Criteria Pollutant Modeling Analysis for Arkansas

Final Report

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14-003

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1 Introduction

This document describes an air quality modeling study of future-year air pollutant concentrations for the State of Arkansas. The pollutants of interest are ozone, fine particulate matter ($PM_{2.5}$), nitrogen dioxide (NO_2) and sulfur dioxide (SO_2). The modeling analysis includes two base years (2005 and 2008) and a future year (2015).

1.1 Objectives

The objectives of the modeling study are to identify areas within potential ozone, $PM_{2.5}$, SO_2, and NO_2 issues throughout the state, examine the expected changes in these pollutants between the base and future years, and identify areas within the state where additional air quality monitoring may be used to ensure compliance with existing National Ambient Air Quality Standards (NAAQS).

1.2 Overview of the Modeling Study

The air quality modeling was conducted using version 5.0 of the Community Multiscale Air Quality (CMAQ) model. The meteorological and emissions inputs to the model were based on modeling databases available from EPA (adapted for the area of interest).

The modeling focused on two base years, 2005 and 2008, and a future year of 2015. The modeling domain consists of a 36-km resolution outer grid encompassing the U.S. (the CONUS grid), a 12-km resolution grid over the central states, and a high-resolution 4-km grid over the entire state of Arkansas. Two annual simulation periods were simulated.

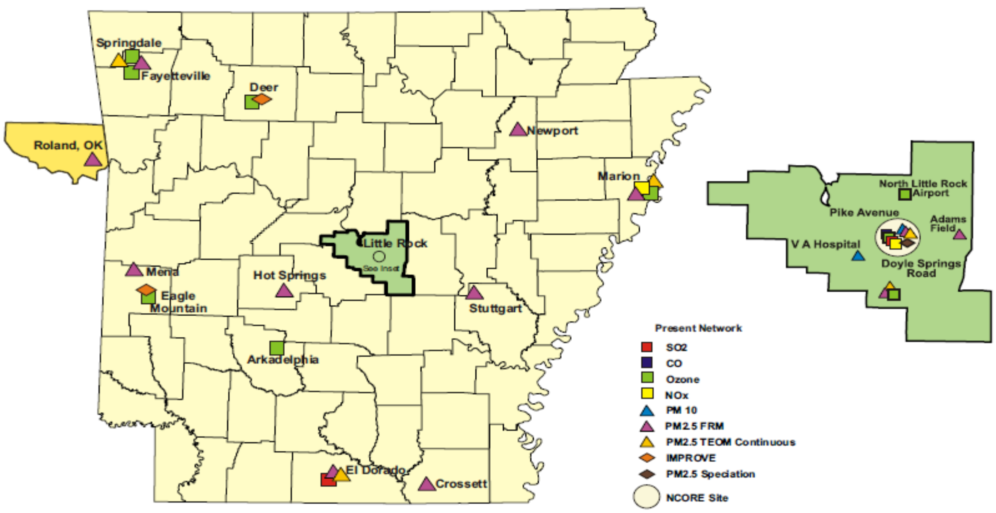
The modeling inventories were processed and prepared for CMAQ using EPA's Sparse-Matrix Operator Kernel Emissions (SMOKE) software (version 3.1).

The modeling analysis included the evaluation of model performance for the two base years. EPA's Modeled Attainment Test Software (MATS) was used in the analysis of the future-year modeling results for monitored and unmonitored areas.

2 Overview of Air Quality in Arkansas

Figure 2-1 depicts the locations of currently operating air quality monitoring sites within Arkansas.

Figure 2-1. Air Quality Monitoring Network for Arkansas



Source: ADEQ (2014)

Current air quality and air quality trends for ozone, $PM_{2.5}$, NO_2, and SO_2 based on data from the ADEQ monitoring network are summarized in the remainder of this section. Since, all of these pollutants can contribute to visibility impairment, visibility within the two Class I[1] areas in Arkansas is also summarized, based on data from Interagency Monitoring of Protected Visual Environments (IMPROVE) network.

