I area in the VISTAS 12 domain (Appendix F).

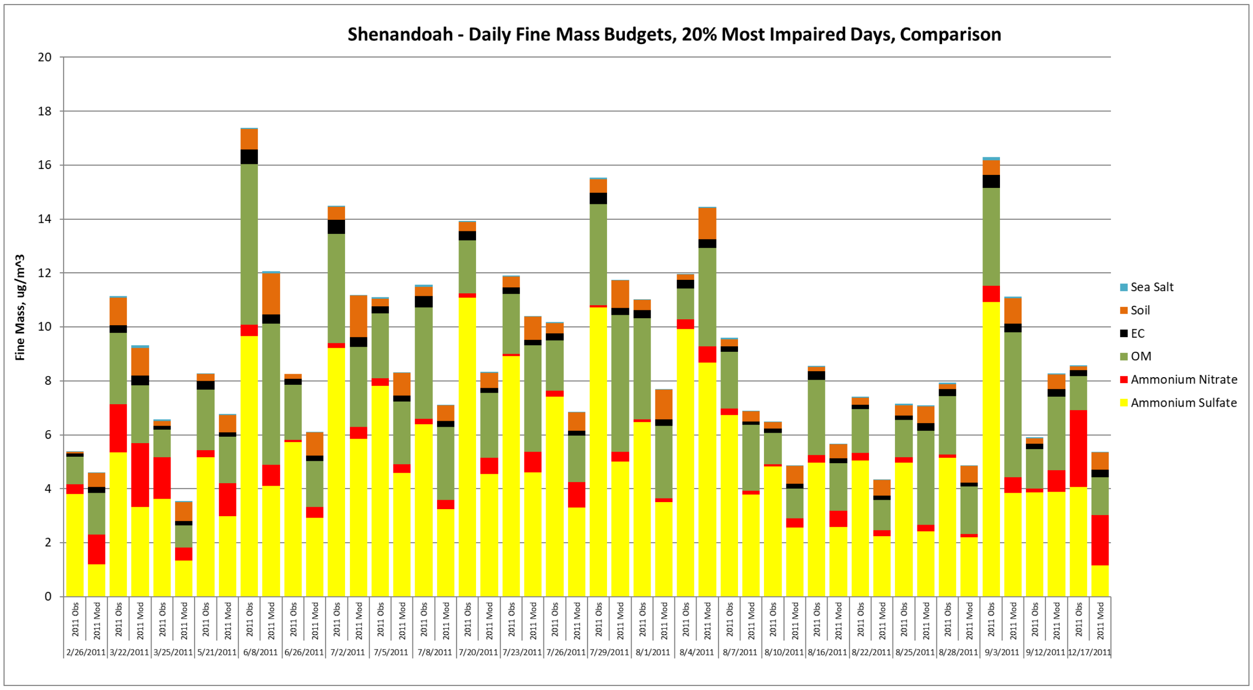


Figure 2-6. Example Mass Daily Stacked Bar Chart for $PM_{2.5}$ Species on the 20% Most Anthropogenically Impaired Days at Shaenandoah.

- **Extinction daily stacked bar charts** (Figure 2-7) compare 2011 observations to 2011 model values by $PM_{2.5}$ species light extinction. Extinction daily stacked bar charts have been prepared for the 20% clearest and 20% most anthropogenically impaired days at each Class I area in the VISTAS 12 domain (Appendix F).

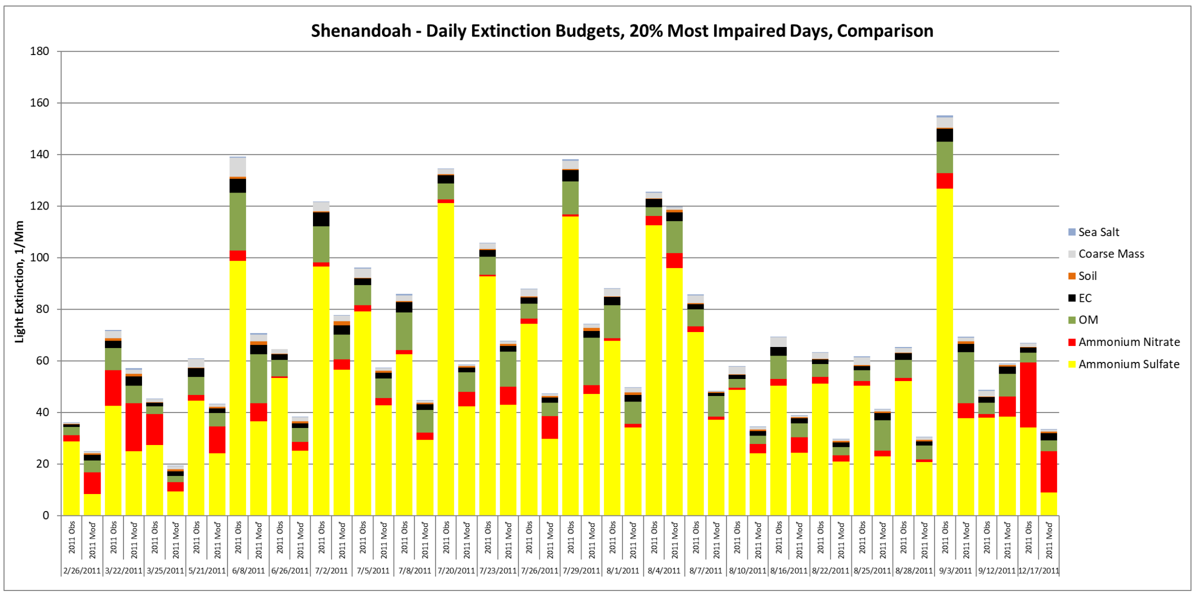


Figure 2-7. Example Extinction Daily Stacked Bar Chart for $PM_{2.5}$ Species on the 20% Most Anthropogenically Impaired Days at Shaenandoah.

- **Mass average stacked bar charts** (Figure 2-8) compare 2011 average $PM_{2.5}$ species mass concentration observations to 2011 average model values. Mass average stacked bar charts have been prepared for the 20% clearest and 20% most anthropogenically impaired days at each Class I area in the VISTAS 12 domain (Appendix F).
- **Extinction average stacked bar charts** (also Figure 2-8) compare 2011 average $PM_{2.5}$ species light extinction observations to 2011 average model values. Mass average stacked bar charts have been prepared for the observed 20% clearest and 20% most anthropogenically impaired days at each Class I area in the VISTAS 12 domain (Appendix F).

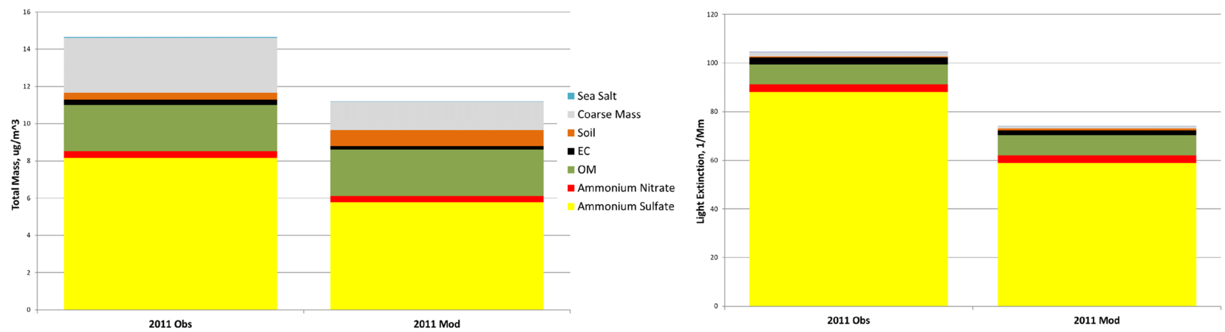


Figure 2-8. Example Observed (Obs) and Predicted (Mod) Mass Concentrations (Left) and Light Extinctions (Right) at the Dolly Sods Wilderness on the Observed 20% Most Anthropogenically Impaired Days.

2.2 Ambient Measurement Networks

Provided below is an overview of the various ambient air monitoring networks used in this evaluation. Network methods and procedures are subject to change annually due to systematic review and/or updates to the existing monitoring network/program.

2.2.1 Ambient Air Quality Observations

Year 2011 data from available ambient air monitoring networks for PM species are used in the model performance evaluation. Table 2-2 summarizes routine PM monitoring networks used in this analysis. Alpine focused on the ambient data collected from the IMPROVE network. This network began in 1985 as a cooperative visibility monitoring effort between EPA, federal land management agencies, and state air agencies (IMPROVE, 2011). Data are collected at Class I areas across the United States mostly at National Parks, National Wilderness Areas, and other protected pristine areas. Currently, there are approximately 181 IMPROVE sites that have complete annual $PM_{2.5}$ mass and/or $PM_{2.5}$ species data. There are 110 IMPROVE monitoring sites which represent air quality at the 156 designated Class I areas. The 71 additional IMPROVE sites are “IMPROVE protocol” sites which are generally located in rural areas throughout the U.S. Although these sites use the IMPROVE monitoring samplers and collection routines, they are not located at Class I areas.

Table 2-2. Overview of Utilized Ambient Data Monitoring Networks

Monitoring Network	Chemical Species Measured	Sampling Period
IMPROVE	Speciated $PM_{2.5}$ and PM_{10}; light extinction data	1 in 3 days; 24-hour average
CASTNET	Speciated $PM_{2.5}$, and O_3	Approximately 1-week average
CSN	Speciated $PM_{2.5}$	24-hour average

2.2.2 IMPROVE

The IMPROVE network began in 1985 as a cooperative visibility monitoring effort between EPA, federal land management agencies, and state air agencies (IMPROVE, 2011). Data are collected at Class I areas across the U.S., mostly at national parks, national wilderness areas, and national wildlife refuges. As of 2018, there were approximately 160 IMPROVE sites that have complete annual $PM_{2.5}$ mass and/or $PM_{2.5}$ species data. There are 110 IMPROVE monitoring sites which represent air quality at the 156 designated Class I areas. The additional IMPROVE sites are "IMPROVE protocol" sites, which are generally located in rural areas throughout the U.S., although there are also a handful of urban sites in the U.S. These protocol sites provide additional spatial information across the country, being generally located in areas where there are few Class I areas. The protocol sites use the IMPROVE monitoring samplers and collection routines. In addition to IMPROVE data that is available in AQS, the IMPROVE program provides summary datasets that contains information and pre-calculated data needed for Regional Haze Rule analyses. This includes daily average and annual data for the 20% most impaired and 20% clearest visibility days.

2.2.3 CASTNET

Established in 1987, CASTNET is a dry deposition monitoring network where PM data are collected and reported as weekly average data (U.S. EPA, 2012a). In addition, this network measures and reports hourly ozone concentrations. CASTNET provides atmospheric data on the dry deposition component of total acid deposition, ground-level ozone and other forms of atmospheric pollution. The data (except for ozone) are collected in filter packs that sample the ambient air continuously during the week. As of 2018, CASTNET is comprised of 95 monitoring stations across the U.S. The longest data records are primarily at eastern U.S. sites.

2.2.4 CSN

CSN, formerly known as STN: The Speciation Trends Network, began operation in 1999 to provide nationally consistent speciated $PM_{2.5}$ data for the assessment of trends at representative sites in urban areas in the U.S. The CSN was established by regulation and is a companion network to the mass-based Federal Reference Method (FRM) network implemented in support of the $PM_{2.5}$ NAAQS. As part of a routine monitoring program, the CSN quantifies mass concentrations and $PM_{2.5}$ constituents, including numerous trace elements, ions (sulfate, nitrate, sodium, potassium, and ammonium), elemental carbon (EC), and organic carbon (OC). As of 2018, there were 52 trends sites in the CSN nationally. CSN trends sites are largely static urban monitoring stations with protocols for sampling methods that are dedicated to characterizing aerosol mass components in urban areas of the U.S. to discern long term trends and provide an accountability mechanism to assess the effectiveness of control programs. In addition, in 2018, there were approximately 100 supplemental speciation sites that are also part of the CSN. The CSN data at trends sites are collected 1 in every 3 days, whereas supplemental sites collect data either 1 in every 3 days or 1 in every 6 days.

2.3 CAMx Species Mapping

The CAMx model species are not directly comparable with the species measured at the monitoring networks described in Section 2.2. The CAMx species mapping was presented in the modeling protocol and is repeated in Table 2-3.

Table 2-3. Species Mapping from CAMx into Observation Network

Network	Observed Species	CAMx Species
IMPROVE	NO_3	PNO3
	SO_4	PSO4
	NH_4	PNH4
	OM = 1.8*OC	SOA1+SOA2+SOA3+SOA4 +SOPA+SOPB+POA
	EC	PEC
	SOIL	FPRM+FCRS
	$PM_{2.5}$	PSO4+PNO3+PNH4+SOA1+SOA2+SOA3+SOA4 +SOPA+SOPB+POA+PEC+FPRM+FCRS+NA+PCL
CSN	$PM_{2.5}$	PSO4+PNO3+PNH4+SOA1+SOA2+SOA3+SOA4 +SOPA+SOPB+POA+PEC+FPRM+FCRS+NA+PCL
	NO_3	PNO3
	SO_4	PSO4
	NH_4	PNH4

Table 2-3. Species Mapping from CAMx into Observation Network

Network	Observed Species	CAMx Species
	OM = 1.4*OC	SOA1+SOA2+SOA3+SOA4 +SOPA+SOPB+POA
	EC	PEC

2.4 Summary and Comparison to EPA MPE Results

Comparing model performance statistics of EPA's CAMx 6.32 and VISTAS CAMx 6.40 simulations using EPA's 2011el modeling platform showed relatively similar results with the VISTAS results showing slightly improved performance for all $PM_{2.5}$ species except sulfate and OC at IMPROVE, CSN, and CASTNET monitors in the southeastern state region.

For sulfate and OC, CAMx 6.40 concentrations were lower than CAMx 6.32 creating an under prediction bias for most of the VISTAS12 modeling domain and seasons in VISTAS simulation compared to EPA's CAMx 6.32 results. For nitrate, ammonium, and EC, the CAMx 6.32 and CAMx 6.40 results differed slightly, with neither version of the model consistently demonstrating performance better than the other. The total $PM_{2.5}$ performance results were consistent between both simulations even as results generally showed higher CAMx 6.32 concentrations compared to CAMx 6.40 at lower concentration levels, with consistent performance at higher concentrations. There appears to be a trend where CAMx 6.40 concentrations are generally slightly higher that CAMx 6.32 during dry periods and CAMx 6.32 generally slightly higher during wet periods. This is not surprising given the update to the wet deposition algorithm between CAMx 6.32 and 6.40.

The comparison of CAMx 6.32 and 6.40 showed differences in model concentration estimates with little difference noted in performance between the two model configurations for most species. The only noted differences were seen in sulfate performance. This was expected given the changes to the model due to the inclusion of new science in CAMx6.40. Alpine Geophysics does not see any features in the modeling that would preclude the use of the more up-to-date science in CAMx 6.40 for use in the VISTAS air quality planning.

3.0 $PM_{2.5}$ SULFATE

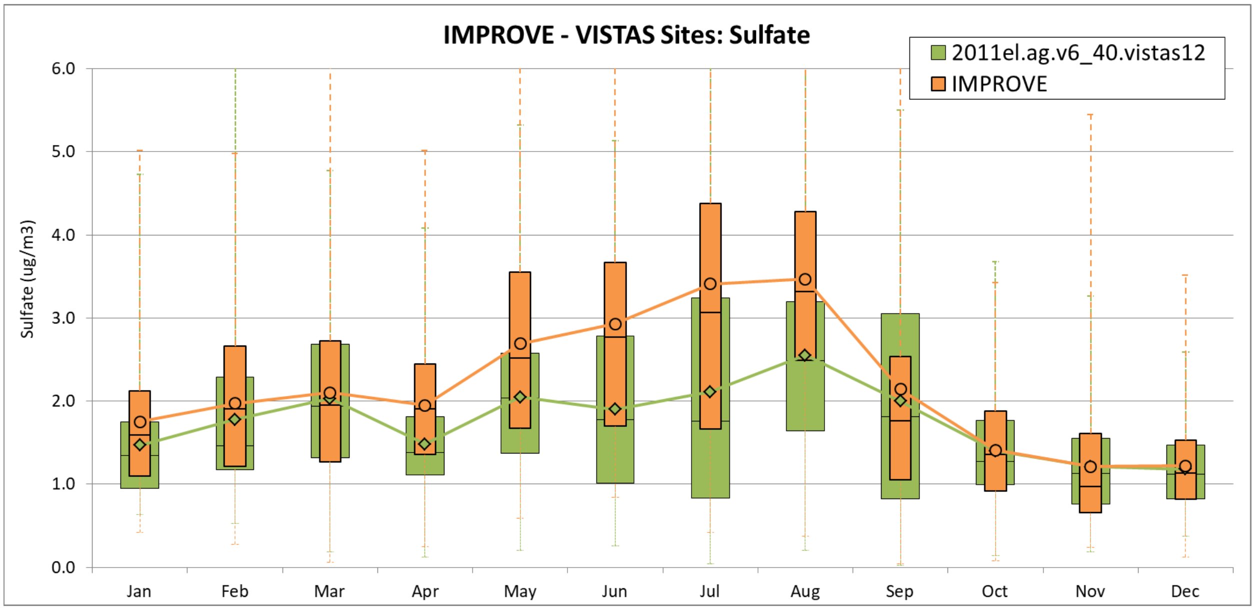
Table 3-1 summarizes model performance statistics for $PM_{2.5}$ sulfate. Boxplot comparisons of model predictions and observations (IMPROVE, CSN, and CASTNET) by month for each climate region are shown in Figures 3-1, 3-2, and 3-3. VISTAS12 modeling domain spatial plots of NMB and NME for each season are shown in Figures 3-4 and 3-5.

Sulfate performance across seasons, networks, and regions is generally mixed. A notable under prediction of sulfate is observed across the VISTAS12 domain consistent with our findings of CAMx v. 6.40 in comparison to the CAMx v. 6.32 simulations from EPA. NMBs range from - -37.5% to -3.38% in the VISTAS states across all seasons and networks. Both the observations and the model consistently predicted the highest average sulfate concentrations in the summer, although the model performance is showing the largest underestimation in the summer. This under prediction is also noticeable during all other seasons, though the magnitude of the under prediction is less. Sulfate is also under predicted outside of the VISTAS states in all networks with the single notable over prediction at non-VISTAS IMPROVE sites in the fall (0.13%).

The greatest over prediction of sulfate is seen on the western boundary of the VISTAS12 modeling domain during winter months and in the northeastern region of the domain during spring and summer months. Under predictions are noted along the southern boundary of the domain during summer months.

Table 3-1. Model Performance Statistics for $PM_{2.5}$ Sulfate by Region, Network, and Season.

Region	Network	Season	N	Avg. Obs. (µg/m³)	Avg. Pre. (µg/m³)	r	NMB (%)	NME (%)	MB (µg/m³)	ME (µg/m³)
VISTAS	IMPROVE	Winter	389	1.65	1.48	0.59	-10.40	34.17	-0.17	0.56
		Spring	405	2.24	1.87	0.60	-16.64	34.14	-0.37	0.76
		Summer	390	3.28	2.20	0.73	-32.81	38.58	-1.08	1.27
		Fall	381	1.61	1.55	0.75	-3.38	33.54	-0.05	0.54
		All	1565	2.20	1.78	0.71	-19.13	35.69	-0.42	0.78
	CSN	Winter	623	1.94	1.60	0.52	-17.40	36.32	-0.34	0.70
		Spring	647	2.67	2.20	0.58	-17.60	34.01	-0.47	0.91
		Summer	674	3.56	2.52	0.70	-29.17	35.17	-1.04	1.25
		Fall	638	1.72	1.63	0.58	-5.39	27.80	-0.09	0.48
		All	2582	2.49	2.00	0.70	-19.79	33.82	-0.49	0.84
	CASTNET	Winter	241	2.16	1.54	0.28	-28.71	39.26	-0.62	0.85
		Spring	302	2.84	1.77	0.31	-37.50	42.94	-1.06	1.22
		Summer	274	3.75	2.38	0.64	-36.57	43.33	-1.37	1.62
		Fall	277	1.70	1.50	0.18	-12.18	50.52	-0.21	0.86
		All	1094	2.63	1.80	0.52	-31.43	43.65	-0.83	1.15
Non-VISTAS	IMPROVE	Winter	1612	1.05	0.86	0.70	-18.17	40.99	-0.19	0.43
		Spring	1752	1.32	1.25	0.64	-5.32	41.10	-0.07	0.54
		Summer	1703	1.55	1.20	0.78	-22.85	41.62	-0.36	0.65
		Fall	1656	0.99	0.99	0.82	0.13	33.44	0.00	0.33
		All	6723	1.23	1.08	0.73	-12.46	39.72	-0.15	0.49
	CSN	Winter	1783	1.88	1.34	0.57	-28.96	42.24	-0.55	0.80
		Spring	1888	2.08	1.93	0.71	-7.50	31.91	-0.16	0.66
		Summer	1908	2.93	2.32	0.83	-20.86	33.13	-0.61	0.97
		Fall	1831	1.66	1.52	0.81	-8.78	29.87	-0.15	0.50
		All	7410	2.15	1.79	0.77	-16.96	34.13	-0.36	0.73
	CASTNET	Winter	427	1.69	0.99	0.54	-41.49	50.85	-0.70	0.86
		Spring	551	1.91	1.33	0.40	-30.07	49.04	-0.57	0.94
		Summer	521	2.56	1.65	0.51	-35.45	53.51	-0.91	1.37
		Fall	530	1.46	1.32	0.38	-9.55	50.33	-0.14	0.74
		All	2029	1.91	1.34	0.48	-29.94	51.17	-0.57	0.98



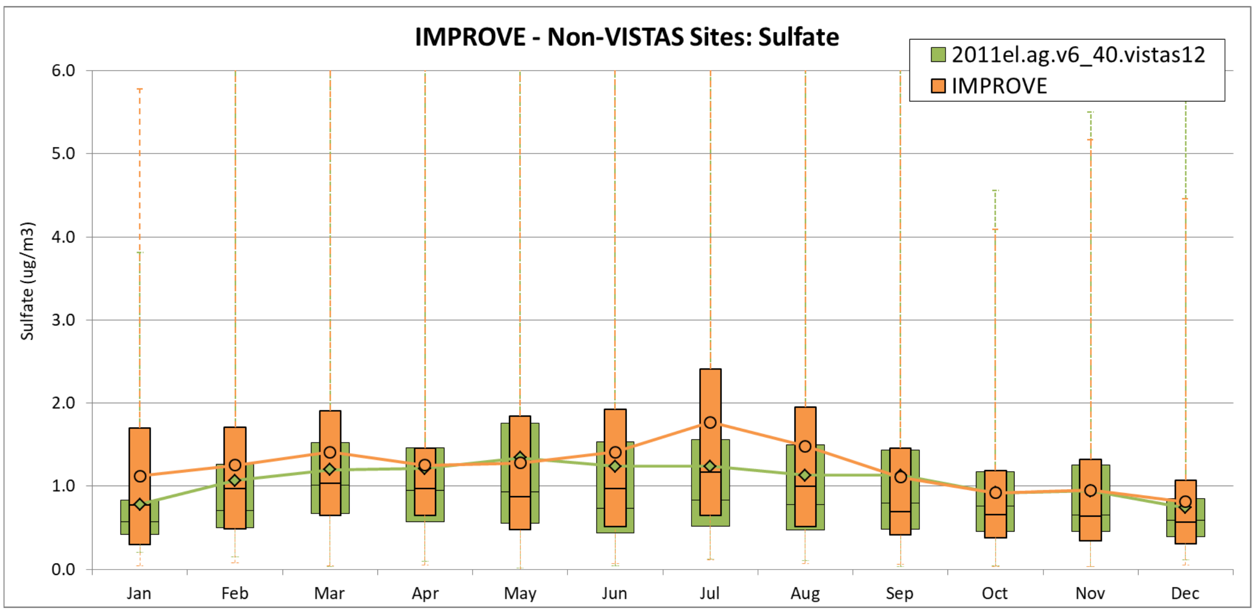
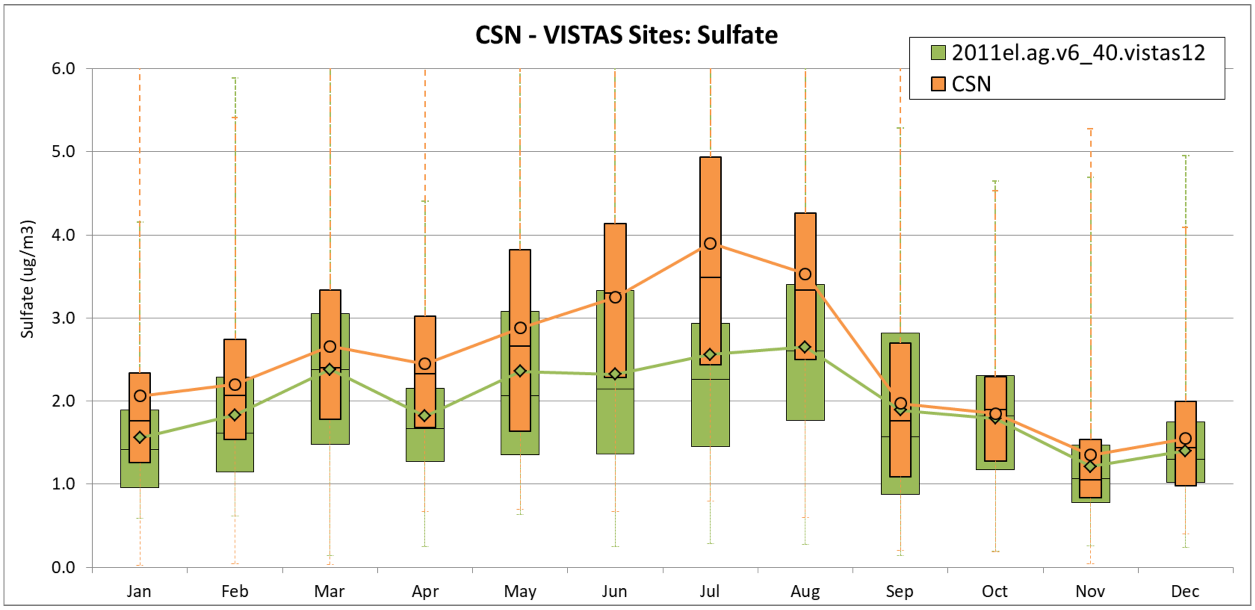


Figure 3-1. Boxplot Comparisons of Model Predictions and IMRPOVE Sulfate Observations for Each Climate Region by Month.



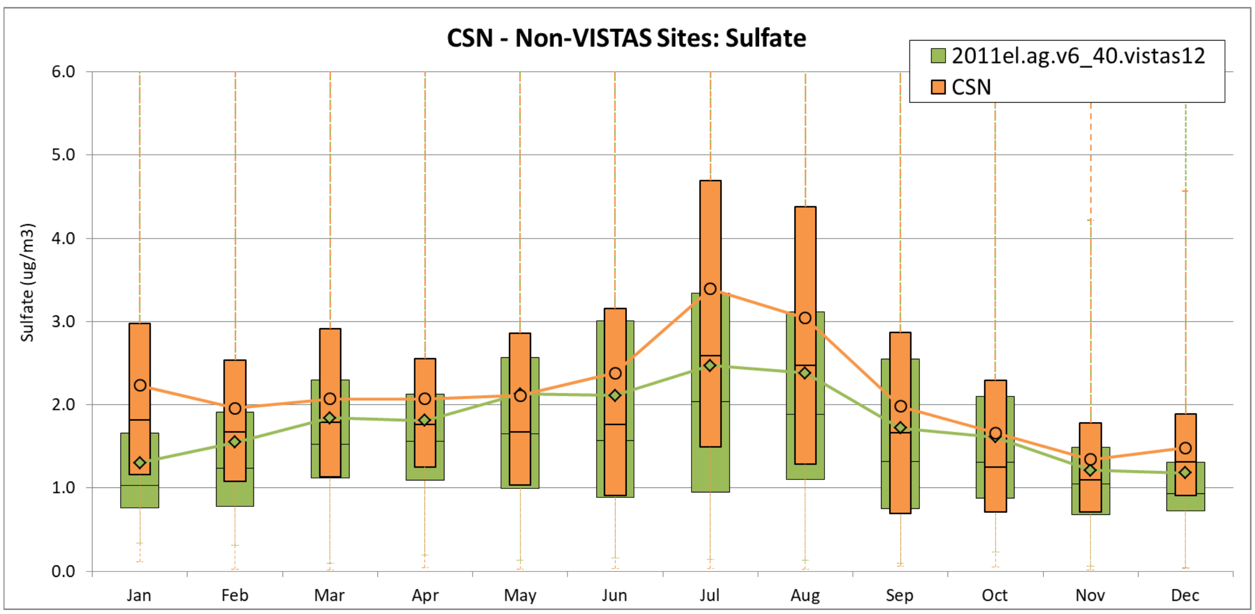


Figure 3-2. Boxplot Comparisons of Model Predictions and CSN Sulfate Observations for Each Climate Region by Month.

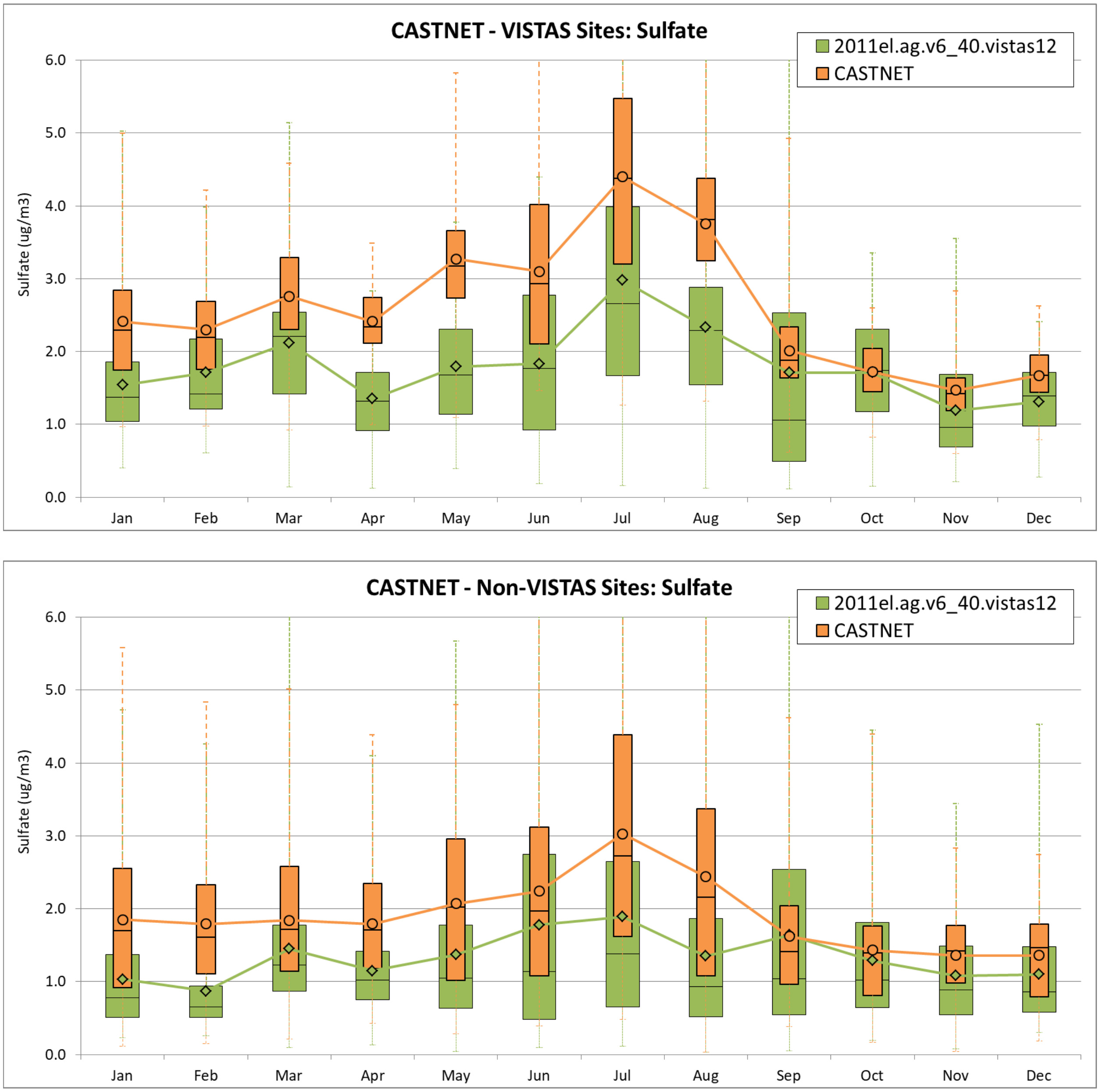


Figure 3-3. Boxplot Comparisons of Model Predictions and CASTNET Sulfate Observations for Each Climate Region by Month.

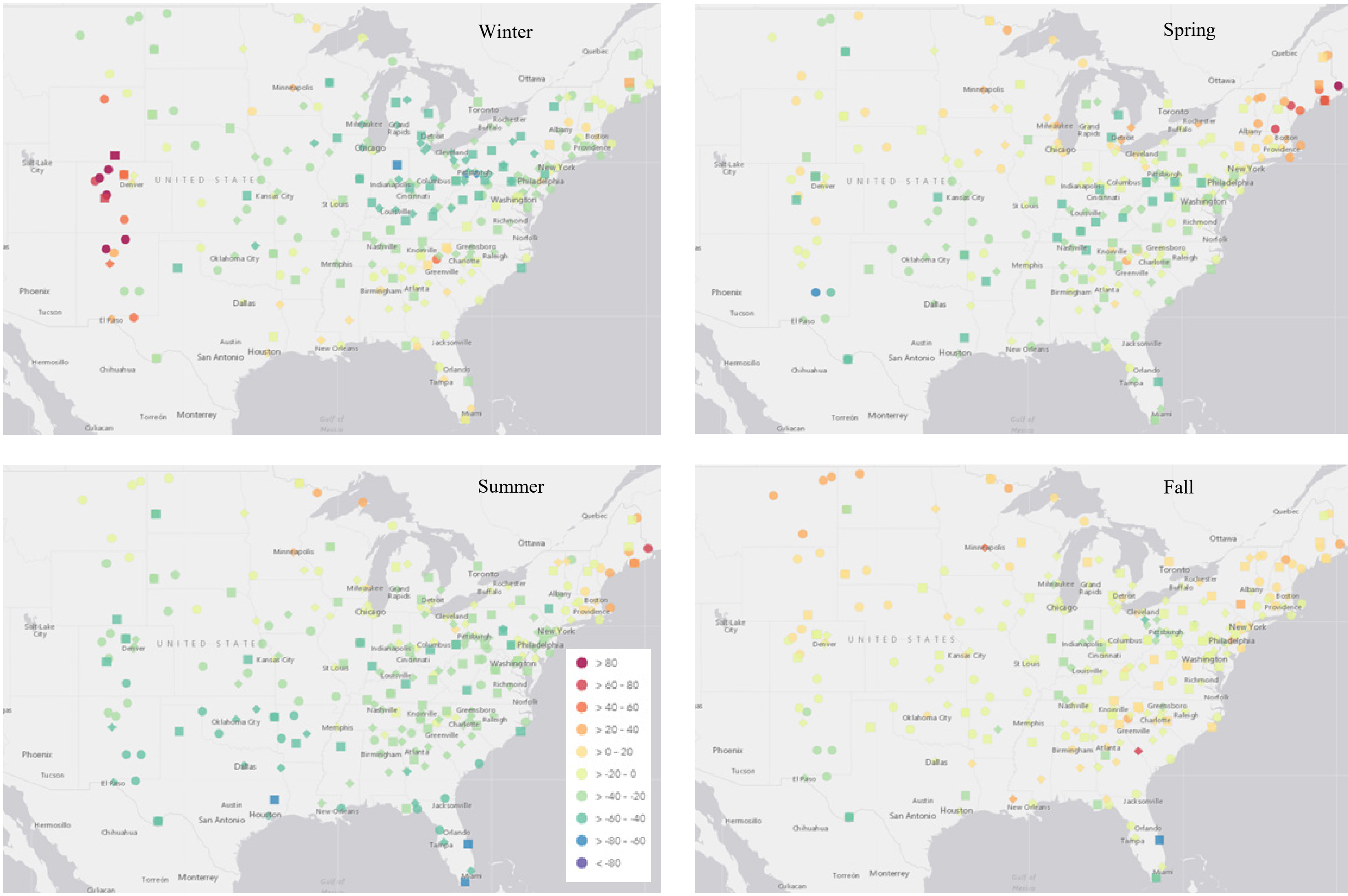


Figure 3-4. Spatial Plots of Sulfate NMB by Season and Network (Circle = IMPROVE, Square = CASTNET, Diamond = CSN).

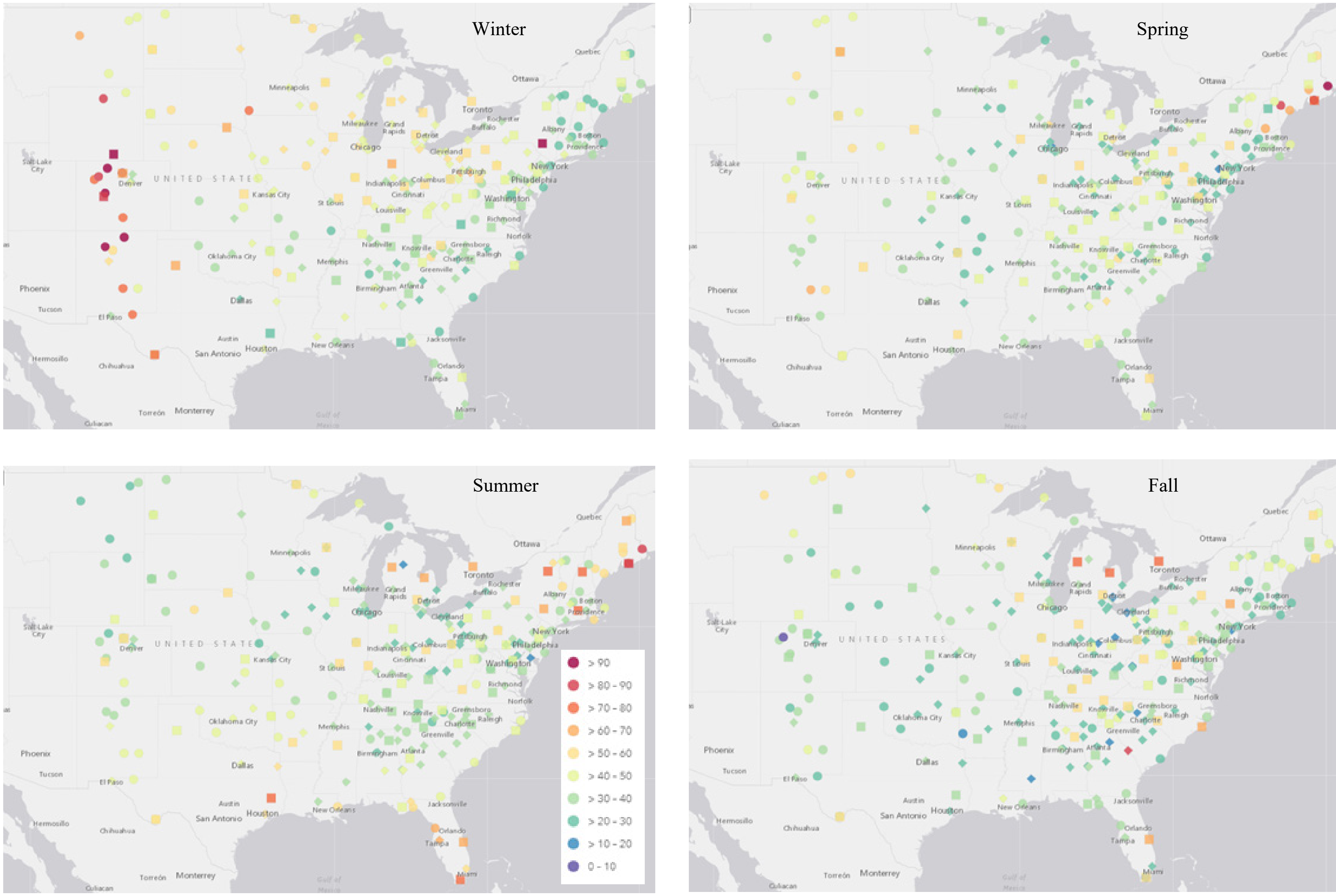


Figure 3-5. Spatial Plots of Sulfate NME by Season and Network (Circle = IMPROVE, Square = CASTNET, Diamond = CSN).

