APPENDIX L

Technical Support Document of Modeling and Analyses to Demonstrate Reasonable Progress for the Regional Haze Planning Period II

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1. Introduction

The Arkansas Department of Energy and Environment's Division of Environmental Quality (DEQ) conducted an emission inventory analyses and air quality photochemical modeling to support the development of a Regional Haze Planning Period II State Implementation Plan (SIP) for the 2018–2028 implementation period. The Regional Haze Rule (RHR)[1] requires states to set goals for each implementation period that ensure reasonable progress toward natural visibility conditions for the 20 percent most impaired days at designated scenic wilderness areas and national parks, referred to as Class I areas, by 2064. DEQ used the Comprehensive Air Quality Model with Extensions (CAMx) to simulate visibility conditions at Arkansas Class I areas, taking into consideration the control strategy in Arkansas Planning Period II SIP, to establish reasonable progress goals for 2028 and to evaluate the effect of Arkansas's control strategy on Class I areas in other states that are reasonably anticipated to be impacted by sources in Arkansas.

The CAMx model is a state-of-science "one-atmosphere" photochemical grid model that can simulate the formation, transport, and fate of pollutants—such as particulate matter, ozone, etc.—in the atmosphere[2]. The modeling setup for DEQ's CAMx modeling follows the same approach as the U.S. Environmental Protection Agency's (EPA) modeling platform version 2016v1 for Regional Haze.[3] DEQ's modeling analysis focused on Class I areas in Arkansas and Class I areas identified by Arkansas or other states as reasonably anticipated to be impacted by emissions from sources in Arkansas. These Class I areas are listed in Table 1. See Chapters II and III of the Planning Period II SIP narrative for further discussion supporting the identification of Class I areas that may be impacted by sources in Arkansas.

Table 1: Interagency Monitoring of Protected Visual Environments (IMPROVE) Sites Representing Class I Areas

Class I Areas	IMPROVE Site	State	Latitude	Longitude
Caney Creek Wilderness Area	CACR1	AR	34.4544	-94.1429
Upper Buffalo Wilderness Area	UPBU1	AR	35.8258	-93.2029
Hercules-Glades	HEGL1	MO	36.6137	-92.9220
Mammoth Cave	MACA1	KY	37.1317	-86.1478
Mingo	MING1	MO	36.9716	-90.1432
Shining Rock	SHRO1	NC	35.3936	-82.7743
Sipsey	SIPS1	AL	34.3433	-87.3387
Wichita Mountain	WIMO1	OK	34.7322	-98.7129

[1] 40 CFR 51.308(f)(1)(vi)(B).
[2] http://camx-wp.azurewebsites.net/Files/CAMxUsersGuide_v7.00.pdf
[3] Guidance on Regional Haze State Implementation Plans for the Second Implementation Period. Available at: https://www.epa.gov/visibility/guidance-regional-haze-state-implementation-plans-second-implementation-period

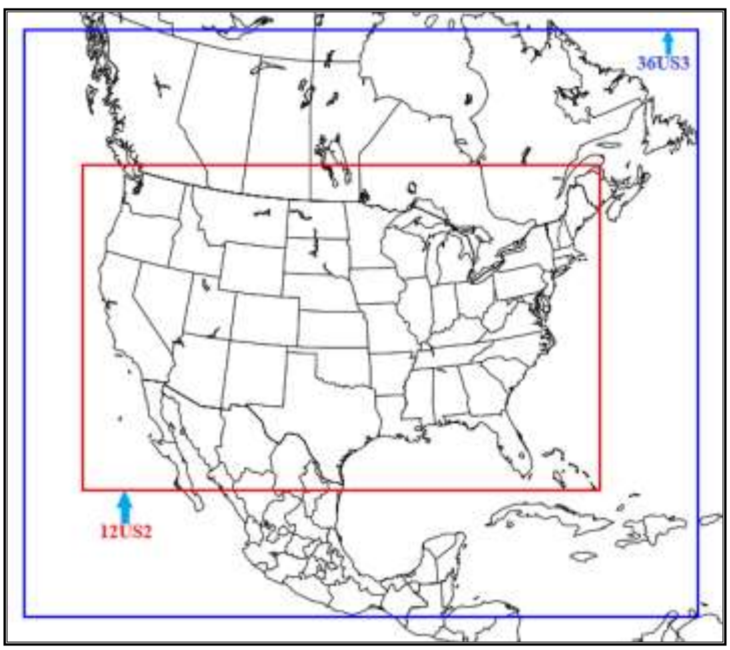
This Technical Support Document (TSD) describes how DEQ processed emissions, simulated 2016 base year (BY) and 2028 future year (FY) air quality using CAMx, and post-processed CAMx outputs to evaluate the above Class I areas' anticipated progress toward natural visibility conditions.

2. Air Quality Modeling Platform

Computerized air quality modeling is a crucial part of air quality planning. It integrates existing knowledge into software that can project future conditions based on projected emissions inventories. This section describes the methodology DEQ used to simulate 2016 BY air quality and project visibility conditions to 2028.

DEQ used EPA's 2016v1 platform to project the 2028 FY visibility conditions. EPA's v1 platform used a 12-km domain embedded in a North America 36-km domain (Figure 1). Both the 2016 BY and the 2028 FY DEQ simulations used the same inputs as the 2016v1 EPA modeling platform, except for some modifications to projected emission rates in 2028. DEQ obtained data developed by EPA and Multi-Jurisdictional Organizations (MJOs) to use in the modeling simulations. This data is available on the Intermountain West Data Warehouse (IWDW)[4].

Figure 1: CAMx 12-km and 36-km Domains



2.1 Initial and Boundary Conditions

DEQ used EPA 2016v1 platform's initial and boundary conditions that were generated from a hemispheric simulation of the Community Multiscale Air Quality (CMAQ) model. The model

[4] https://views.cira.colostate.edu/iwdw/

included a polar stereographic projection with a 108 km resolution to cover Northern hemisphere[5]. The 108 km resolution predictions were used to provide one-way dynamic boundary concentrations at one-hour intervals and an initial concentration field for the CAMx modeling.

2.2 Meteorological Data

The meteorological data used by DEQ for both the 2016 BY and the 2028 FY was developed by EPA using the Weather Research and Forecasting Model (WRF) v3.8, which was a component of EPA 2016v1 modeling platform. The WRF model was initialized using the 12km North American Model (12NAM) analysis and used 40km Eta Data Assimilation System (EDAS) analysis where 12NAM data were unavailable. The meteorological outputs from WRF include temperature, vertical diffusion rates, moisture, hourly-varying horizontal wind components, and rainfall rates for each vertical layer in each grid cell[3]. DEQ also used the ozone column data, photolysis rates, and land use data obtained from EPA's 2016v1 platform.

2.3 Emissions Data Processing

2.3.1 Emissions Data

The EPA/MJO inventory collaborative data for the 2016v1 modeling platform (2016fh/2028fh) are the primary sources of the emissions data for the 2016 BY and the 2028 FY modeling[6]. DEQ used the 2016v1 platform's 2016 BY emissions data without any modifications. For the 2028 FY, the following modifications were made in the Electricity Generation Unit (EGU) and Point non-EGU sectors:

2.3.1.1 point non-EGU (ptnonipm) sector

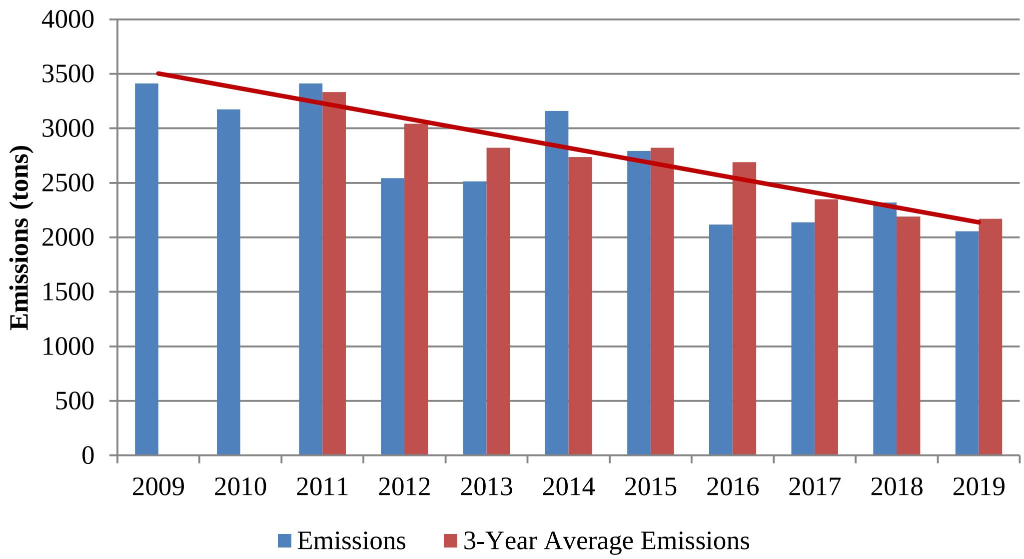
DEQ made the following emissions modifications for two Arkansas's facilities in EPA's 2028 FY point non-egu emissions data file:

i. DEQ removed the emissions data for all pollutants for SN-03 (Power Boiler #1; Unit ID#47419313) at the Domtar A.W. LLC, Ashdown Mill because this unit retired on April 15, 2020.[7]
ii. For the 3 Coal Fired Boilers (SN-6M01-01) represented by Emissions Inventory System (EIS) Unit #46923213 of Futurefuel Chemical Company, EPA 2028 FY emissions projection was 5399.712 tons of SO_2. DEQ determined that 2171 tons of SO_2 is a reasonable projection for the 2028 FY before taking into account Arkansas's Planning

[5] Technical Support Document for EPA's Updated 2028 Regional Haze Modeling. Available at: https://www.epa.gov/sites/default/files/2019-10/documents/updated_2028_regional_haze_modeling-tsd-2019_0.pdf
[6] Inventory Collaborative 2016v1 Emissions Modeling Platform. Available at: http://views.cira.colostate.edu/wiki/wiki/10202
[7] ADEQ Operating Air Permit, 2020. Available at: https://www.adeq.state.ar.us/downloads/WebDatabases/PermitsOnline/Air/0287-AOP-R23.pdf

Period II control strategy. DEQ generated this estimated annual emissions rate based on a recent three year average (2017–2019) and a 2009–2019 SO_2 emission trend analyses (Figure 2). As described in DEQ's RHR Planning Period II SIP (Section V. Reasonable Progress Analysis), DEQ determined that fuel-switching to two percent sulfur content coal would reduce 2028 FY SO_2 emissions by 27.20% to 1580.35 tons per year and this value was used in the 2028 FY emission file as an emission model input.

Figure 2: Futurefuel Chemical Company Historical Emissions



2.3.1.2 point EGU (ptegu) sector

EPA's 2016v1 platform used the Integrated Planning Model (IPM) for the 2028 point-EGU sector projection. DEQ replaced the IPM emissions projection with inventories derived from the Eastern Regional Technical Advisory Committee (ERTAC) v16.1 model[8] because this inventory was the most recently updated and used state-reported changes to EGUs received by ERTAC through September 2020. DEQ modified the ERTACv16.1 2028 FY emissions data for the following EGUs:

i. DEQ zeroed out all emissions from the Entergy White Bluff facility in Arkansas as a state and federally enforceable administrative order requires the cessation of coal-fired operations by no later than December 31, 2028.
ii. For the Flint Creek Power Plant in Arkansas, the 2028 FY ERTAC projection for SO_2 and NOx emissions are 1934.28 and 2491.05 tons per year, respectively. DEQ modified the ERTAC emissions to 799.33 and 2519.91 tons per year for SO_2 and NOx based on a two-year (2018-2019) average emission rate using the data available at the time of this

[8] ERTAC EGU. Available at: https://marama.org/technical-center/ertac-egu-projection-tool/#1567588060961-2bdf1042-292364fd-889e

evaluation following the installation and tuning of dry scrubbers and low NOx burners with overfire air and the projected ERTAC 2028 FY heat input .

iii. The Kentucky Division for Air Quality reviewed the 2028 FY ERTAC projection for the Tennessee Valley Authority (TVA) Shawnee Fossil Plant units and provided the below updated emissions data (Table 2) for the specified units, which DEQ used in the 2028 FY emission file as model inputs.