2.1 Air Quality Conditions and Trends

2.1.1 Ozone

Ozone is a secondary pollutant that is not directly emitted into the atmosphere but instead is formed in the lower atmosphere by a series of reactions involving ultra violet (UV) radiation and precursor emissions of oxides of nitrogen (NO_x) and volatile organic compounds (VOCs). NO_x consists of nitric oxide (NO) and nitrogen dioxide (NO_2), which are primarily emitted from anthropogenic sources. VOCs consist of thousands of individual hydrocarbon and oxygenated hydrocarbon species emitted from anthropogenic, biogenic, and geogenic sources. Ozone formation in the troposphere is affected by local weather conditions: winds, temperature, solar radiation, and horizontal and vertical dispersion characteristics, which influence precursor concentrations, reaction rates, formation, transport, and

[1] Class I air quality areas include national parks larger than 6,000 acres and wilderness areas larger than 5,000 acres that existed or were authorized as of August 7, 1977. The two Class I areas in Arkansas are Caney Creek Wilderness and Upper Buffalo Wilderness.

deposition. Because the primary ozone-forming reaction is photochemically driven (i.e., by the sun), ozone concentrations typically peak during the daylight hours and decrease after sunset.

Health effects studies have determined that exposure to ozone can reduce lung function and increase the incidence and severity of respiratory illnesses such as asthma. Repeated exposure to ozone may also damage vegetation and trees. To protect public health, the U.S. EPA established the first NAAQS for ozone in 1971 and has since revised the level and form of the standard several times. The most recent revision occurred in March 2008 and set the 8-hour ozone standard to 75 parts per billion (ppb). Note that the official level of the 8-hour ozone standard is 0.075 parts per million (ppm), equivalent to 75 ppb. To attain this standard, the three-year average of the annual fourth highest daily maximum 8-hour ozone concentration at all sites within a designated area must be less than or equal to 75 ppb. The three-year average, or "design value", is calculated for each site, and the maximum value over all sites within an area determines the design value for the area. EPA issued attainment/non-attainment designations in April 2012. For most areas, compliance with the new standard was determined using data collected during the period 2008–2010.

Table 2-1 lists the currently operating ozone monitoring sites located within Arkansas and the 8-hour ozone design values for each site for the three three-year periods ending in 2010, 2011, and 2012.

Table 2-1. Ozone Monitoring Sites and 8-Hour Ozone Design Values for the Three-Year Periods Ending in 2010, 2011, and 2012

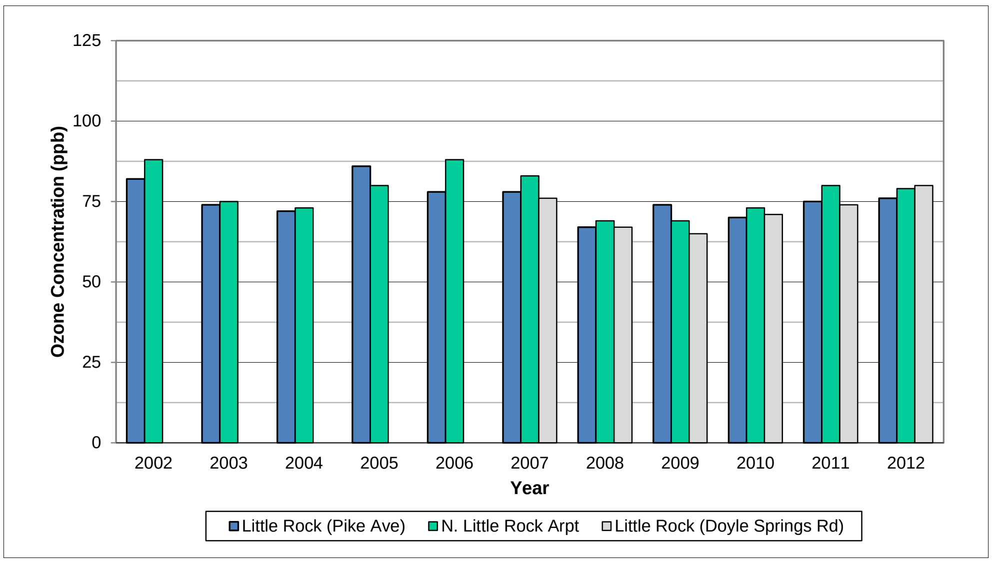
Site Name	ID	County	2008–2010 8-Hour Ozone Design Value (ppb)	2009–2011 8-Hour Ozone Design Value (ppb)	2010–2012 8-Hour Ozone Design Value (ppb)
North Little Rock (Pike Ave)	051190007	Pulaski	70	73	73
North Little Rock Airport	051191002	Pulaski	70	74	77
Little Rock (Doyle Springs Rd)	051191008	Pulaski	67	70	75
Marion	050350005	Crittenden	74	77	79
Deer	051010002	Newton	66	68	69
Springdale	051430005	Washington	64	68	73
Fayetteville	051430006	Washington	—	—	79[1]
Mena	051130003	Polk	70	73	73
Arkadelphia (CASTNet)[3]	050199991	Clark	—	64[1]	64[2]