4.0 $PM_{2.5}$ NITRATE

Table 4-1 summarizes model performance statistics for $PM_{2.5}$ nitrate. Boxplot comparisons of model predictions and observations (IMPROVE, CSN, and CASTNET) by month for each climate region are shown in Figures 4-1, 4-2, and 4-3. VISTAS12 modeling domain spatial plots of NMB and NME for each season are shown in Figures 4-4 and 4-5.

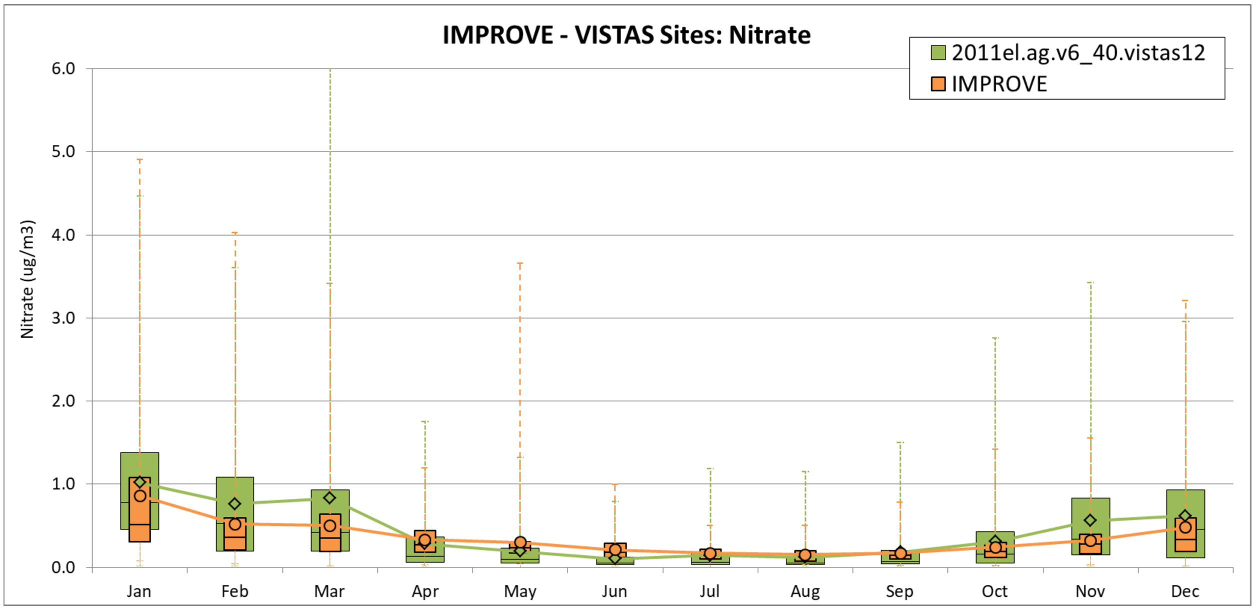
Nitrate performance in the VISTAS12 modeling domain shows strong seasonal variation. The model under predicts at networks in the summer months (-30.96% to -49.69%) and over predicts at networks during the fall (7.60% to 51.78%). Both the model and the observation show the lowest average nitrate concentrations in the summer. Under predictions of nitrate persist across all seasons and networks with low observed nitrate concentrations and significantly over predictions during months when observed nitrate is highest. An exception is noted regarding under prediction in non-VISTAS states in both the CASTNET and CSN observations during the highest observed nitrate concentrations in winter months.

Over prediction of nitrate is seen geographically across most of the VISTAS12 modeling domain especially in the northeast during most months and the northwestern quadrant of the domain during the cooler months of winter and fall.

Under prediction of nitrate is noted at networks in most of the VISTAS states during the summer months and along the western border of the domain in spring and summer.

Table 4-1. Model Performance Statistics for $PM_{2.5}$ Nitrate by Region, Network, and Season.

Region	Network	Season	N	Avg. Obs. (µg/m³)	Avg. Pre. (µg/m³)	r	NMB (%)	NME (%)	MB (µg/m³)	ME (µg/m³)
VISTAS	IMPROVE	Winter	389	0.62	0.81	0.55	29.14	75.87	0.18	0.47
		Spring	405	0.39	0.46	0.32	20.09	97.74	0.08	0.38
		Summer	390	0.18	0.12	0.22	-30.96	78.32	-0.05	0.14
		Fall	381	0.24	0.34	0.43	41.04	102.06	0.10	0.25
		All	1565	0.36	0.43	0.51	21.25	86.61	0.08	0.31
	CSN	Winter	623	1.07	1.40	0.52	31.82	70.18	0.34	0.75
		Spring	647	0.55	0.68	0.38	23.04	84.80	0.13	0.47
		Summer	675	0.28	0.17	0.26	-37.94	62.40	-0.10	0.17
		Fall	636	0.39	0.60	0.49	51.78	94.99	0.20	0.37
		All	2581	0.56	0.70	0.58	24.18	77.02	0.14	0.43
	CASTNET	Winter	241	1.26	1.12	0.47	-11.28	60.57	-0.14	0.77
		Spring	302	0.61	0.49	0.22	-20.01	77.22	-0.12	0.47
		Summer	274	0.28	0.14	0.31	-49.69	78.85	-0.14	0.22
		Fall	277	0.52	0.56	0.17	7.60	87.38	0.04	0.45
		All	1094	0.65	0.56	0.48	-13.89	72.31	-0.09	0.47
Non-VISTAS	IMPROVE	Winter	1611	1.05	1.26	0.70	19.69	66.59	0.21	0.70
		Spring	1750	0.60	0.75	0.82	25.43	69.75	0.15	0.42
		Summer	1703	0.19	0.11	0.52	-39.73	76.22	-0.08	0.15
		Fall	1655	0.33	0.50	0.80	52.12	91.85	0.17	0.30
		All	6719	0.54	0.65	0.76	20.89	72.17	0.11	0.39
	CSN	Winter	1784	2.67	2.53	0.70	-5.45	41.71	-0.15	1.11
		Spring	1889	1.48	1.62	0.79	9.15	51.33	0.14	0.76
		Summer	1899	0.52	0.34	0.52	-34.52	64.58	-0.18	0.34
		Fall	1829	0.94	1.14	0.75	20.28	59.15	0.19	0.56
		All	7401	1.39	1.39	0.78	0.06	49.46	0.00	0.69
	CASTNET	Winter	427	1.88	1.77	0.46	-6.09	70.27	-0.11	1.32
		Spring	551	0.85	0.99	0.56	17.1	88.84	0.14	0.75
		Summer	521	0.33	0.22	0.10	-35.05	99.67	-0.12	0.33
		Fall	530	0.73	0.97	0.52	34.12	100.28	0.25	0.73
		All	2029	0.90	0.95	0.54	5.56	84.10	0.05	0.76



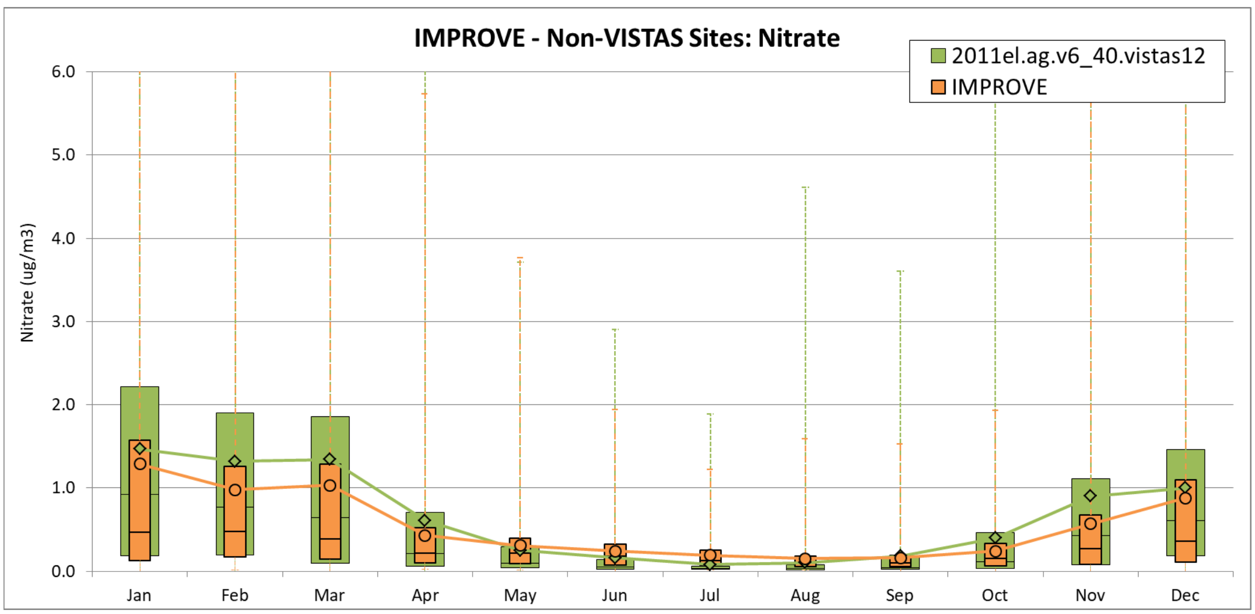


Figure 4-1. Boxplot Comparisons of Model Predictions and IMPROVE Nitrate Observations for Each Climate Region by Month.

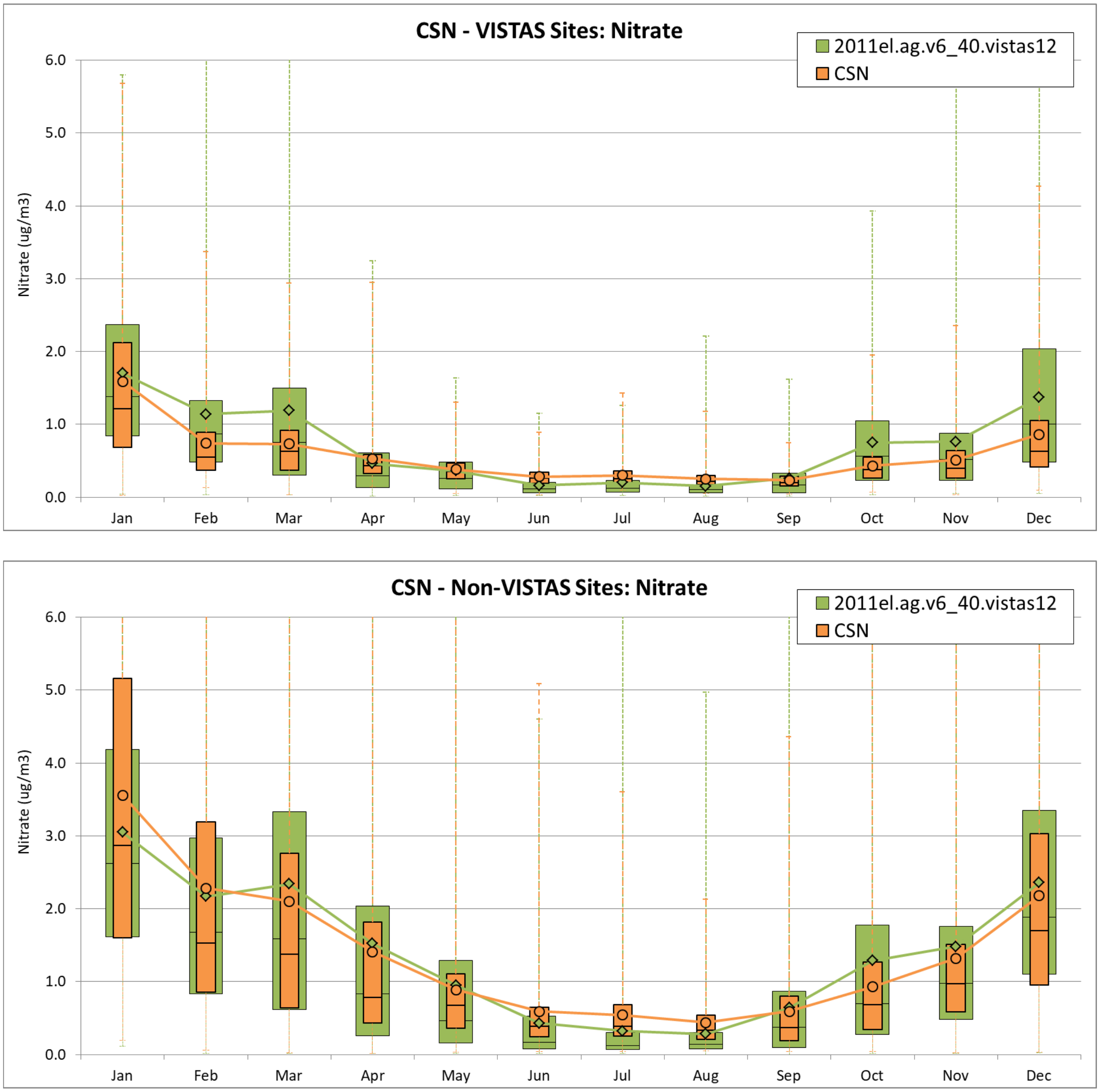
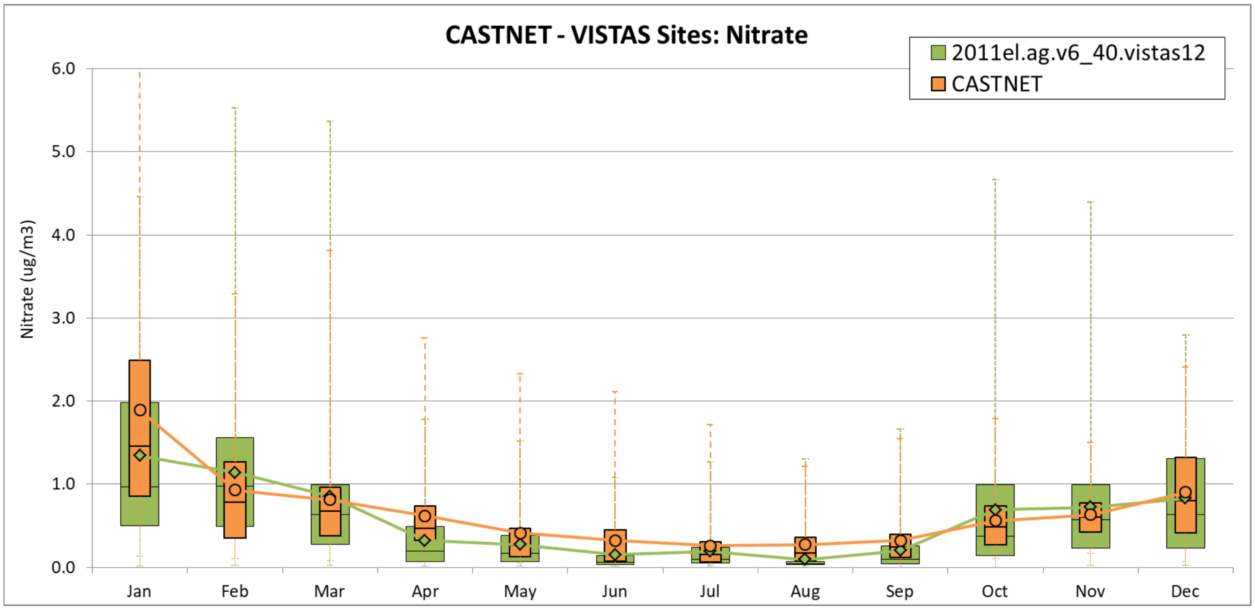


Figure 4-2. Boxplot Comparisons of Model Predictions and CSN Nitrate Observations for Each Climate Region by Month.



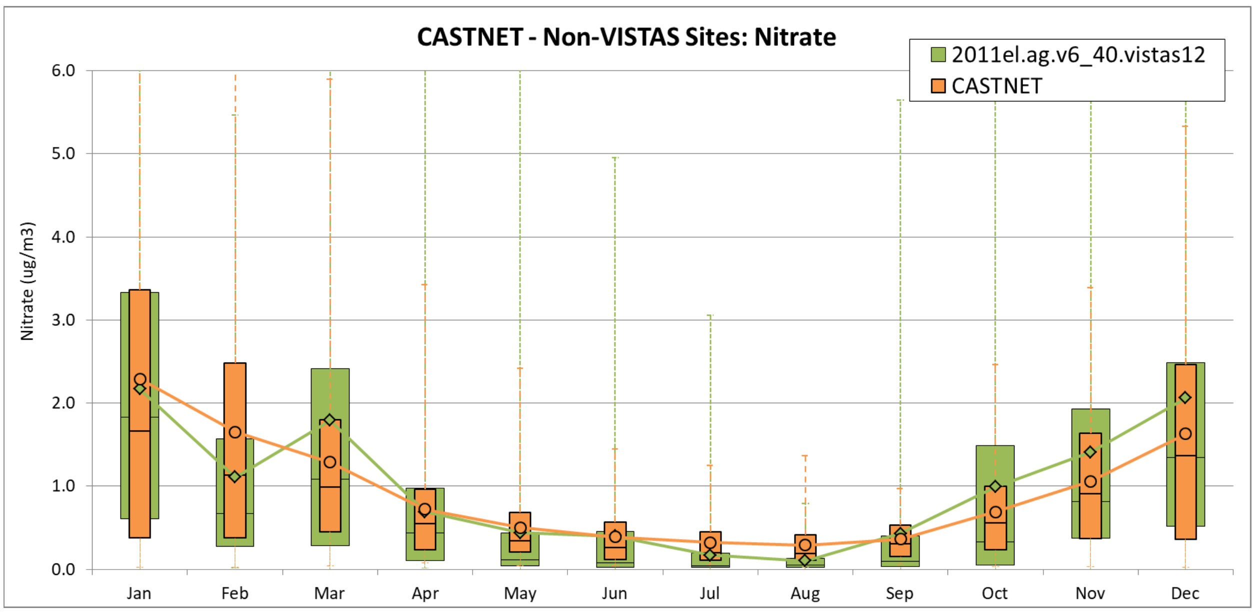


Figure 4-3. Boxplot Comparisons of Model Predictions and CASTNET Nitrate Observations for Each Climate Region by Month.

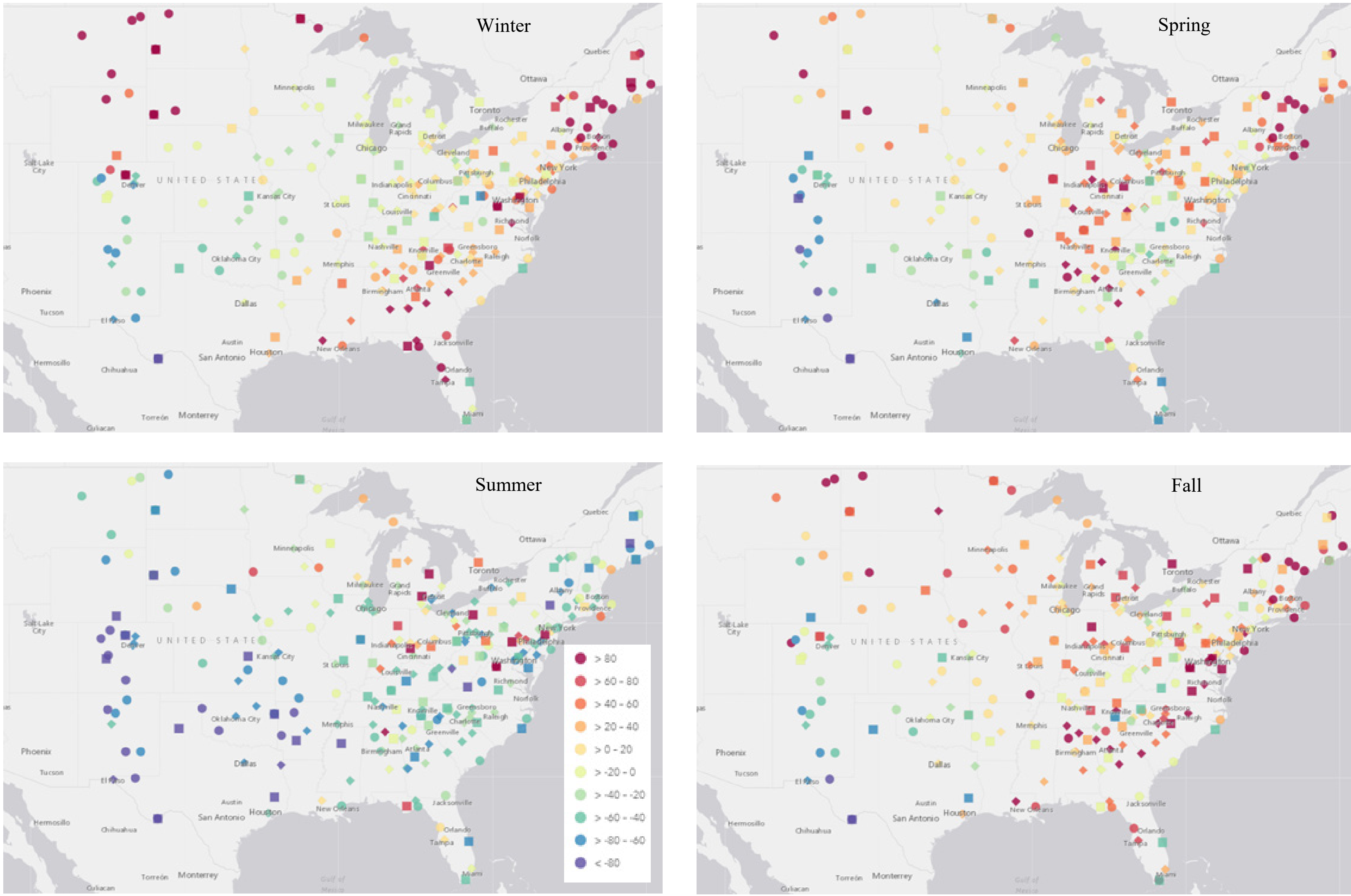


Figure 4-4. Spatial Plots of Nitrate NMB by Season and Network (Circle = IMPROVE, Square = CASTNET, Diamond = CSN).

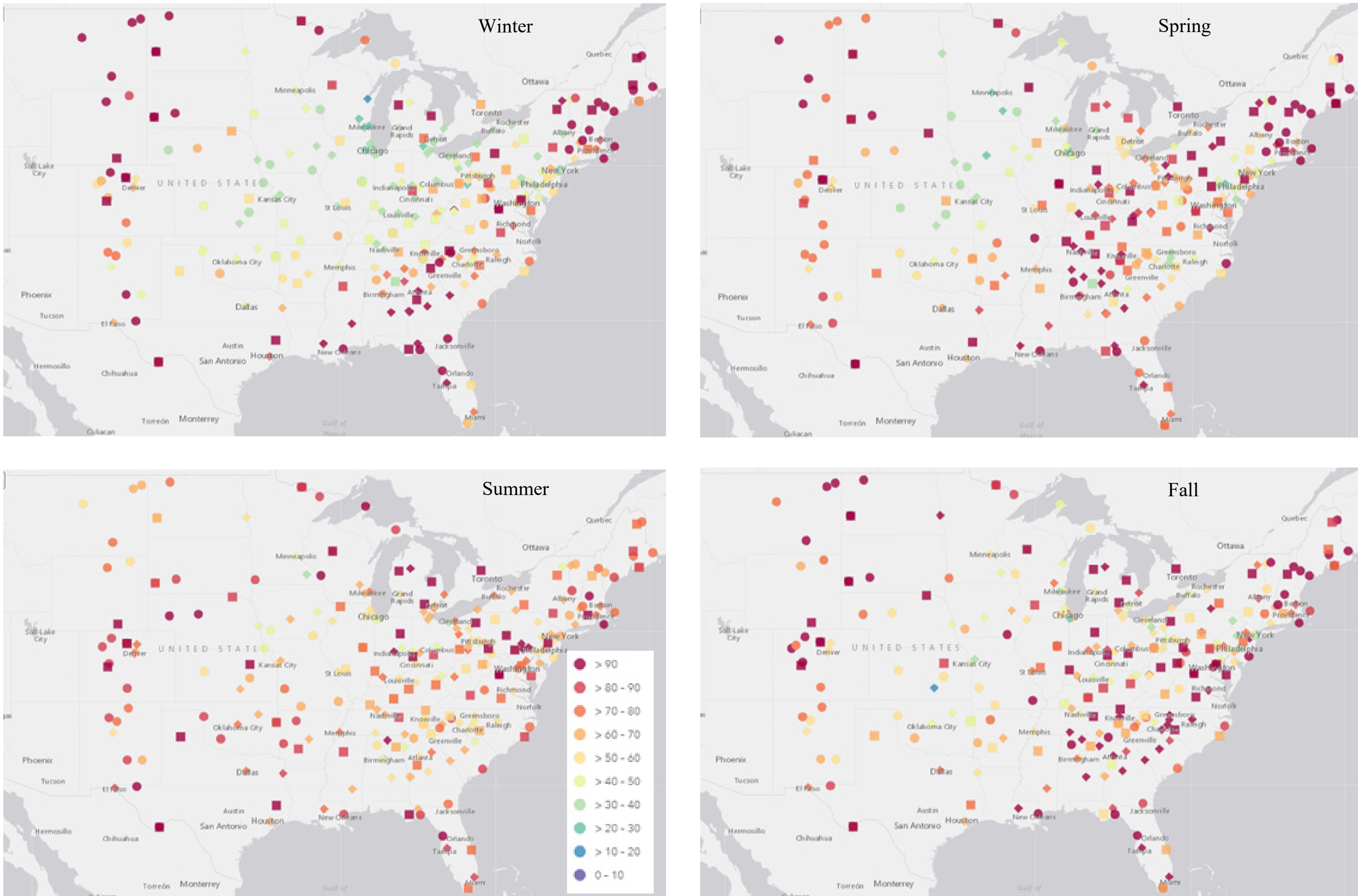


Figure 4-5. Spatial Plots of Nitrate NME by Season and Network (Circle = IMPROVE, Square = CASTNET, Diamond = CSN).

5.0 $PM_{2.5}$ AMMONIUM

Table 5-1 summarizes model performance statistics for $PM_{2.5}$ ammonium. Boxplot comparisons of model predictions and observations (CSN and CASTNET) by month for each climate region are shown in Figures 5-1 and 5-2. VISTAS12 modeling domain spatial plots of NMB and NME for each season are shown in Figures 5-3 and 5-4 (note that the IMPROVE network does not measure ammonium).

Ammonium is generally under predicted across the VISTAS12 domain in all seasons, with the exception of over prediction in the fall months. In the VISTAS state receptor networks, ammonium is generally under predicted with a significant over prediction observed during the lowest observed concentration fall months in the CSN. While both the model and the observations in the VISTAS states show the lowest average ammonium concentrations in the fall, the model predictions show less seasonal variability than the observations.

Over prediction of ammonium is seen across much of the eastern half of the VISTAS12 modeling domain during fall months and along the northern border of the domain during most seasons with noted under prediction seen at peninsular Florida CASTNET sites across most seasons.

Table 5-1. Model Performance Statistics for $PM_{2.5}$ Ammonium by Region, Network, and Season

Region	Network	Season	N	Avg. Obs. (µg/m³)	Avg. Pre. (µg/m³)	r	NMB (%)	NME (%)	MB (µg/m³)	ME (µg/m³)
VISTAS	CSN	Winter	618	0.82	0.88	0.61	7.65	42.73	0.06	0.35
		Spring	644	0.82	0.80	0.61	-2.93	41.52	-0.02	0.34
		Summer	673	0.88	0.80	0.69	-8.88	34.35	-0.08	0.30
		Fall	624	0.42	0.67	0.68	60.09	70.46	0.25	0.29
		All	2559	0.74	0.79	0.63	6.73	43.58	0.05	0.32
	CASTNET	Winter	241	0.93	0.71	0.57	-23.39	38.57	-0.22	0.36
		Spring	302	0.87	0.63	0.42	-28.38	44.38	-0.25	0.39
		Summer	274	1.17	0.70	0.61	-40.17	45.97	-0.47	0.54
		Fall	277	0.55	0.57	0.32	2.89	59.60	0.02	0.33
		All	1094	0.88	0.65	0.48	-26.16	45.97	-0.23	0.40
Non-VISTAS	CSN	Winter	1781	1.31	1.19	0.69	-9.57	38.97	-0.13	0.51
		Spring	1873	1.01	1.10	0.78	8.25	37.59	0.08	0.38
		Summer	1884	0.87	0.83	0.79	-5.17	37.97	-0.05	0.33
		Fall	1796	0.62	0.82	0.77	32.80	52.20	0.20	0.32
		All	7334	0.95	0.98	0.75	3.02	40.46	0.03	0.39
	CASTNET	Winter	427	1.02	0.82	0.55	-20.05	51.55	-0.20	0.53
		Spring	551	0.74	0.71	0.57	-4.44	50.62	-0.03	0.38
		Summer	521	0.85	0.59	0.50	-31.14	53.61	-0.27	0.46
		Fall	530	0.59	0.69	0.39	16.02	66.97	0.10	0.40
		All	2029	0.79	0.70	0.48	-12.06	54.91	-0.10	0.43

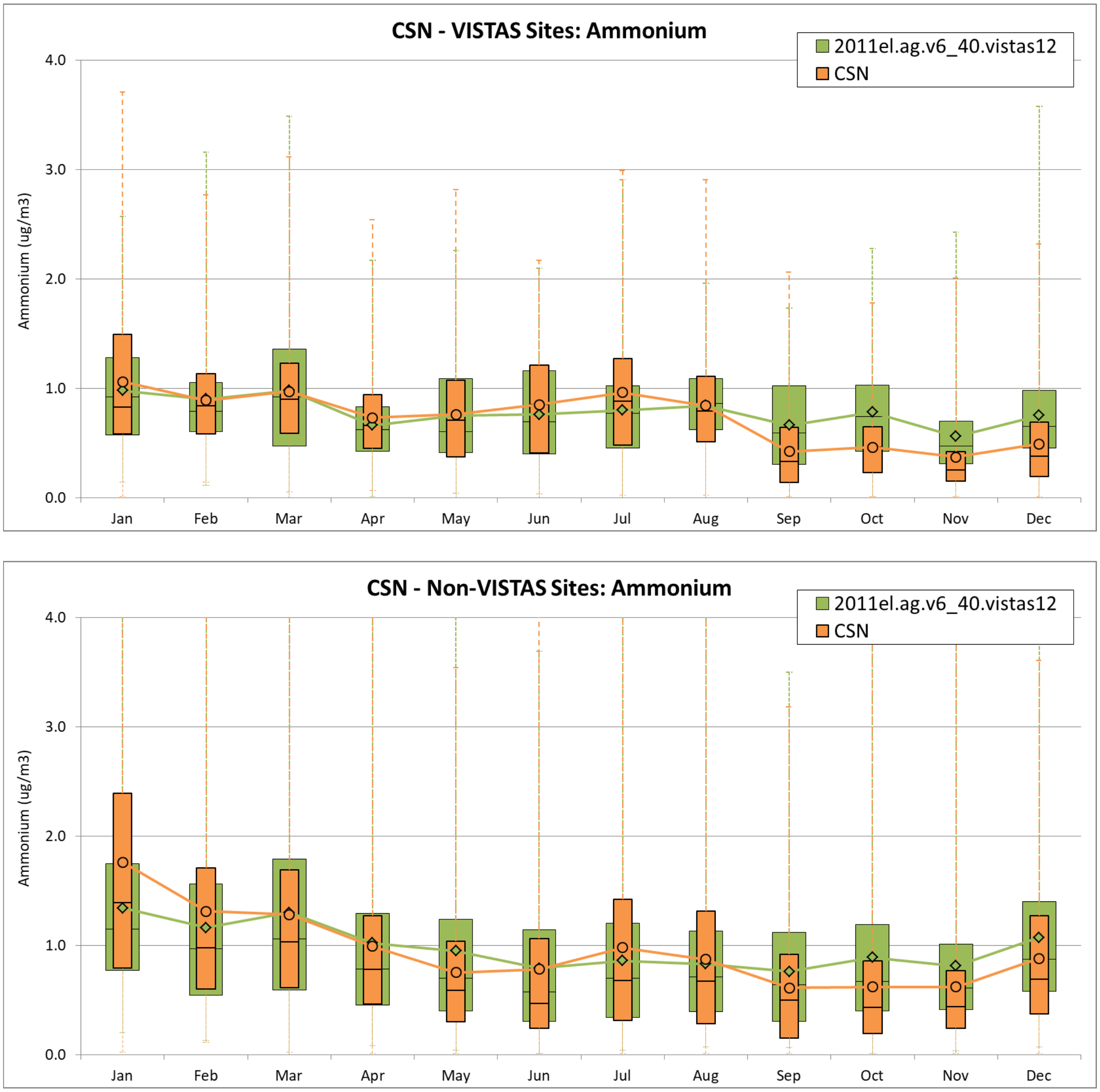
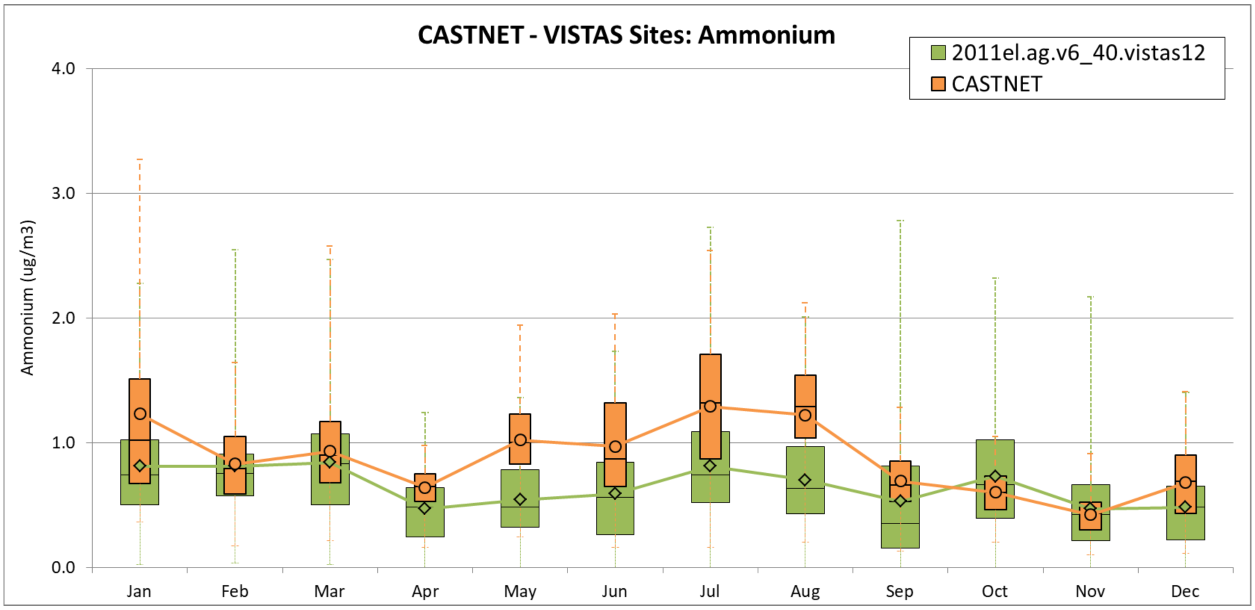


Figure 5-1. Boxplot Comparisons of Model Predictions and CSN Ammonium Observations for Each Climate Region by Month.



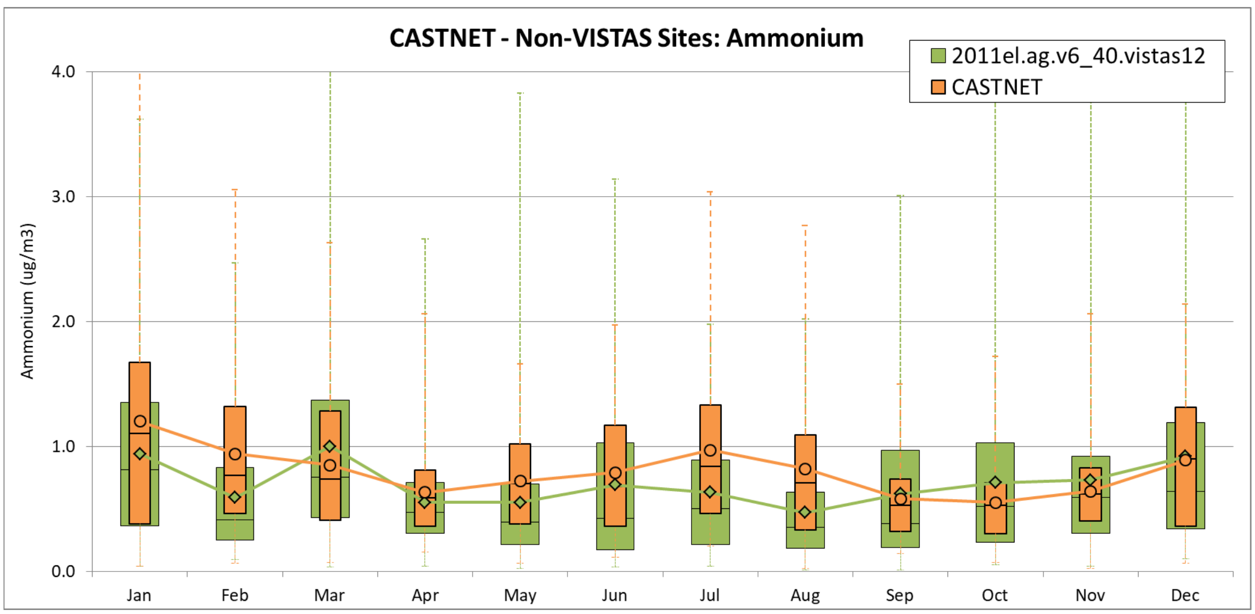


Figure 5-2. Boxplot Comparisons of Model Predictions and CASTNET Ammonium Observations for Each Climate Region by Month.