Table 2: Revised TVA Shawnee EGU Data for the Future Year 2028

Unit Id	SO_2 (tons)	NOx (tons)
2	1863.48	971.39
3	1875.82	999.16
5	1830.07	1000.98
6	2494.63	1240.58
7	1988.18	975.14
8	2152.35	1045.44
9	2095.17	1031.22

2.3.2 Emissions Modeling

DEQ used the Sparse Matrix Operating Kernel for Emissions (SMOKE) modeling system v4.7 to process Flat File 2010 (FF10) emissions files for the ptegu and ptnonipm sector emissions into horizontal and vertical grid cells in the modeling domain, keeping the same modeling setup as EPA's emission processing for the 2016v1 platform.[9] Each emissions sector was processed separately. Also, DEQ simulated SMOKE runs for the 36-km and the 12-km resolution domains separately. For the ptnonipm sector, the temporal approach selected was "mwdss," which uses hourly emissions for one representative Monday, representative weekdays (Tuesday through Friday), a representative Saturday, and a representative Sunday for each month. The ptegu sector has only "in-line" emissions, meaning the plume rise calculations are conducted inside the CAMx model instead of being computed by SMOKE and all the emissions are treated as elevated sources. In the ptnonipm sector, both "in-inline" and two-dimensional layer-1 "emis-mole" files were created by SMOKE.

2.3.3 Emissions Preparation for the CAMx Model

The output from the SMOKE model is in the Community Multiscale Air Quality Modeling System (CMAQ) format, which cannot be used directly in the CAMx modeling. Therefore, DEQ

[9] Preparation of Emissions Inventories for the version 7.2 2016 North American Emissions Modeling Platform, 2019. Available at : https://www.epa.gov/sites/default/files/2019-09/documents/2016v7.2_regionalhaze_emismod_tsd_508.pdf ; FTP directory 2016v1. Available at: ftp://newftp.epa.gov/air/emismod/2016/v1/

used the “cmaq2camx” software tool[10] to convert the SMOKE output to a CAMx ready input emissions file considering CB6 chemical mechanism mapping. In the SMOKE modeling, a 12US1 domain was used that then windowed to 12US2 by utilizing the “window”[11] program for using ptnonipm emission files in the CAMx model.

2.4 CAMx Model Configuration

DEQ used CAMx version 7.0 to simulate the entire year for both 2016 BY and 2028 FY and the CAMx configuration was consistent with the EPA 2016v1 platform. Table 3 shows the configurations and options used in the DEQ’s modeling. The modeling was performed using a 10-day spin-up period at the end of December 2015 before the first day (January 1, 2016) of the 2016 BY and 2028 FY. The modeling domain consists of 35 vertical layers with a model top at about 50 milibars, or 17,550 meters. The 2016 BY and 2028 FY model simulations produce air quality concentrations for each grid cell across the modeling domains. A sample CAMx control script in Appendix L.1 shows the detail configurations of the modeling set-up.

Table 3: CAMx Model Configurations

Model science options	CAMx configuration
Model version	CAMx v7.0
Time Zone	UTC
Horizontal Grids	36-km (172 col x 148 row) with nested 12-km(396 col x 246 row)
Vertical Grid	35 Layers
Chemistry Mechanism	CB6r4
Aerosol Chemistry	CF + SOAP2.2
Chemistry Solver	Euler Backward Iterative (EBI)
Advection Solver	Piecewise Parabolic Method (PPM)
Dry Deposition	Zhang model
Wet Deposition	CAMx-specific formulation
Vertical Diffusion (Mixing) Options	K-theory
Inline Ix Emissions	True

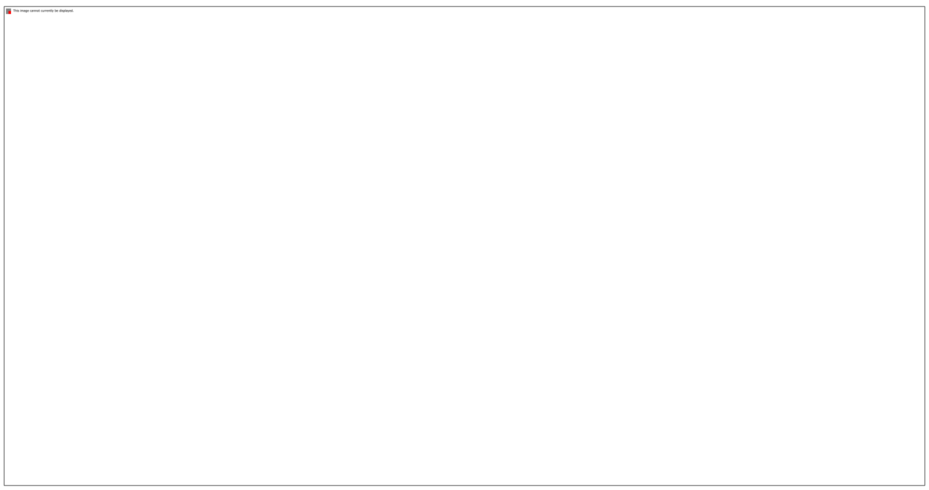
2.5 CAMx Model Performance Evaluation

This section describes model performance for the 2016 BY run using the Atmospheric Model Evaluation Tool (AMETv1.4). AMET software generates statistics and plots of model performance by pairing the model results and the historic surface observations in space and time.[12] DEQ utilized 2016 ambient air quality measurement data from the Air Quality System

[10] CAMx support software, 2021. Available at: https://www.camx.com/download/support-software/
[11] https://camx-wp.azurewebsites.net/getmedia/window.6may13_1.tgz
[12] The Atmospheric Model Evaluation Tool. Available at : https://www.epa.gov/cmaq/atmospheric-model-evaluation-tool

(AQS), Interagency Monitoring of Protected Visual Environments (IMPROVE), and Speciation Monitoring Network (CSN) databases for the AMET evaluations. DEQ focused its model performance analysis on Arkansas and nearby states that have the greatest probability of visibility impacts resulting from emissions by sources in Arkansas based on CenSARA's Areas of Influence (AOI) analyses[13]. DEQ performed a Model Performance Evaluation (MPE) for Ozone (O_3), $PM_{2.5}$, and individual $PM_{2.5}$ species annually and seasonally in the selected states (MPE Region) identified in Figure 3.

Figure 3: Selected Region for the Model Performance Evaluation



This analysis considered several statistical parameters, including correlation coefficients, normalized mean biases, normalized mean errors, fractionalized biases, and fractional errors for the MPE Region. The following equations were used to calculate these statistical measures for the observed (O) and predicted (P) concentrations for the given number of samples (N)[14]:

1. Normalized mean bias (NMB), NMB (%) = $\frac{\sum_{i=1}^{N}(P_i - O_i)}{\sum_{i=1}^{N}(O_i)} * 100$
2. Normalized mean error (NME), NME (%) = $\frac{\sum_{i=1}^{N}|P_i - O_i|}{\sum_{i=1}^{N} O_i} * 100$
3. Fractionalized Bias (FB), FB $= \frac{2}{N}\sum_{i=1}^{N}\left(\frac{P_i - O_i}{P_i + O_i}\right)$
4. Fractional Error (FE), FE $= \frac{2}{N}\sum_{i=1}^{N}\left|\frac{P_i - O_i}{P_i + O_i}\right|$
5. Correlation Coefficient (r), r $= \frac{\sum_{i=1}^{N}[(P_i - \bar{P})(O_i - \bar{O})]}{\sqrt{\sum_{i=1}^{N}(P_i - \bar{P})^2}\sqrt{\sum_{i=1}^{N}(O_i - \bar{O})^2}}$

[13] Determining Areas of Influence –CENSARA Round Two Regional Haze, 2018. Available at: https://www.ladco.org/wp-content/uploads/Projects/Regional-Haze/Round2/ramboll-aoi-report-censara-rh-final.pdf
[14] Technical Support Document for EPA's Updated 2028 Regional Haze Modeling. Available at: https://www.epa.gov/sites/default/files/2019-10/documents/updated_2028_regional_haze_modeling-tsd-2019_0.pdf

Table 4 lists air quality model performance "goals" and "criteria" used in DEQ's analysis to assist in interpreting model performance.

Table 4: Model Performance Criteria and Goals[15]

Species	NMB		NME		r	
	Goal	Criteria	Goal	Criteria	Goal	Criteria
1-hr or MDA8 Ozone	<±5%	<±15%	<15%	<25%	>0.75	>0.50
Fine Particulate ($PM_{2.5}$), Sulfate (SO_4), Ammonia (NH_4)	<±10%	<±30%	<35%	<50%	>0.70	>0.40
Nitrate (NO_3)	<±15%	<±65%	<65%	<115%	None	None
Organic Carbon (OC)	<±15%	<±50%	<45%	<65%	None	None
Elemental Carbon (EC)	<±20%	<±40%	<50%	<75%	None	None

DEQ also used FB and FE goals for the 24-hr total and speciated $PM_{2.5}$ of <±30% and <50%, respectively, and criteria of <±60% and <75%, respectively[16]. For ozone, FB values of ≤ ±15% and ≤ ±30% would be considered "good" and "acceptable" model performance, respectively[17]. DEQ also employed graphical plots such as time series, scatter diagrams, etc. to evaluate model performance in conjunction with calculated statistics.

2.5.1 Annual Model Performance Results

Table 5 provides the annual model performance statistics for all the states selected in the MPE. The model predictions are within the performance goals for the maximum daily average 8-hour (MDA8) ozone for all statistical parameters. The simulation overestimated the $PM_{2.5}$, SO_4, OC, and EC concentrations at IMPROVE sites while NO_3 and NH_4 concentrations were underestimated. Table 6 provides the annual model performance statistics for Arkansas' two IMPROVE monitor sites at Arkansas' Class I areas. Here, the simulation overestimated OC at both Class I areas.