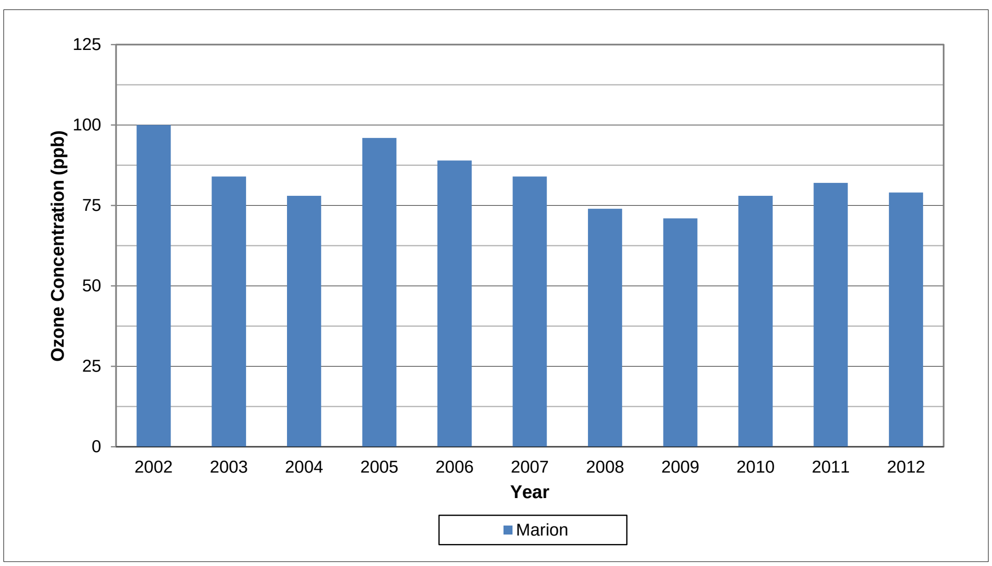
[1] Based on one year of monitoring data.
[2] Based on two years of monitoring data.
[3] Clean Air Status and Trends Network.

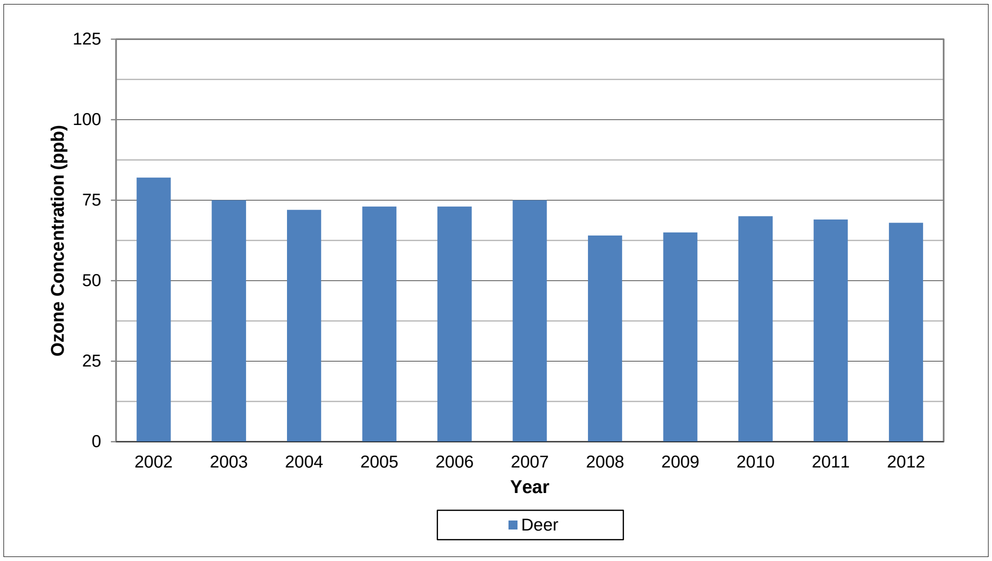
For the three year period ending in 2012, the 8-hour ozone design values are greater than 75 ppb for the North Little Rock Airport and Marion sites (and thus for the Little Rock and Memphis areas). The estimated design values for the newly established Fayetteville site is also greater than 75 ppb, but the estimate is based on only one year of monitoring data.