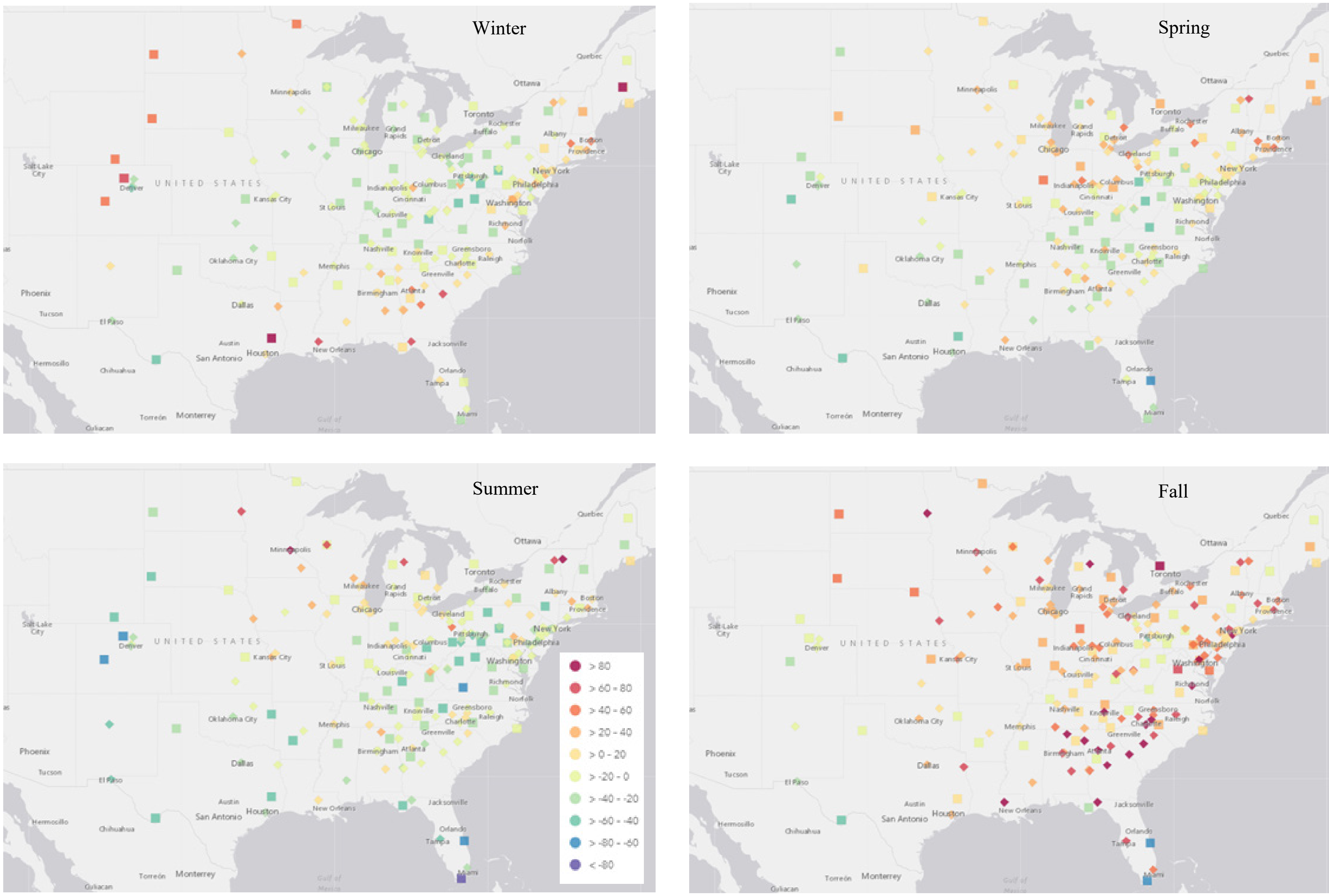


Figure 5-3. Spatial Plots of Ammonium NMB by Season and Network (Square = CASTNET, Diamond = CSN).

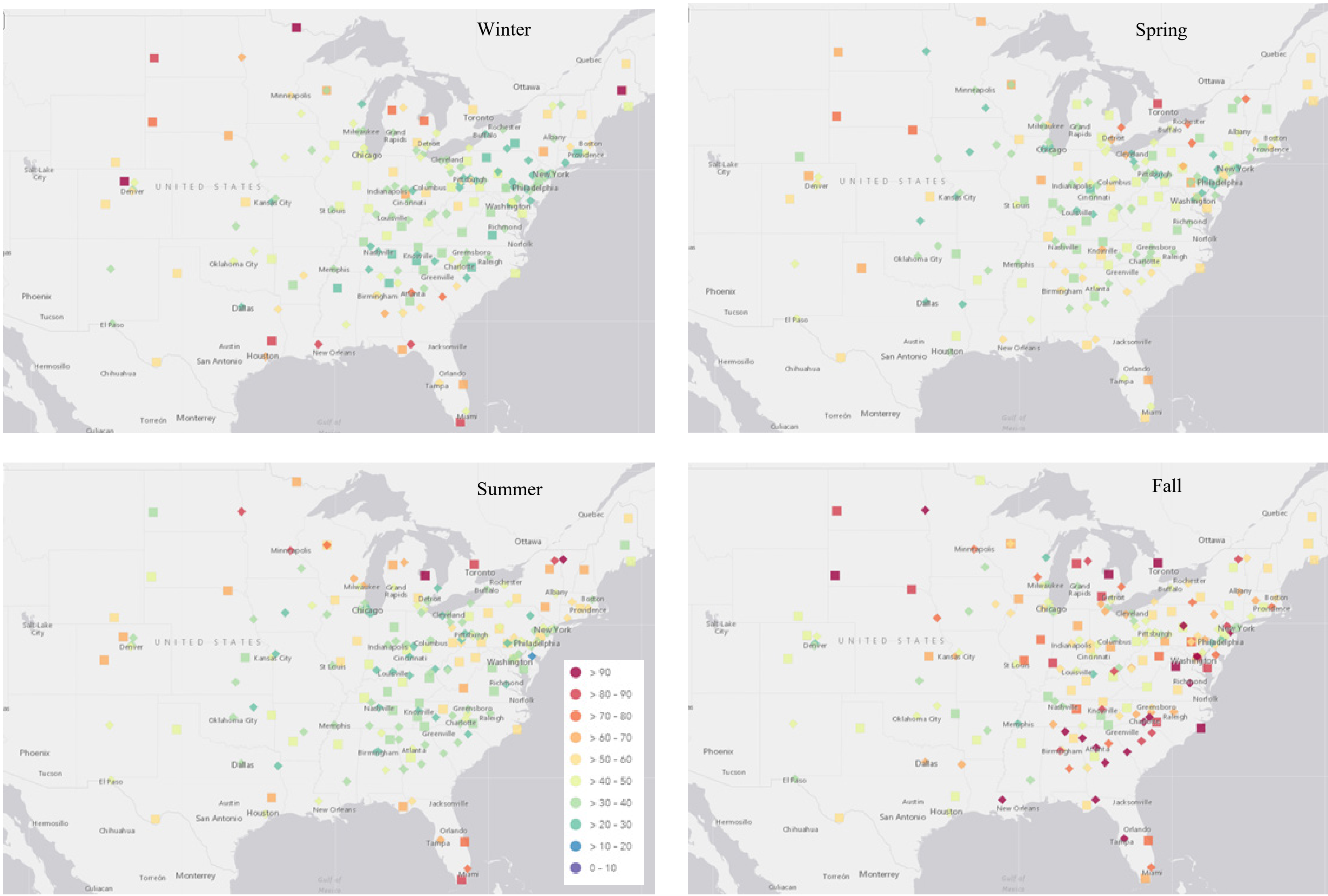


Figure 5-4. Spatial Plots of Ammonium NME by Season and Network (Square = CASTNET, Diamond = CSN).

6.0 $PM_{2.5}$ OC

Table 6-1 summarizes model performance statistics for $PM_{2.5}$ organic carbon (OC). To provide a direct comparison to the observational data, as noted in Table 2-2, CAMx's OM was divided by 1.8 and 1.4, respectively, to generate OC for IMPROVE and CSN receptors. Boxplot comparisons of model predictions and observations (IMPROVE and CSN) by month for each climate region are shown in Figures 6-1 and 6-2. VISTAS12 modeling domain spatial plots of NMB and NME for each season are shown in Figures 6-3 and 6-4.

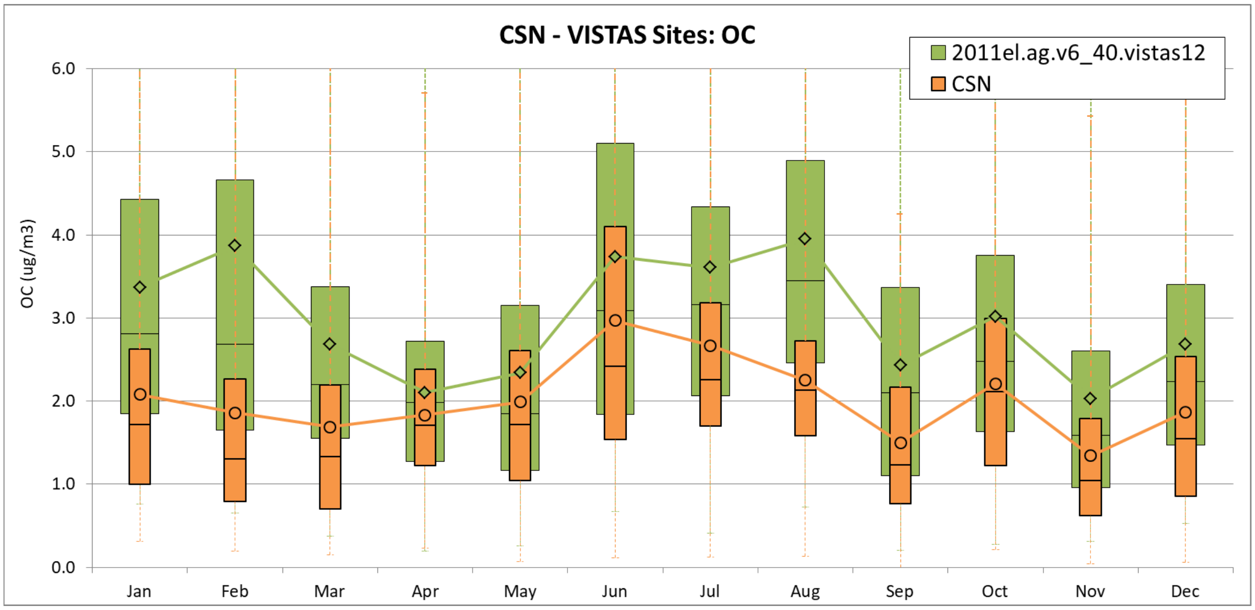
Both the model and the observations show the highest average OC concentrations in the summer. OC is generally overestimated for the CSN network and underestimated for the IMPROVE network. OC is generally over predicted in the VISTAS12 domain across seasons outside of the summer. The greatest noted NMB includes winter month over prediction (163.33%) in non-VISTAS receptors from the CSN.

The most significant over prediction of OC is seen across the northern half of the VISTAS12 modeling domain during winter months with high over predictions also seen in the region during spring and fall seasons.

Table 6-1. Model Performance Statistics for $PM_{2.5}$ OC by Region, Network, and Season.

Region	Network	Season	N	Avg. Obs. ($\mu g/m^3$)	Avg. Pre. ($\mu g/m^3$)	r	NMB (%)	NME (%)	MB ($\mu g/m^3$)	ME ($\mu g/m^3$)
VISTAS	IMPROVE	Winter	406	1.32	1.49	0.63	12.62	48.46	0.17	0.64
		Spring	433	1.81	1.22	0.35	-32.46	49.52	-0.59	0.90
		Summer	425	2.18	1.60	0.31	-26.87	47.47	-0.59	1.04
		Fall	411	1.31	1.09	0.38	-16.76	48.67	-0.22	0.64
		All	1675	1.66	1.35	0.35	-18.89	48.47	-0.31	0.81
	CSN	Winter	607	1.94	3.31	0.57	71.02	85.84	1.37	1.66
		Spring	612	1.83	2.38	0.60	29.73	51.48	0.55	0.94
		Summer	664	2.61	3.78	0.39	44.82	64.15	1.17	1.67
		Fall	617	1.68	2.49	0.63	48.12	63.72	0.81	1.07
		All	2500	2.03	3.00	0.55	48.22	66.28	0.98	1.34
Non-VISTAS	IMPROVE	Winter	1666	0.75	1.19	0.51	59.06	87.07	0.44	0.65
		Spring	1831	0.84	0.81	0.57	-3.52	56.96	-0.03	0.48
		Summer	1764	1.43	1.15	0.49	-19.53	46.28	-0.28	0.66
		Fall	1700	0.98	1.06	0.70	8.30	55.31	0.08	0.54
		All	6961	1.00	1.05	0.62	4.69	58.08	0.05	0.58
	CSN	Winter	1706	1.57	4.13	0.52	163.33	169.30	2.56	2.66
		Spring	1824	1.27	2.20	0.30	72.88	90.62	0.93	1.15
		Summer	1903	2.01	2.35	0.54	16.61	40.83	0.33	0.82
		Fall	1763	1.44	2.41	0.64	68.03	76.19	0.98	1.09
		All	7196	1.58	2.75	0.40	74.16	89.18	1.17	1.41

Figure 6-1. Boxplot Comparisons of Model Predictions and IMPROVE Organic Carbon (OC) Observations for Each Climate Region by Month.



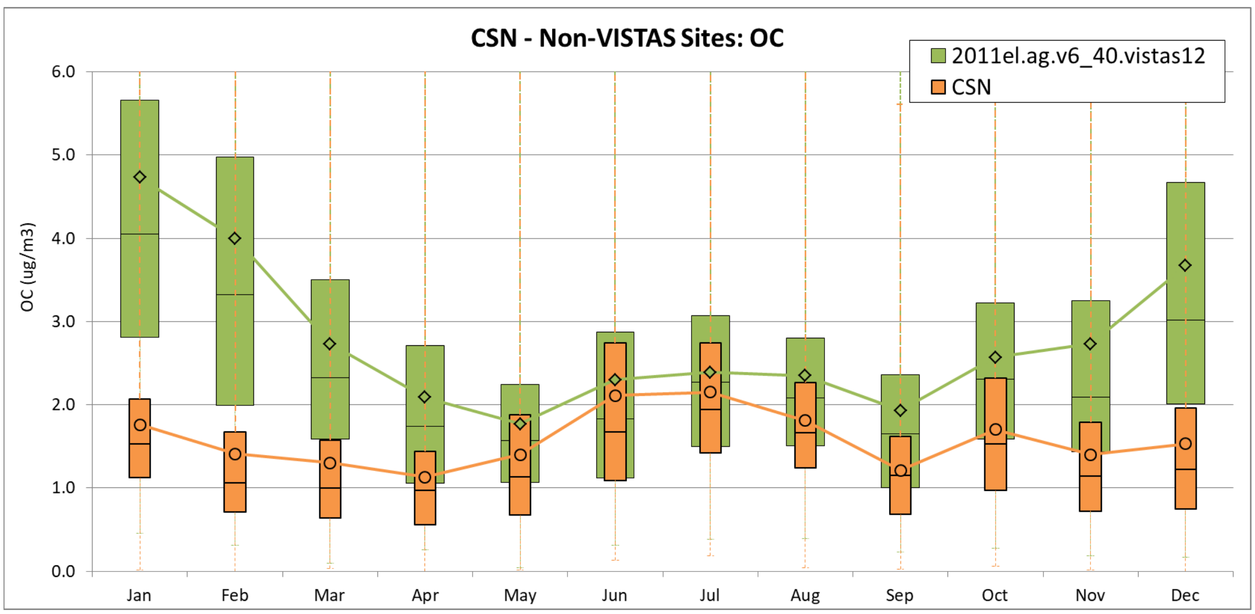


Figure 6-2. Boxplot Comparisons of Model Predictions and CSN Organic Carbon (OC) Observations for Each Climate Region by Month.

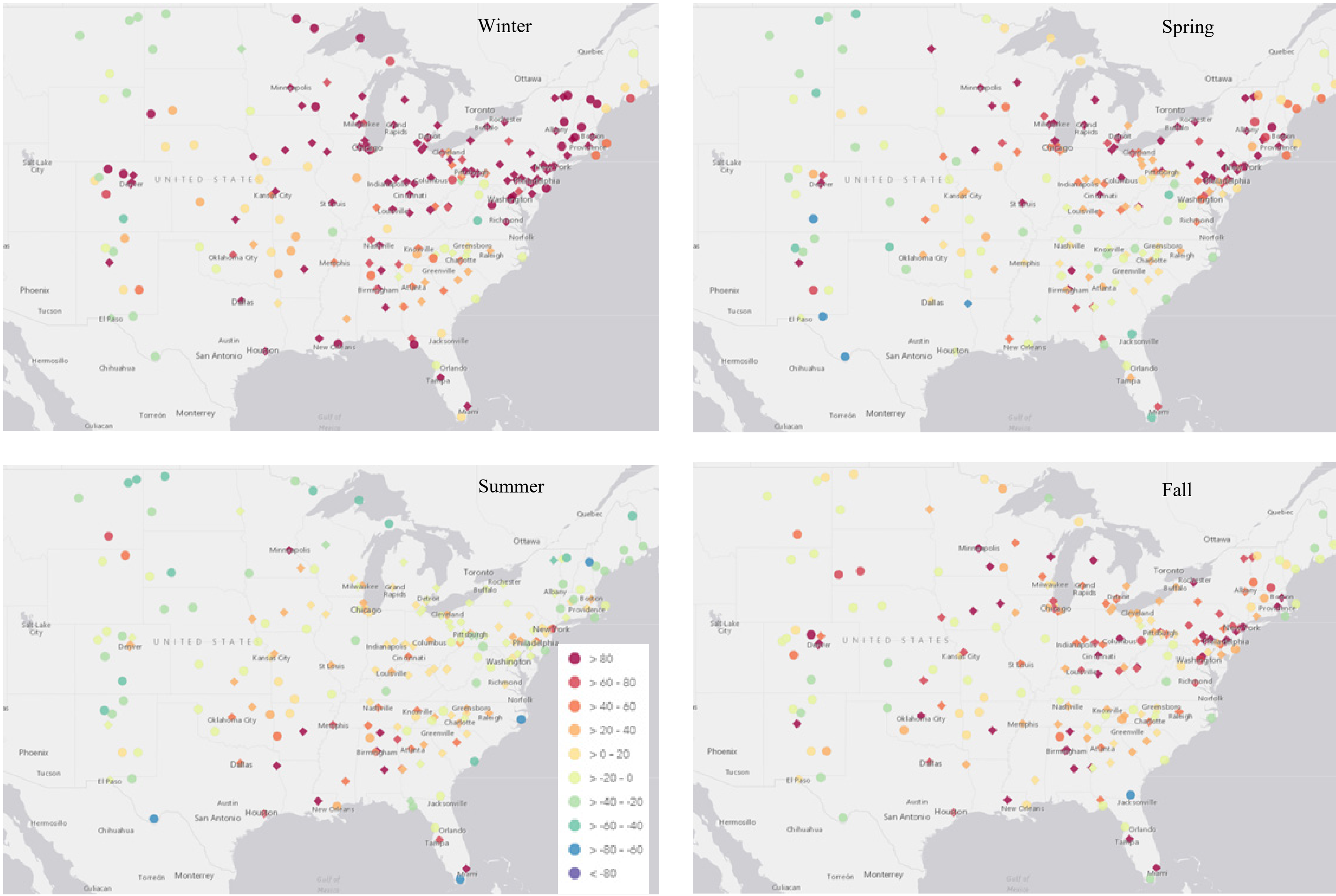


Figure 6-3. Spatial plots of organic carbon (OC) NMB by season and network (Circle = IMPROVE, Diamond = CSN).

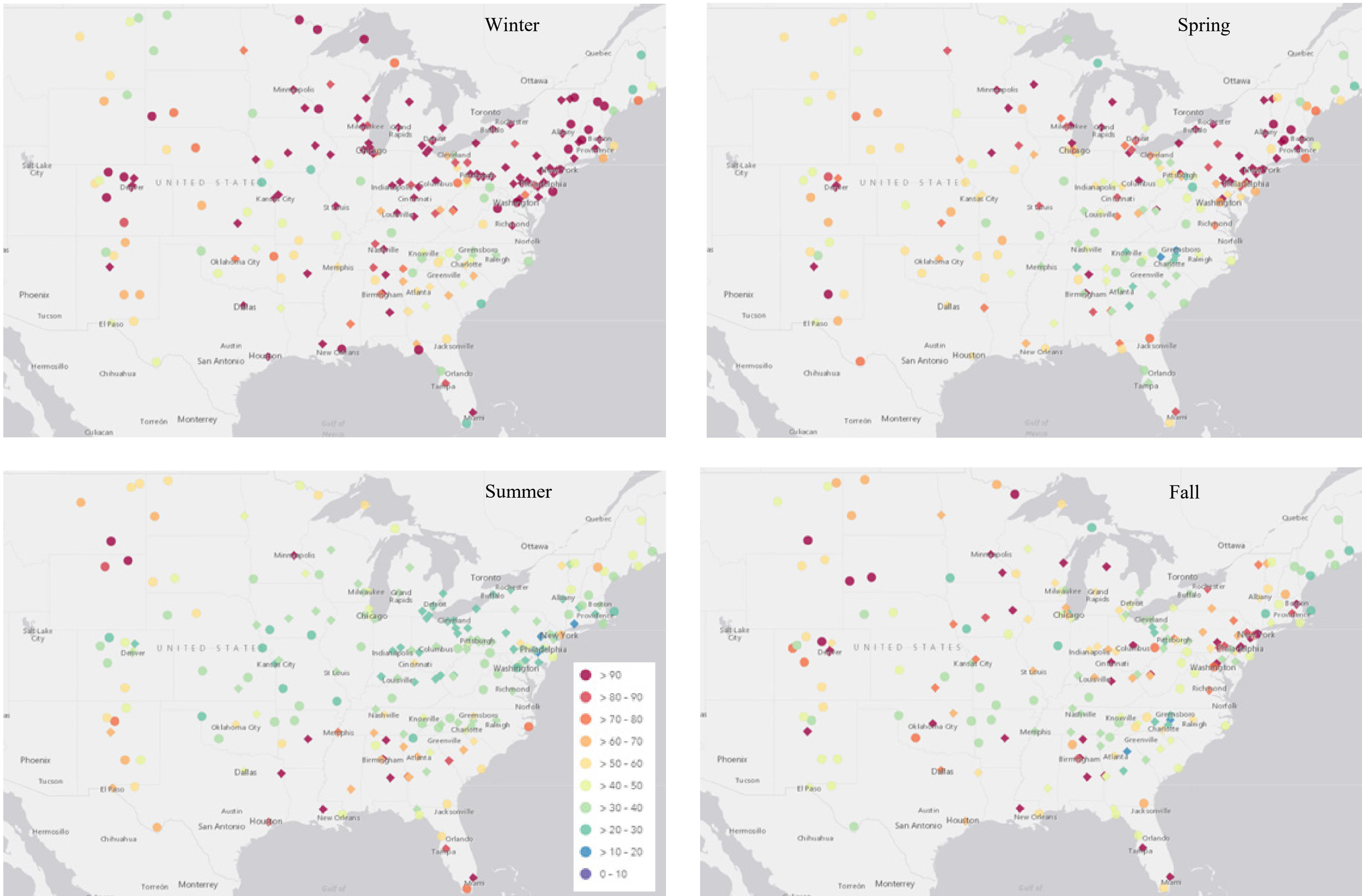


Figure 6-4. Spatial plots of organic carbon (OC) NME by season and network (Circle = IMPROVE, Diamond = CSN).

7.0 $PM_{2.5}$ EC

Table 7-1 summarizes model performance statistics for $PM_{2.5}$ EC. Boxplot comparisons of model predictions and observations (IMPROVE and CSN) by month for each climate region are shown in Figures 7-1 and 7-2. VISTAS12 modeling domain spatial plots of NMB and NME for each season are shown in Figures 7-3 and 7-4.

In the VISTAS states, EC concentrations averaged over the entire year show fairly close agreement with observations with a NMB of 0.20% at the IMPROVE monitors and 14.58% at the CSN monitors. However, on a seasonal basis the model is underestimating EC in the spring and summer and overestimating in the winter at the IMPROVE monitors. At the CSN monitors the model is overestimating except in the summer where the model NMB is a very low 0.26%.

Significant over prediction of EC is seen across most of the VISTAS12 modeling domain during winter months with high over predictions also seen in the northern half of the domain during spring and fall seasons.

Table 7-1. Model Performance Statistics for $PM_{2.5}$ EC by Region, Network, and Season.

Region	Network	Season	N	Avg. Obs. (µg/m³)	Avg. Pre. (µg/m³)	r	NMB (%)	NME (%)	MB (µg/m³)	ME (µg/m³)
VISTAS	IMPROVE	Winter	406	0.30	0.40	0.64	34.89	56.66	0.10	0.17
		Spring	433	0.31	0.27	0.38	-10.71	45.46	-0.03	0.14
		Summer	423	0.28	0.21	0.46	-24.74	42.01	-0.07	0.12
		Fall	412	0.25	0.25	0.60	0.18	38.63	0.00	0.10
		All	1674	0.28	0.28	0.45	-0.20	45.98	0.00	0.13
	CSN	Winter	610	0.67	0.87	0.56	29.28	58.09	0.20	0.39
		Spring	613	0.56	0.63	0.49	12.19	48.72	0.07	0.27
		Summer	664	0.67	0.67	0.29	-0.26	47.28	0.00	0.32
		Fall	619	0.61	0.72	0.55	18.32	49.89	0.11	0.31
		All	2506	0.63	0.72	0.49	14.58	51.03	0.09	0.32
Non-VISTAS	IMPROVE	Winter	1671	0.19	0.31	0.63	62.79	83.18	0.12	0.16
		Spring	1829	0.17	0.21	0.65	25.86	59.94	0.04	0.10
		Summer	1763	0.21	0.21	0.55	-0.97	44.60	0.00	0.10
		Fall	1702	0.20	0.28	0.61	36.63	62.53	0.07	0.13
		All	6965	0.19	0.25	0.56	29.70	61.71	0.06	0.12
	CSN	Winter	1713	0.61	1.10	0.57	80.48	95.49	0.49	0.58
		Spring	1834	0.49	0.75	0.48	53.10	72.00	0.26	0.35
		Summer	1904	0.70	0.79	0.56	12.60	44.43	0.09	0.31
		Fall	1774	0.66	0.94	0.67	42.67	60.96	0.28	0.40
		All	7225	0.62	0.89	0.56	44.59	66.31	0.27	0.41

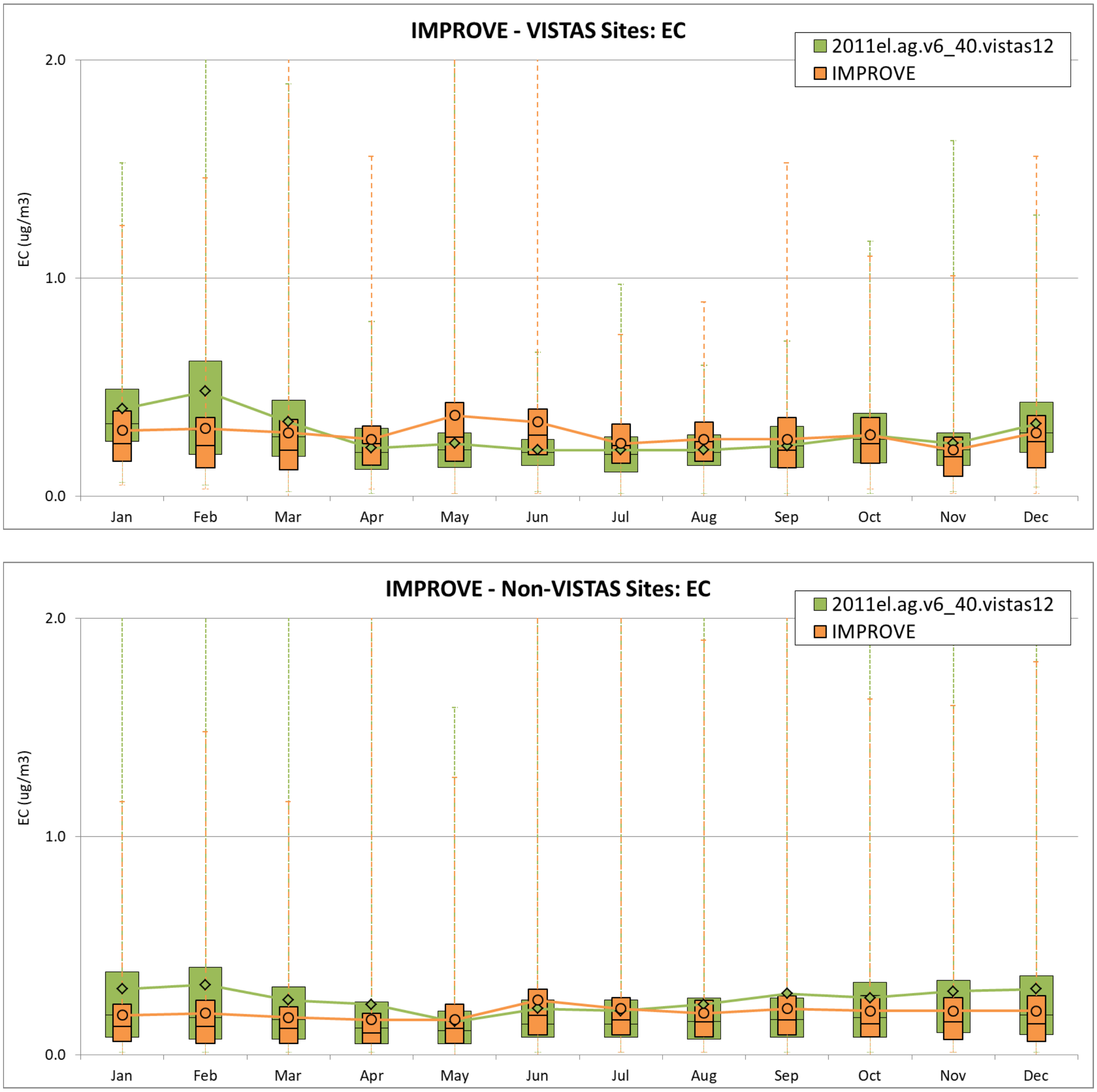


Figure 7-1. Boxplot Comparisons of Model Predictions and IMPROVE Elemental Carbon (EC) Observations for Each Climate Region by Month.

Figure 7-2. Boxplot Comparisons of Model Predictions and CSN Elemental Carbon (EC) Observations for Each Climate Region by Month.

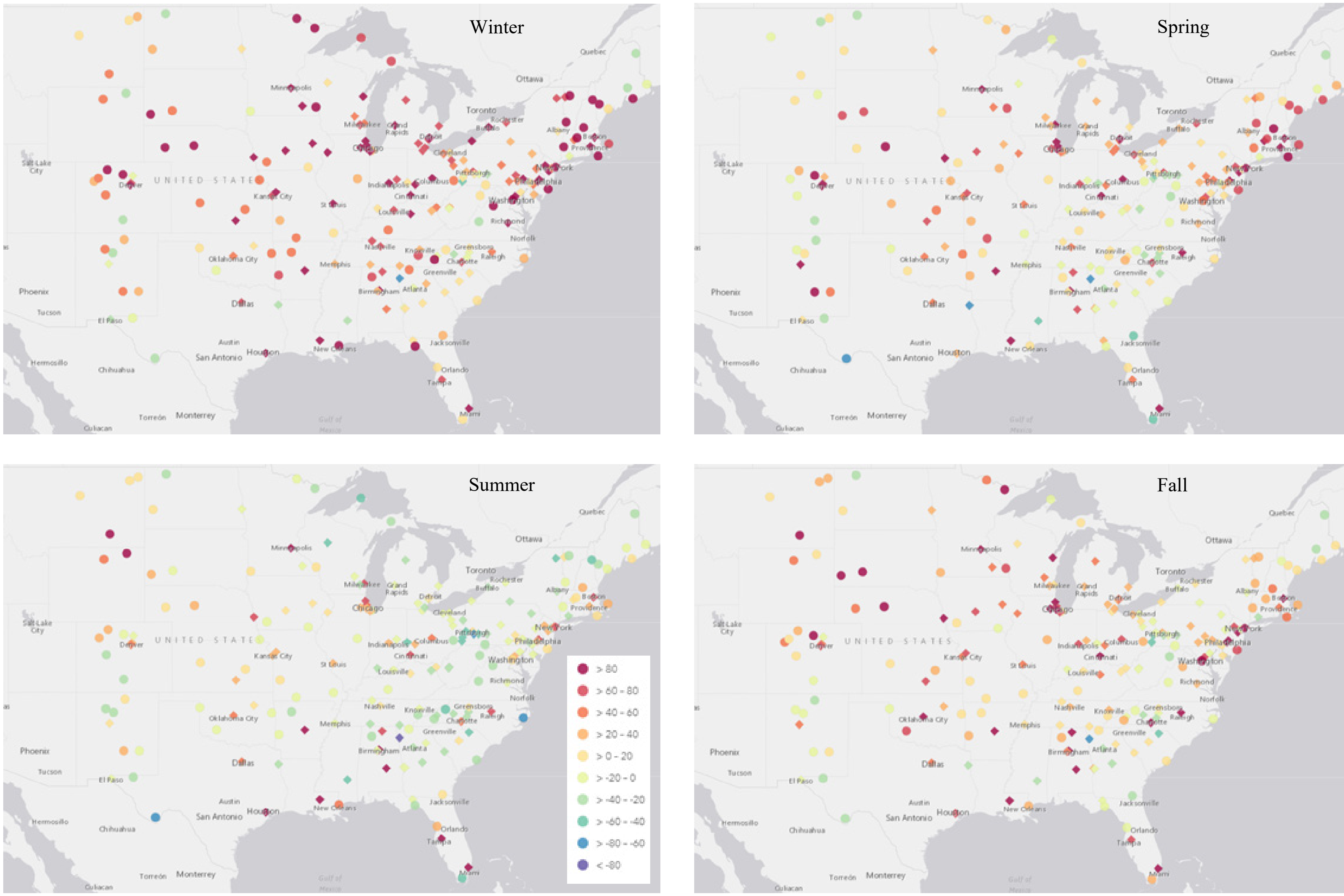


Figure 7-3. Spatial plots of elemental carbon (EC) NMB by season and network (Circle = IMPROVE, Diamond = CSN).

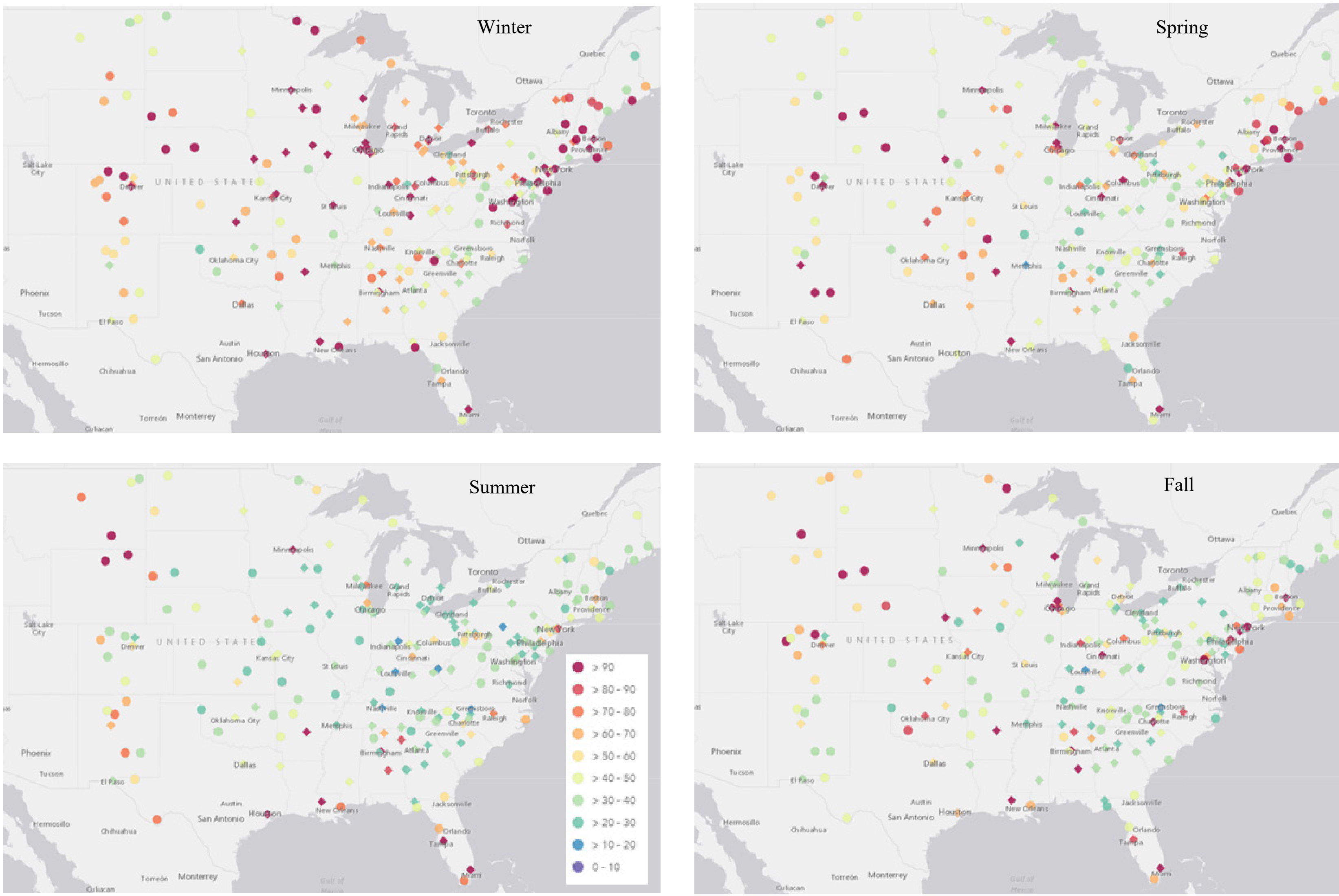


Figure 7-4. Spatial plots of elemental carbon (EC) NME by season and network (Circle = IMPROVE, Diamond = CSN).