[15] Emery, Christopher, Zhen Liu, Armistead G. Russell, M. Talat Odman, Greg Yarwood & Naresh Kumar. 2017. Recommendations on statistics and benchmarks to assess photochemical model performance, Journal of the Air & Waste Management Association, 67:5, 582-598, DOI: 10.1080/10962247.2016.1265027

[16] Boylan, J.W., and A.G. Russell. 2006. PM and light extinction model performance metrics, goals, and criteria for three-dimensional air quality models. Atmos. Environ. 40:4946–59. doi:10.1016/j.atmosenv.2005.09.087

[17] Air Quality Modeling of 2017 Ozone Episodes in the City of Albuquerque. Available at: https://www.cabq.gov/airquality/documents/air-quality-modeling-of-2017-ozone-episodes-in-the-city-of-albuquerque.pdf; Hossan, I., Botlaguduru, V.S.V., Du, H.B., Kommalapati,R.R. and Huque, Z. (2018) Air Quality Impact of Biomass Co-Firing with Coal at a Power Plant in the Greater Houston Area. Open Journal of Air Pollution, 7, 263-285. https://doi.org/10.4236/ojap.2018.73013

Table 5: Annual CAMx 2016 Model Performance[18]

Species	Network	Mean_Obs	Mean_Mod	r	FB (%)	FE (%)	NMB (%)	NME (%)
$PM_{2.5}$	IMPROVE	6.17	7.81	0.32	20.20	38.20	26.40	46.90
	CSN	9.08	10.98	0.61	20.30	32.80	20.80	35.60
SO_4	IMPROVE	1.18	1.38	0.63	17.00	36.60	17.20	38.10
	CSN	1.15	1.55	0.62	34.30	43.80	35.70	49.10
NO_3	IMPROVE	0.42	0.37	0.50	-9.79	65.00	-10.70	64.80
	CSN	0.51	0.68	0.58	26.80	56.80	33.70	73.70
EC	IMPROVE	0.22	0.22	0.44	4.94	44.80	3.17	53.60
	CSN	0.57	0.55	0.60	5.99	36.60	-3.63	38.60
NH_4	IMPROVE	0.56	0.49	0.54	-17.80	43.60	-14.00	37.80
	CSN	0.34	0.63	0.53	68.10	77.00	84.70	100.00
OC	IMPROVE	1.42	2.56	0.18	51.30	58.60	80.90	99.90
	CSN	2.18	3.29	0.62	44.80	49.30	51.30	61.10
O_3	AQS	42.18	43.49	0.77	3.61	13.90	3.12	13.40

Table 6: Annual MPE for the Arkansas's IMPROVE Monitors[18]

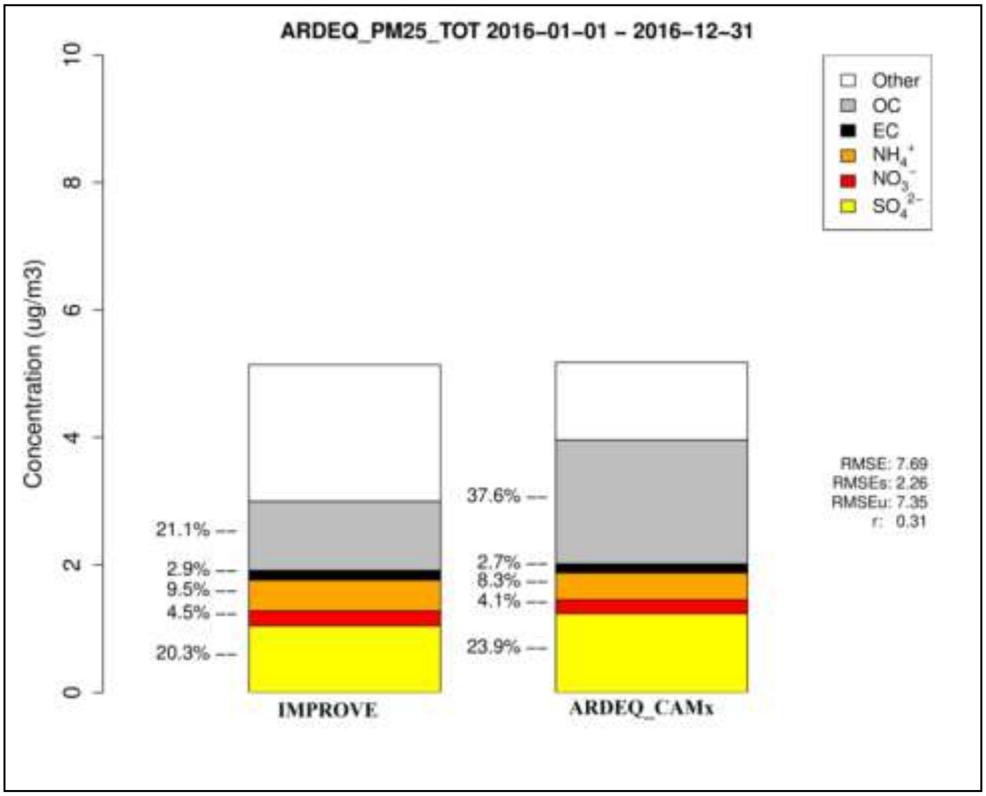
Species	Site	Mean_Obs	Mean_Mod	r	FB(%)	FE(%)	NMB(%)	NME(%)
$PM_{2.5}$	CACR1	6.16	7.88	0.63	29.70	41.40	27.83	43.98
	UPBU1	6.15	7.21	0.54	17.80	36.10	17.11	39.80
SO_4	CACR1	1.25	1.44	0.53	17.50	41.70	14.87	42.96
	UPBU1	1.16	1.32	0.61	17.40	39.30	14.01	39.69
NO_3	CACR1	0.41	0.36	0.62	-15.70	61.80	-10.97	59.30
	UPBU1	0.49	0.41	0.56	-16.40	60.70	-16.12	58.98
OC	CACR1	1.23	2.59	0.69	72.90	74.10	110.51	113.87
	UPBU1	1.31	2.28	0.69	52.70	57.40	74.53	80.01
EC	CACR1	0.14	0.14	0.72	11.90	45.10	-2.54	38.41
	UPBU1	0.15	0.14	0.57	7.20	46.60	-2.11	45.81
NH_4	CACR1	0.59	0.53	0.52	-6.90	38.10	-9.31	36.97
	UPBU1	0.58	0.52	0.56	-9.50	34.60	-10.76	33.53

A stacked bar plot for the IMPROVE monitors in the MPE region, along with the percentage of total $PM_{2.5}$ that each species comprises, is shown in Figure 4, which demonstrates that the model overprediction for the $PM_{2.5}$ is primarily driven by OC. Note that AMET scripts[19] were used to

[18] Mean_Obs and Mean_Mod is in ppb for O_3 and µg/m³ for all other pollutants
[19] https://www.epa.gov/cmaq/atmospheric-model-evaluation-tool

generate the Figure 4 stacked bar plot and AMET removes all species-specific values for the particular observation time and location if AMET runs into any missing species for this same particular observation time and location, so Figure 4 values may not equal Table 5 values. Also, the plot provides root mean square error (RMSE), systematic RMSE, and unsystematic RMSE.

Figure 4: Annual Stacked Bar Plot of $PM_{2.5}$ Species for the IMPROVE Monitors in the MPE Region



Spatial plots summarizing observations and model results for total $PM_{2.5}$ NMB and NME are shown in Figure 5 and Figure 6, respectively. AMET scripts were used to generate spatial plots with a 25% data coverage limit which means that any site with 25% or greater observation data completeness was plotted. Spatial plots for all $PM_{2.5}$ species are presented in the Appendix L.2.

Figure 5: Spatial Plot of $PM_{2.5}$ Annual Performance for NMB (%)

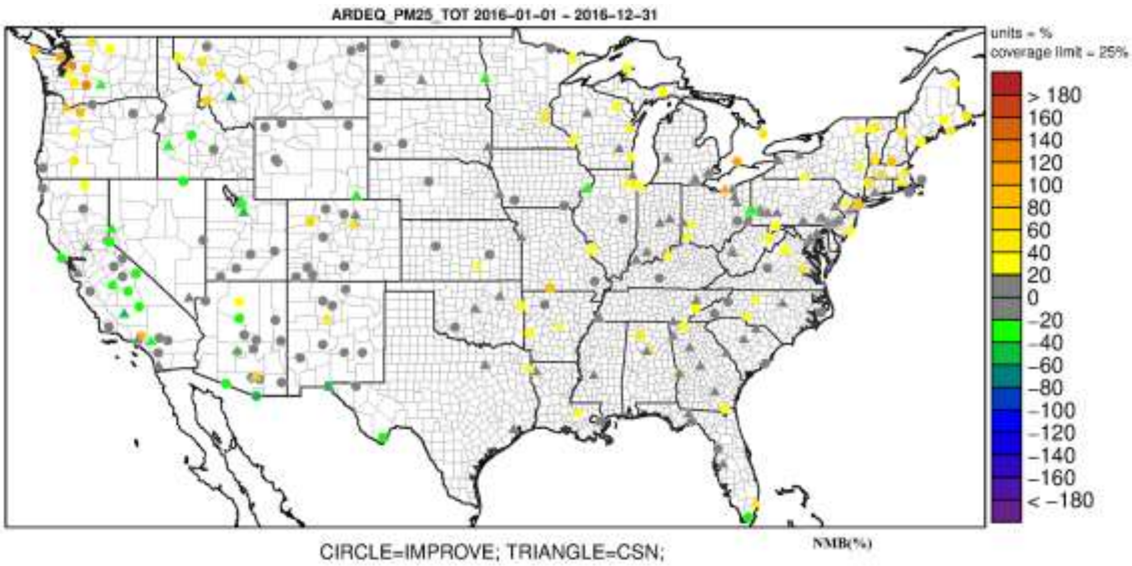


Figure 6: Spatial Plot of $PM_{2.5}$ Annual Performance for NME (%)

2.5.2 Seasonal Model Performance Results

Table 7 provides model performance by season. The total $PM_{2.5}$ performance achieved the MPE goals or criteria in all seasons, except in the winter for the IMPROVE network for NMB and NME. The simulation also achieved the MPE goals and/or criteria for all seasons for the EC and NO_3 species. Model performance achieved the ±30% bias criteria for NH_4 at all the IMPROVE monitors, while exceeding the bias criteria for the CSN network. For the OC species, the model performed better at the CSN sites compared to the IMPROVE sites, particularly during fall and winter.

Table 7: Seasonal CAMx Model Performance[20]

Spring (March, April, May)								
Species	Network	Mean_Obs	Mean_Mod	r	FB %	FE %	NMB %	NME %
$PM_{2.5}$	IMPROVE	5.59	7.58	0.35	22.80	35.80	35.60	48.90
	CSN	8.37	9.95	0.68	18.20	29.20	18.90	30.70
SO_4	IMPROVE	1.12	1.37	0.69	22.40	32.30	22.50	34.60
	CSN	1.08	1.56	0.61	39.60	45.20	44.90	53.10
NO_3	IMPROVE	0.33	0.30	0.43	-11.10	57.20	-8.57	56.40
	CSN	0.42	0.48	0.41	21.80	53.50	15.00	65.60
EC	IMPROVE	0.21	0.23	0.46	3.46	44.30	12.30	57.30
	CSN	0.52	0.50	0.50	4.70	35.20	-3.05	39.40
NH_4	IMPROVE	0.52	0.45	0.46	-14.00	37.10	-12.50	33.30
	CSN	0.32	0.57	0.43	67.50	76.10	79.90	97.40
OC	IMPROVE	1.21	2.44	0.25	50.50	55.90	101.00	108.00
	CSN	1.80	2.89	0.68	47.70	50.80	60.80	65.00
O_3	AQS	45.83	44.20	0.73	-2.98	12.70	-3.56	11.90
Summer (June, July, August)								
$PM_{2.5}$	IMPROVE	7.35	7.60	0.62	-1.59	32.40	3.41	31.60
	CSN	9.32	10.93	0.48	17.80	33.40	17.20	34.80
SO_4	IMPROVE	1.39	1.34	0.58	-6.75	37.10	-3.74	34.60
	CSN	1.35	1.52	0.55	15.50	35.30	13.00	37.10
NO_3	IMPROVE	0.19	0.16	0.12	-23.10	71.00	-12.70	69.30
	CSN	0.23	0.29	0.11	10.40	50.10	22.50	65.80
EC	IMPROVE	0.15	0.16	0.75	5.93	42.40	4.04	42.80
	CSN	0.49	0.52	0.52	9.50	35.60	5.20	37.80
NH_4	IMPROVE	0.58	0.44	0.51	-35.20	52.10	-24.40	40.70
	CSN	0.32	0.51	0.56	55.30	67.60	62.30	78.90
OC	IMPROVE	1.38	2.52	0.71	52.90	57.10	83.60	86.70
	CSN	2.08	3.63	0.60	52.70	54.80	75.10	78.40
O_3	AQS	41.87	45.70	0.81	9.38	15.10	9.14	15.00