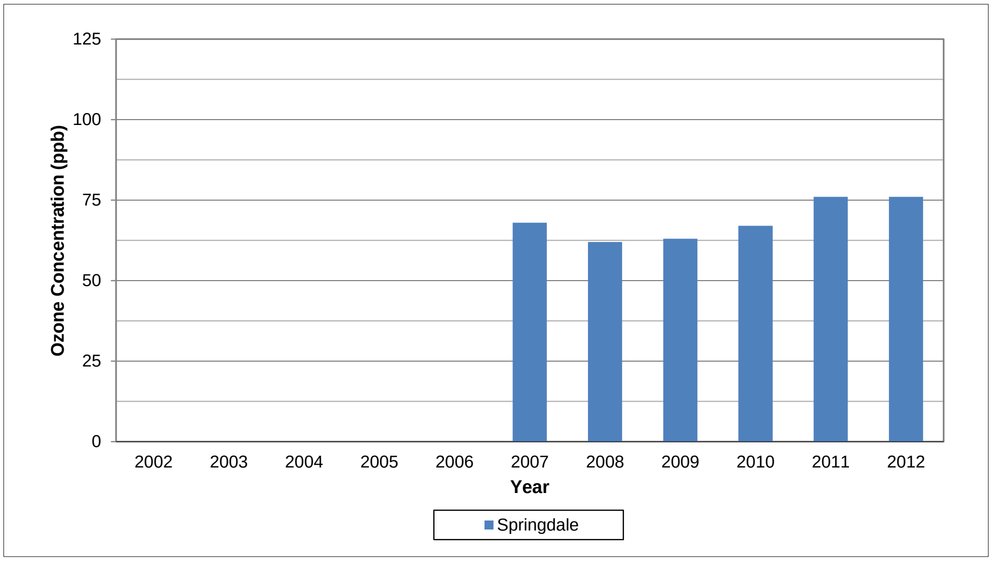
Figure 2-2 displays the fourth highest 8-hour average ozone concentrations and Figure 2-3 displays the 8-hour ozone design values for all currently operating monitoring sites with five or more years of data. Data for years with incomplete data and design values based on fewer than three years of data are not included in the displays. As noted earlier, the fourth highest 8-hour average ozone concentration for each year is used to calculate the design value and assess compliance with the ozone NAAQS. Note that the Little Rock sites are grouped together and that the maximum value for any site in the Little Rock area represents the design value for the area.

Figure 2-2. Fourth Highest 8-Hour Average Ozone Concentration (ppb) for Monitoring Sites within Arkansas






125
100
75
50
25
0
Ozone Concentration (ppb)
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Year
Deer


125
100
75
50
25
0
Ozone Concentration (ppb)
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Year
Springdale