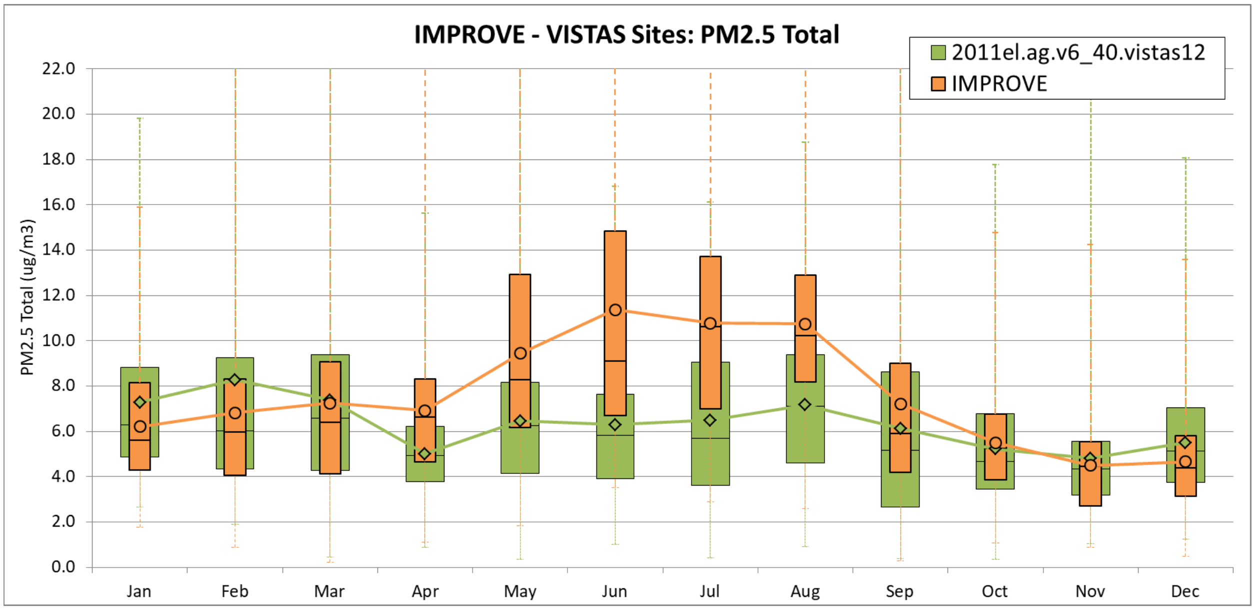
8.0 TOTAL $PM_{2.5}$

Table 8-1 summarizes model performance statistics for total $PM_{2.5}$. Boxplot comparisons of model predictions and observations (IMPROVE and CSN) by month for each climate region are shown in Figures 8-1 and 8-2. VISTAS12 modeling domain spatial plots of NMB and NME for each season are shown in Figures 8-3 and 8-4.

$PM_{2.5}$ is over predicted across both networks during the winter season and under predicted across both networks during the summer season. Model performance varies between VISTAS and non-VISTAS regions, especially during the spring and fall seasons, with slightly better performance typically seen at the VISTAS state locations (compared to non-VISTAS receptors) at high observed concentrations and slightly worse performance at these same locations at low observed concentrations.

Table 8-1. Model Performance Statistics for $PM_{2.5}$ by Region, Network, and Season.

Region	Network	Season	N	Avg. Obs. (µg/m^3)	Avg. Pre. (µg/m^3)	r	NMB (%)	NME (%)	MB (µg/m^3)	ME (µg/m^3)
VISTAS	IMPROVE	Winter	403	5.86	6.96	0.67	18.87	38.66	1.11	2.26
		Spring	413	7.86	6.35	0.53	-19.16	36.82	-1.51	2.89
		Summer	423	10.95	6.68	0.57	-39.02	42.12	-4.27	4.61
		Fall	413	5.79	5.40	0.74	-6.63	31.04	-0.38	1.80
		All	1652	7.64	6.35	0.55	-16.96	38.01	-1.30	2.91
	CSN	Winter	627	9.86	11.25	0.64	14.08	35.17	1.39	3.47
		Spring	651	11.00	9.35	0.54	-15.00	33.16	-1.65	3.65
		Summer	677	15.85	11.25	0.52	-29.03	36.52	-4.60	5.79
		Fall	639	8.80	8.84	0.65	0.54	30.89	0.05	2.72
		All	2594	11.45	10.18	0.55	-11.07	34.36	-1.27	3.93
Non-VISTAS	IMPROVE	Winter	1660	4.55	5.97	0.68	31.36	53.57	1.43	2.44
		Spring	1812	5.29	5.11	0.63	-3.30	44.48	-0.17	2.35
		Summer	1762	6.92	4.80	0.66	-30.69	40.01	-2.12	2.77
		Fall	1704	4.54	4.86	0.63	7.08	40.04	0.32	1.82
		All	6938	5.34	5.18	0.61	-3.09	43.93	-0.16	2.35
	CSN	Winter	1773	11.26	13.83	0.61	22.84	42.32	2.57	4.76
		Spring	1881	9.44	10.17	0.56	7.70	36.89	0.73	3.48
		Summer	1906	12.75	9.55	0.72	-25.12	32.43	-3.20	4.14
		Fall	1826	8.67	9.82	0.61	13.27	37.14	1.15	3.22
		All	7386	10.54	10.80	0.58	2.47	36.94	0.26	3.89



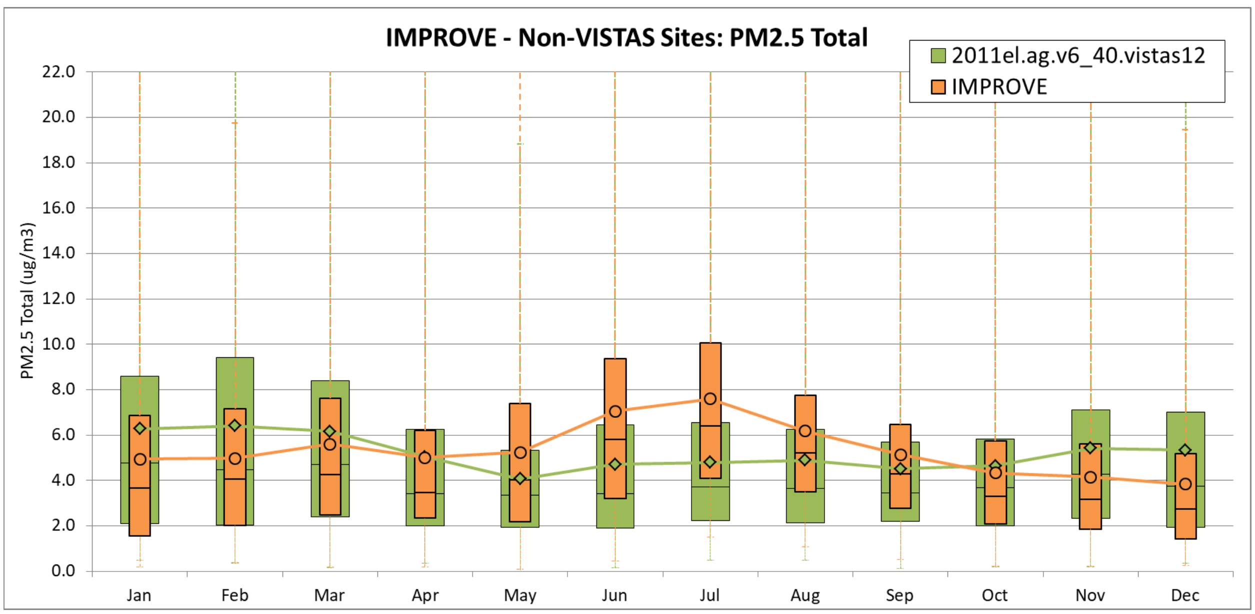
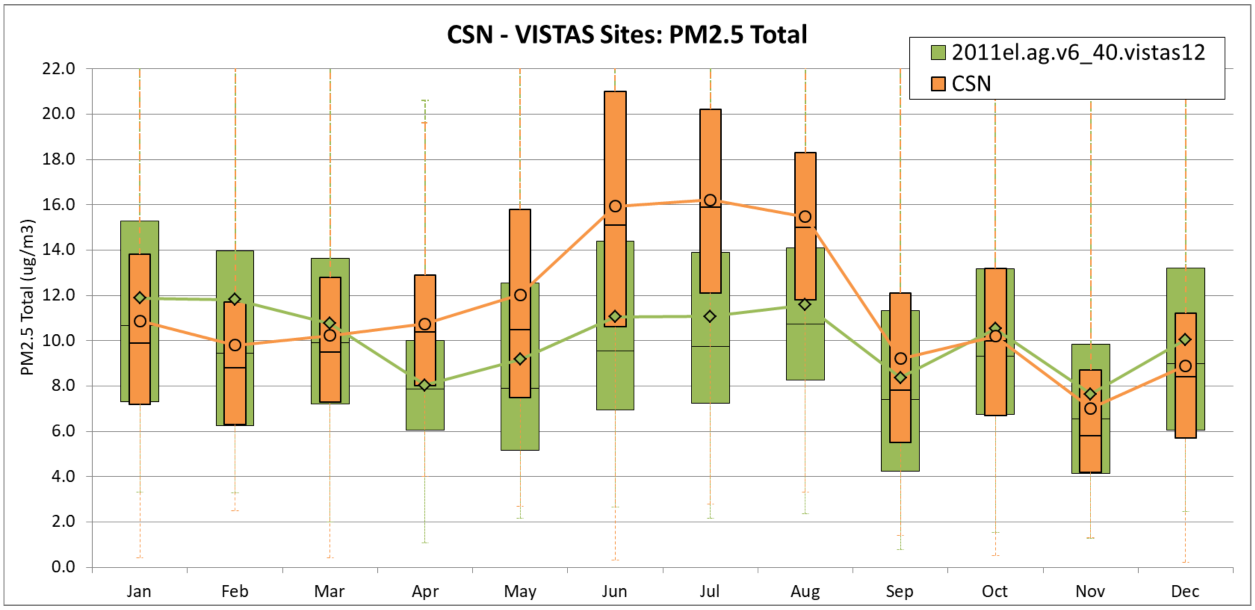


Figure 8-1. Boxplot Comparisons of Model Predictions and IMPROVE Total $PM_{2.5}$ Observations for Each Climate Region by Month.



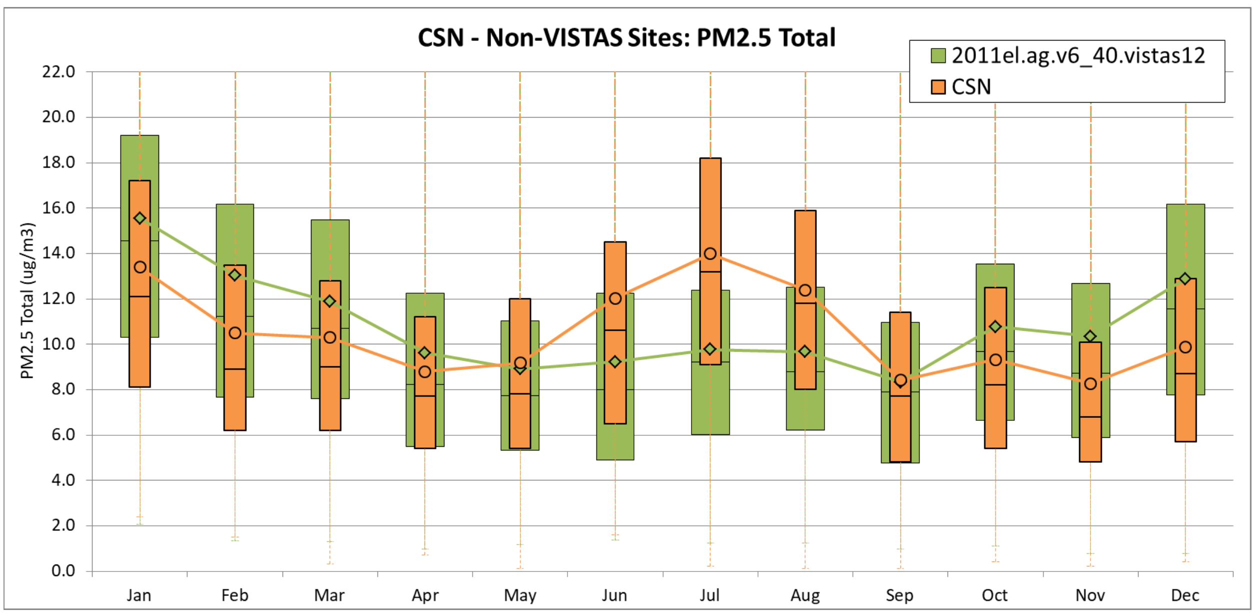


Figure 8-2. Boxplot Comparisons of Model Predictions and CSN Total $PM_{2.5}$ Observations for Each Climate Region by Month.

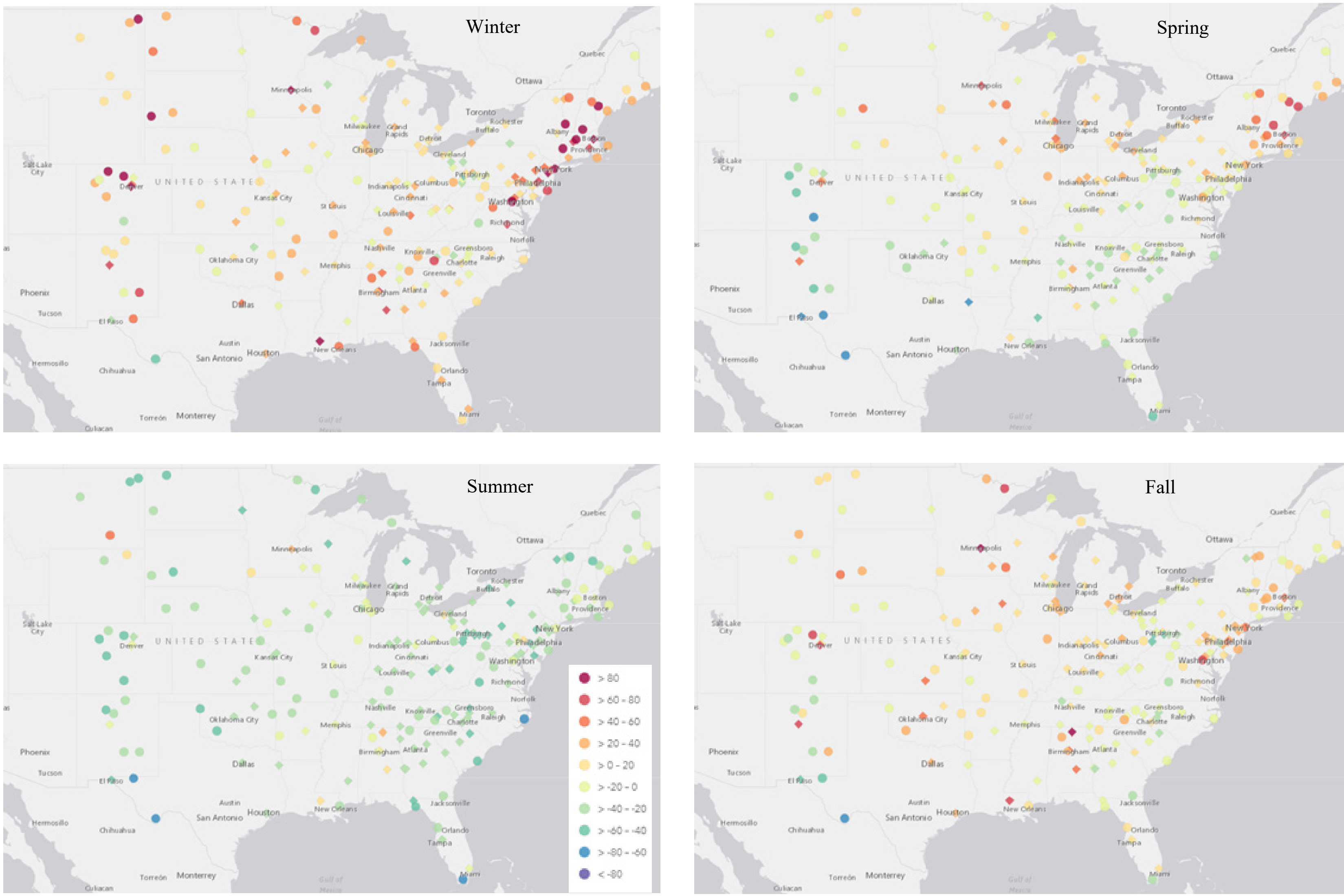


Figure 8-3. Spatial plots of total $PM_{2.5}$ NMB by season and network (Circle = IMPROVE, Diamond = CSN).

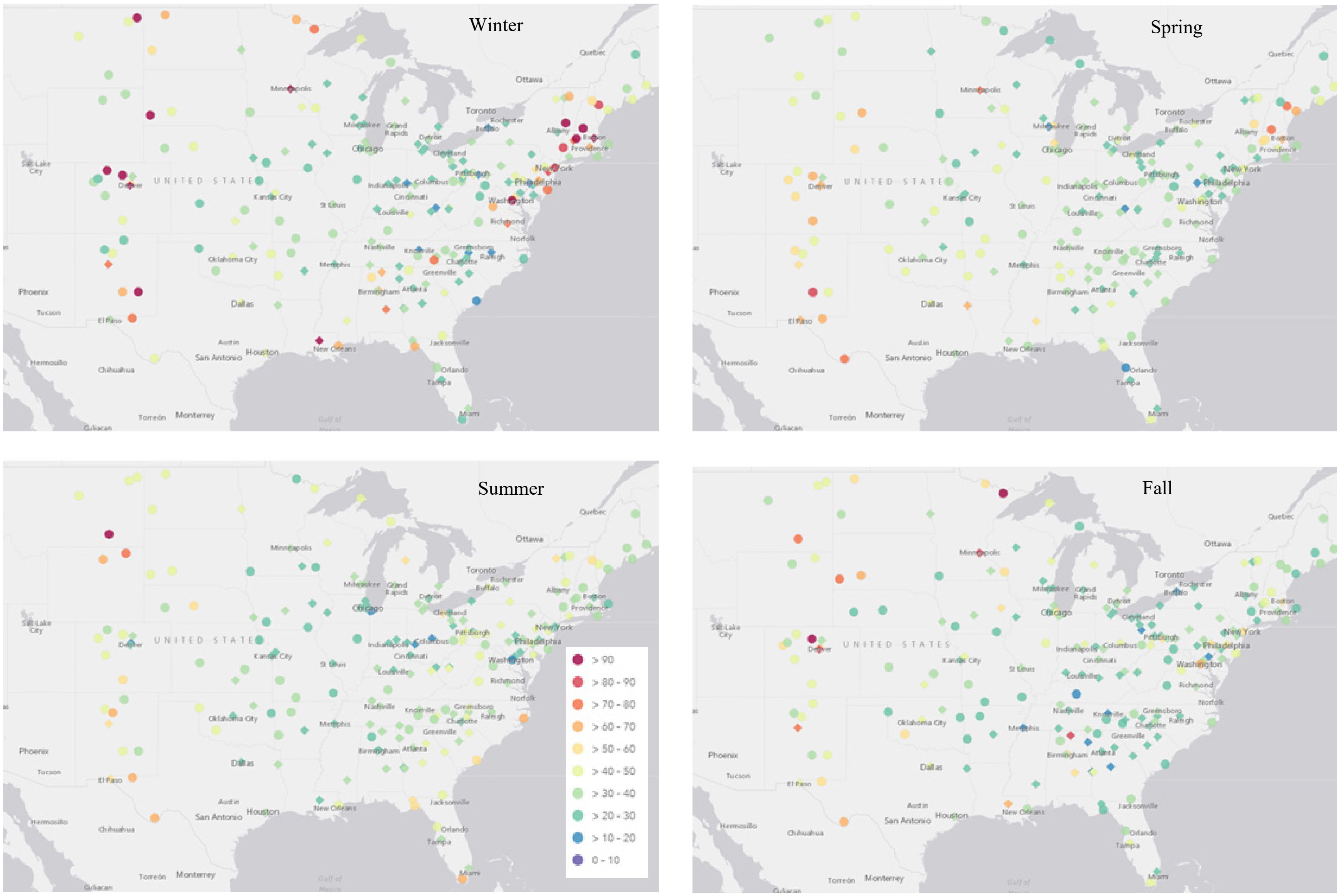


Figure 8-4. Spatial plots of total $PM_{2.5}$ NME by season and network (Circle = IMPROVE, Diamond = CSN).

9.0 PERFORMANCE ON 20% MOST-IMPAIRED DAYS

Spatial plots summarizing IMPROVE observations and model NMB on the 20% most-impaired days are shown in Figures 9-1 through 9-6. In each figure the top graphic presents the observed concentration and the bottom graphic presents the NMB.

For sulfate (Figure 9-1), predictions on the 20% most-impaired days are biased low across all regions, with the most significant percentage under predictions occurring in the southwest quarter of the VISTAS12 modeling domain. Some isolated over predictions are observed in a few Class I areas near the outer domain boundaries and in the northeast.

Predictions of nitrate (Figure 9-2) on the 20% most-impaired days in the VISTAS12 modeling domain are mixed with a high positive bias in the north and a mix of negative and positive bias in the southeast.

A general positive bias of OC (Figure 9-3) is observed across the region on the 20% most-impaired days. In the SESARM states the OC has approximately the same NMB at monitors with high observed concentrations as monitors with lower observed concentrations. For EC (Figure 9-4) the model shows a slight under prediction at monitors in the northern portion of the SESARM states and a positive bias at monitors in the southern SESARM region.

On the 20% most-impaired days, model performance for total $PM_{2.5}$ is overall biased low across most quadrants of the VISTAS12 modeling domain (corresponding closely to the sulfate performance). A slight over prediction of $PM_{2.5}$ on those days is observed in the Northern Plains and Upper Midwest, primarily along the Canadian border (corresponding closely to high nitrate concentrations and performance).

Sodium chloride (NACL) is generally over predicted along boundaries with ocean water bodies (Atlantic Ocean and Gulf of Mexico) and is expectedly under predicted across the rest of the VISTAS12 modeling domain.

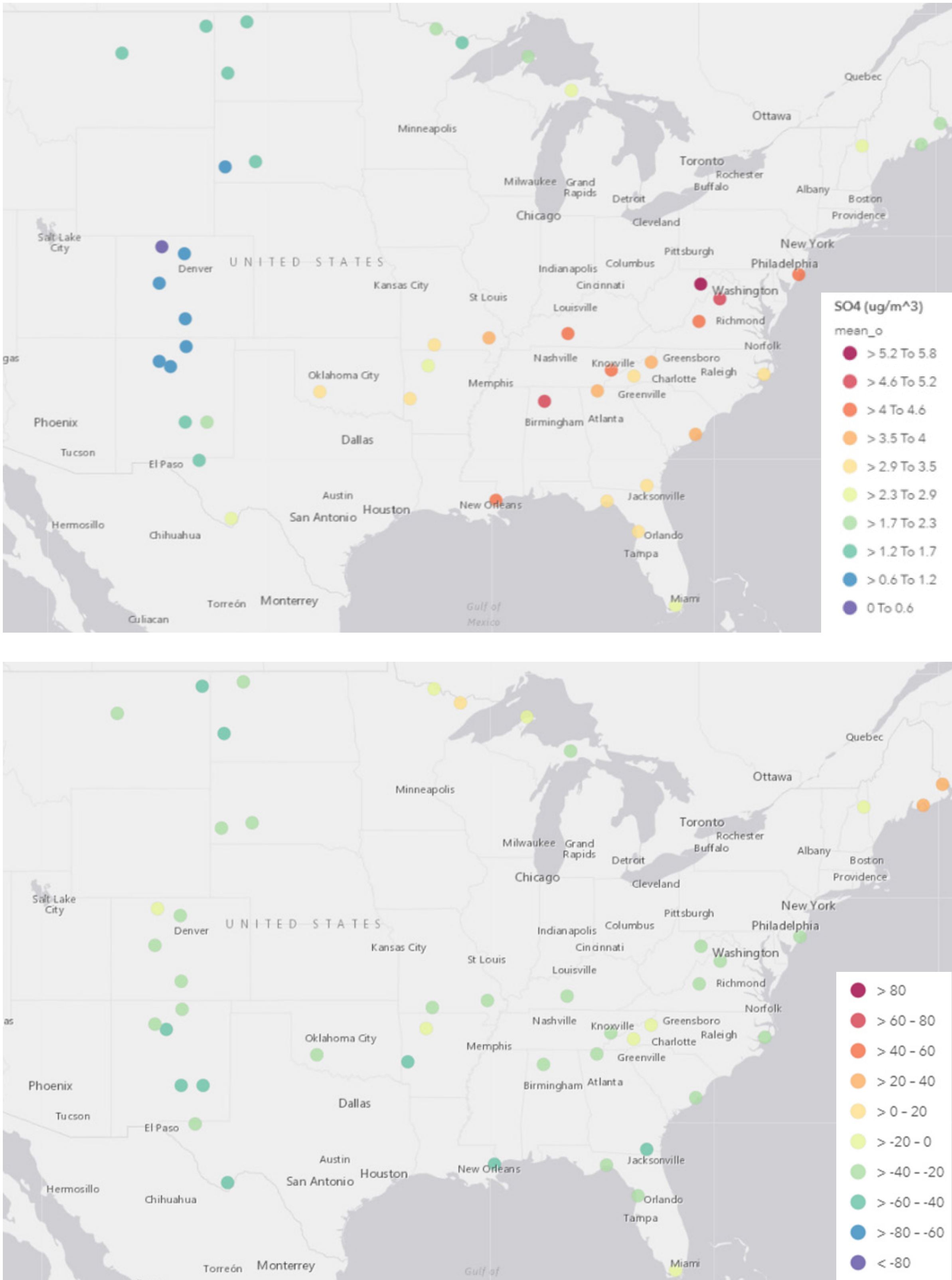


Figure 9-1. Observed Sulfate (Top) and Modeled NMB (Bottom) for Sulfate on the 20% Most-impaired Days at IMPROVE Monitor Locations.

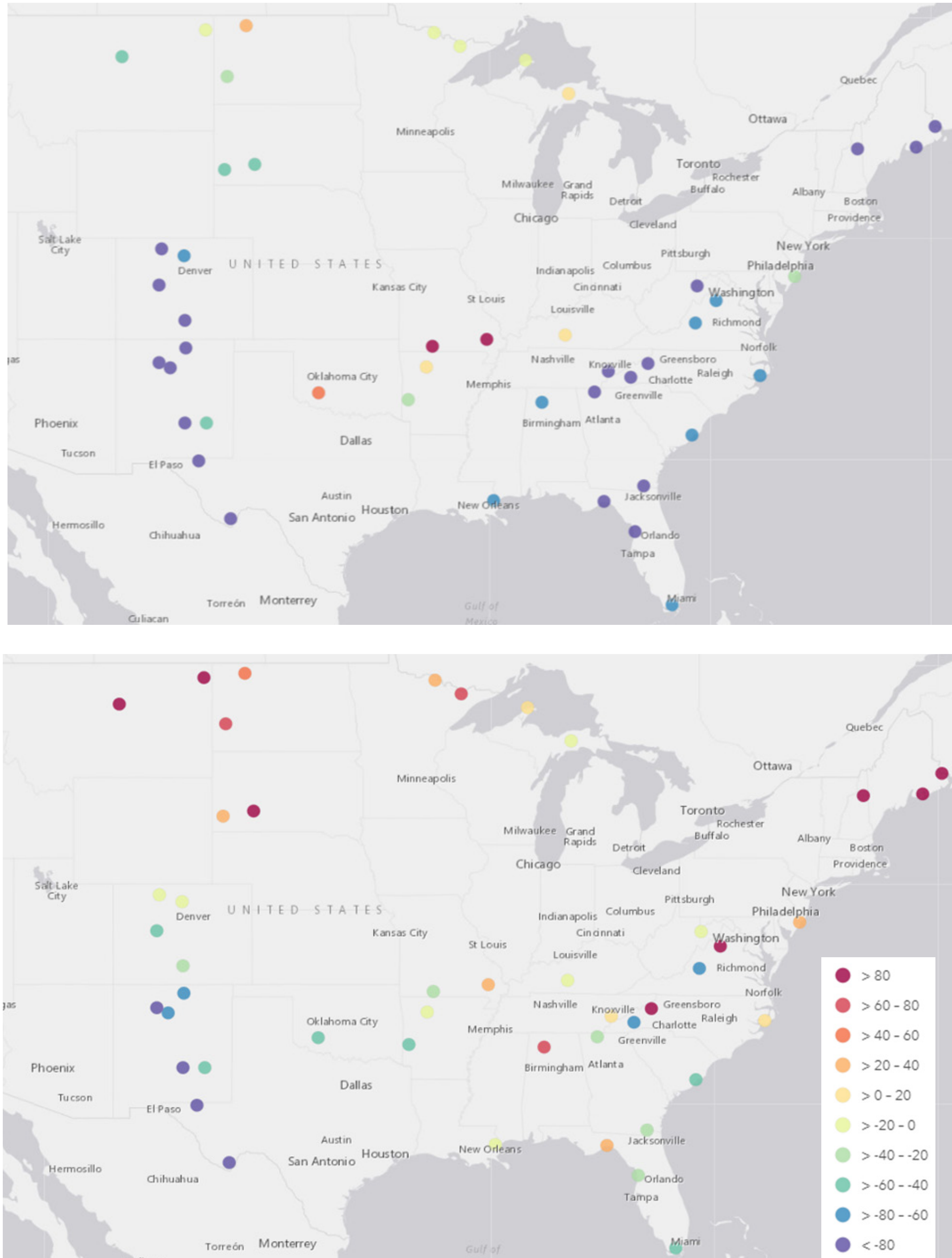
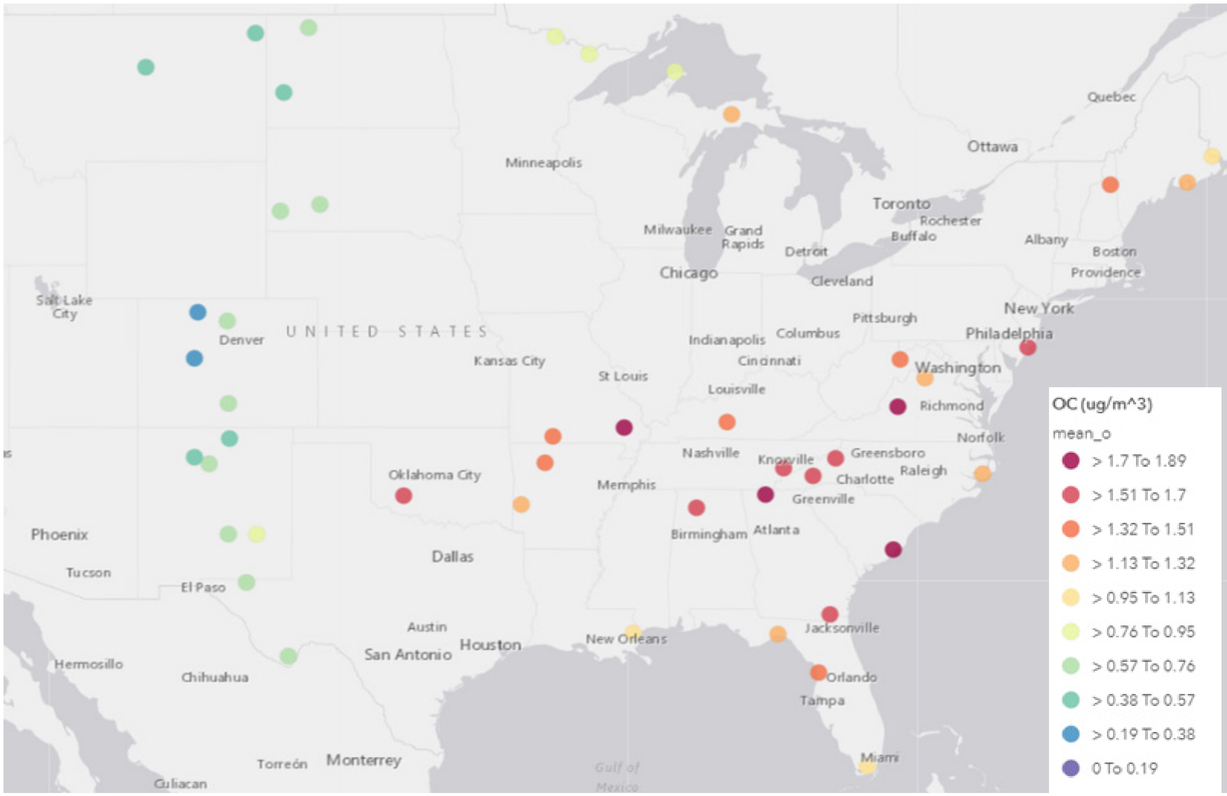


Figure 9-2. Observed Nitrate (Top) and Modeled NMB (Bottom) for Nitrate on the 20% Most-impaired Days at IMPROVE Monitor Locations.



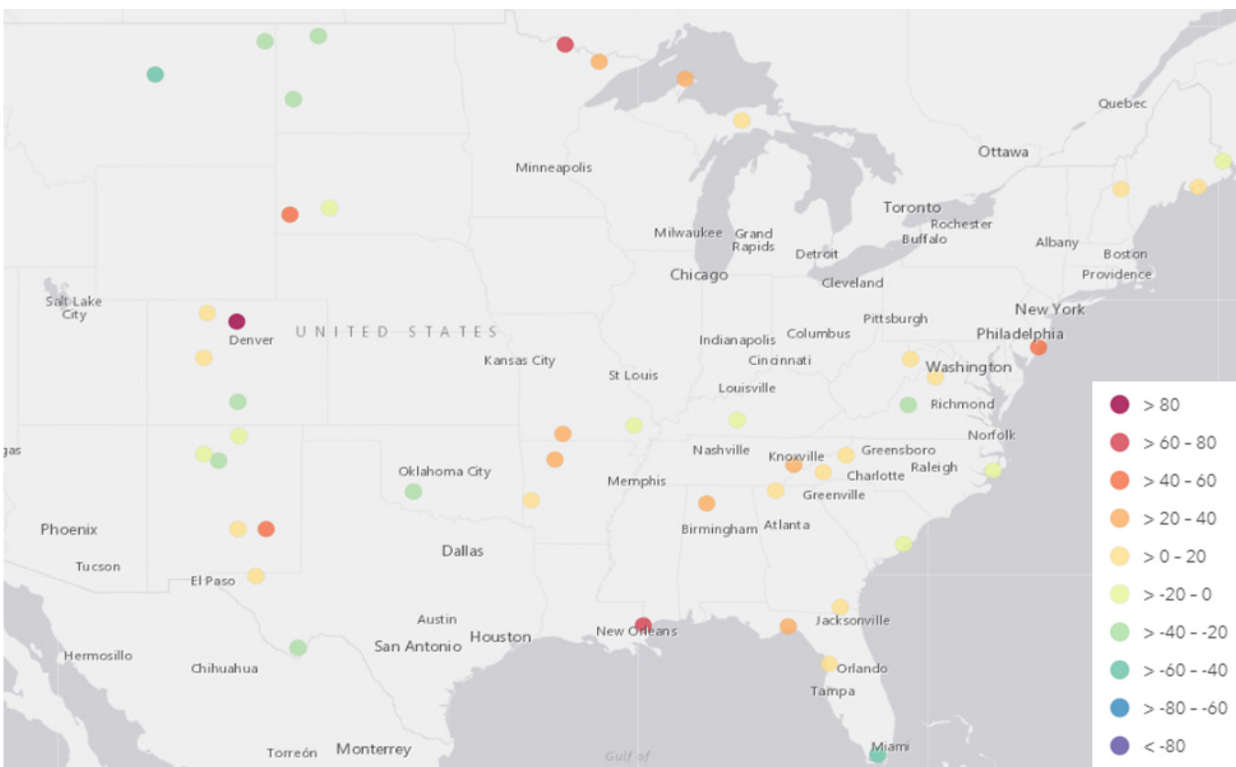


Figure 9-3. Observed OC (Top) and Modeled NMB (Bottom) for OC on the 20% Most-impaired Days at IMPROVE Monitor Locations.