Fall (September, October, November)								
Species	Network	Mean_Obs	Mean_Mod	r	FB %	FE %	NMB %	NME %
$PM_{2.5}$	IMPROVE	7.28	8.45	0.55	19.40	33.40	16.10	37.90
	CSN	10.25	12.52	0.62	22.30	32.70	22.10	36.30

[20] Mean_Obs and Mean_Mod is in ppb for O_3 and μg/m³ for all other pollutants

SO_4	IMPROVE	1.21	1.51	0.77	21.90	32.00	24.30	35.50
	CSN	1.14	1.64	0.71	38.30	44.00	44.50	52.10
NO_3	IMPROVE	0.33	0.35	0.54	14.20	62.00	7.04	65.70
	CSN	0.40	0.72	0.57	44.70	62.20	78.20	98.80
EC	IMPROVE	0.30	0.23	0.75	-9.68	42.30	-23.50	42.80
	CSN	0.73	0.62	0.66	-4.21	36.50	-15.30	38.70
NH_4	IMPROVE	0.55	0.52	0.67	-10.80	37.70	-6.24	32.00
	CSN	0.32	0.66	0.54	73.10	81.10	103.00	114.00
OC	IMPROVE	2.02	2.63	0.47	43.10	55.50	30.00	70.50
	CSN	2.94	3.78	0.60	31.60	40.80	28.40	48.30
O_3	AQS	41.49	44.36	0.80	7.32	12.60	6.91	12.20
Winter (December, January, February)								
$PM_{2.5}$	IMPROVE	4.50	7.61	0.28	40.40	51.30	69.20	84.00
	CSN	8.45	10.58	0.59	22.90	36.20	25.20	40.50
SO_4	IMPROVE	0.98	1.31	0.58	31.70	45.80	33.80	51.50
	CSN	1.02	1.49	0.71	43.70	50.80	46.30	57.30
NO_3	IMPROVE	0.87	0.71	0.35	-18.80	70.40	-18.10	66.90
	CSN	0.99	1.25	0.52	30.90	61.50	26.60	69.00
EC	IMPROVE	0.21	0.27	0.32	21.10	50.50	33.20	74.80
	CSN	0.54	0.56	0.66	14.00	39.00	3.59	38.30
NH_4	IMPROVE	0.62	0.54	0.52	-10.50	47.70	-12.10	44.10
	CSN	0.41	0.79	0.56	76.30	83.30	91.70	108.00
OC	IMPROVE	1.05	2.67	0.22	59.30	66.40	154.00	169.00
	CSN	1.93	2.93	0.73	46.80	50.70	51.90	58.70
O_3	AQS	34.23	31.35	0.73	-6.90	16.90	-8.41	15.90

Table 8 presents the MPE results for modeling bias and error at Arkansas's two IMPROVE sites, which show better results in the spring, summer, and fall seasons than winter for total $PM_{2.5}$. While all $PM_{2.5}$ species performed well for most of the seasons, the model tends to overestimate OC in all seasons. The species definition equation used in the MPE analysis for the OC (µg/m3) =POA[1]/1.6+SOA1[1]/2.0+SOA2[1]/2+SOA3[1]/1.7+SOA4[1]/1.7+SOPA[1]/2.1+SOPB[1]/2.1. The species definition file used for this MPE is presented in Appendix L.2.

Table 8: Seasonal CAMx Model Performance for Class I Areas in Arkansas[21]

Species	Site	Mean_Obs	Mean_Mod	r	FB %	FE %	NMB %	NME %
Spring (March, April, May)								
$PM_{2.5}$	CACR1	4.48	6.10	0.70	31.90	40.20	36.21	44.56
	UPBU1	5.24	6.26	0.59	19.50	32.40	19.49	41.28
SO_4	CACR1	0.90	1.10	0.77	21.70	31.80	21.92	31.98

[21] Mean_Obs and Mean_Mod is in ppb for O3 and µg/m³ for all other pollutants

	UPBU1	0.94	1.06	0.64	24.90	36.10	12.38	39.70
NO_3	CACR1	0.25	0.21	0.80	-15.50	50.70	-13.67	39.15
	UPBU1	0.35	0.31	0.71	-18.50	53.30	-12.97	46.74
OC	CACR1	0.91	1.97	0.74	71.70	72.20	116.22	117.06
	UPBU1	1.12	2.00	0.83	58.00	60.30	78.83	82.38
EC	CACR1	0.12	0.13	0.56	21.20	49.20	11.82	44.90
	UPBU1	0.15	0.17	0.67	10.60	47.60	10.56	50.72
NH_4	CACR1	0.41	0.39	0.82	-4.60	26.30	-6.02	23.95
	UPBU1	0.45	0.40	0.61	-5.40	29.20	-11.48	30.28
Summer (June, July, August)								
$PM_{2.5}$	CACR1	9.00	9.25	0.41	6.90	36.70	2.73	36.12
	UPBU1	8.97	7.82	0.64	-14.10	27.60	-12.78	24.72
SO_4	CACR1	1.89	1.60	0.50	-13.00	42.10	-15.10	34.43
	UPBU1	1.67	1.46	0.69	-16.80	36.40	-12.82	29.72
NO_3	CACR1	0.24	0.11	-0.06	-54.10	85.00	-53.20	71.55
	UPBU1	0.21	0.11	0.06	-48.00	70.00	-46.31	61.17
OC	CACR1	1.38	3.34	0.75	81.10	81.80	142.78	142.78
	UPBU1	1.71	2.68	0.76	41.10	45.30	56.46	58.55
EC	CACR1	0.09	0.09	0.63	19.80	48.90	8.57	40.87
	UPBU1	0.09	0.09	0.61	15.30	50.80	-2.83	43.82
NH_4	CACR1	0.78	0.53	0.32	-33.90	54.20	-32.06	42.67
	UPBU1	0.69	0.49	0.57	-36.00	47.30	-28.66	36.40

Fall (September, October, November)								
$PM_{2.5}$	CACR1	6.65	8.28	0.79	23.90	27.70	24.56	29.13
	UPBU1	6.00	7.29	0.73	22.60	30.40	21.48	31.94
SO_4	CACR1	1.31	1.61	0.76	22.20	32.20	22.81	34.61
	UPBU1	1.20	1.47	0.80	22.60	31.20	22.61	32.16
NO_3	CACR1	0.27	0.28	0.80	9.80	47.00	0.83	45.52
	UPBU1	0.28	0.29	0.67	10.50	51.80	1.37	50.71
OC	CACR1	1.40	2.68	0.55	64.00	66.60	91.07	95.28
	UPBU1	1.36	2.25	0.57	51.10	57.90	65.08	74.68
EC	CACR1	0.19	0.15	0.64	-15.60	37.40	-23.05	34.71
	UPBU1	0.17	0.14	0.50	-10.70	44.50	-17.86	38.36
NH_4	CACR1	0.57	0.56	0.80	0.70	22.30	-1.06	20.80
	UPBU1	0.53	0.53	0.84	2.00	22.60	0.00	20.99
Winter (December, January, February)								
$PM_{2.5}$	CACR1	4.58	7.95	0.68	55.90	61.10	73.41	80.36
	UPBU1	4.67	7.49	0.56	39.90	53.00	60.44	74.29
SO_4	CACR1	0.87	1.44	0.33	41.50	62.50	65.84	89.43
	UPBU1	0.85	1.31	0.59	36.90	53.90	53.73	69.98

NO_3	CACR1	0.92	0.90	0.44	-0.90	64.00	-1.70	66.16
	UPBU1	1.13	0.95	0.25	-12.90	68.90	-16.38	64.78
OC	CACR1	1.24	2.35	0.74	74.60	76.40	89.79	98.32
	UPBU1	1.06	2.23	0.69	60.20	65.60	110.71	118.10
EC	CACR1	0.18	0.19	0.80	22.10	44.40	4.58	36.64
	UPBU1	0.17	0.18	0.46	14.40	43.90	2.79	49.93
NH_4	CACR1	0.59	0.67	0.45	12.50	50.40	12.64	55.33
	UPBU1	0.65	0.64	0.41	-0.60	41.00	-1.38	44.01

The stacked bar plots in Figure 7 through Figure 10 compare the observed (left bar) and modeled (right bar) $PM_{2.5}$ species averaged across all IMROVE monitors in the MPE region. In these figures, the "other" category includes Fine Other Primary Particulate (FPRM) and Fine Crustal Particulate (FCRS) among others.

Figure 7: Stacked Bar Plot of $PM_{2.5}$ Species for IMPROVE Monitors in the MPE Region (Spring)

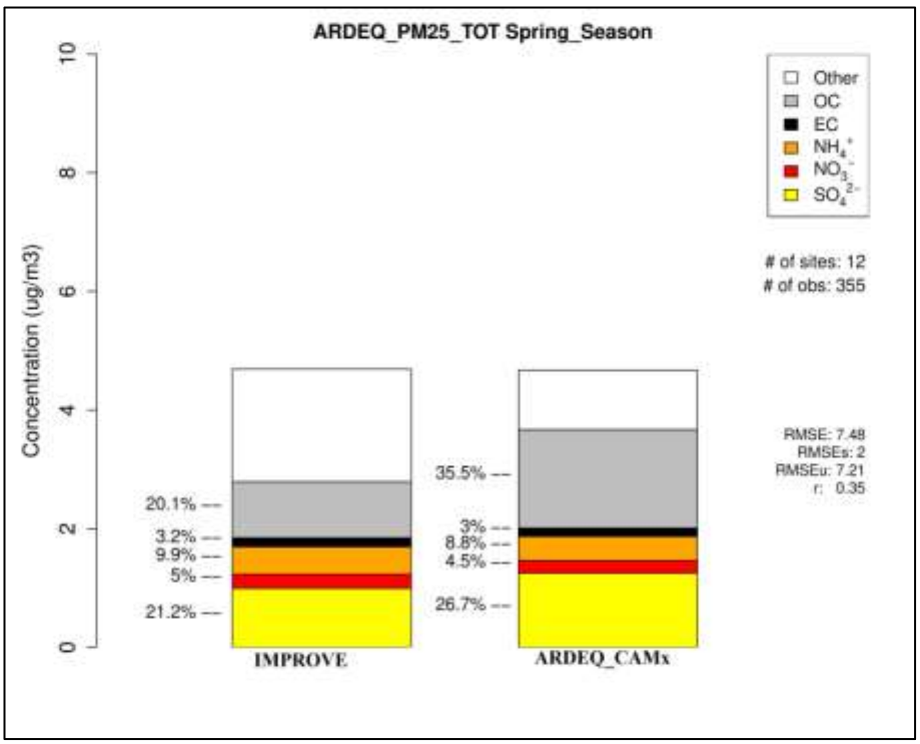


Figure 8: Stacked Bar Plot of PM2.5 Species for IMPROVE Monitors in the MPE Region (Summer)