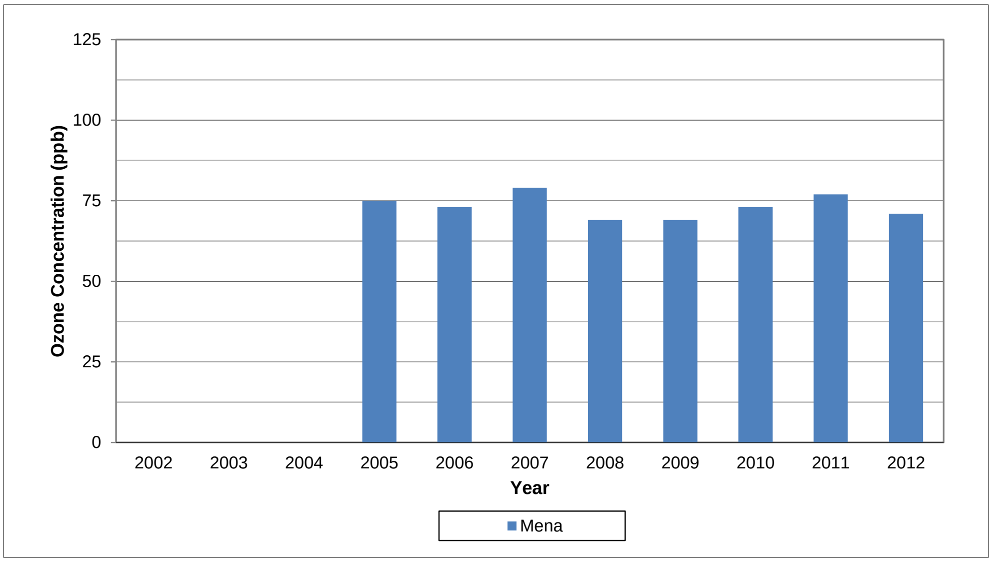
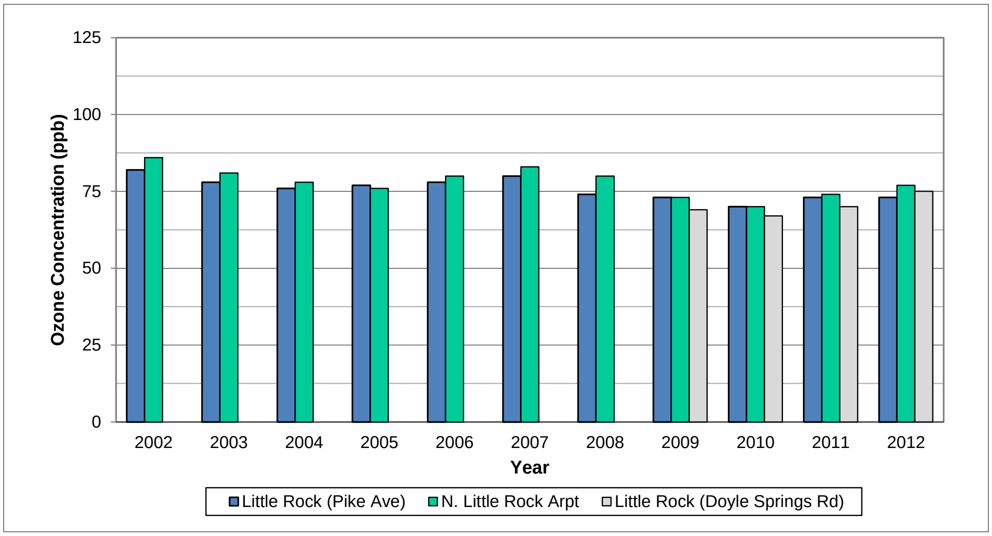
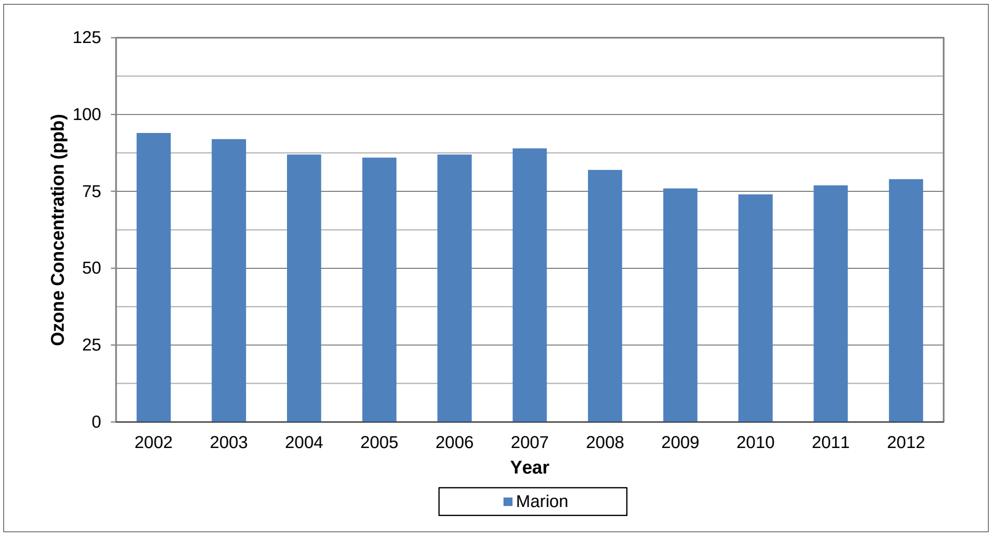