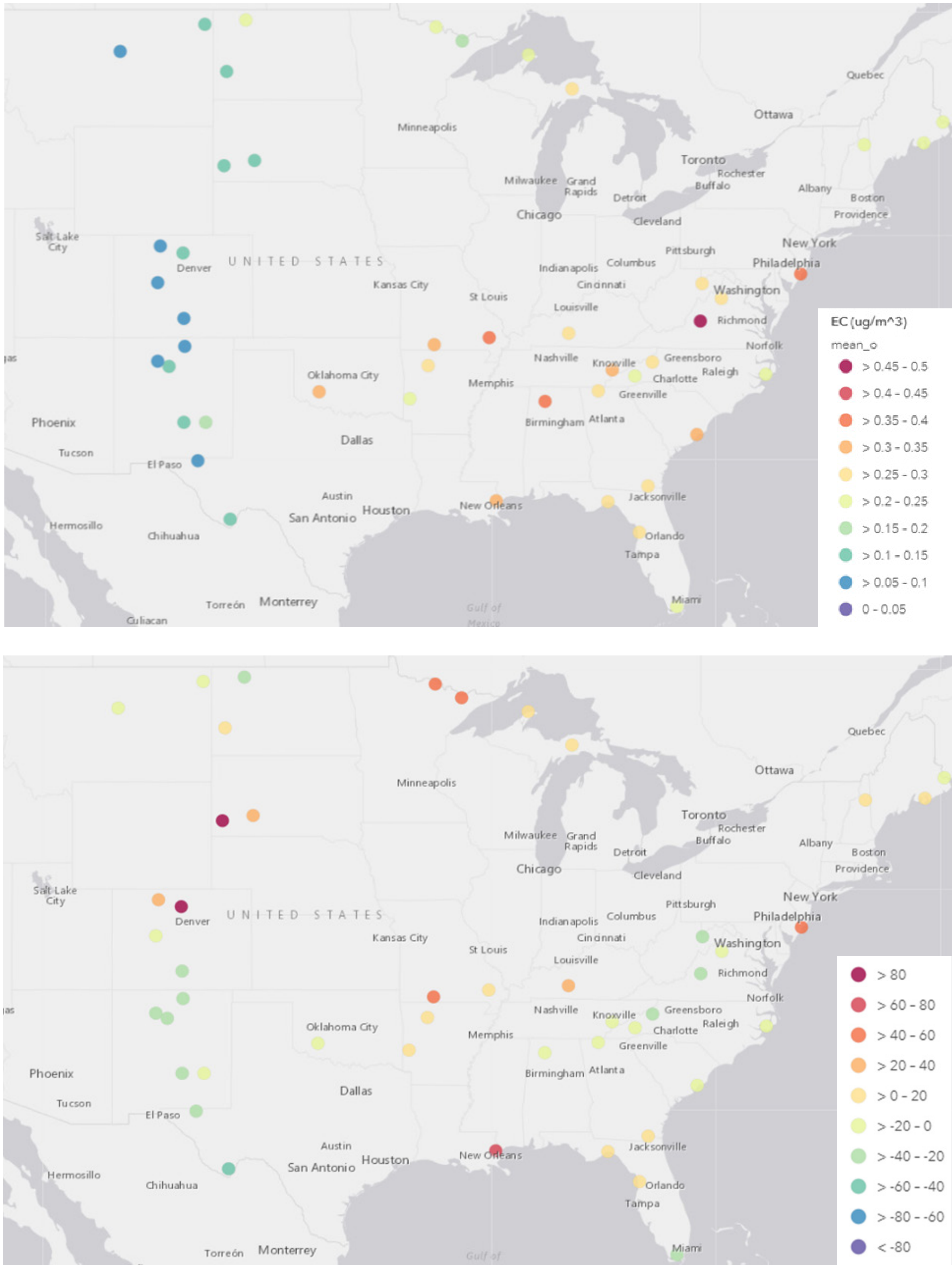
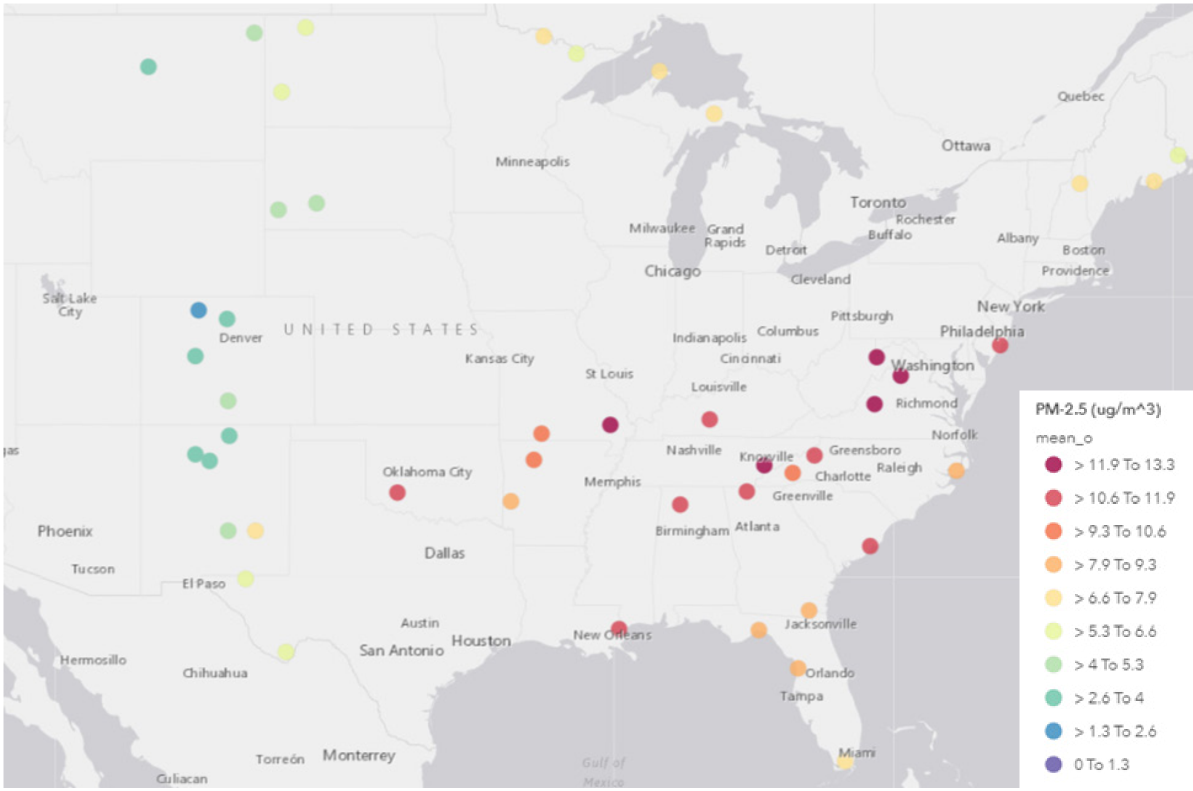


Figure 9-4. Observed EC (Top) and Modeled NMB (Bottom) for EC on the 20% Most-impaired Days at IMPROVE Monitor Locations.



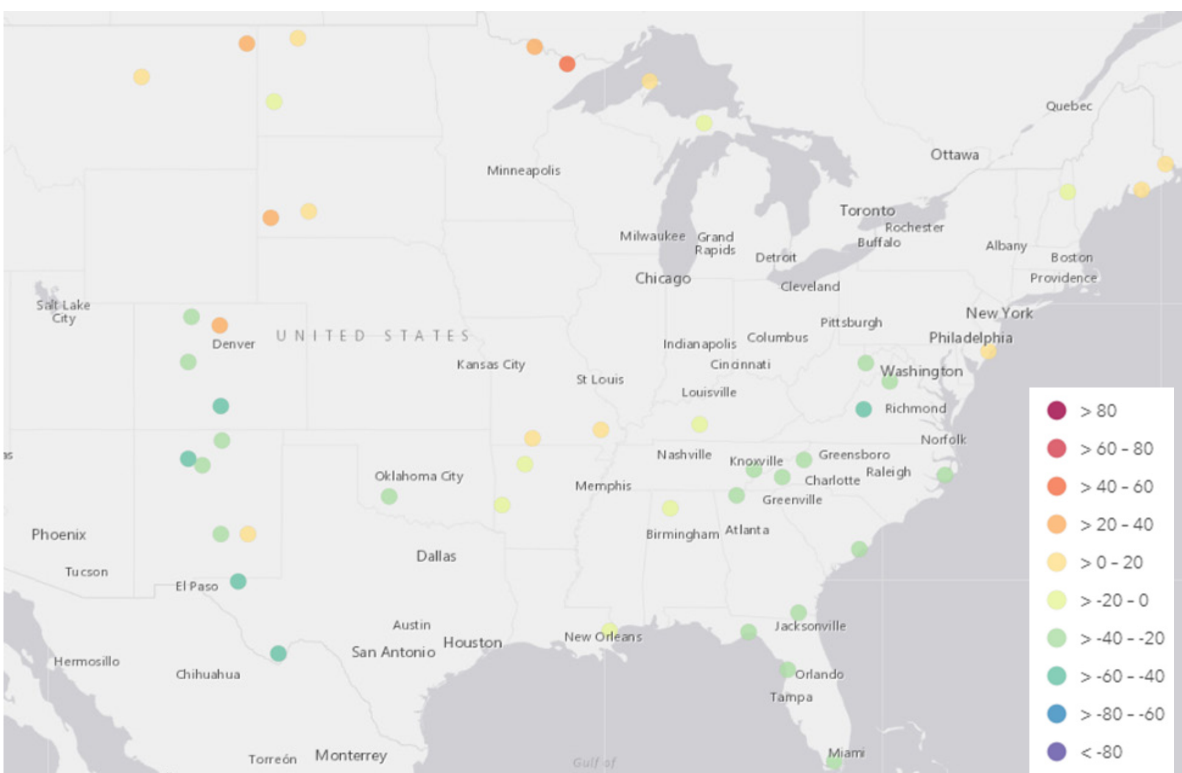
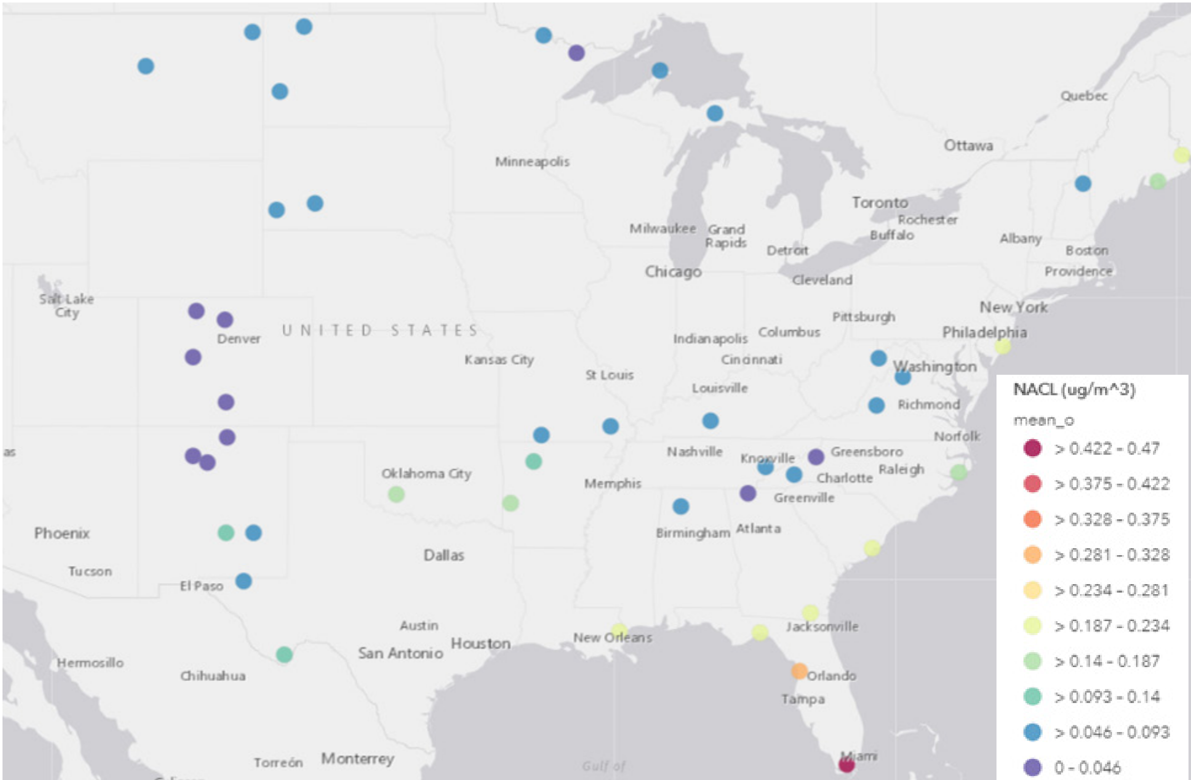


Figure 9-5. Observed Total $PM_{2.5}$ (Top) and Modeled NMB (Bottom) for Total $PM_{2.5}$ on the 20% Most-impaired Days at IMPROVE Monitor Locations.



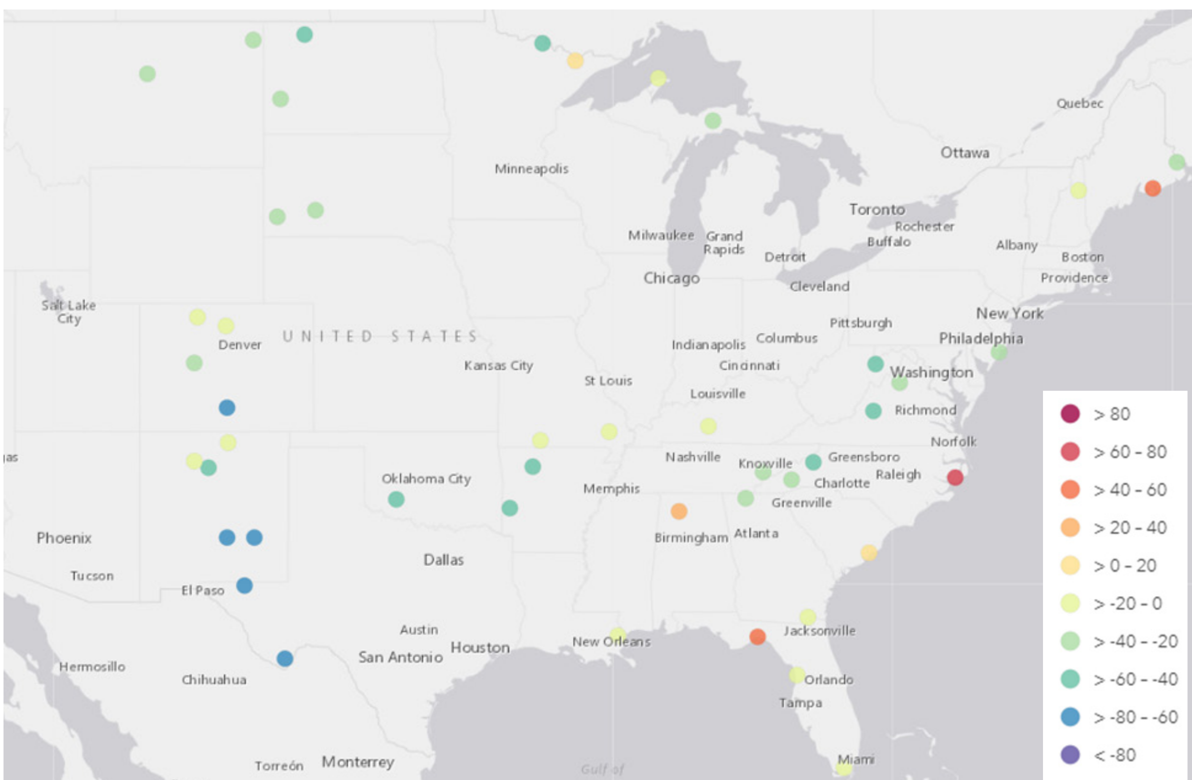


Figure 9-6. Observed NACL (Top) and Modeled NMB (Bottom) for NACL on the 20% Most-impaired Days at IMPROVE Monitor Locations.

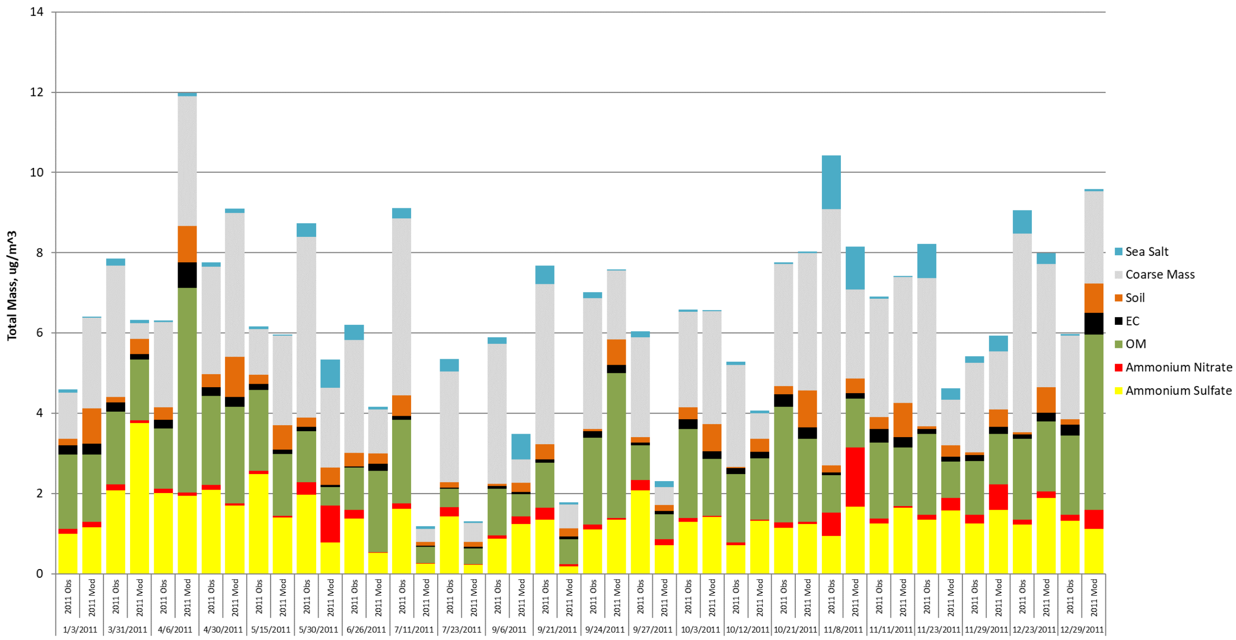
10.0 $PM_{2.5}$ COMPOSITION AND CONTRIBUTIONS TO LIGHT EXTINCTION

Charts for each of the VISTAS_12 modeling domain's Class I areas can be generated using the provided Excel file titled "APP_F_PM_EXTINCTION_MPE.xlsx" in Appendix F. These stacked bar charts detail the daily and averaged composition of $PM_{2.5}$ on the 20% most impaired and clearest days for both modeled and observed concentration (µg/m^3) and light extinction (bext^{-1}) at each IMPROVE monitoring site located within the VISTAS12 modeling domain. Total mass plots display the amount of total particle mass using concentrations of coarse mass (CM), crustal (soil), ammonium nitrate (NO_3), ammonium sulfate (SO_4), EC, organic mass carbon (OMC), and sea salt.

Daily concentration values by day are presented for SAMA's 20% clearest days on the top of Figure 10-1 below. The amount of light extinction due to each aforementioned species by day is displayed in the daily light extinction tab of Appendix F and is presented on the bottom of Figure 10-1. An example of the averaged concentration across all days is presented for SAMA's 20% clearest days on the left of Figure 10-2 below. The average amount of light extinction due to each species is displayed in the average light extinction tab of Appendix F and is presented on the right of Figure 10-2.

Predicted (modeled) results for all locations are based on across all daily results for each Class I area's impairment classification (20% clearest or 20% most anthropogenically impaired) using CAMx v6.40 and calculated using the new IMPROVE equation. Observations, clearest, and most impaired days and associated observational concentrations and light extinction data by IMPROVE receptor were identified and provided by EPA in their Preliminary Regional Haze Modeling.[5]

[5] https://www.epa.gov/visibility/regional-haze-guidance-technical-support-document-and-data-file



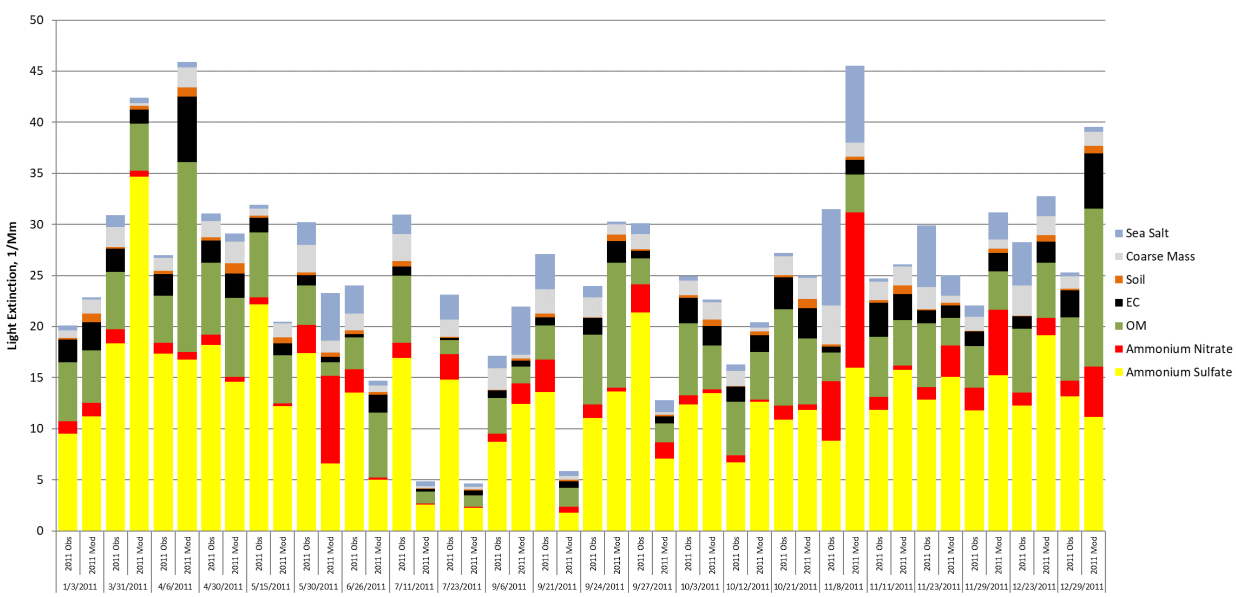


Figure 10-1. Example Daily Observed (Obs) and Predicted (Mod) Total Mass Concentrations (Top) and Light Extinctions (Bottom) at the St. Mark's Wildlife Refuge on the Observed 20% Clearest Days.

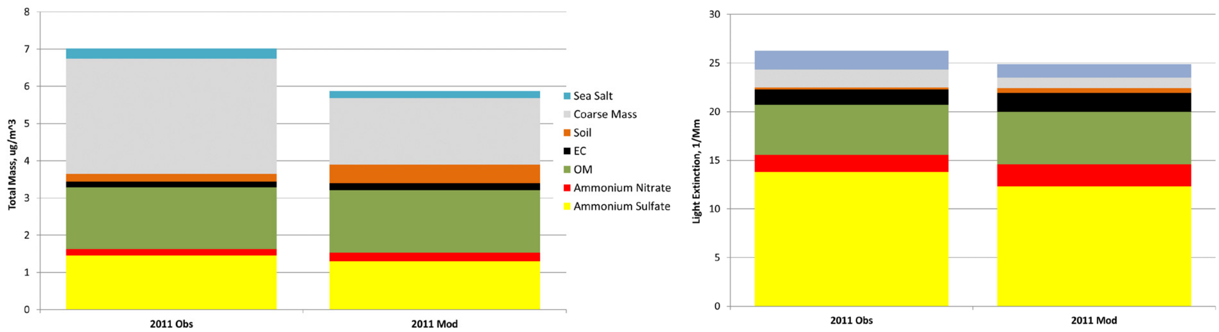


Figure 10-2. Example Averaged Observed (Obs) and Predicted (Mod) Total Mass Concentrations (Left) and Light Extinctions (Right) at the St. Mark's Wildlife Refuge on the Observed 20% Clearest Days.

Appendix A

VISTAS12 Modeling Domain
Model Performance Metrics by Network, Station, Pollutant, and Season

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Appendix A-1

VISTAS12 Modeling Domain
CASTNET Model Performance Metrics by Station, Pollutant, and Season

(see MPE by Station and Season-1.pdf)

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Appendix A-2

VISTAS12 Modeling Domain
CSN Model Performance Metrics by Station, Pollutant, and Season

(see MPE by Station and Season-2.pdf)

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Appendix A-3

VISTAS12 Modeling Domain
IMPROVE Model Performance Metrics by Station, Pollutant, and Season

(see MPE by Station and Season-3.pdf)

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Appendix B

VISTAS12 Modeling Domain
Scatter Plots of $PM_{2.5}$ Species by Network, Pollutant, and Month

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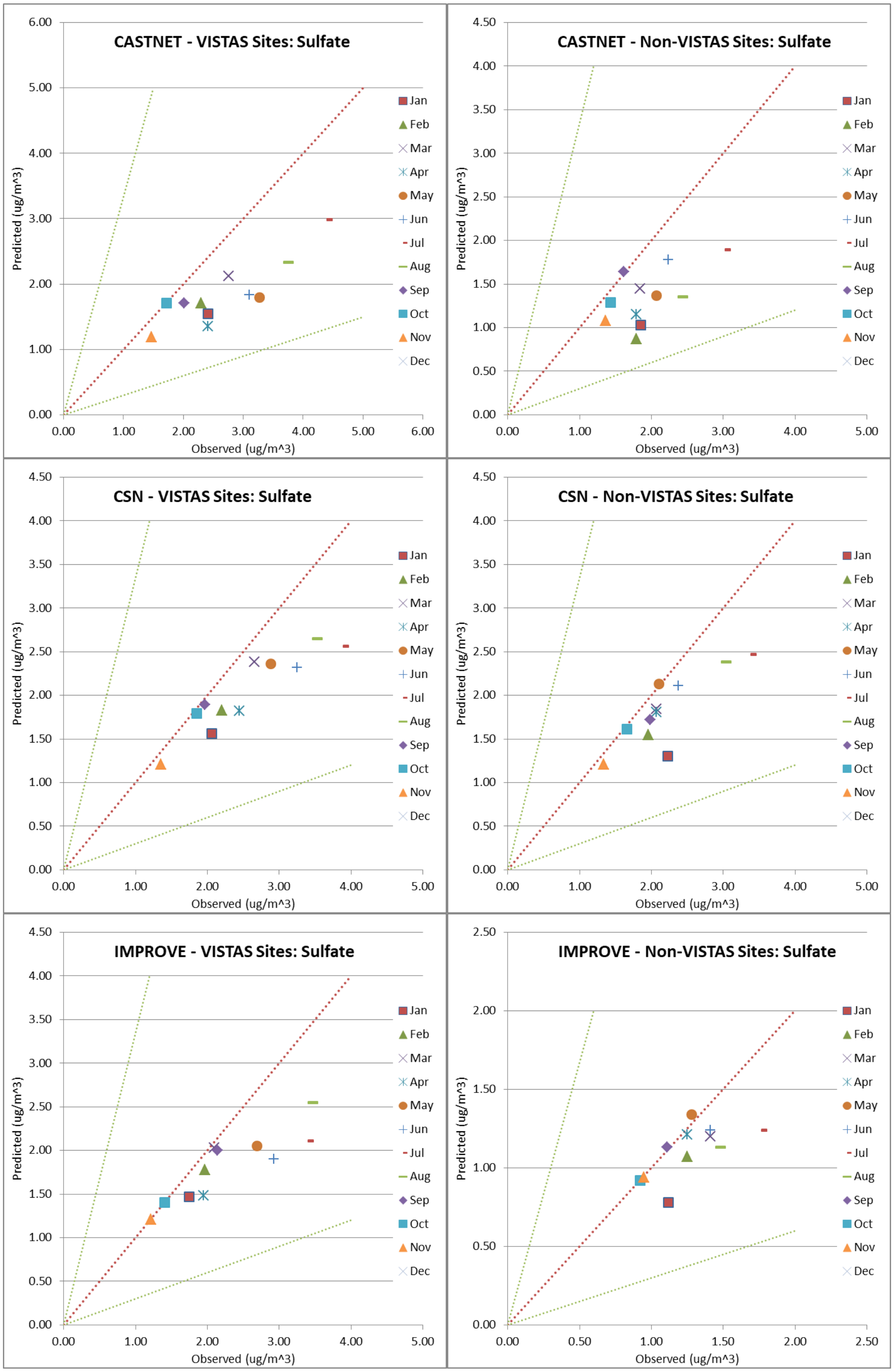

Figure B-1. Scatter Plots of Sulfate by Network and Month for VISTAS and Non-VISTAS Sites.

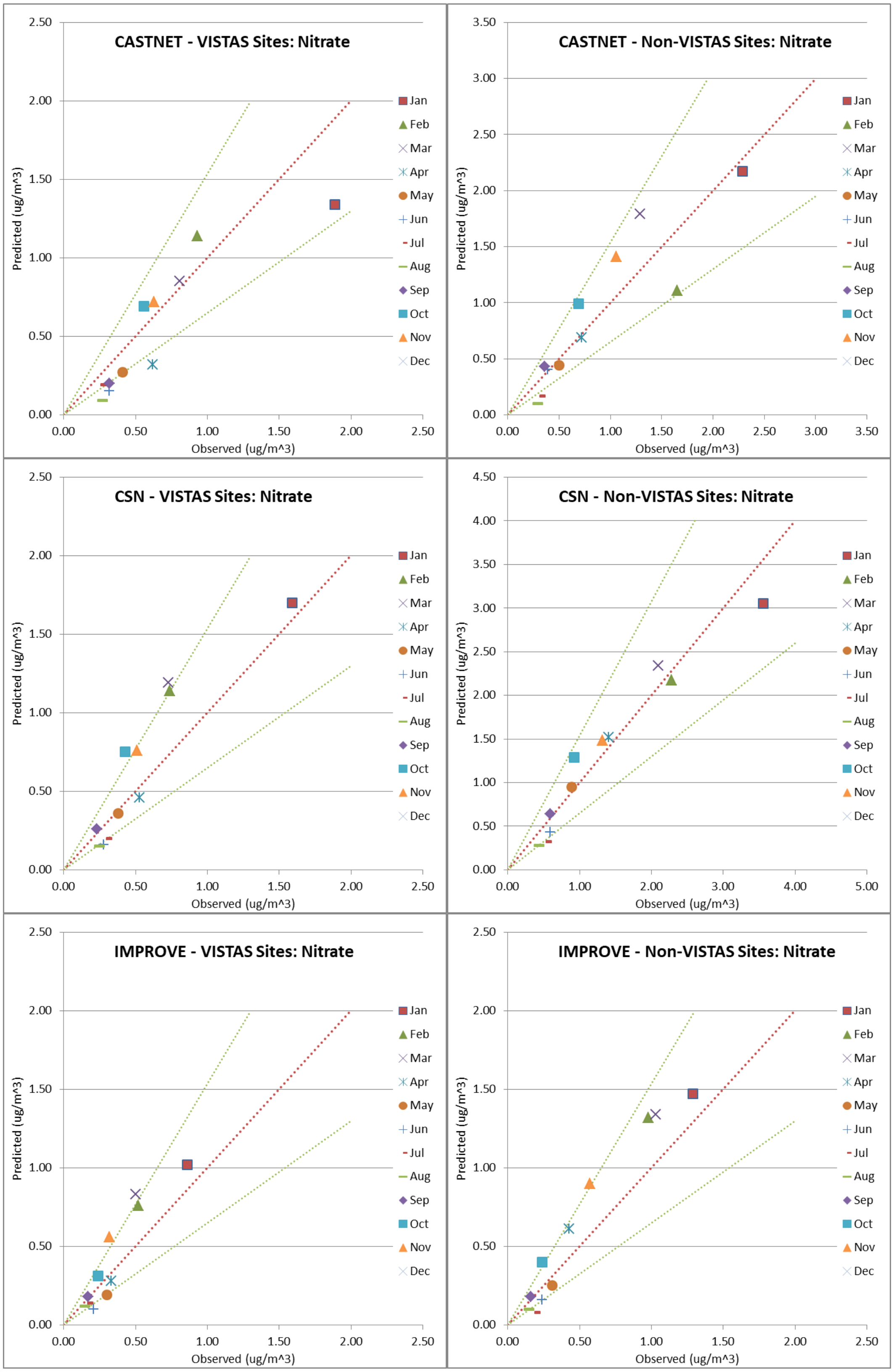

Figure B-2. Scatter Plots of Nitrate by Network and Month for VISTAS and Non-VISTAS Sites.

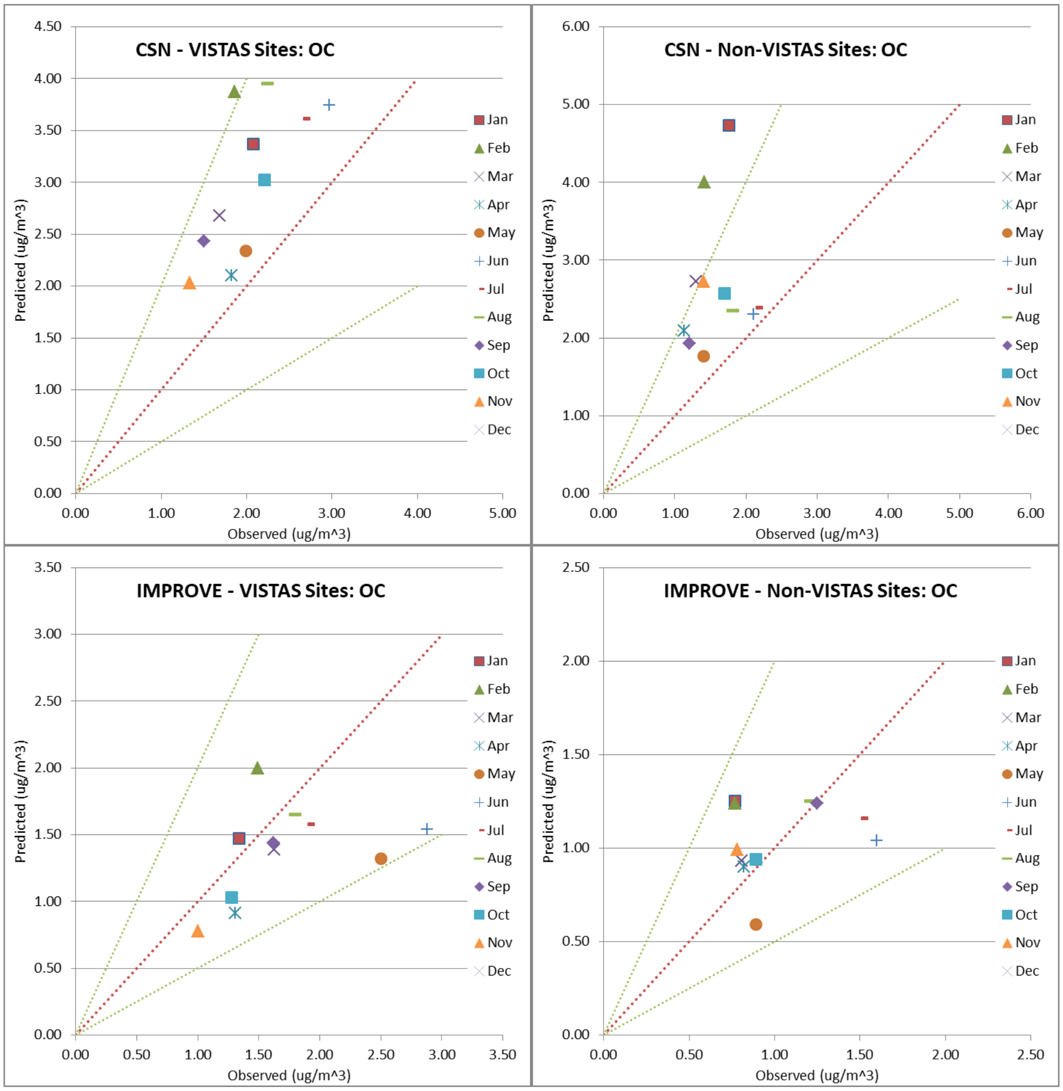

Figure B-3. Scatter Plots of OC by Network and Month for VISTAS and Non-VISTAS Sites.

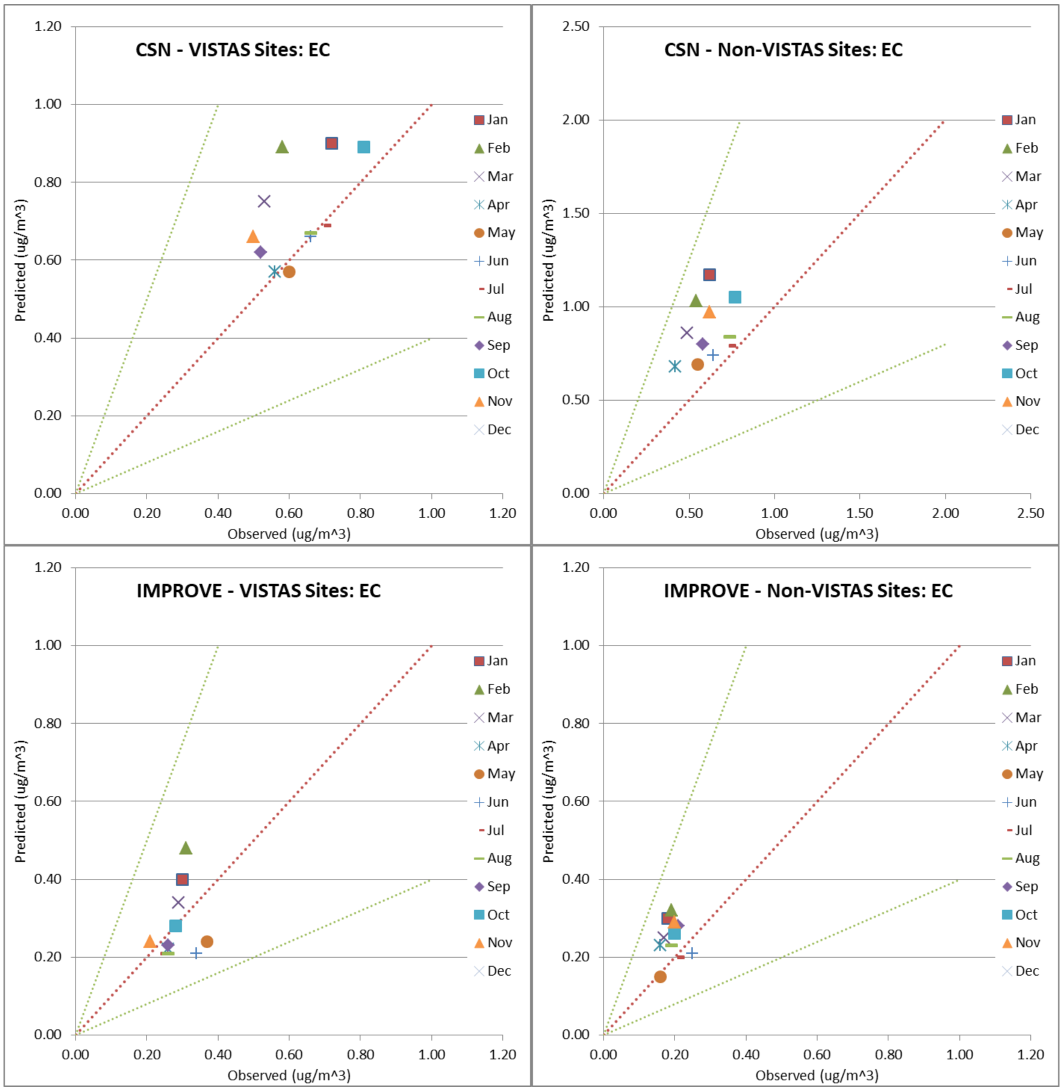

Figure B-4. Scatter Plots of EC by Network and Month for VISTAS and Non-VISTAS Sites.

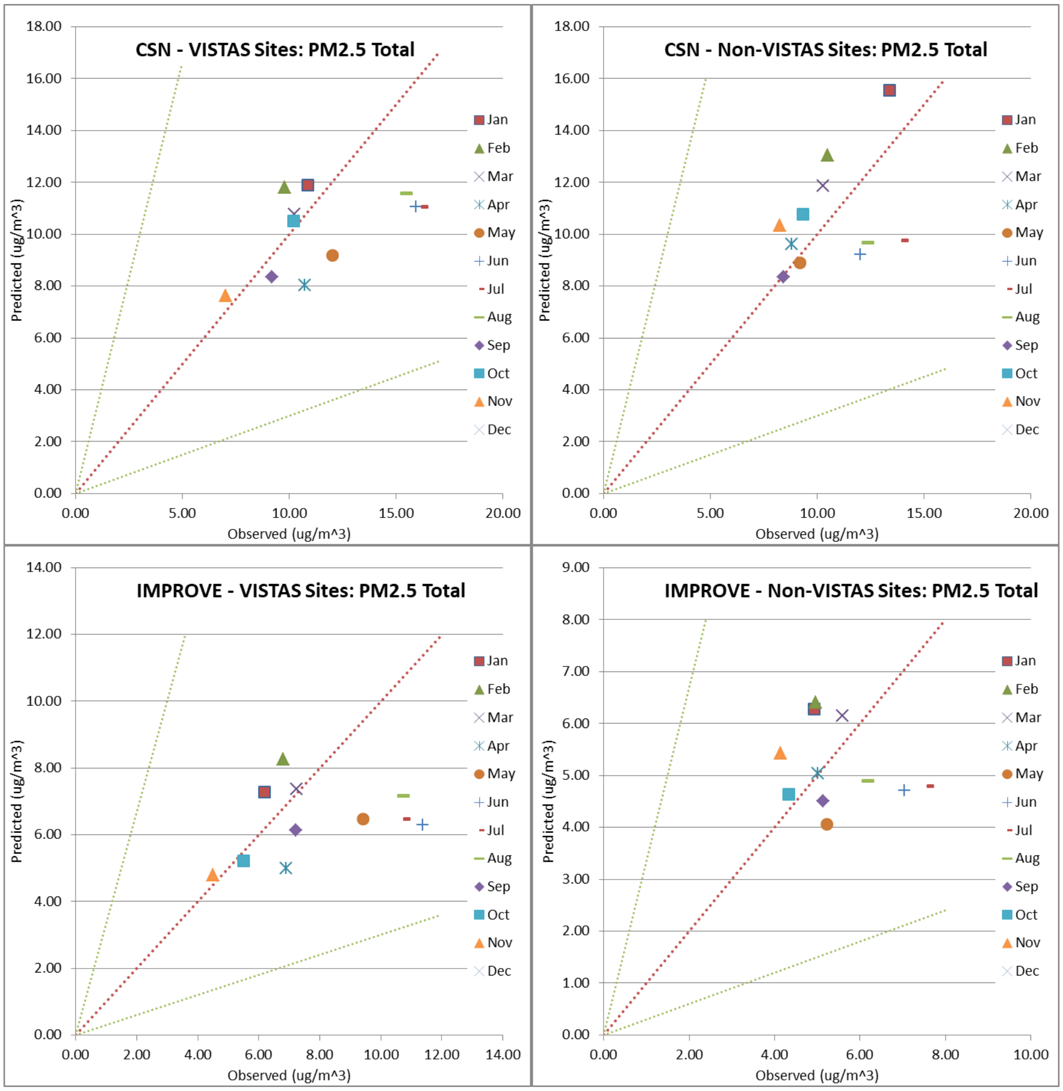

Figure B-5. Scatter Plots of Total $PM_{2.5}$ by Network and Month for VISTAS and Non-VISTAS sites.