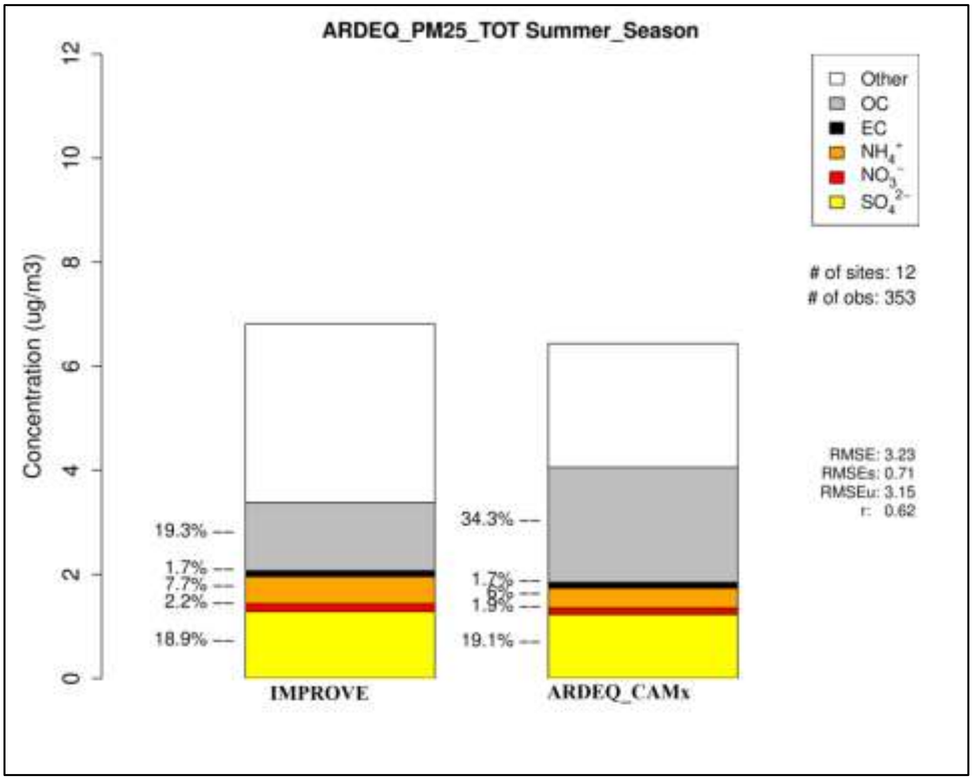


Figure 9: Stacked Bar Plot of PM2.5 Species for IMPROVE Monitors in the MPE Region (Fall)

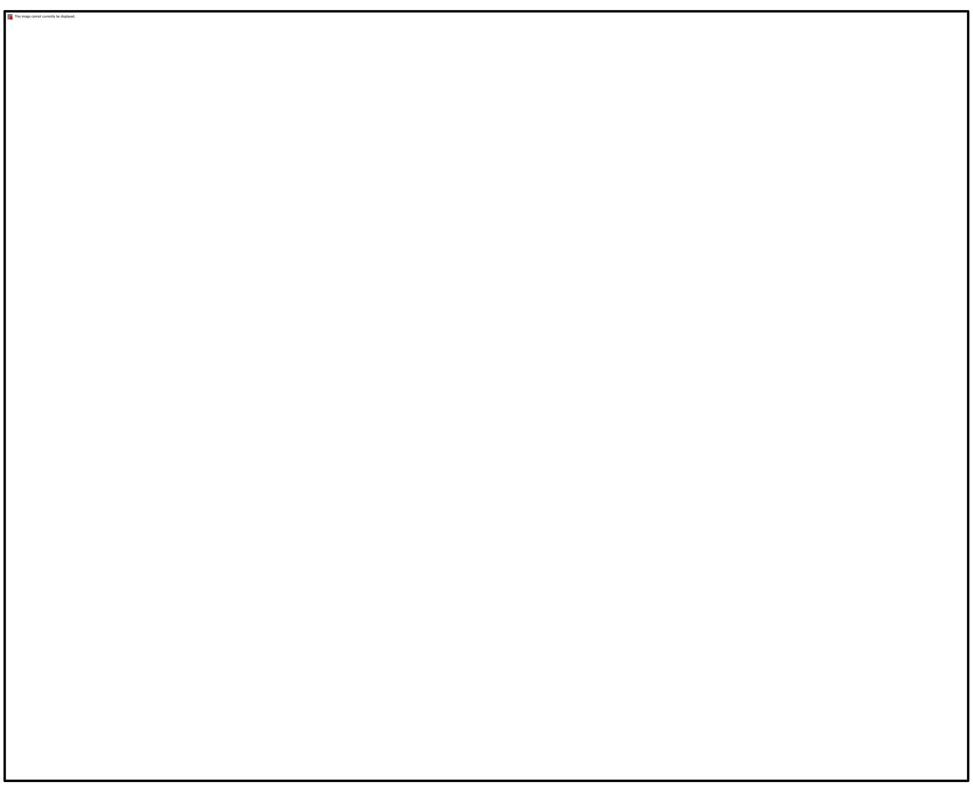


Figure 10: Stacked Bar Plot of $PM_{2.5}$ Species for IMPROVE Monitors in the MPE Region (Winter)

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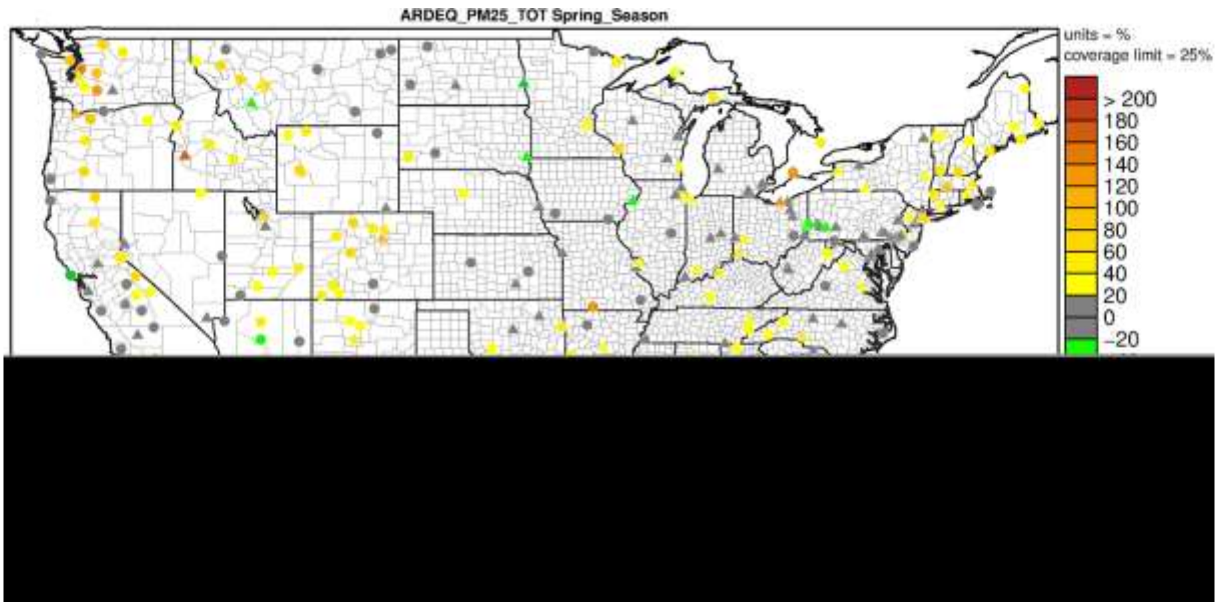
Seasonal total $PM_{2.5}$ model predictions are shown in the spatial plots for NMB and NME (Figure 11 through Figure 18). These plots show that most of the sites with a 25% coverage limit are within MPE criteria limit for the NME and NMB. Similar types of plots for each $PM_{2.5}$ species are included in Appendix L.2.

Figure 11: Seasonal Spatial Plots of $PM_{2.5}$ for the NMB (Spring)



[redacted]

Figure 12: Seasonal spatial Plots of PM2.5 for the NMB (Summer)

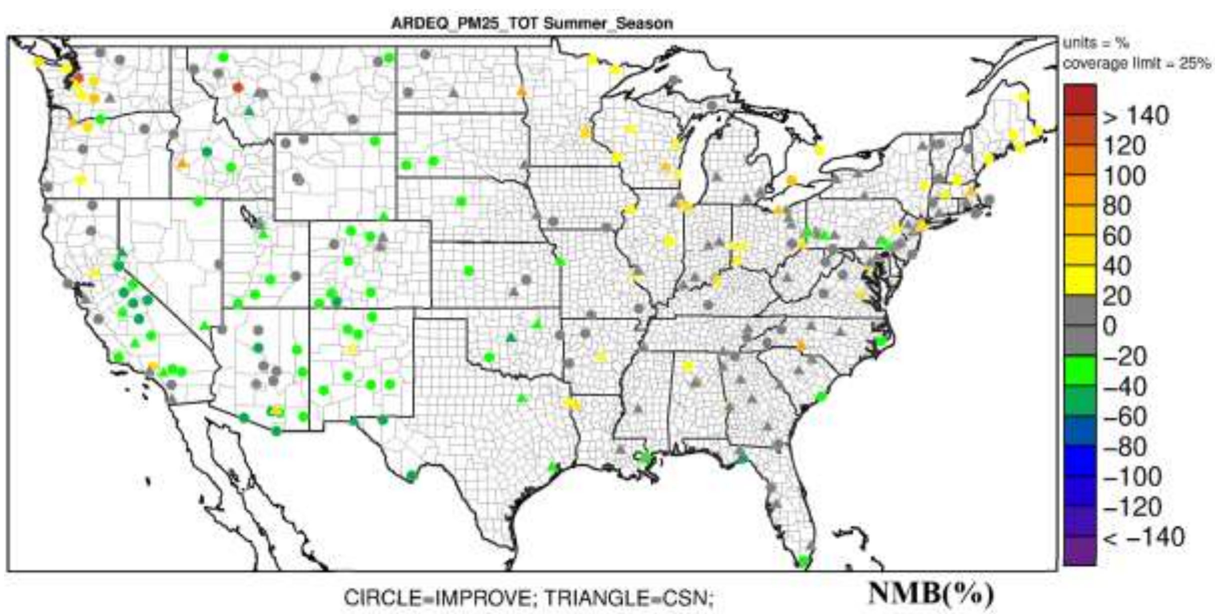


Figure 13: Seasonal spatial Plots of PM2.5 for the NMB (Winter)