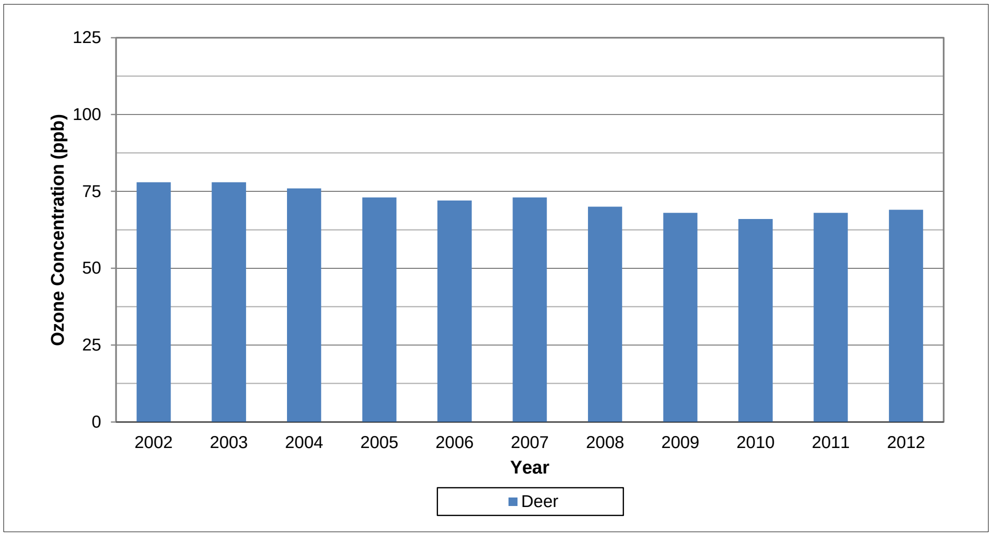
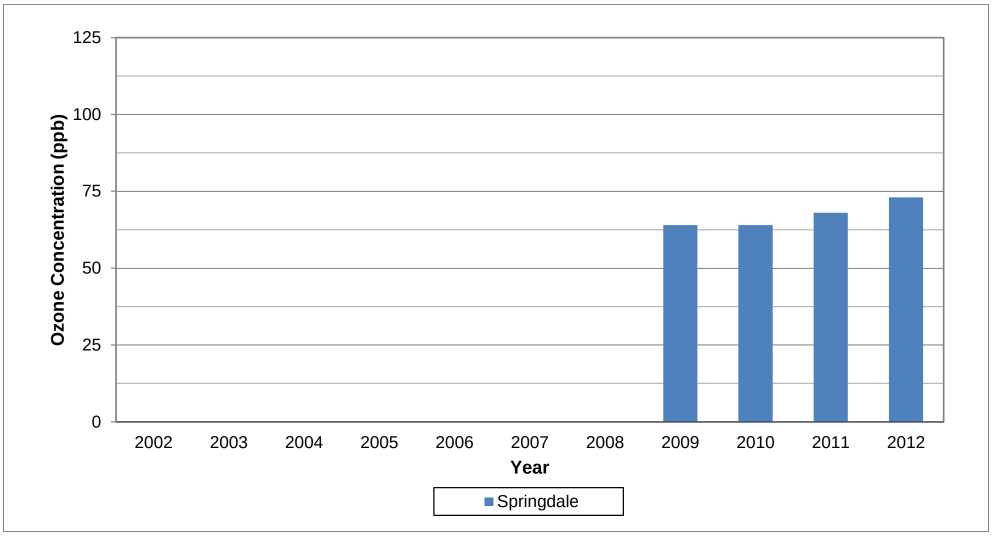