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Appendix C

VISTAS12 Modeling Domain
Scatter, Soccer, and Bugle Plots by Site for the 20% Most Impaired Days and 20% Clearest Days
(see “APP_C_maps_pred_obs_mpe_results_station_all_dates_improve.xlsx”)

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Appendix D

VISTAS12 Modeling Domain
Soccer Plots of $PM_{2.5}$ Species by Network, Pollutant, and Month

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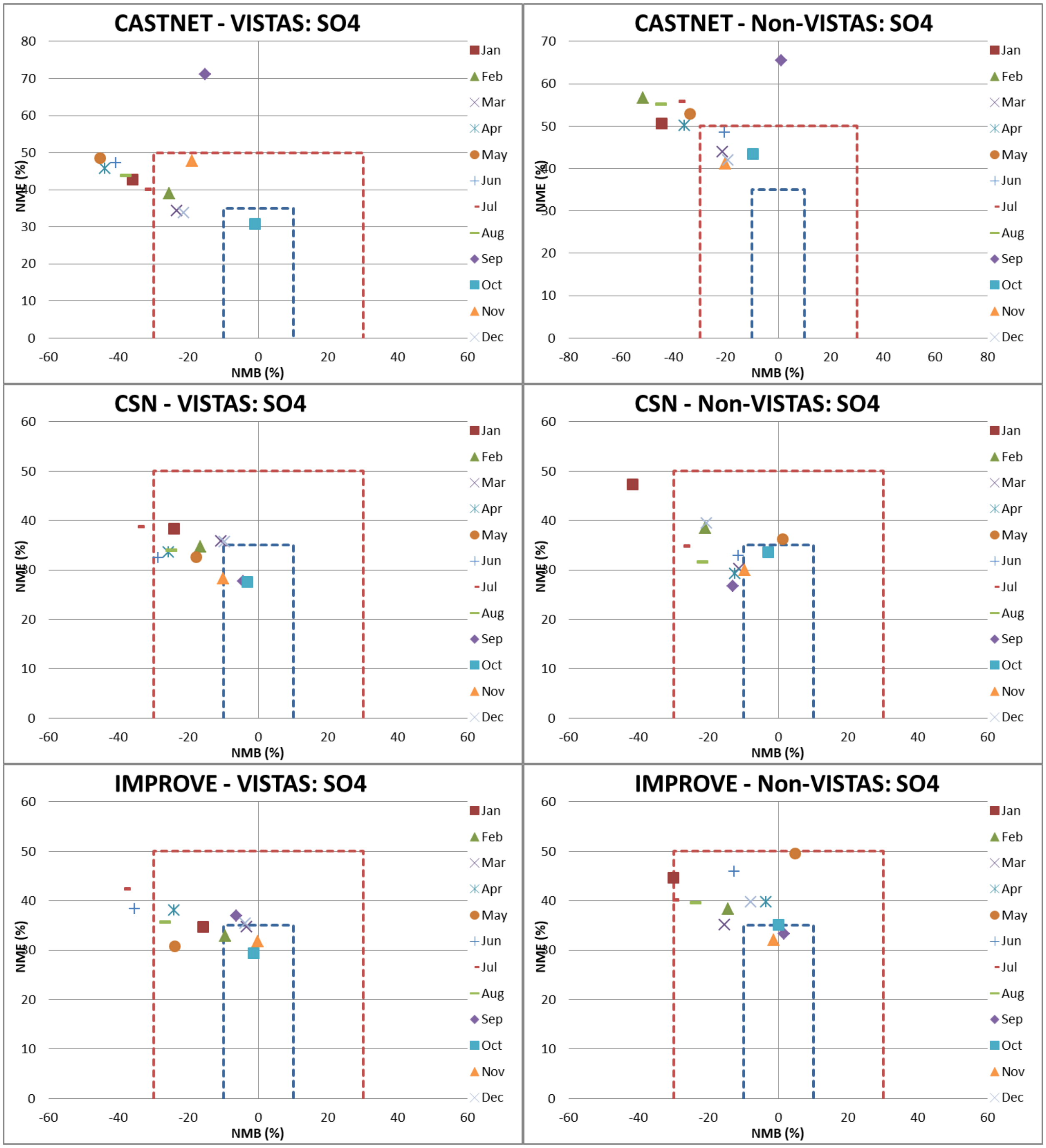

Figure D-1. Soccer Plot of Sulfate by Network and Month for VISTAS and Non-VISTAS Sites.

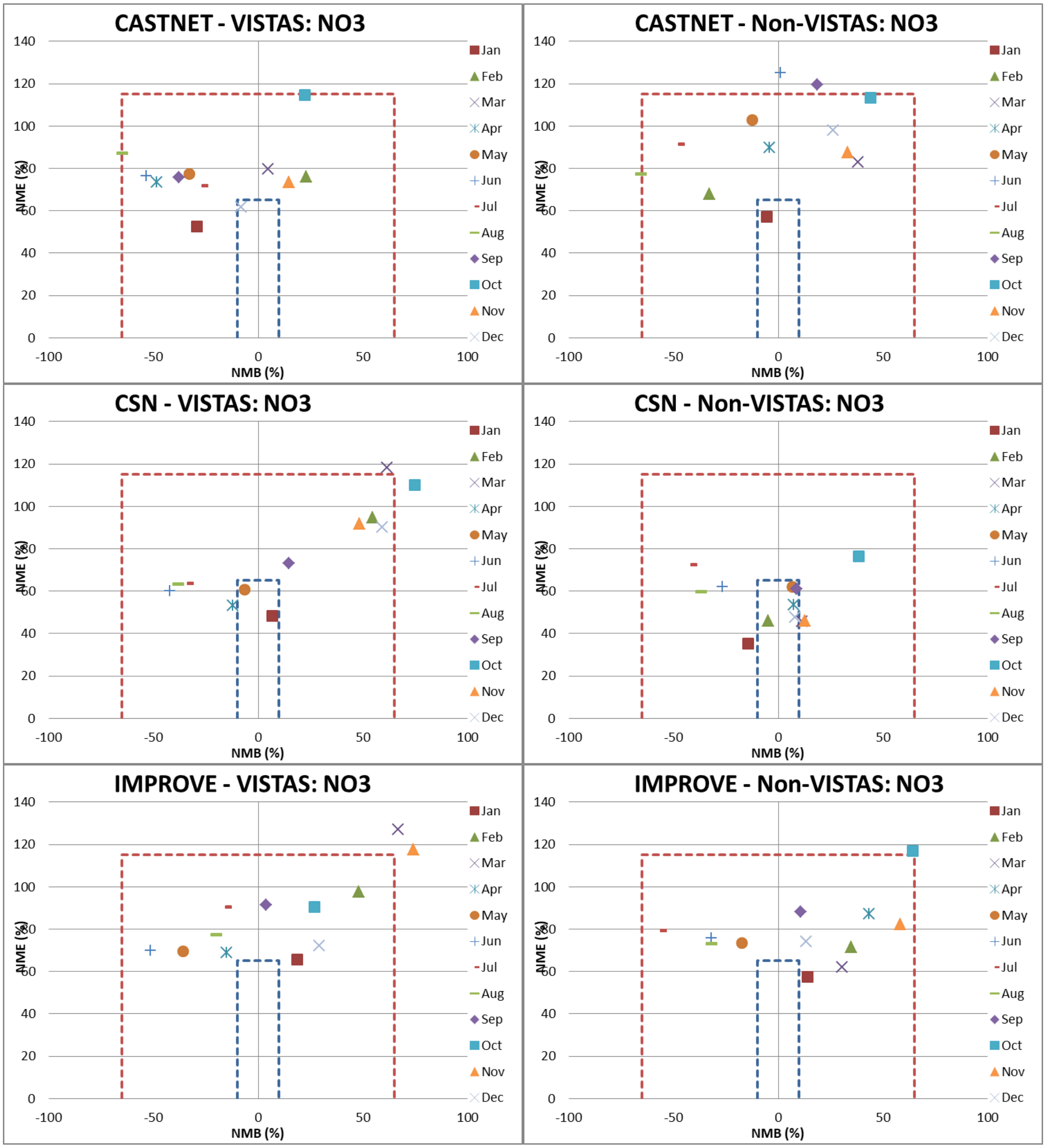

Figure D-2. Soccer Plot of Nitrate by Network and Month for VISTAS and Non-VISTAS Sites.

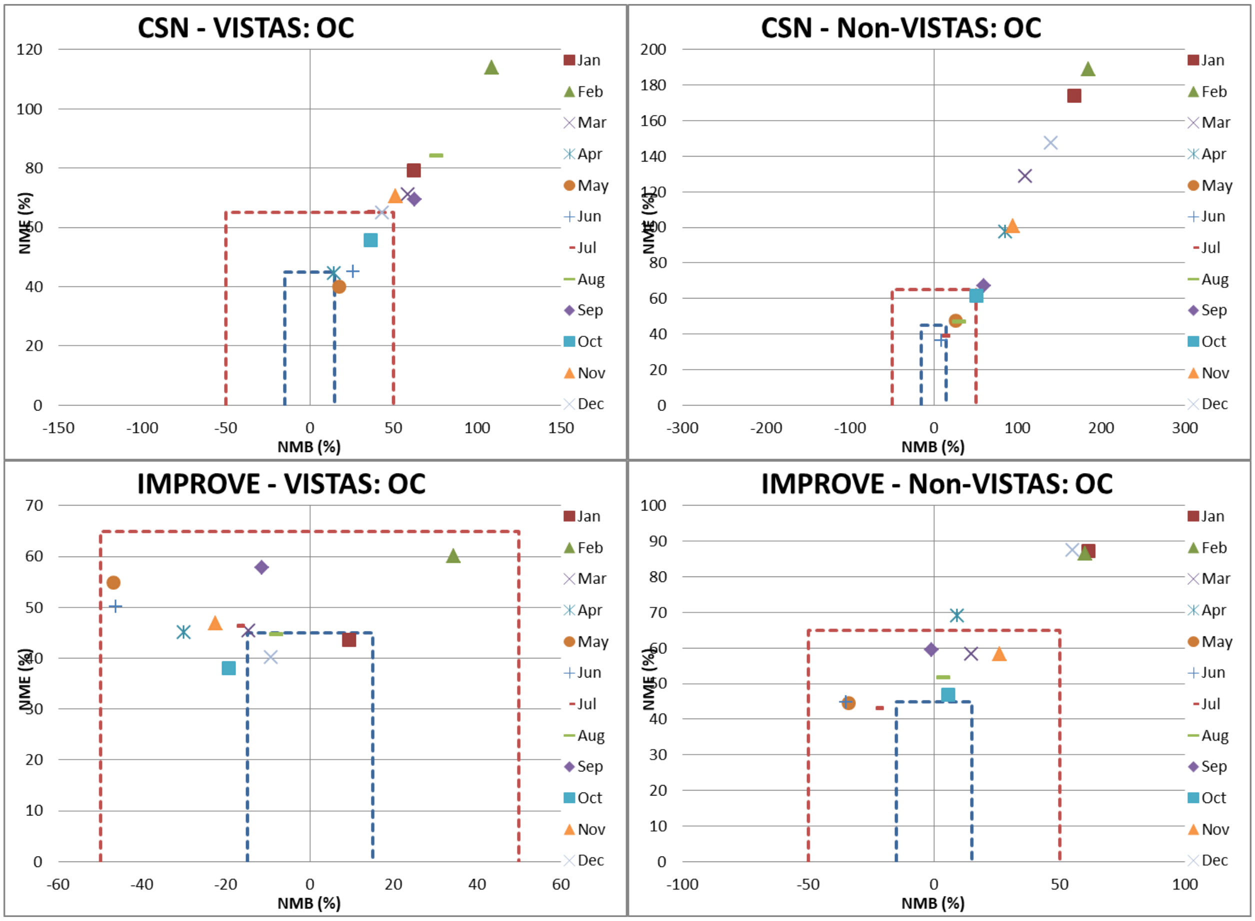

Figure D-3. Soccer Plot of OC by Network and Month for VISTAS and Non-VISTAS Sites.

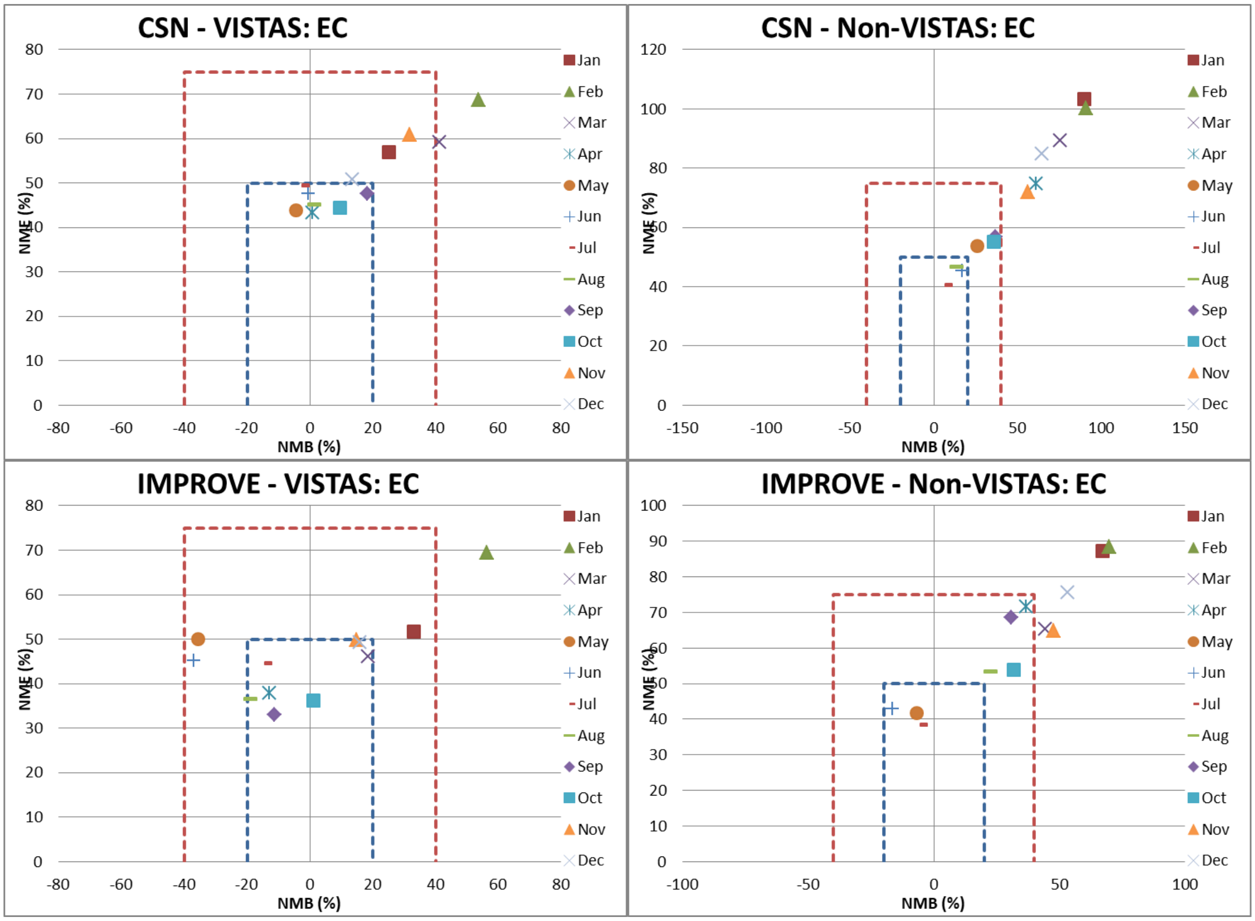

Figure D-4. Soccer Plot of EC by Network and Month for VISTAS and Non-VISTAS Sites.

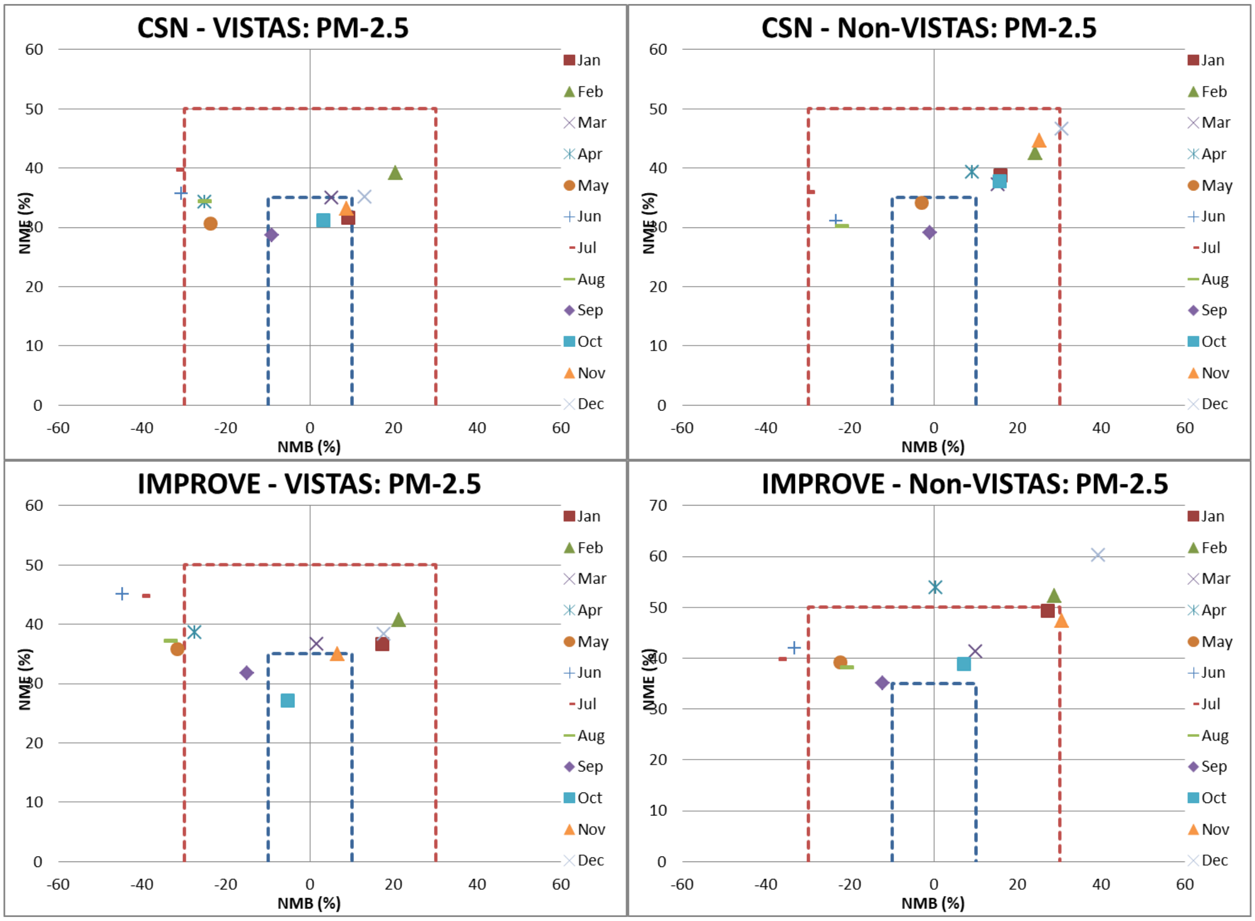

Figure D-5. Soccer Plot of Total $PM_{2.5}$ by Network and Month for VISTAS and Non-VISTAS Sites.

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Appendix E

VISTAS12 Modeling Domain
Bugle Plots of $PM_{2.5}$ Species by Network, Pollutant, and Month

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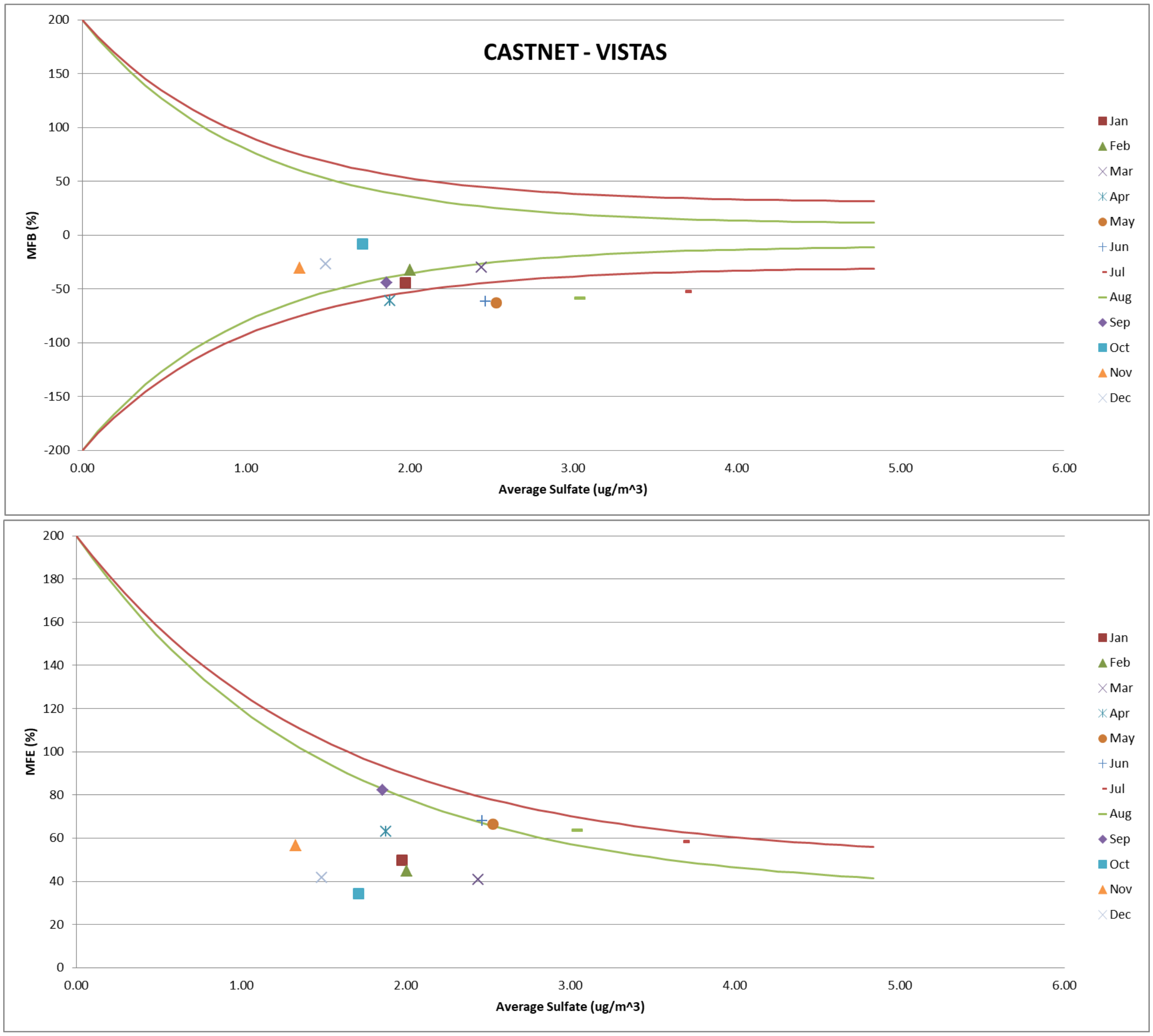


Figure E-1. Bugle Plot of Monthly Sulfate at VISTAS State CASTNET Sites.

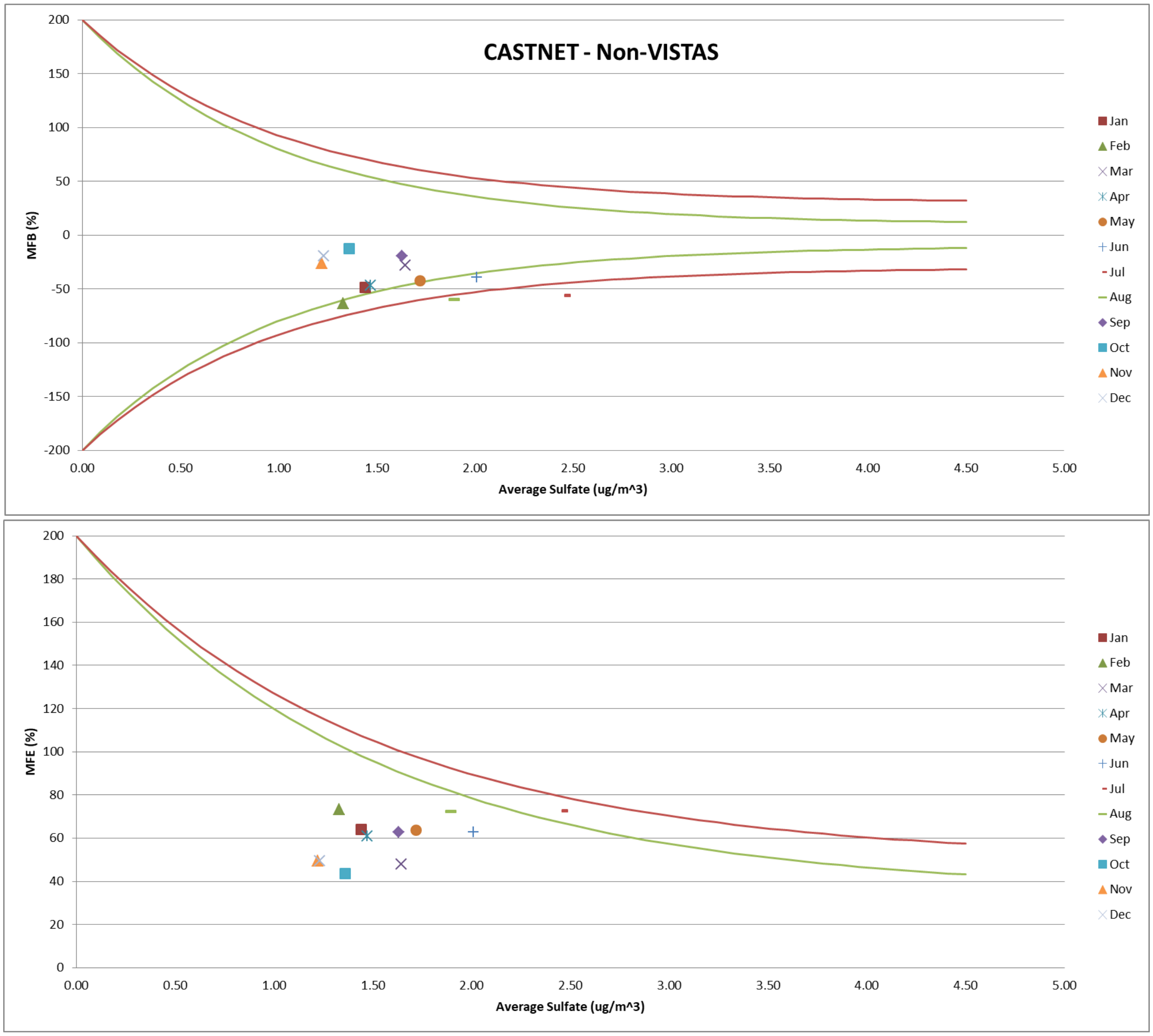
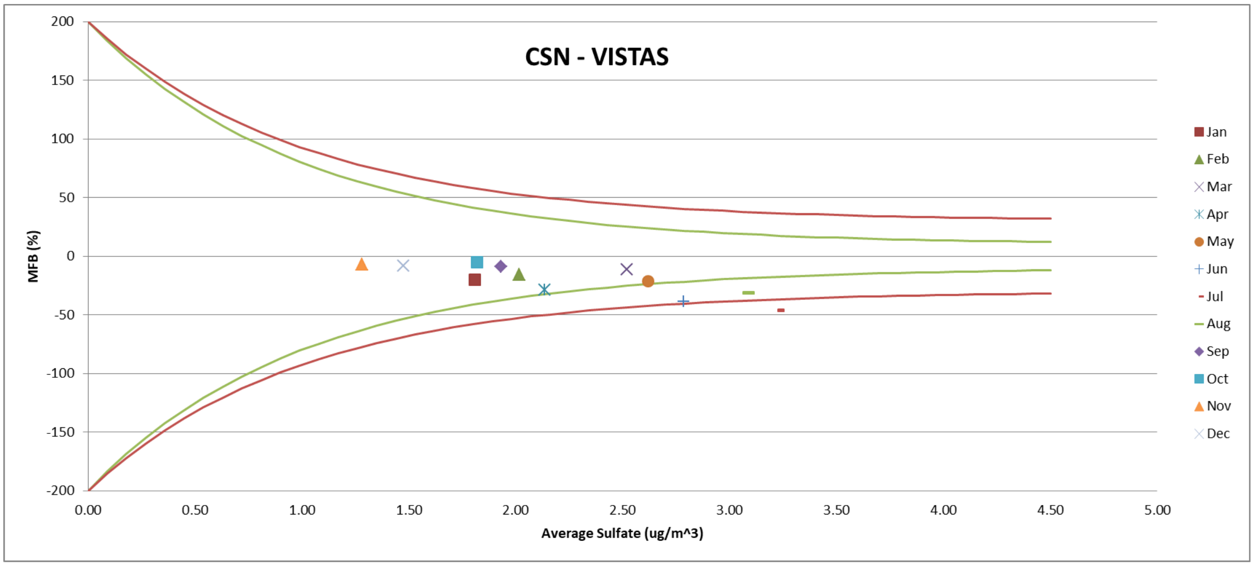


Figure E-2. Bugle Plot of Monthly Sulfate at Non-VISTAS State CASTNET Sites.



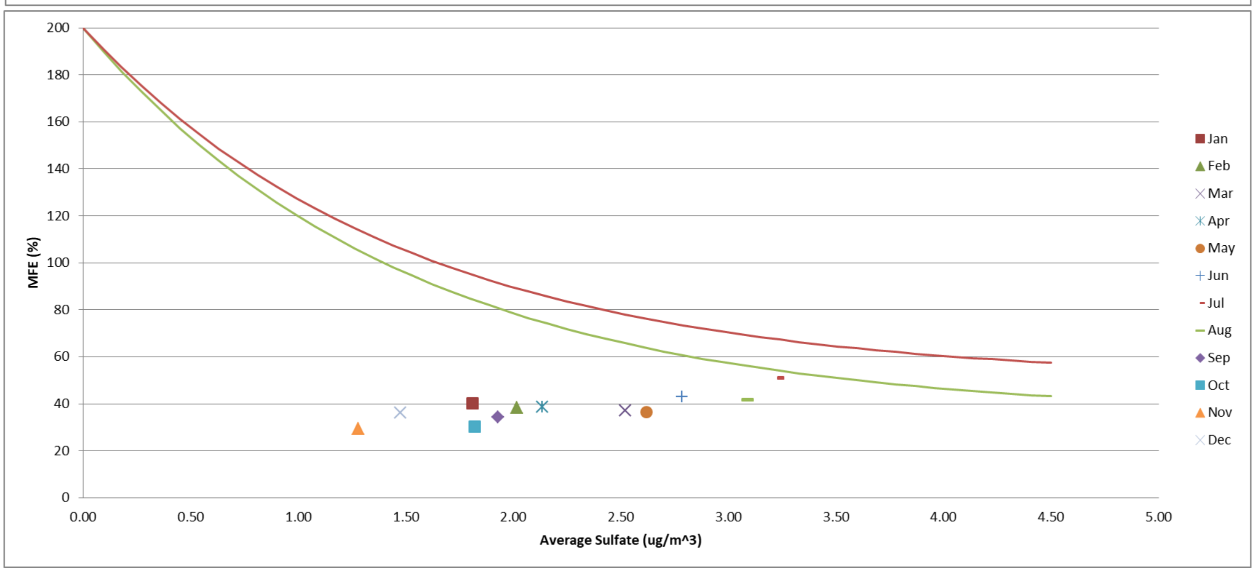


Figure E-3. Bugle Plot of Monthly Sulfate at VISTAS State CSN Sites.

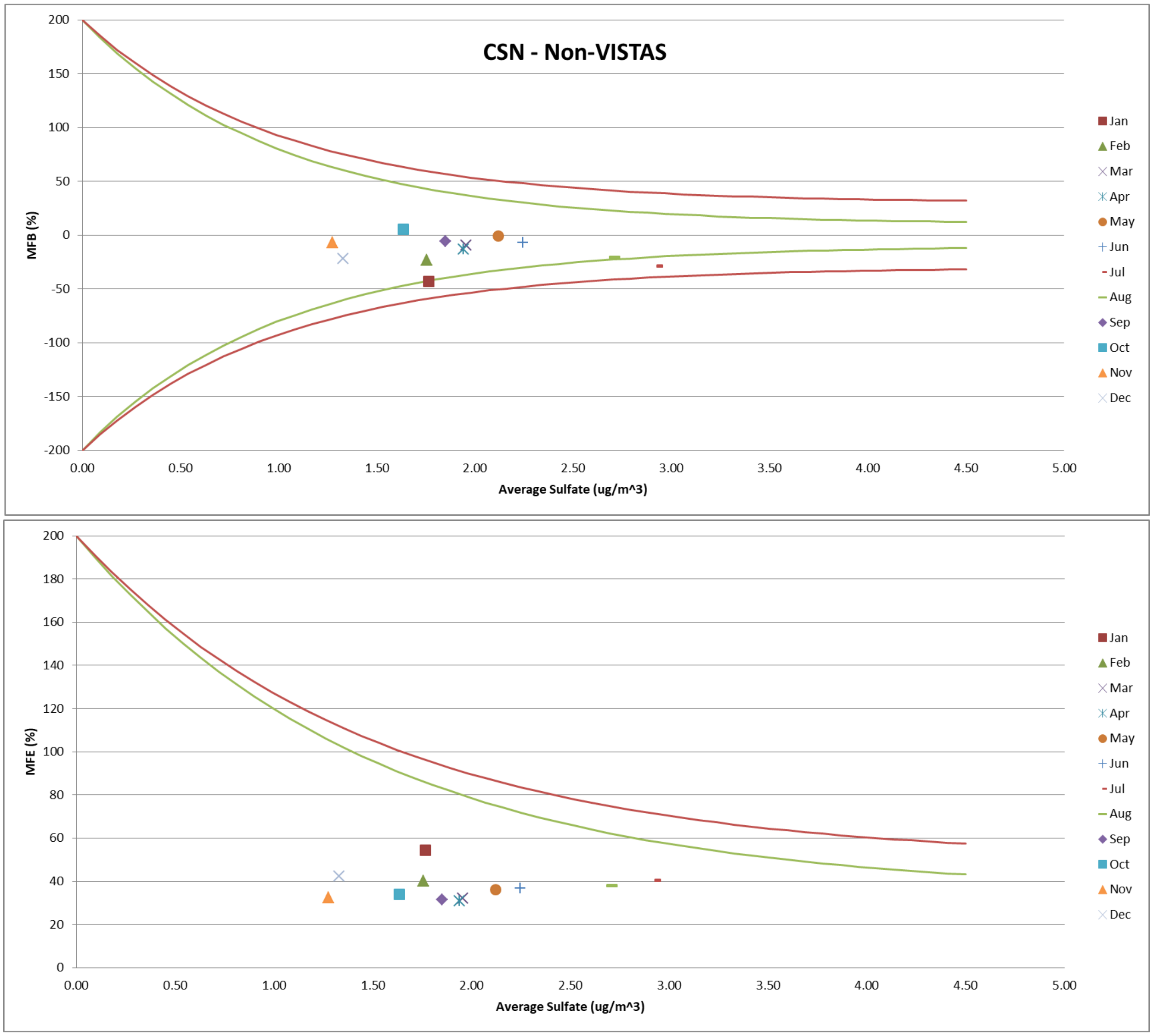


Figure E-4. Bugle Plot of Monthly Sulfate at Non-VISTAS State CSN Sites.