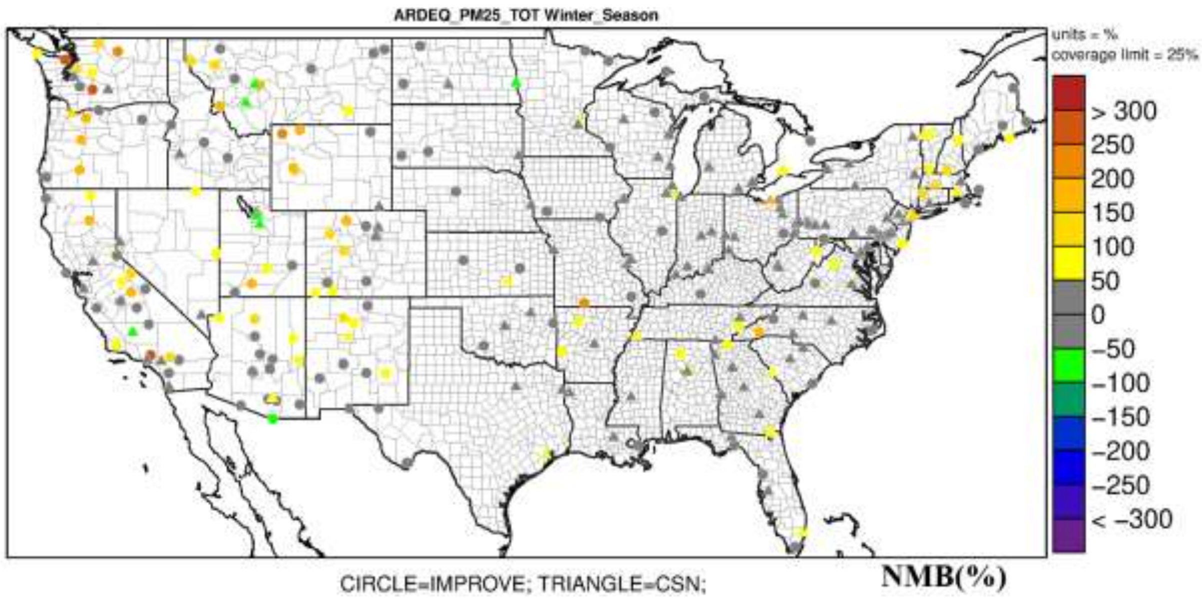


Figure 14: Seasonal spatial Plots of PM2.5 for the NMB (Fall)

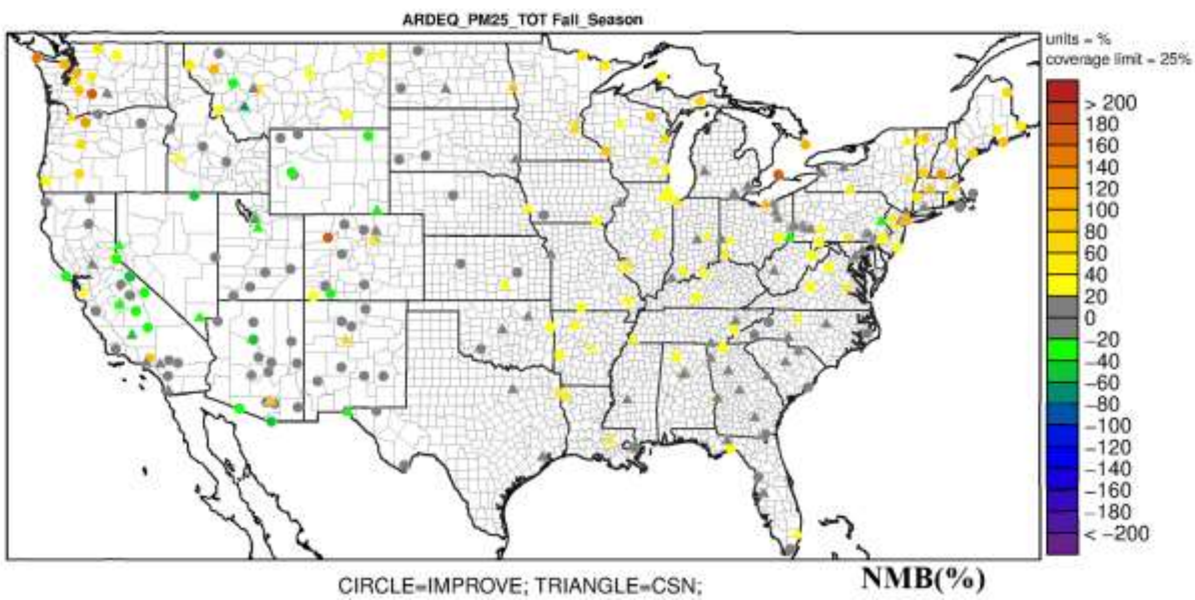


Figure 15: Seasonal Spatial Plots of $PM_{2.5}$ for NME (Spring)

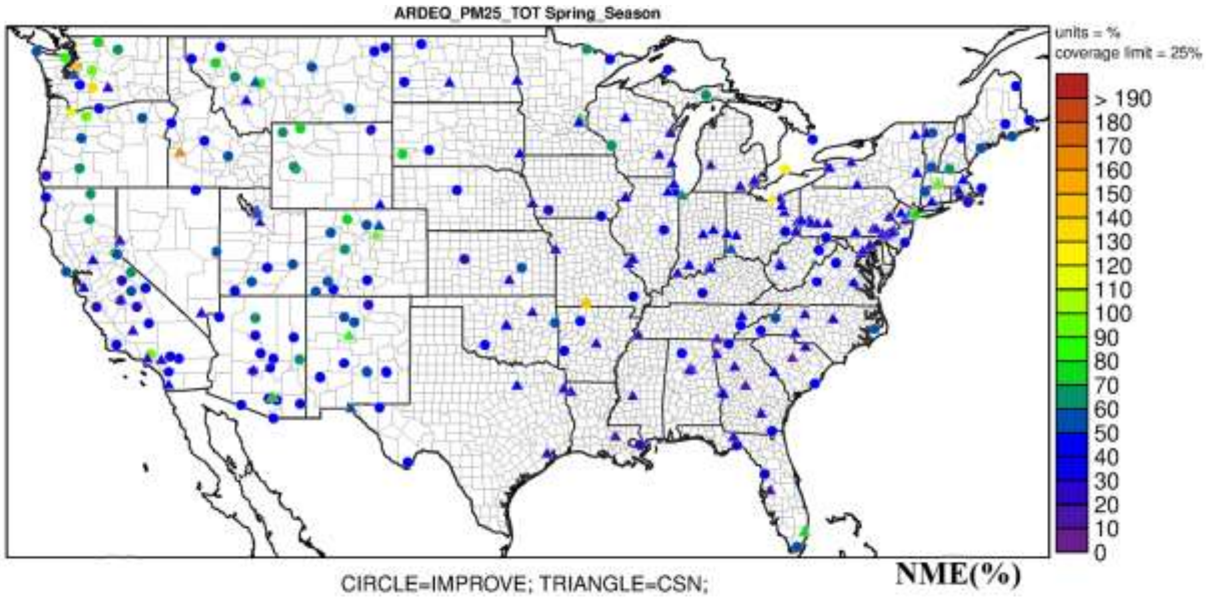


Figure 16: Seasonal Spatial Plots of $PM_{2.5}$ for NME (Summer)

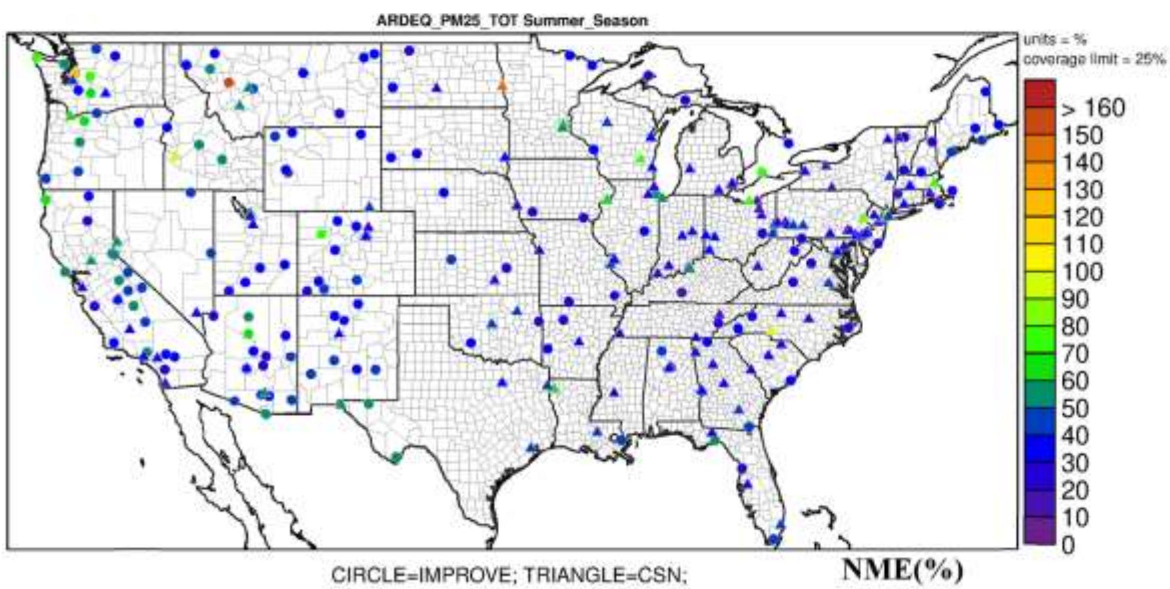


Figure 17: Seasonal Spatial Plots of PM2.5 for NME (Fall)

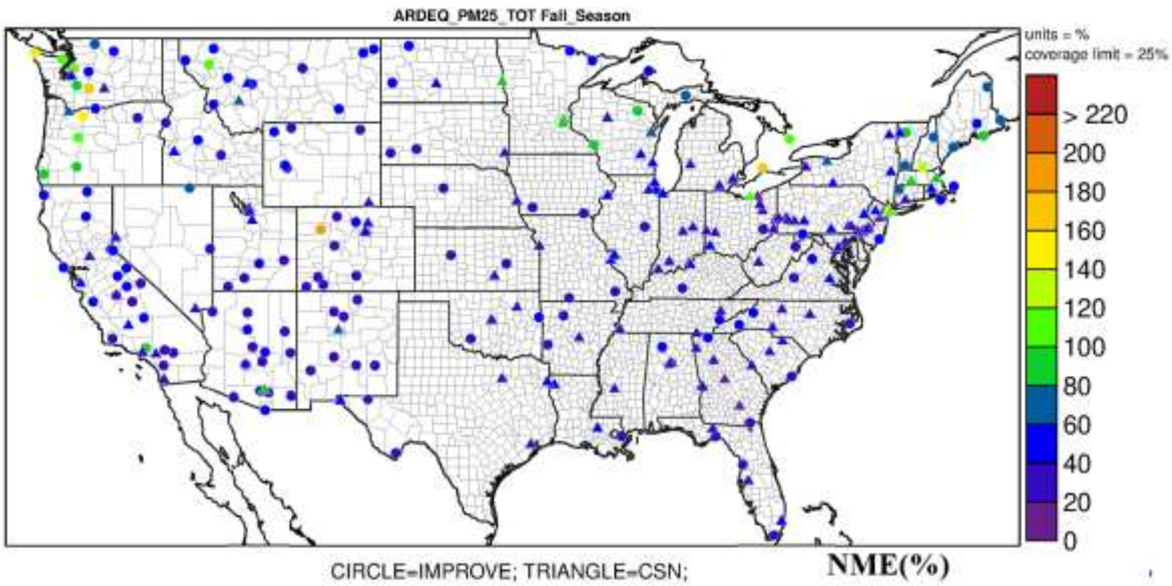
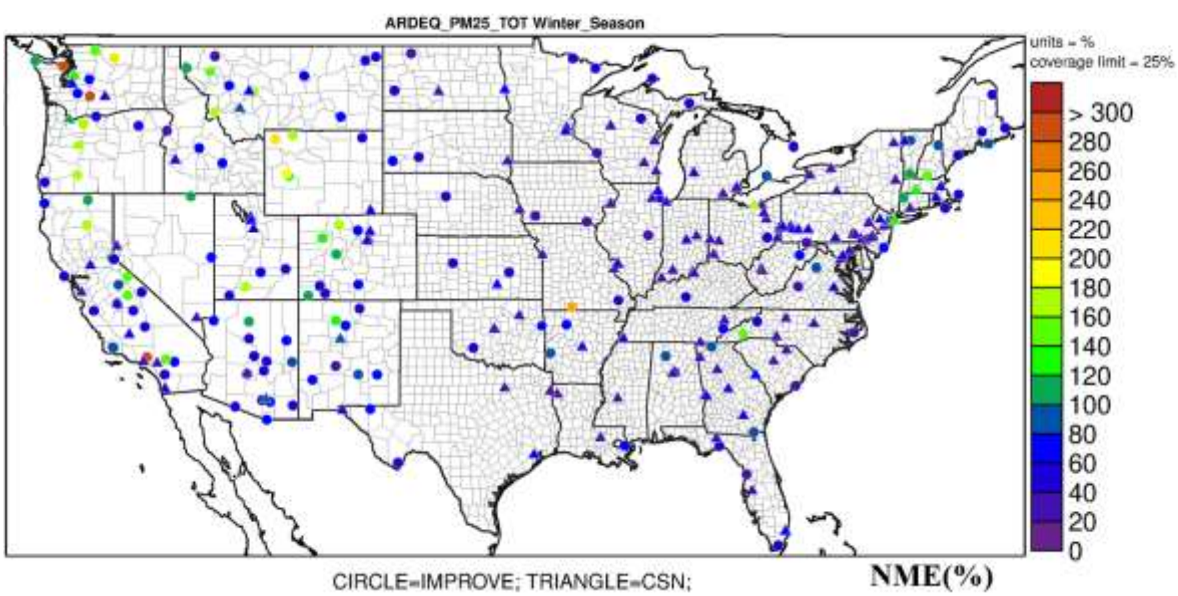