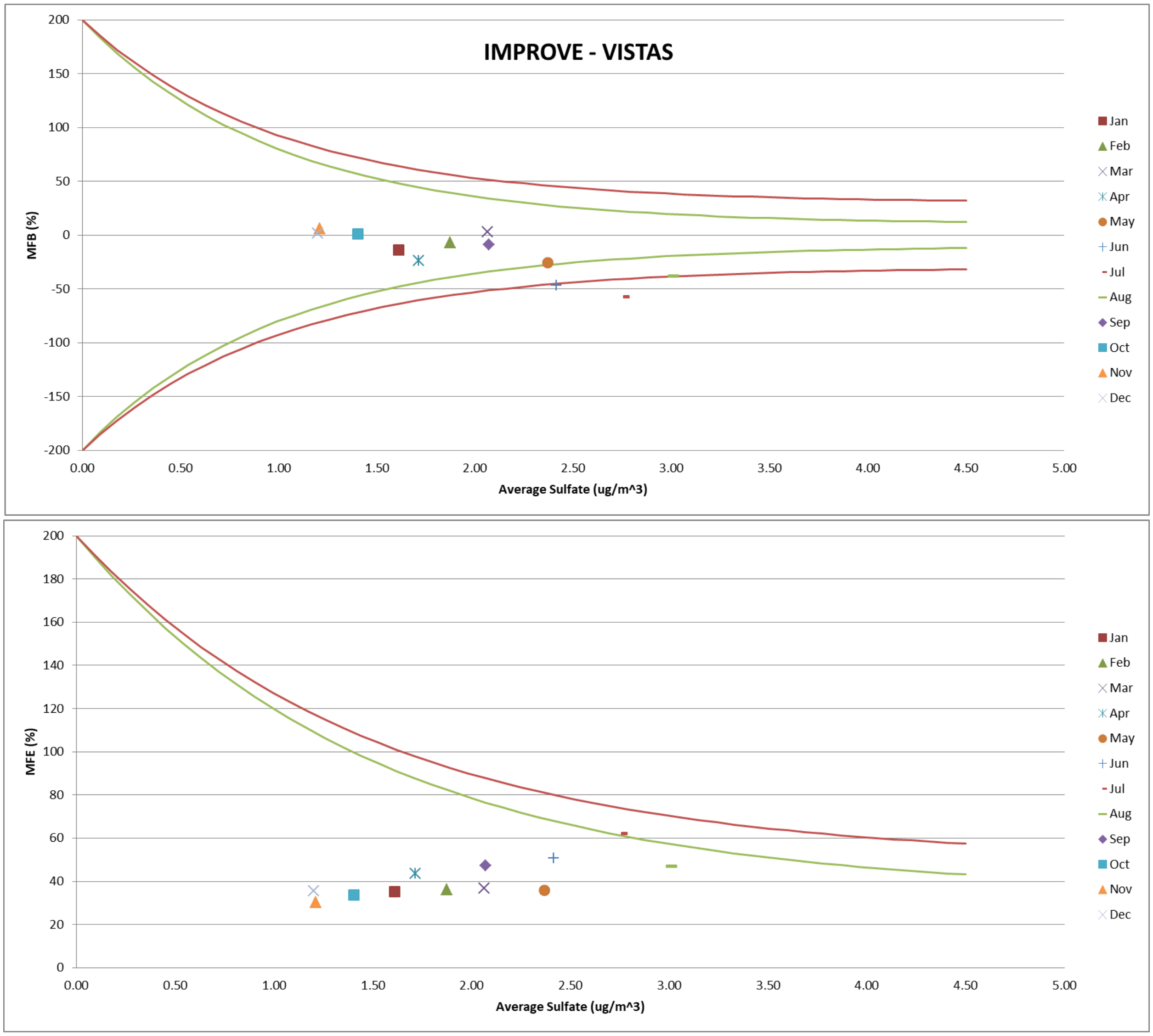


Figure E-5. Bugle Plot of Monthly Sulfate at VISTAS State IMPROVE Sites.

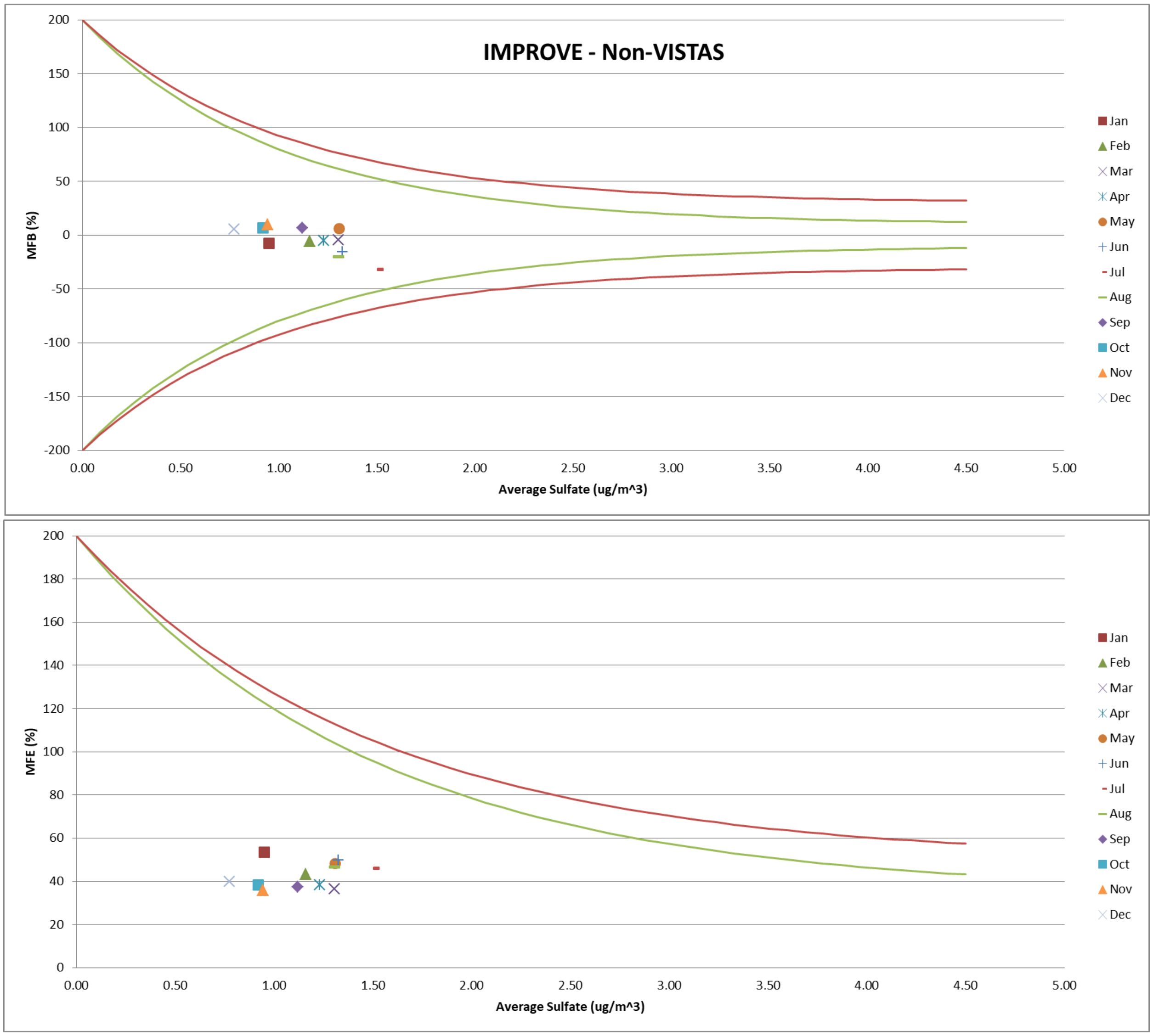


Figure E-6. Bugle Plot of Monthly Sulfate at Non-VISTAS State IMPROVE Sites.

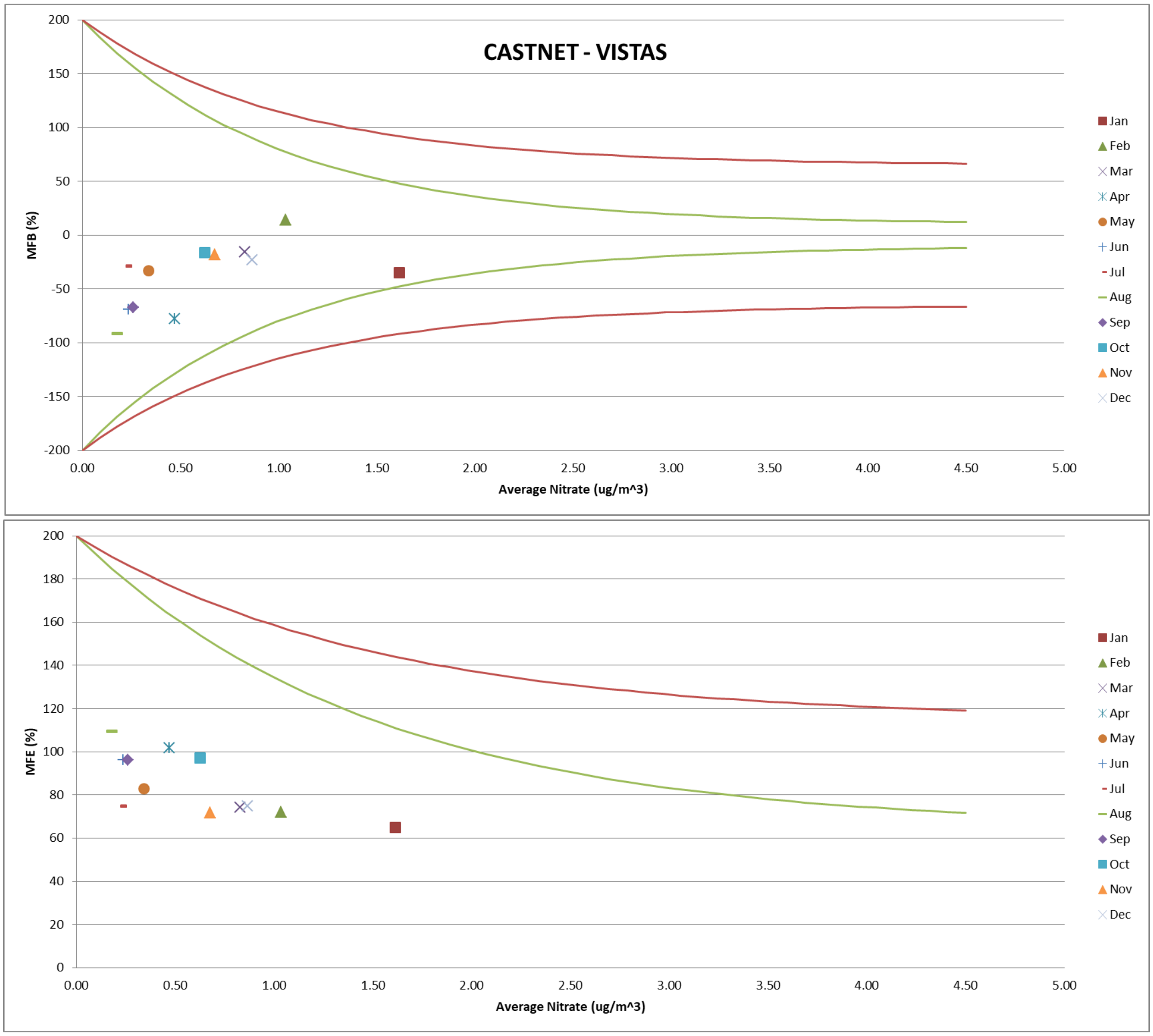


Figure E-7. Bugle Plot of Monthly Nitrate at VISTAS State CASTNET Sites.

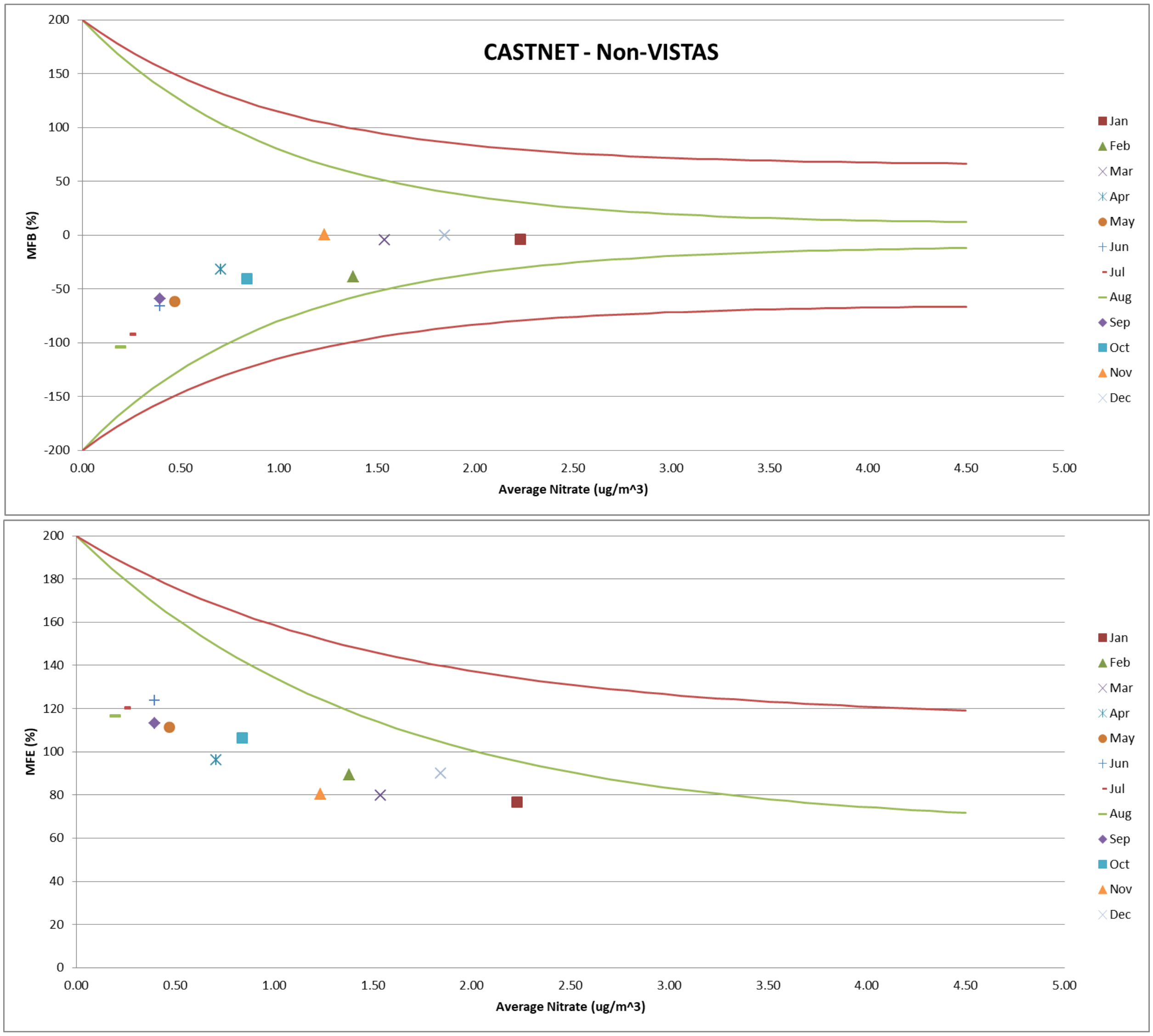
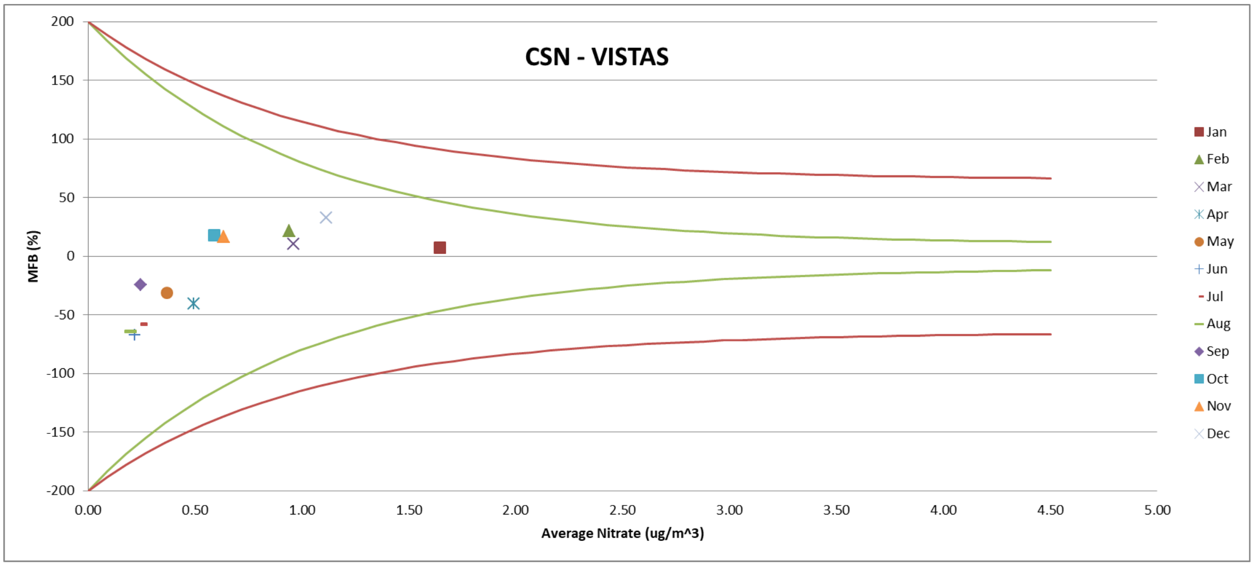


Figure E-8. Bugle Plot of Monthly Nitrate at Non-VISTAS State CASTNET Sites.



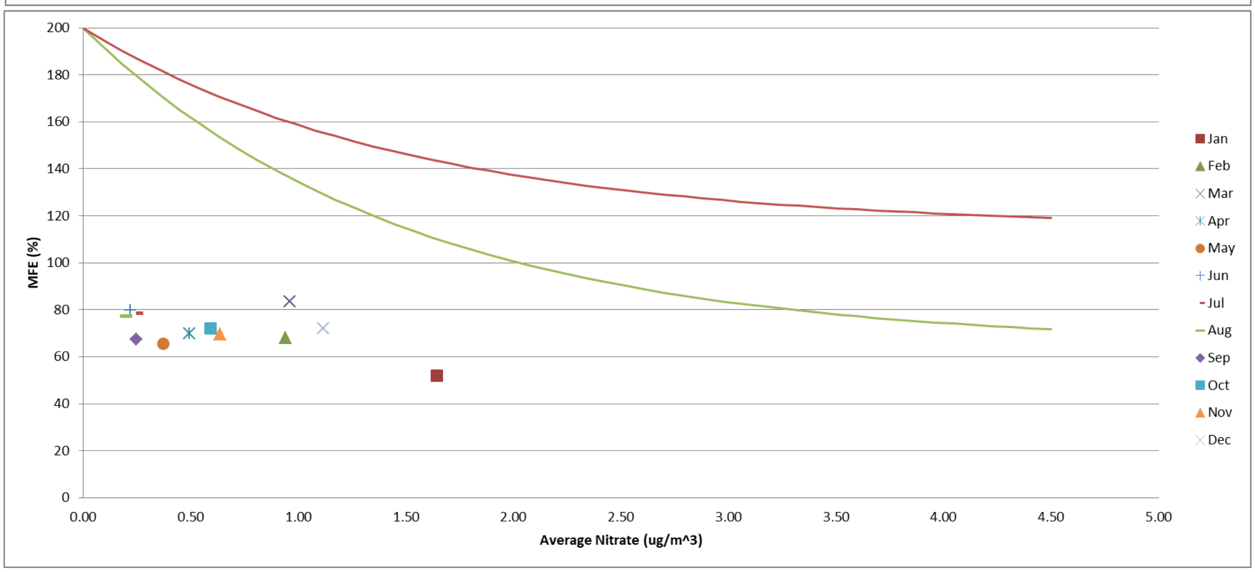


Figure E-9. Bugle Plot of Monthly Nitrate at VISTAS State CSN Sites.

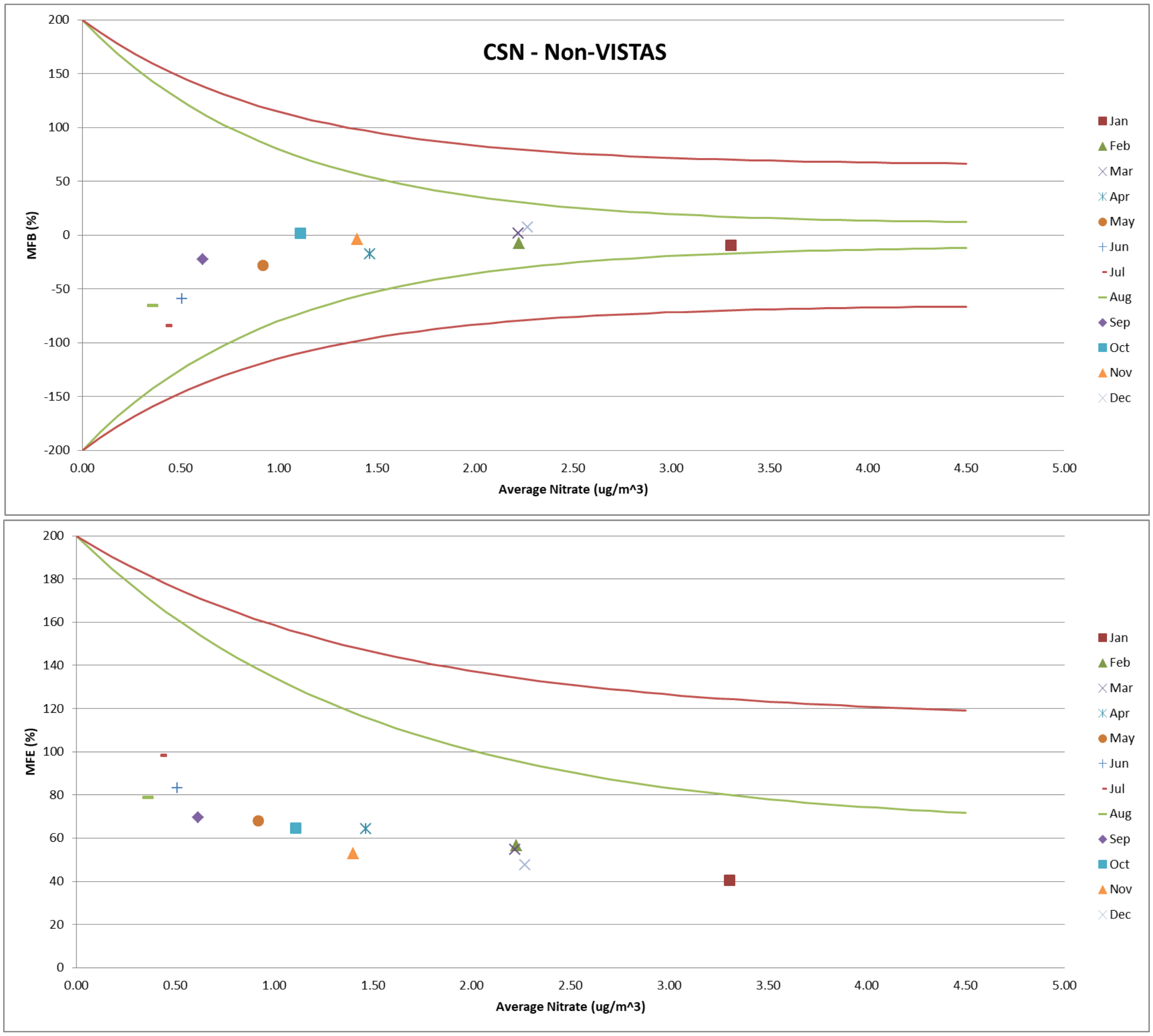


Figure E-10. Bugle Plot of Monthly Nitrate at Non-VISTAS State CSN Sites.

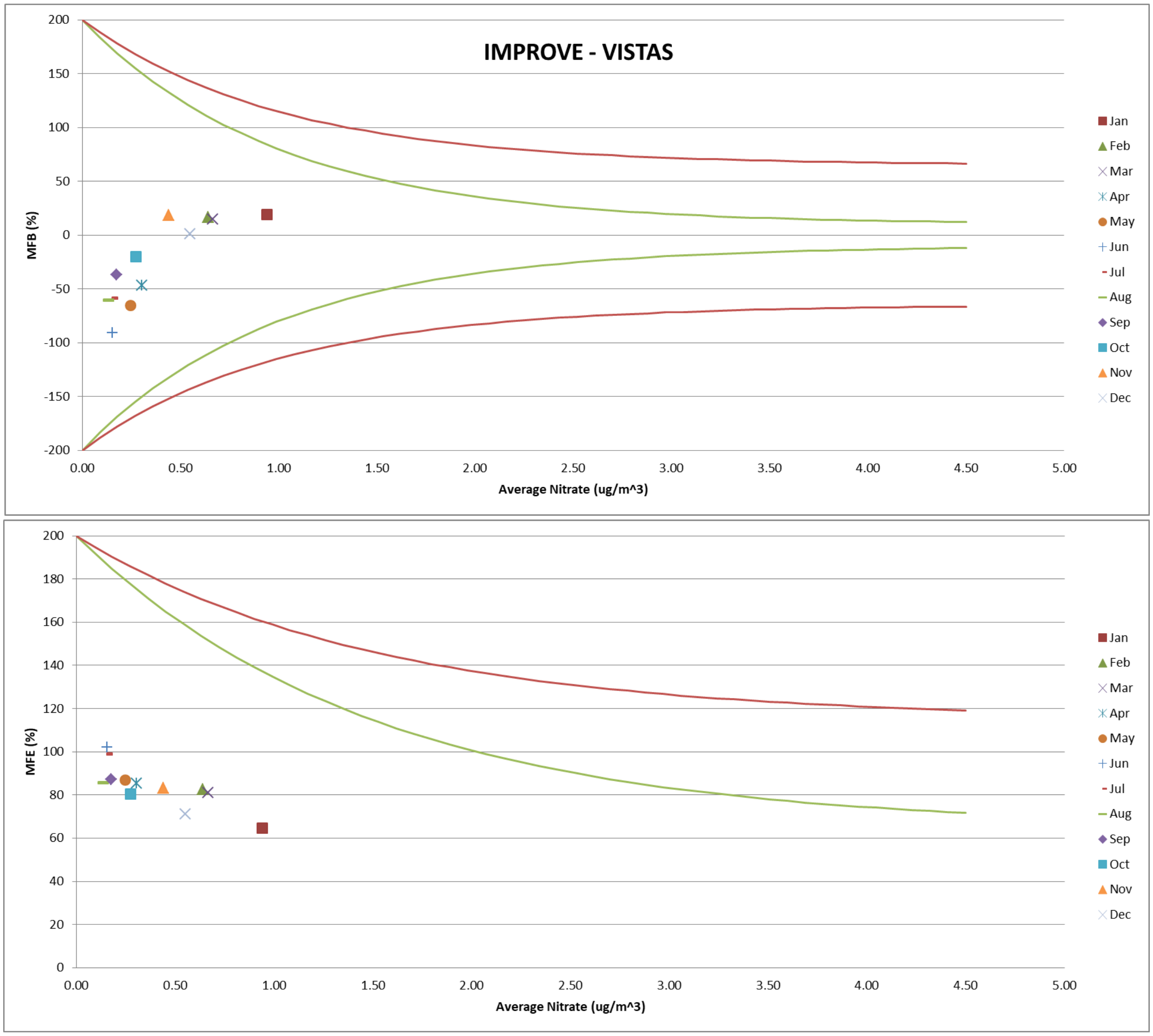


Figure E-11. Bugle Plot of Monthly Nitrate at VISTAS State IMPROVE Sites.

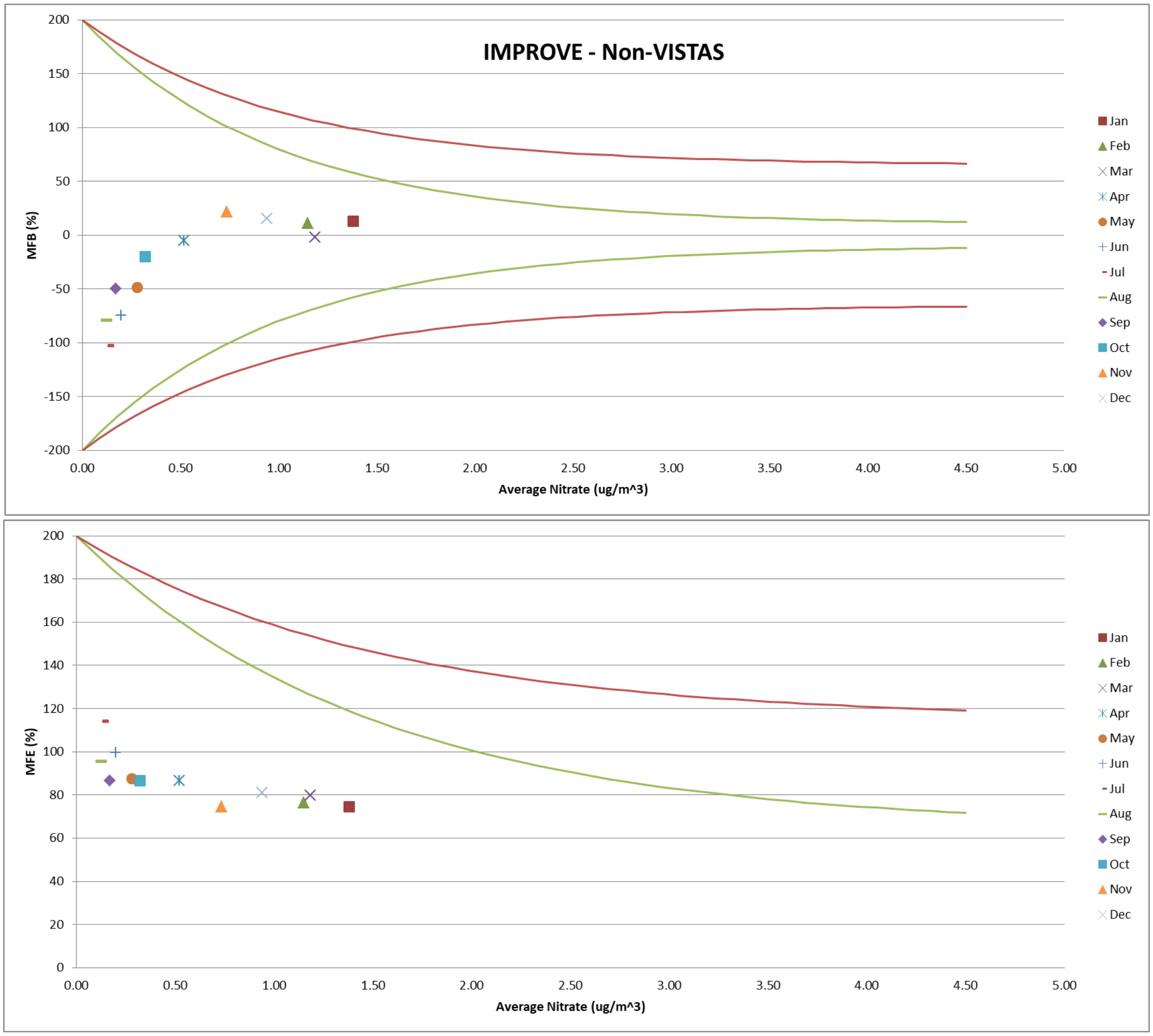


Figure E-12. Bugle Plot of Monthly Nitrate at Non-VISTAS State IMPROVE Sites.

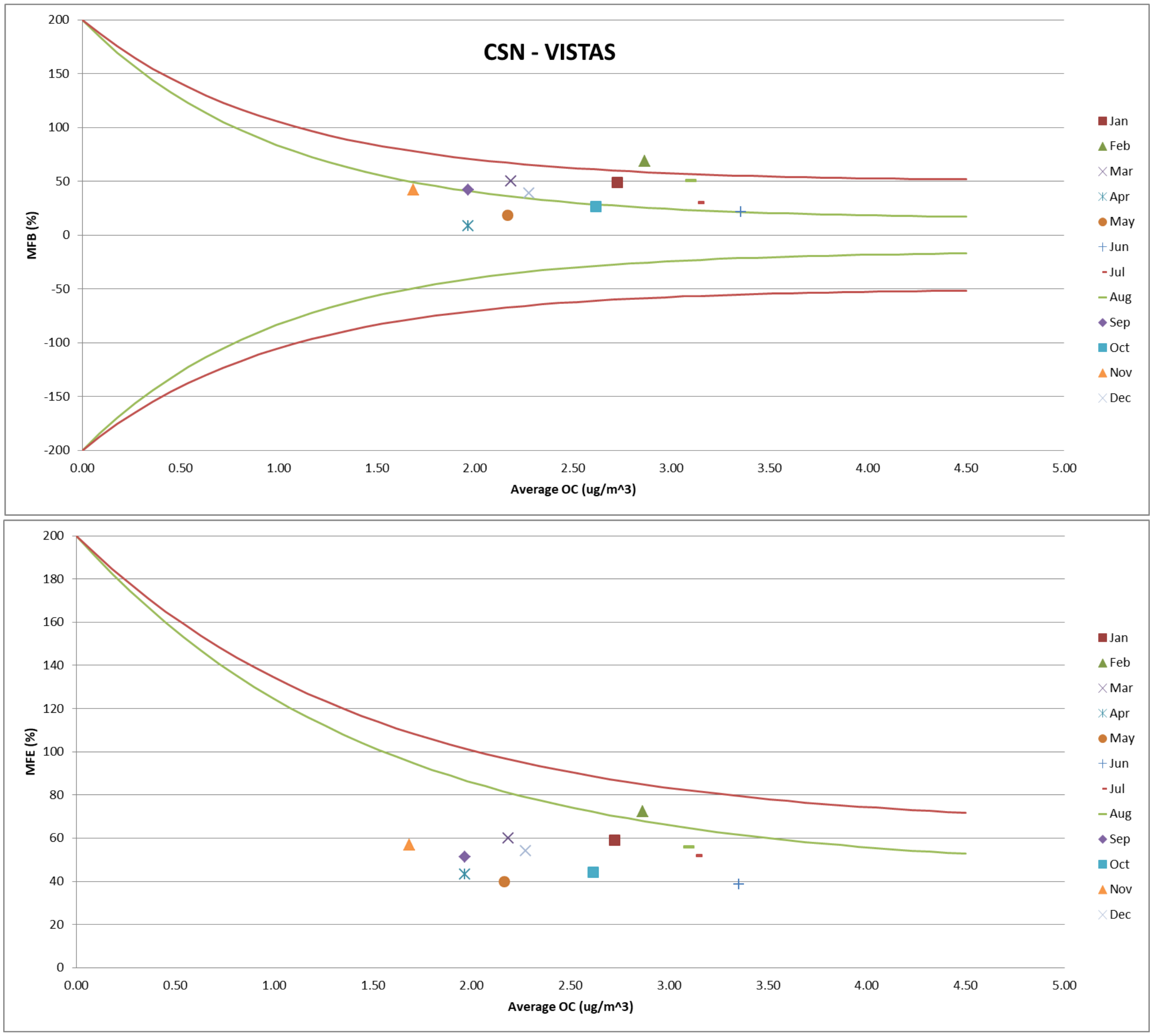


Figure E-13. Bugle Plot of Monthly OC at VISTAS State CSN Sites.

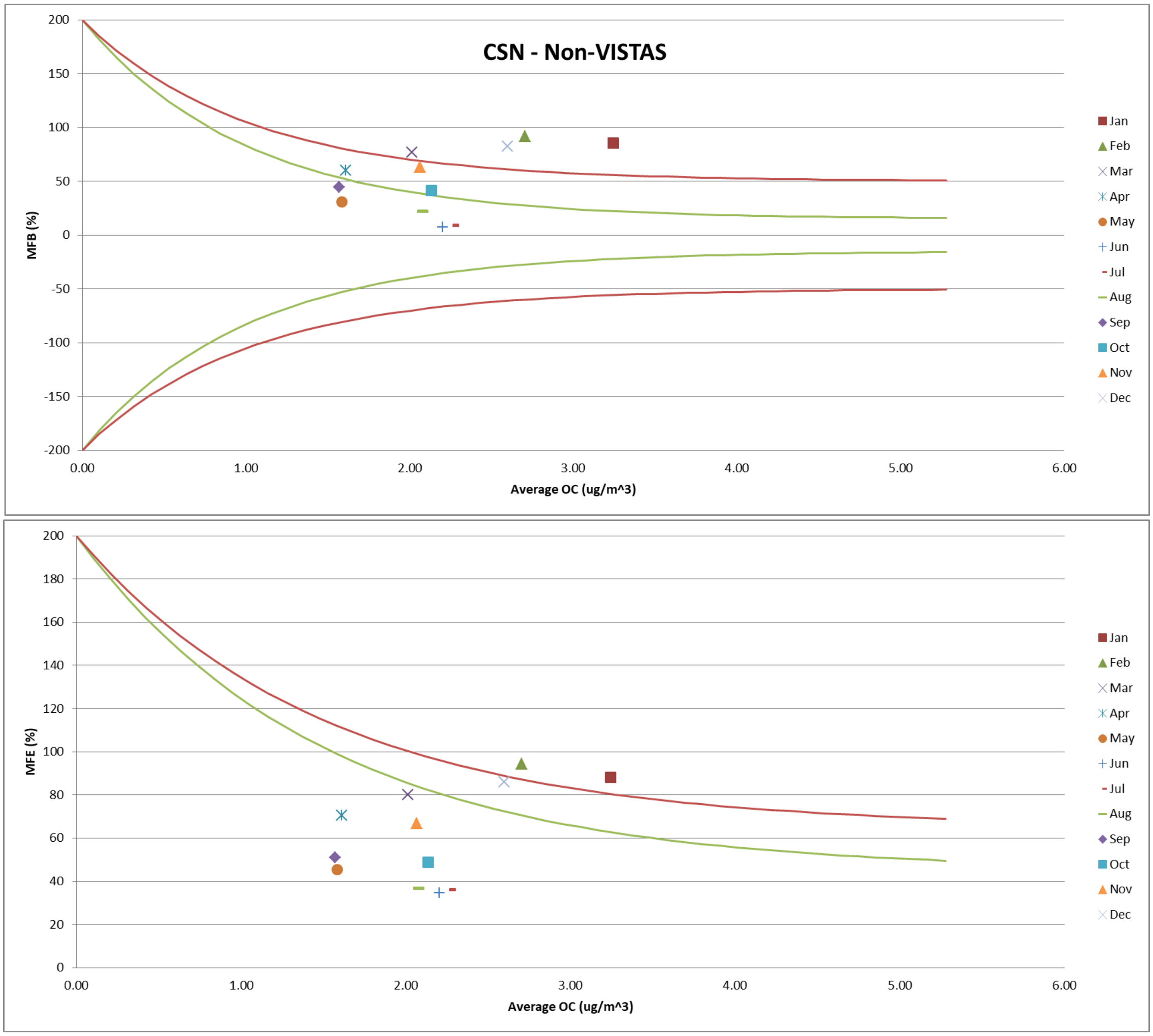


Figure E-14. Bugle Plot of Monthly OC at Non-VISTAS State CSN Sites.