Figure 18: Seasonal Spatial Plots of PM2.5 for NME (Winter)



Box plots in Figure 19 and Figure 20 show the monthly patterns of modeled and observed data for $PM_{2.5}$. Box plots for all other species are included in Appendix L.2. The box plots show the median values for both observed and modeled values with a 25–75% interquartile range.

Figure 19: Box Plots Comparison of $PM_{2.5}$ Observed and Modeled Data in the MPE Region at CSN monitors

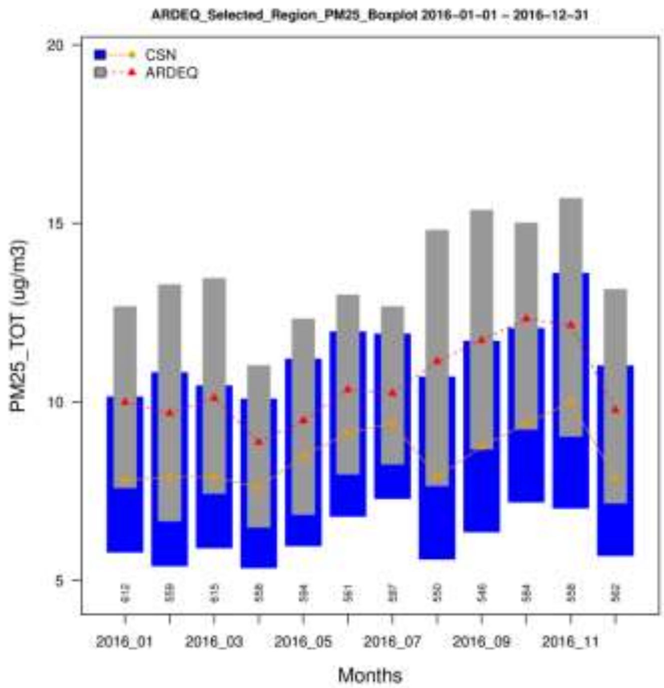
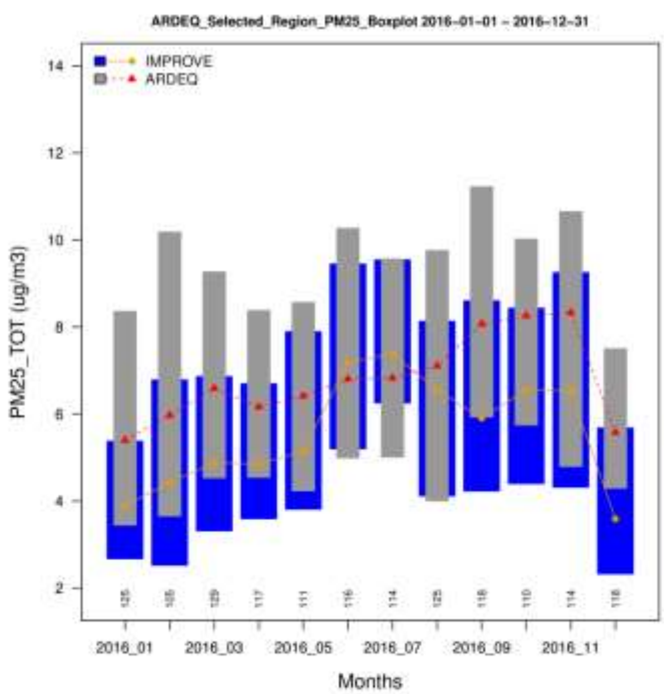


Figure 20: Box Plots Comparison of $PM_{2.5}$ Observed and Modeled Data in the MPE Region at IMPROVE monitors



The model performance described in this document is similar to EPA's regional haze modeling performance. DEQ analyzed model data for the total $PM_{2.5}$ of IMPROVE network data considering climate regions "Central", "South", and "Southeast", defined by EPA in their regional haze technical support document[22]. The IMPROVE sites selected by DEQ for this comparison for "South" are BIBE1, BRIS1, CACR1, CEBL1, GUMO1, STIL1, TALL1, UPBU1, and WIMO1; "Southeast" are ATLA1, BIRM1,CHAS1, COHU1, EVER1, JARI1, LIGO1, OKEF1, ROMA1, SAMA1, SHEN1, SHRO1, SIPS1, and SWAN1; and for "Central" are BOND1, DOSO1, GRSM1, HEGL1, MACA1, MING1, and QUCI1. Table 9 shows that both the EPA and DEQ models performed well for particulate matter and MPE statistics are within the MPE annual "goals" and/or "criteria".

Table 9: Comparison between DEQ and EPA Modeling Performance for the $PM_{2.5}$

Species	Network	Climate Region	DEQ NMB %	EPA NMB %	DEQ NME %	EPA NME %
$PM_{2.5}$	IMPROVE	South	6.77	1.2	41.2	41.9
		Southeast	11.8	14.2	42.9	47.5
		Central	29.3	23.4	44.5	41.5

Further MPE statistics for selected Class I sites in other states (HEGL1, MACA1, MING1, SHRO1, SIPS1, and WIMO1) are presented in Appendix L.2.

2.5.3 Model Performance Evaluation for Visibility

DEQ evaluated model performance considering light extinction of PM species using the IMPROVE equation with the following PM species equations to calculate species concentrations in µg/m^3:

Ammonium Sulfate ($AmmSO_4$) = 1.375 X PSO4
Ammonium Nitrate ($AmmNO_3$) = 1.290 X PNO3
Organic Aerosol (OA) = POA + SOA1 + SOA2 + SOA3 + SOA4 + SOPB
Elemental Carbon (EC) = PEC
Soil = FPRM + FCRS
Sea Salt = Na + Cl
Coarse Mass (CM) = CPRM + CCRS

Light extinction (Bext) in units of inverse Mm^{-1} were calculated by using the "revised" IMPROVE equation discussed in section 3 of this document.

[22] Updated EPA 2028 Regional Haze Modeling - Technical Support Document. Available at: https://www.epa.gov/sites/default/files/2019-10/documents/updated_2028_regional_haze_modeling-tsd-2019_0.pdf

Stacked bar plots in Figure 21 and Figure 22 show the observed (Obs) and modeled (Mod) visibility light extinction on the 20 percent most impaired days for the CACR1 and UPBU1 Class I areas. Similar plots are presented in Appendix L.2 for the Class I areas located outside of Arkansas.

Figure 21: Light Extinction on the 20 Percent Most Impaired Days at CACR1

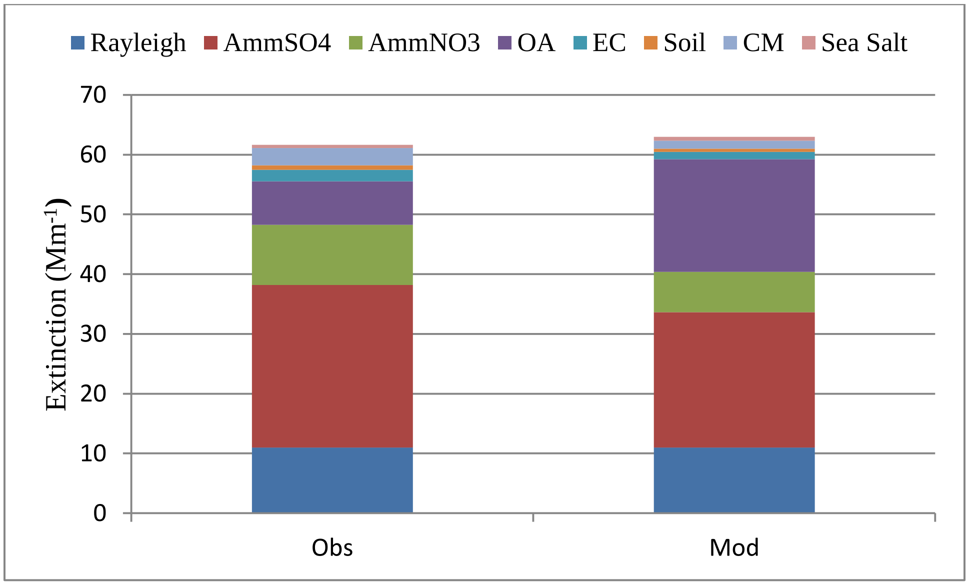
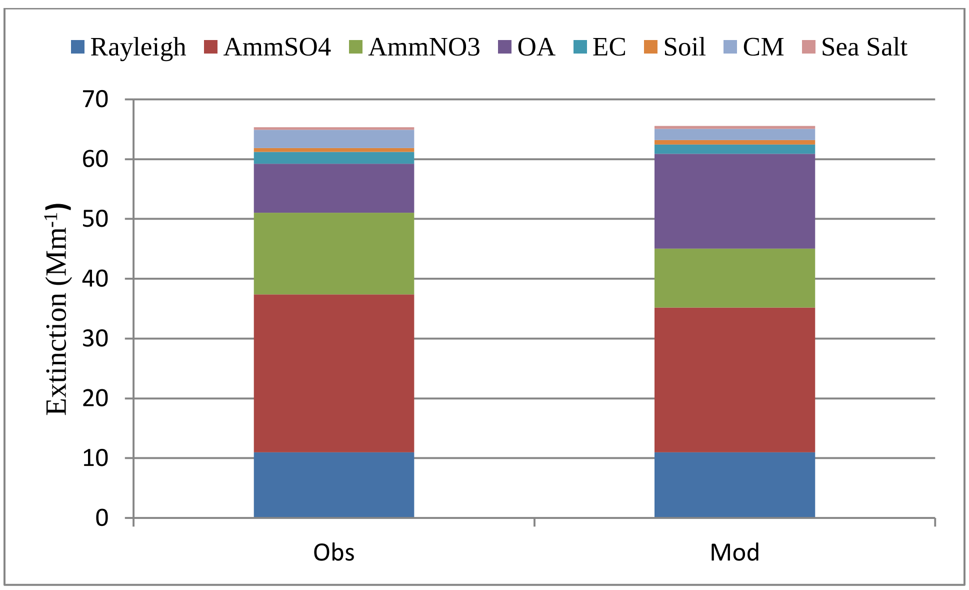


Figure 22: Light Extinction on the 20 Percent Most Impaired Days at UPBU1



DEQ's light extinction model performance for CACR1 and UPBU1 sites is similar to the EPA's modeling performance results.[23] The DEQ simulation underpredicted light extinction for $AmmSO_4$ and $AmmNO_3$ and overpredicted OA for the CACR1 and UPBU1 sites. These three species makes up more than 70% of total extinction. Total contribution from EC, CM, Soil, and Sea Salt are less than 10% of total light extinction. Overall, DEQ's model simulation shows better agreement for the total light extinction on the 20 percent most impaired days at CACR1 and UPBU1.