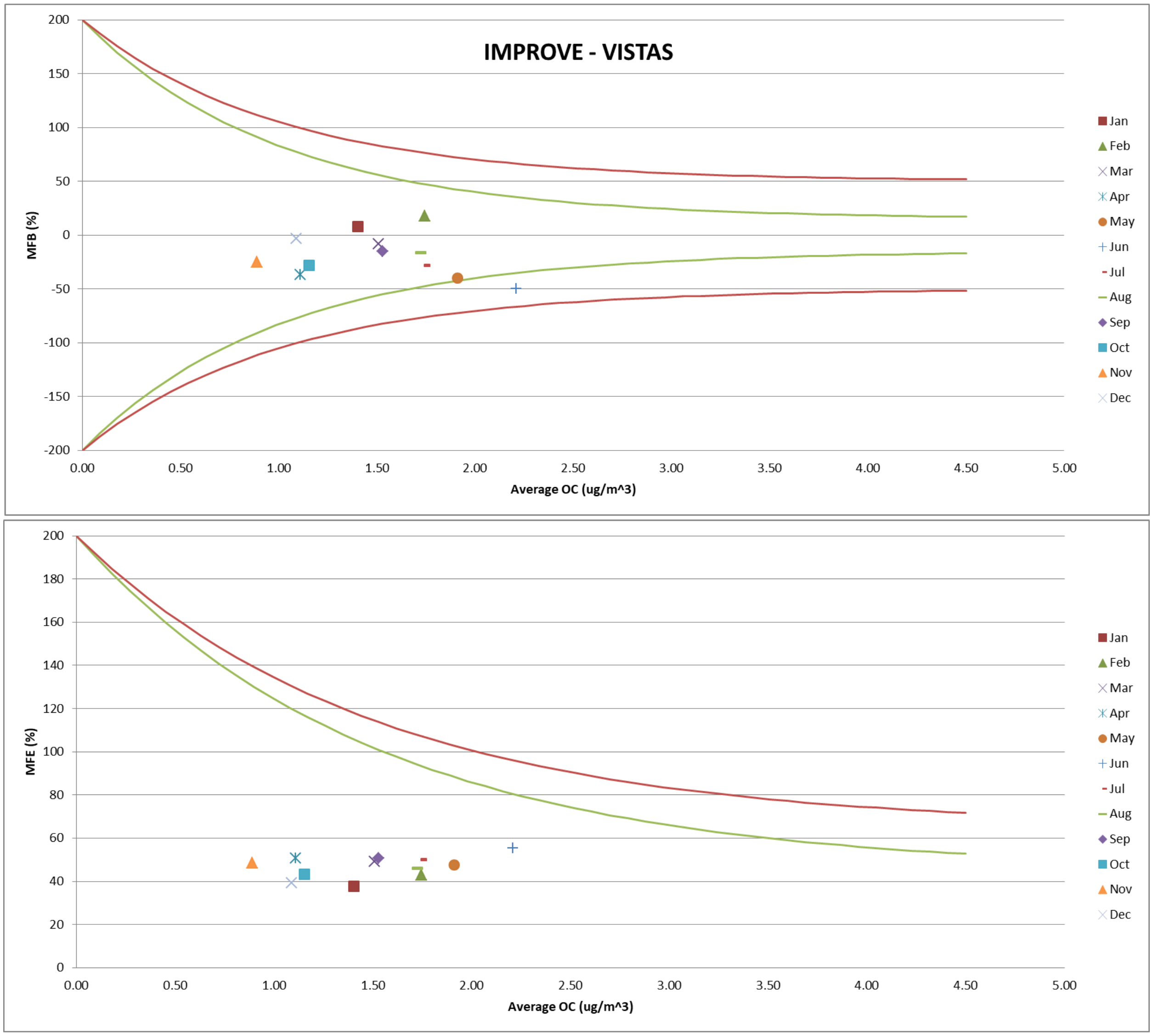


Figure E-15. Bugle Plot of Monthly OC at VISTAS State IMPROVE Sites.

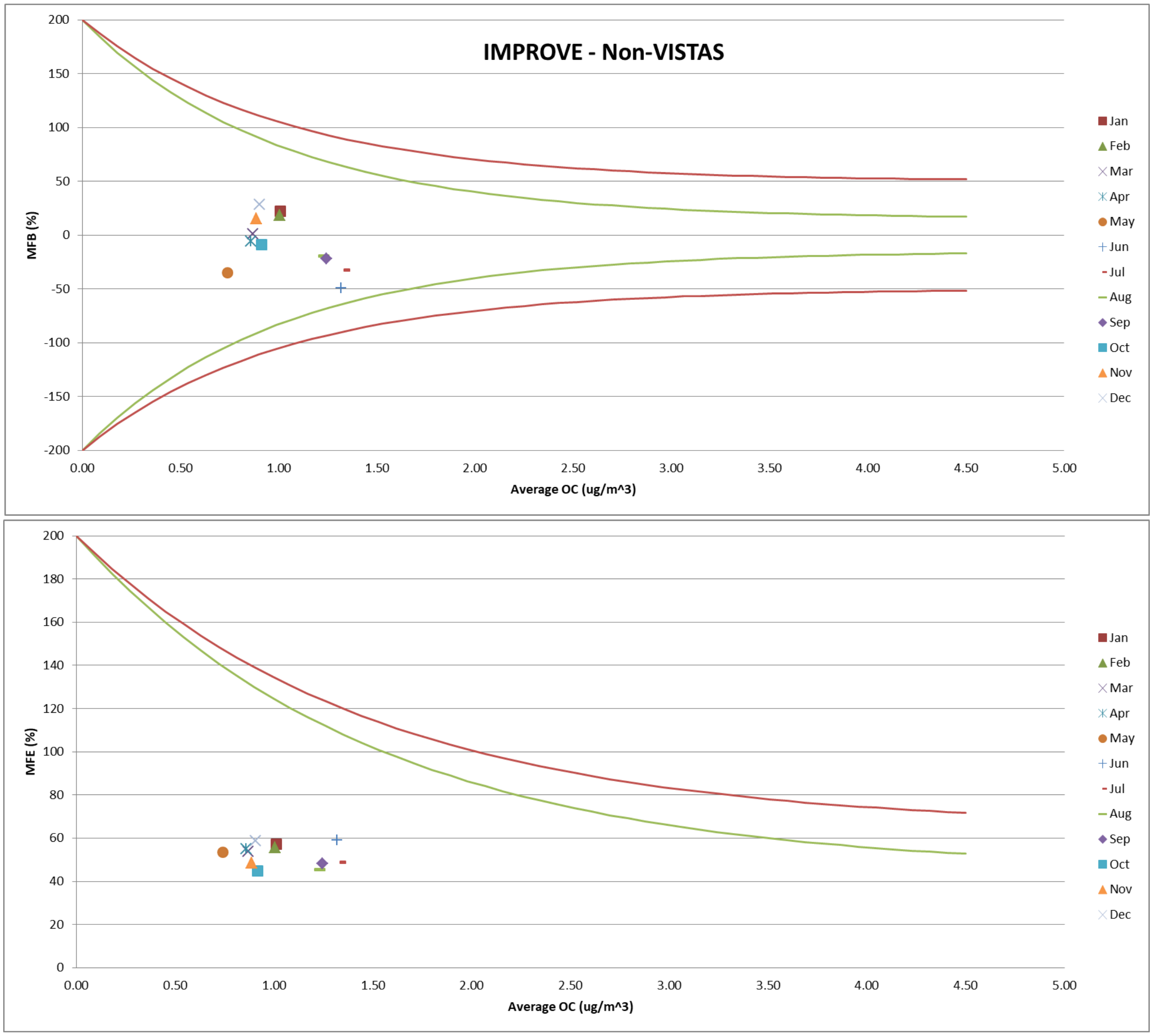
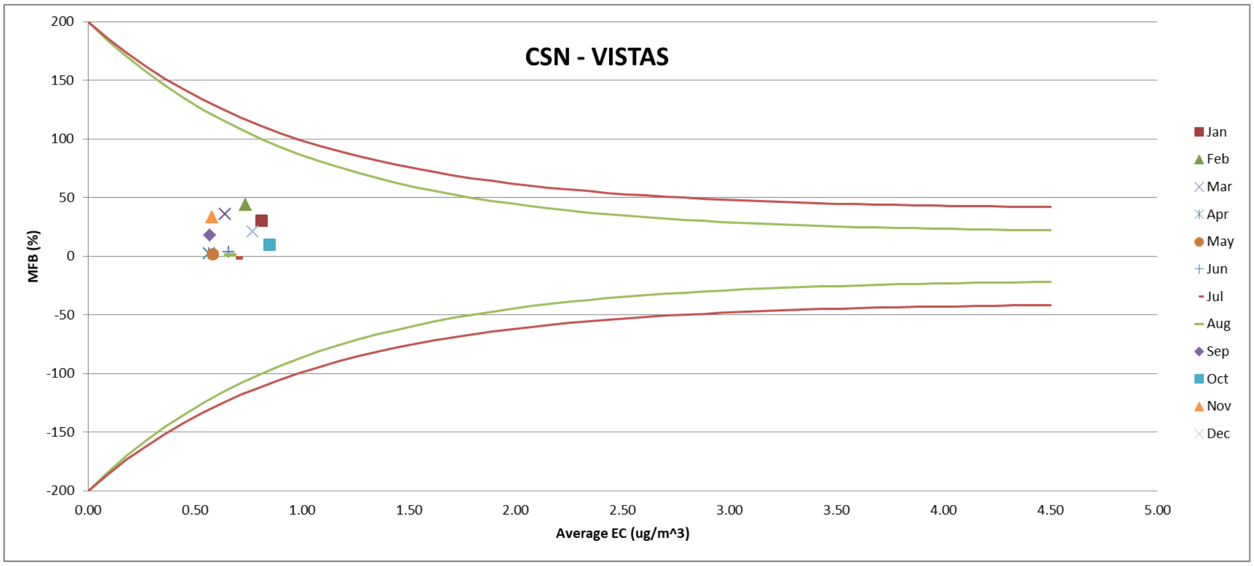


Figure E-16. Bugle Plot of Monthly OC at Non-VISTAS State IMPROVE Sites.



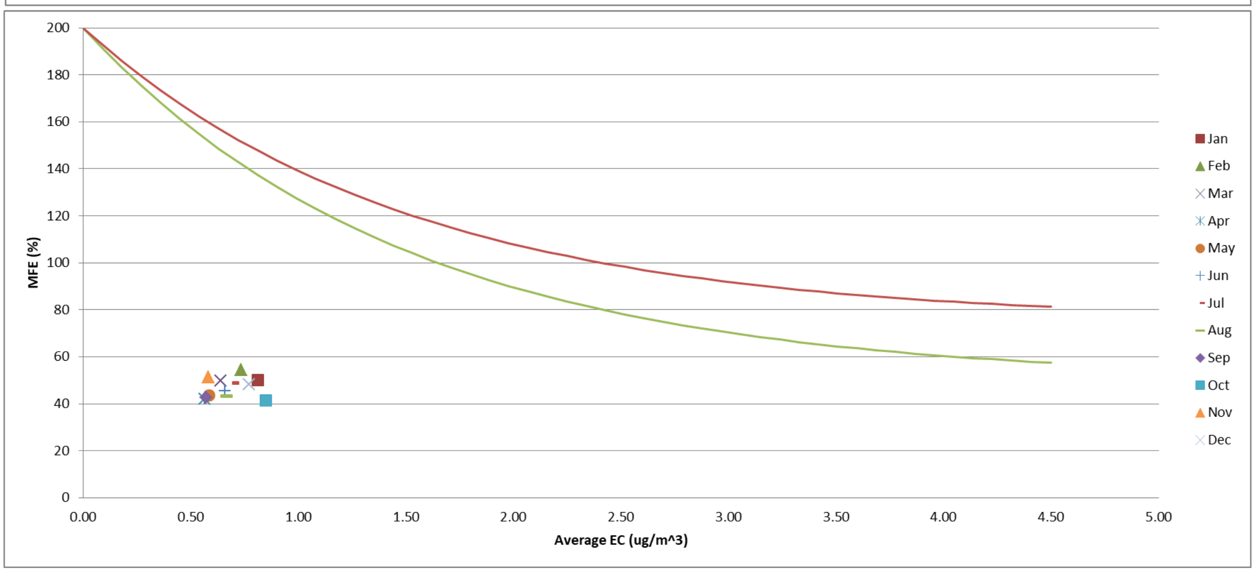
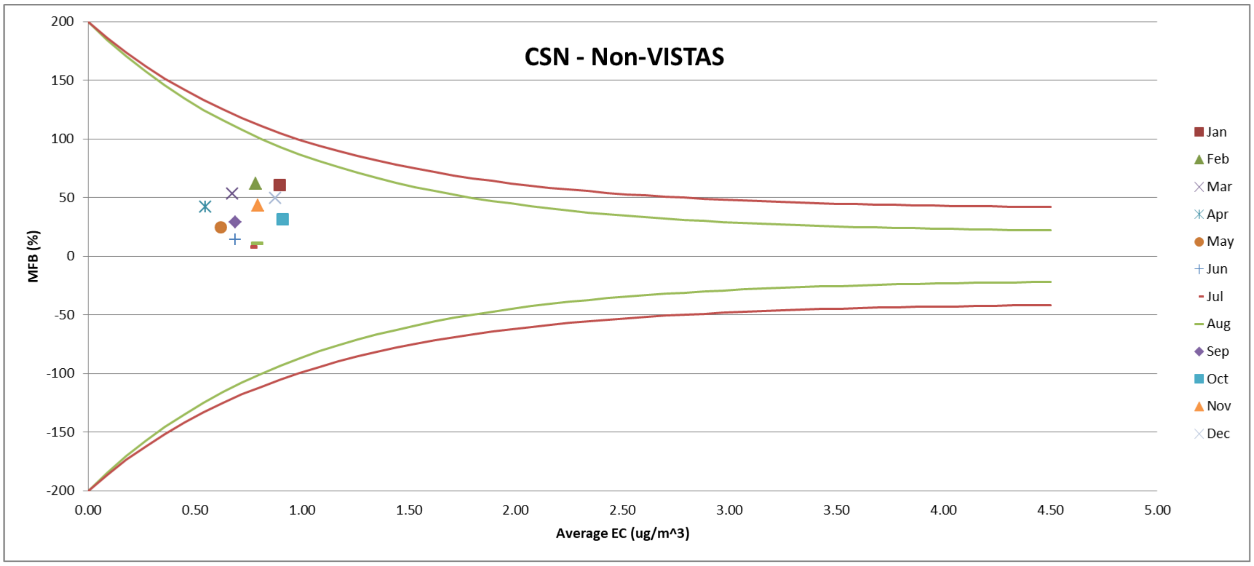


Figure E-17. Bugle Plot of Monthly EC at VISTAS State CSN Sites.



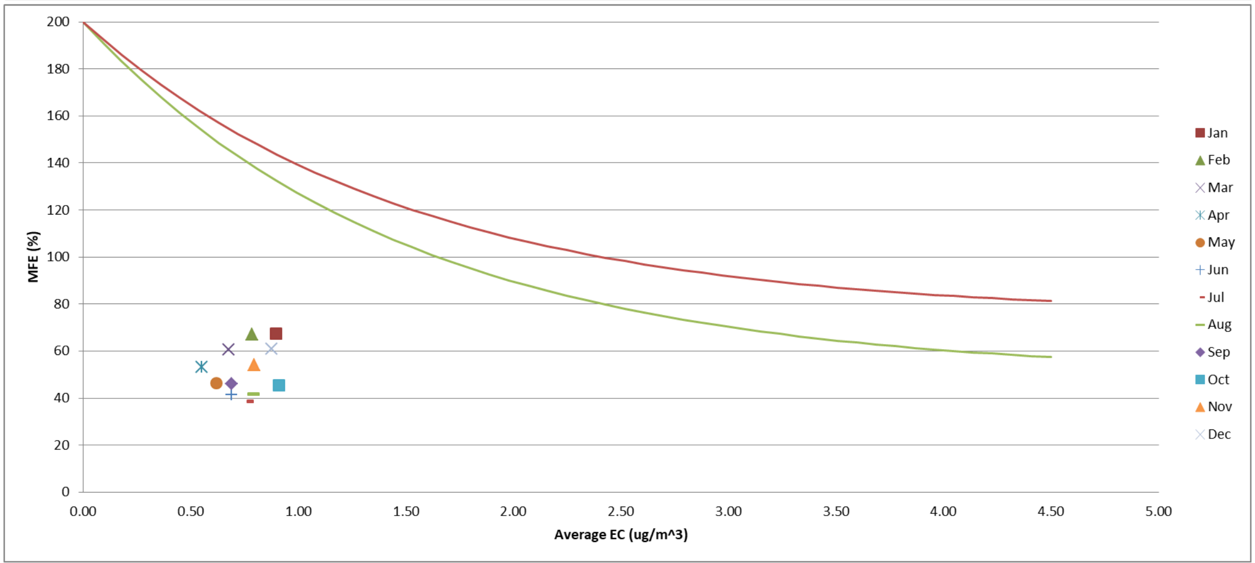


Figure E-18. Bugle Plot of Monthly EC at Non-VISTAS State CSN Sites.

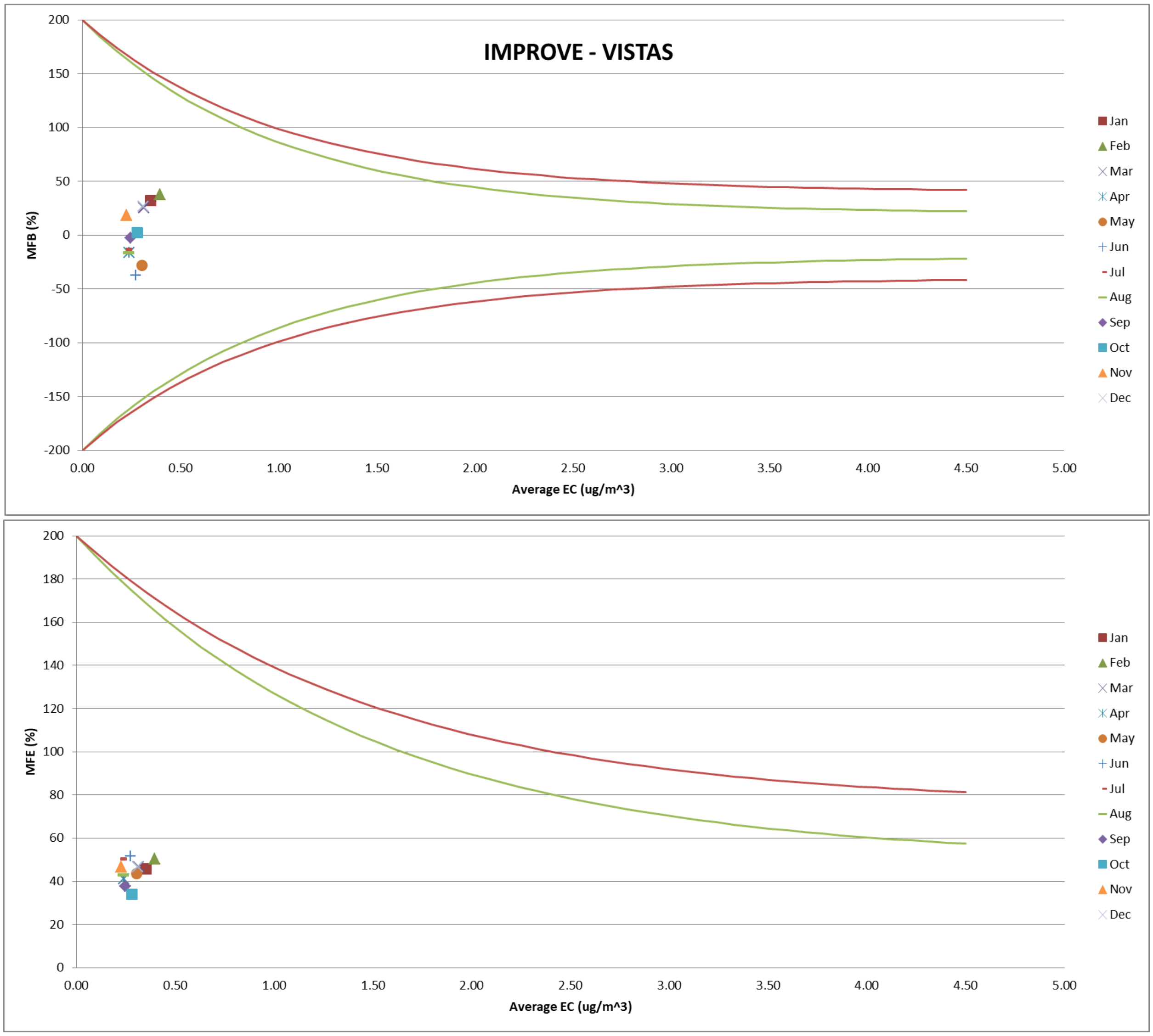


Figure E-19. Bugle Plot of Monthly EC at VISTAS State IMPROVE Sites.

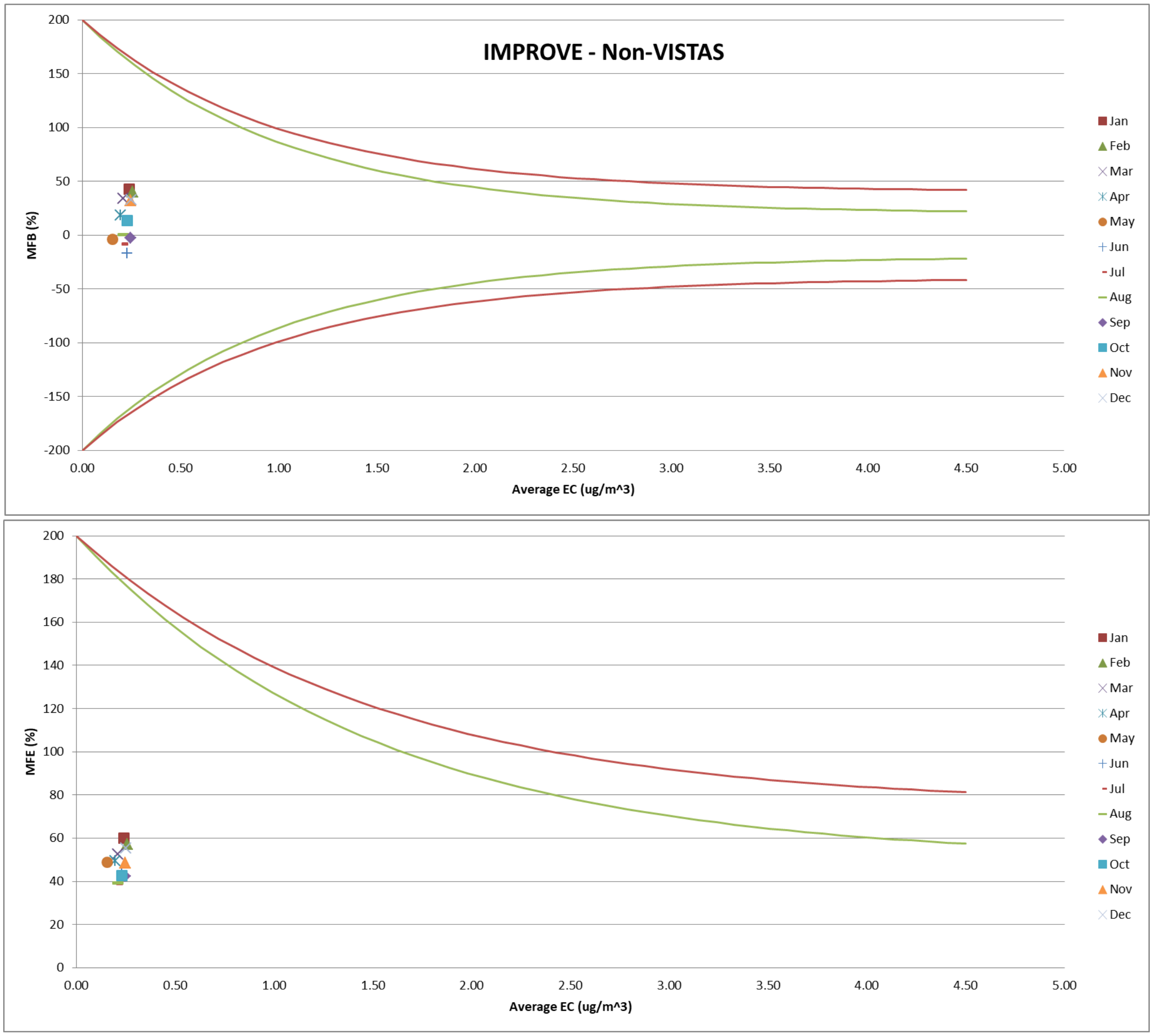


Figure E-20. Bugle Plot of Monthly EC at Non-VISTAS State IMPROVE Sites.

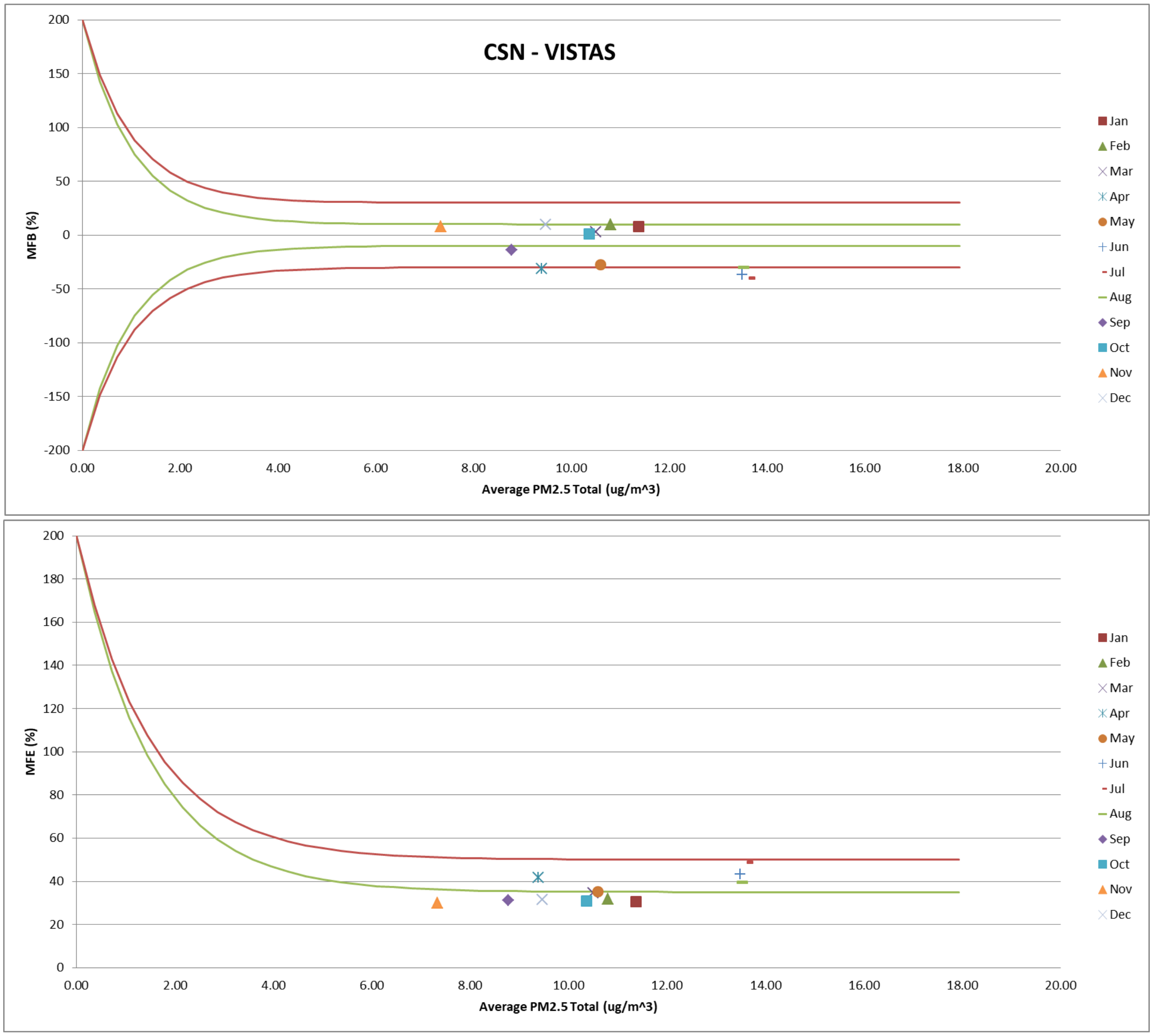


Figure E-21. Bugle Plot of Monthly Total $PM_{2.5}$ at VISTAS State CSN Sites.

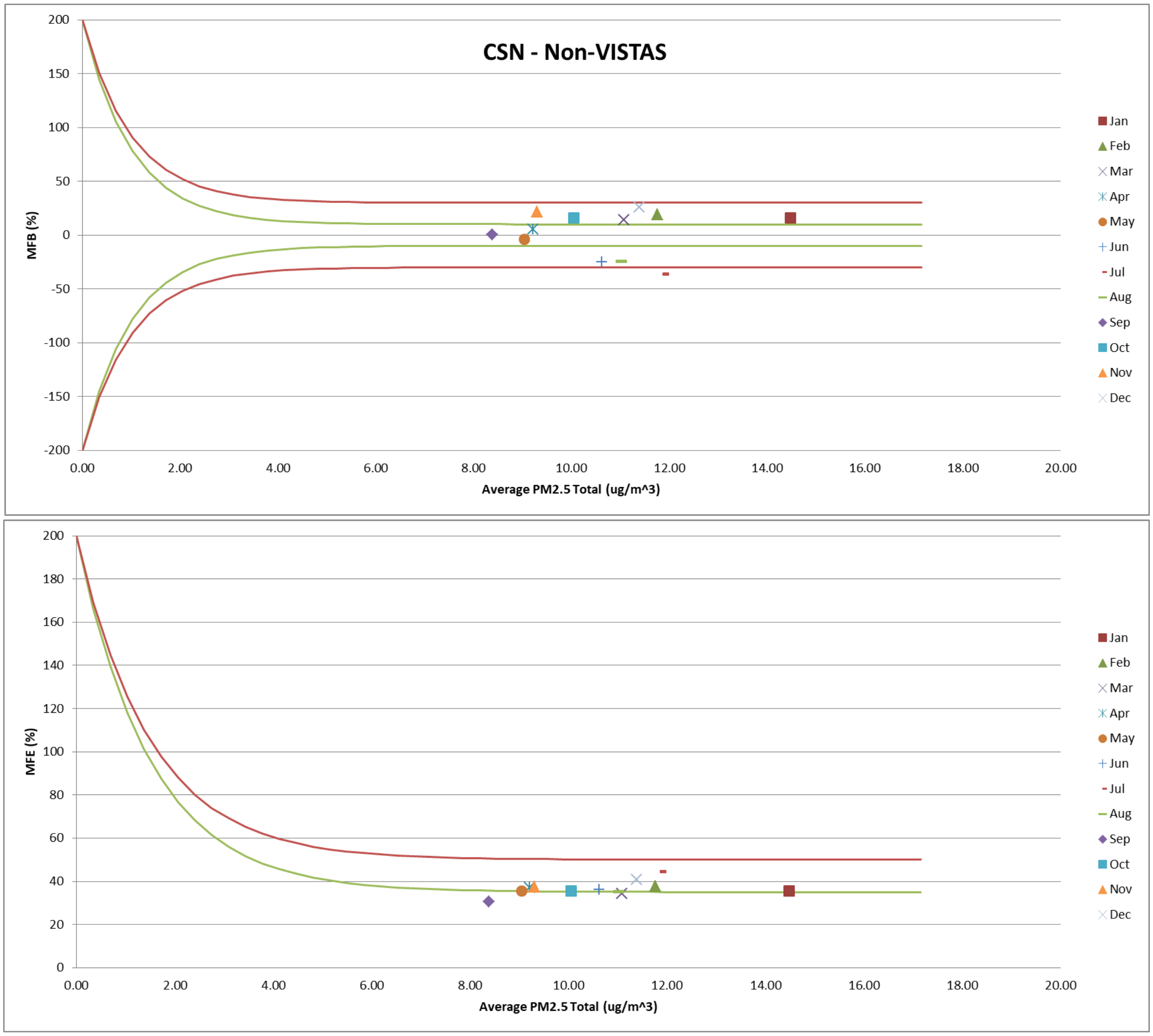


Figure E-22. Bugle Plot of Monthly Total $PM_{2.5}$ at Non-VISTAS State CSN Sites.

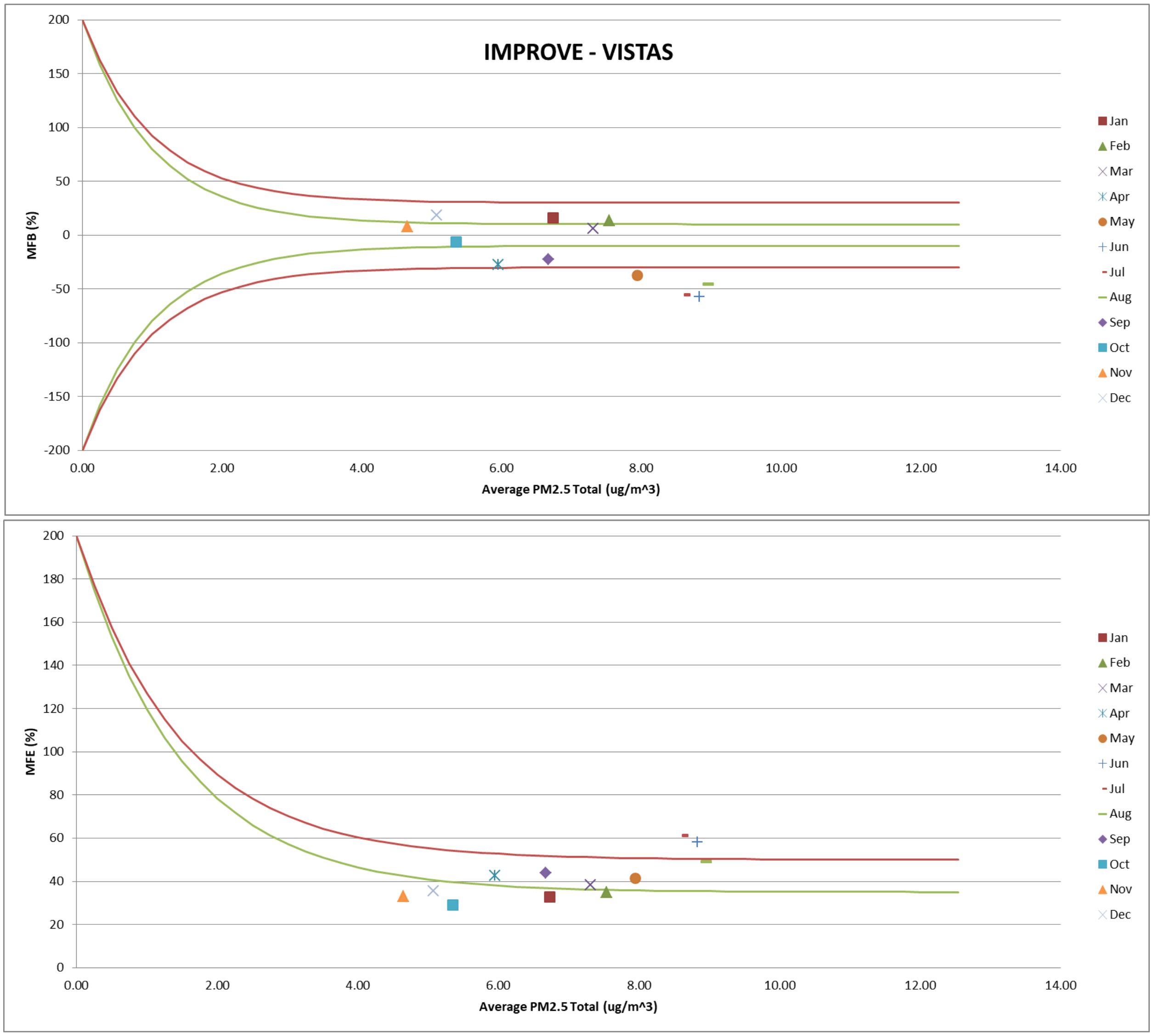


Figure E-23. Bugle Plot of Monthly Total $PM_{2.5}$ at VISTAS State IMPROVE Sites.

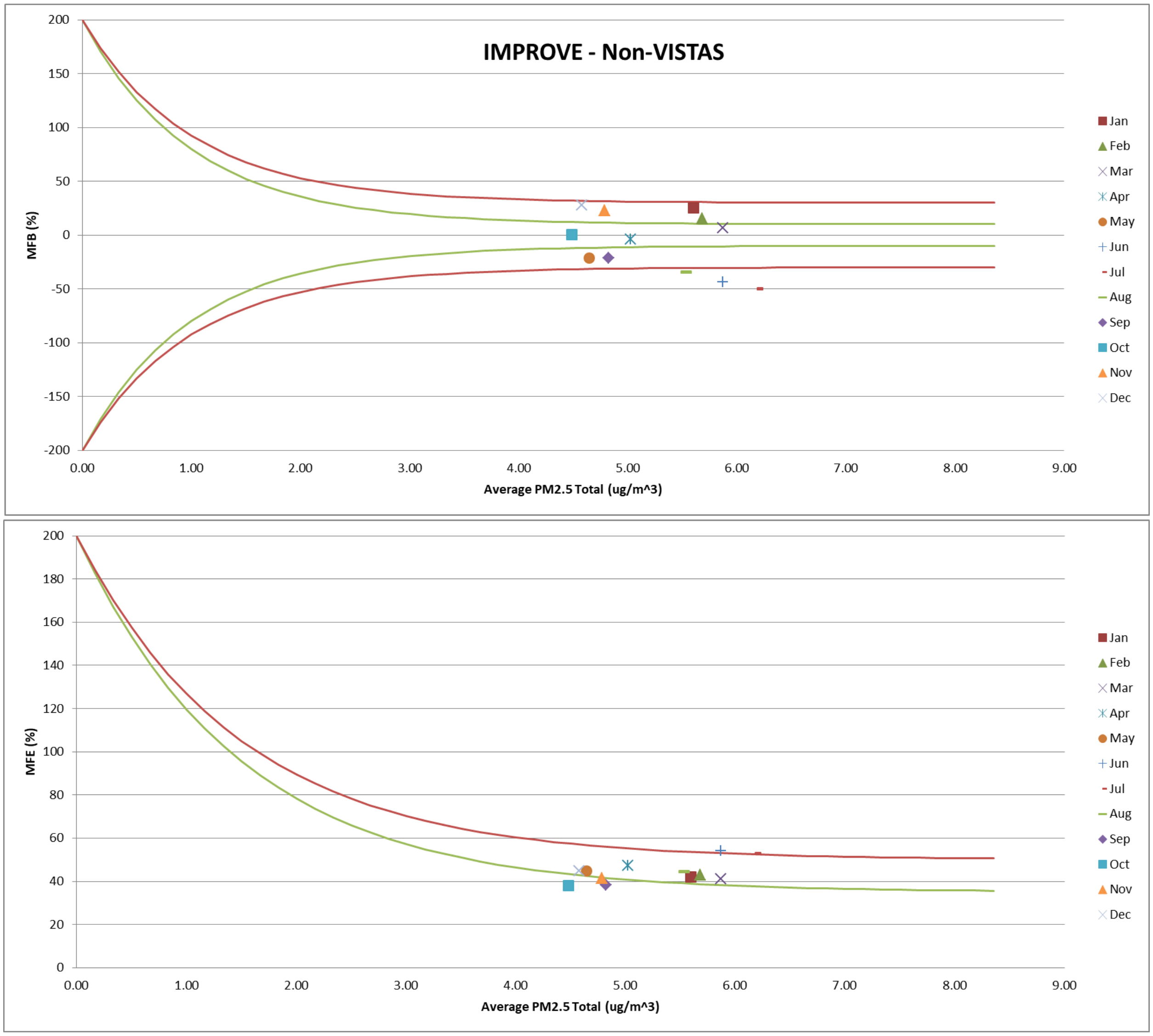


Figure E-24. Bugle Plot of Monthly Total $PM_{2.5}$ at Non-VISTAS State IMPROVE Sites.

Appendix F

VISTAS12 Modeling Domain
Observed and Modeled Concentration and Light Extinction Comparisons
(see "APP_F_PM_EXTINCTION_MPE.xlsx")

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