3. Translating CAMx Outputs to Visibility Conditions

DEQ followed EPA's "Modeling Guidance for Demonstrating Air Quality Goals for Ozone, $PM_{2.5}$, and Regional Haze" [24] to translate CAMx outputs to visibility conditions to guide DEQ's evaluation of the impact of Arkansas's Planning Period II SIP long-term strategy on visibility conditions at Class I areas in Arkansas and other states in 2028.

The 2028 visibility projection for the twenty percent most anthropogenically impaired days and the twenty percent clearest days at each of the IMPROVE monitors representing Class I areas are calculated by utilizing the EPA's Software tool Model Attainment Test–Community Edition (SMAT–CE) version 1.6. The tool extracts model concentrations from the grid cells around Class I areas for the BY and FY and calculates species and site specific relative response factors (RRF) for a set of days, such as the 20 percent most impaired and clearest days. The RRF is defined as fractional changes in pollutant concentrations between the model future year and model base year. DEQ used a 5-year (2014–2018) base period centered about the base modeling year of 2016 for historical ambient monitoring data used in SMAT, consistent with EPA modeling guidance.[25] DEQ used "camx2ioapi," "combine," hr2day," and "nc2SMAT" tools to generate SMAT inputs from the CAMx outputs. Table 10 presents the SMAT configuration used by DEQ.

Table 10: SMAT–CE Configuration for the 2028 Visibility Calculations

SMAT Option	Settings or File Used
IMPROVE algorithm	Use new version
Grid cells at monitor or class I area centroid?	Use grid cells at monitor
IMPROVE data file	ClassIareas_NEWIMPROVEALG_2000to2018_2020_may5_IMPAIRMENT .csv[26]
Temporal adjustment at monitor	3x3

[23] https://www.epa.gov/sites/default/files/2019-10/documents/updated_2028_regional_haze_modeling-tsd-2019_0.pdf

[24] Modeling Guidance for Demonstrating Air Quality Goals for Ozone, $PM_{2.5}$ and Regional Haze, 2018. Available at: https://www.epa.gov/sites/default/files/2020-10/documents/o3-pm-rh-modeling_guidance-2018.pdf

[25] Modeling Guidance for Demonstrating Air Quality Goals for Ozone, $PM_{2.5}$ and Regional Haze, 2018. Available at: https://www.epa.gov/sites/default/files/2020-10/documents/o3-pm-rh-modeling_guidance-2018.pdf

[26] https://gaftp.epa.gov/aqmg/SMAT/Ambient_Data/2018/

Start monitor year	2014
End monitor year	2018
Base model year	2016
Minimum years required for a valid monitor	1

The visibility calculations use the “revised” IMPROVE equation, which uses PM species concentration ($\mu g/m^3$) and relative humidity data, as well as converts to light extinction (b_{ext}) in units of inverse megameters (Mm^{-1}), is represented by the following equation:[27]

b_{ext} = 2.2 x fs(RH) x [Small Sulfate] + 4.8 x fL(RH) x [Large Sulfate] + 2.4 x fs(RH) x [Small Nitrate] + 5.1 x fL(RH) x [Large Nitrate] + 2.8 x {Small Organic Mass] + 6.1 x [Large Organic Mass] + 10 × [Elemental Carbon]+ 1 × [Fine Soil]+1.7×f_SS (RH) ×[Sea Salt]+0.6 × [Coarse Mass] + Rayleigh Scattering (Site Specific) + 0.33 × [NO_2(ppb)]

The total sulfate, nitrate, and organic mass concentrations are each split into two fractions, representing small and large size distributions of those components. SMAT-CE software assumes NO_2 to be zero in visibility analyses. Table 11 shows “species definition” file used to generate data for the SMAT–CE software. SMAT-CE tool uses the following formula to calculate large and small sulfate:

[Large Sulfate] = [Total Sulfate]/20 ug/m3 x [Total Sulfate]; for [Total Sulfate] < 20 ug/m3
[Large Sulfate] = [Total Sulfate]; for [Total Sulfate] ³ ≥ 20 ug/m3
[Small Sulfate] = [Total Sulfate] - [Large Sulfate]

Table 11: Matching of CAMx Raw Output Species to SMAT Input Variables

SMAT-CE Species	Raw CAMx Species
Sulfate	PSO4
Nitrate	PNO3
Ammonium	PNH4
Organic Carbon	POA+SOA1+SOA2+SOPA+SOA3+SOA4+SOPB
Elemental Carbon	PEC
Crustal	FCRS+FPRM
Coarse PM	CCRS+CPRM
$PM_{2.5}$ [28]	FPRM+FCRS+PSO4+PNO3+PNH4+PEC+NA+PCL+ SOA1+SOA2+SOA3+SOA4+SOPA+SOPB+POA

[27] Pitchford, M., W. Malm, B. Schichtel, N. Kumar, D. Lowenthal, J. Hand. 2007. Revised algorithm for estimating light extinction from IMPROVE particle speciation data. J. Air and Waste Mgmt. Assn., 57:11, 1326-1336. Doi: 10.3155/10473289.57.11.1326
[28] $PM_{2.5}$ data is needed as a SMAT input variable but not used in the visibility calculations for the visibility analyses.

SMAT performed the following steps to calculate 2028 visibility conditions:

1) For each Class I area, estimated anthropogenic impairment (Mm^{-1}) on each day using observed speciated particulate matter for each of the five years comprising the base period (2014–2018) and ranked the days for the 20 percent most anthropogenically impaired days and 20 percent clearest days;
2) For each year comprising the base period, calculated mean deciview for the 20 percent most impaired and 20 percent clearest days. Calculated 5-year mean deciview from the five year-specific values for the most impaired and clearest days;
3) Calculated site-specific RRFs for each component of PM identified in the IMPROVE equation from 2016 and 2028 CAMx outputs;
4) Multiplied site-specific RRFs by the measured daily species concentration data during the 2014–2018 base period for each day in the measured twenty percent most impaired and twenty percent clearest days, which results in daily 2028 FY particulate matter species concentration data;
5) Calculated the future daily extinction coefficients for the previously identified impaired and clearest days using the results from Step IV and the IMPROVE equation; and
6) From total daily extinction, calculated daily deciview values and the projected year average mean deciview values for the 20 percent most impaired days and 20 percent clearest days for each year. Then, averaged the five years together to get the final future year mean deciview values for the selected days.

The haze index (deciview) is defined as HI = 10 x $\ln[b_{ext}/10]$. The SMAT tool reports future year visibility using both light extinction and haze index.

Twenty percent most impaired days and twenty percent clearest days are identified as “group 90” and “group 10,” respectively, in the IMPROVE ambient data file. Table 12 shows the BY and FY visibility in deciviews. All eight Class I areas examined by DEQ show a decrease in visibility impairment (in deciviews) in 2028 from 2016. The greatest reduction occurs at CACR1 (10.83%) followed by SHRO1 (10.72%) for the twenty percent most impaired days.

Table 12: BY and FY Visibility in Deciviews for the Twenty Percent Clearest and Twenty Percent Most Impaired Days

	Clearest Days (deciviews)			Most Impaired Days (deciviews)		
Site ID	Base Year	Future Year	% change	Base Year	Future Year	% change
CACR1	8.02	7.50	-6.48	18.29	16.31	-10.83
HEGL1	9.71	9.07	-6.59	18.72	17.30	-7.59
MACA1	11.31	10.47	-7.43	21.02	19.37	-7.85
MING1	11.08	10.47	-5.51	20.13	18.83	-6.46
SHRO1	4.40	4.00	-9.09	15.49	13.83	-10.72

SIPS1	10.76	10.04	-6.69	19.03	17.41	-8.51
UPBU1	8.20	7.72	-5.85	17.95	16.49	-8.13
WIMO1	8.47	8.17	-3.54	18.12	16.81	-7.23

DEQ generated Uniform Rate of Progress (URP) glidepaths for each Class I area to represent a linear rate of visibility progress. Appendices L.3 and L.4 show the glidepaths at CACR1, HEGL1, MACA1, MING1, SHRO1, SIPS1, UPBU1, and WIMO1 for the 20 percent most impaired days and 20 percent clearest days, respectively.

Appendix L.5 provides plots of the 2028 visibility (dv) for the most impaired and clearest days for all the Class I areas in the United States.

DEQ also used a 4-year (2014–2017) base period for SMAT input and a dataset "ClassIareas_NEWIMPROVEALG_2000to2017_2019_feb11_IMPAIRMENT.csv" file for the observed IMPROVE file, as used in the EPA's technical support document,[29] and visibility output is presented in Appendix L.6.

4. Conclusion

Arkansas DEQ used EPA's 2016v1 modeling platform to evaluate visibility at eight Class I areas, including two located in Arkansas. DEQ used ERTACv16.1 emissions data for the electricity generation units and updated emissions for the Entergy White Bluff and Flint Creek facilities located in Arkansas, and the TVA Shawnee Fossil Plant units located in Kentucky for 2028 FY emissions. DEQ also updated emissions data in the EPA's 2028 FY point non-EGU emission file for the Domtar and Futurefuel facilities in Arkansas. The emissions were processed by using SMOKEv4.7 software and then CAMxv7.0 software was used to simulate the 2016 BY and 2028 FY, utilizing all the inputs from the EPA 2016v1 modeling platform except specific emissions updates discussed above for the 2028 FY. Model performance was within acceptable parameters as summarized below:

- DEQ performed an MPE evaluation for ozone, $PM_{2.5}$, and $PM_{2.5}$ species using various monitor networks. The model achieved performance "goals" annually and met "goal" and/or "criteria" in the spring, summer, fall, and winter seasons for ozone. The model underestimated ozone concentrations during spring and winter seasons while overpredicted in summer and fall.

[29] Technical Support Document for EPA's Updated 2028 Regional Haze Modeling, 2019. Available at: https://www.epa.gov/sites/default/files/2019-10/documents/updated_2028_regional_haze_modeling-tsd-2019_0.pdf

- Annual performances of total $PM_{2.5}$ show reasonable results for the MPE statistical parameters NMB and NME at both CSN and IMPROVE networks. CAMx overestimated the total $PM_{2.5}$ concentrations at both monitoring networks.
- Annual model performances are within the MPE "criteria" and/or "goals" for most of the $PM_{2.5}$ species at IMPROVE locations except for OC. Model performance exceeded the MPE criteria for NH_4 at the CSN network while achieved better results for all other species.
- The seasonal MPE shows the $PM_{2.5}$ performed relatively well during the summer and fall seasons. NO_3 and EC showed better results across all seasons than did OC for most seasons. The weaker performance of $PM_{2.5}$ was primarily driven by weak performance of SO_4 and OC during the colder periods of the year. Better performance was observed at the CSN sites compared to IMPROVE sites for the total $PM_{2.5}$ during winter season.
- Model shows better agreement with the observed light extinction (Mm^{-1}) at CACR1 and UPBU1 for the 20 percent most impaired days.