125
100
75
50
25
0
Ozone Concentration (ppb)
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Year
Mena

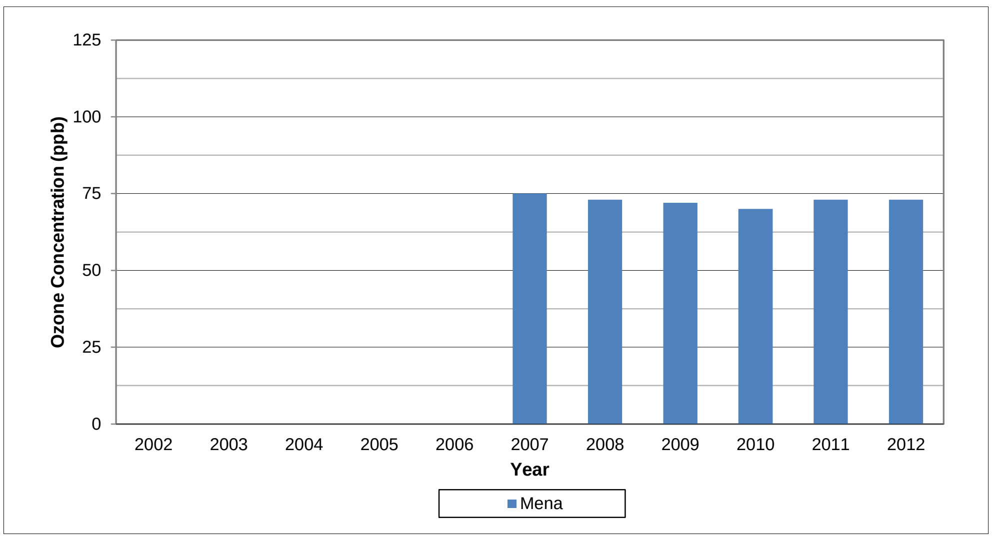
Figure 2-3. 8-Hour Ozone Design Values (ppb) for Monitoring Sites within Arkansas











Note: The NAAQS for 8-hour average ozone concentration is 75 ppb.

The design values displayed in Figure 2-3 are based on three years of data. Overall, the data indicate a downward trend in design value for Marion and Deer, a slight downward trend for Little Rock and Mena, and an upward trend for Springdale.

2.1.2 $PM_{2.5}$

The recent emphasis on $PM_{2.5}$ as an air pollutant of concern is based primarily on epidemiological studies that have indicated a cause and effect relationship between exposure to fine particles and health effects, including respiratory and cardiovascular disease and premature mortality. Particulates are also a primary constituent of regional haze, which limits visibility and the attainment of visibility goals, and ultimately diminishes the natural beauty of the environment.

Fine particulates in the atmosphere consist of primary particles that are emitted directly from sources and secondary particles that form in the atmosphere through chemical and physical processes.

Pollutants that contribute to the formation of secondary aerosols include SO_2, NO_x, and ammonia (NH_3). Natural sources of fine particulates and precursor pollutants include organic aerosols from vegetation, wind-blown dust, sea salt, and forest fires. Anthropogenic contributors include numerous agricultural, mobile, and industrial sources. Meteorology plays an important role in particulate formation and transport and in determination of the ambient particulate concentration levels.

The U.S. EPA established new standards for fine particulate matter in 1997, and subsequently revised the 24-hour standard in 2006 and the annual standard in 2012. Under these standards, fine particles are defined as those with a diameter of less than 2.5 microns; particles of this size are also referred to as $PM_{2.5}$. The annual $PM_{2.5}$ NAAQS requires the three-year average annual mean concentration to be less than or equal to 12 micrograms per cubic meter (μg/m^3). The daily $PM_{2.5}$ standard requires the three-year average of the 98th percentile daily average concentration to be less than or equal to 35 μg/m^3. The averages or "design values" are calculated for each site and then the maximum value over all sites within an area is the design value for the area.

Table 2-2 lists the currently operating $PM_{2.5}$ monitoring sites located within Arkansas and the annual design values for each site for the three three-year periods ending in 2010, 2011, and 2012. Designations for the annual $PM_{2.5}$ standard are expected to be issued in 2014.

Table 2-2. $PM_{2.5}$ Monitoring Sites and Annual $PM_{2.5}$ Design Values for the Three-Year Periods Ending in 2010, 2011, and 2012

Site Name	ID	County	2008–2010 Annual $PM_{2.5}$ Design Value (μg/m^3)	2009–2011 Annual $PM_{2.5}$ Design Value (μg/m^3)	2010–2012 Annual $PM_{2.5}$ Design Value (μg/m^3)
North Little Rock (Pike Ave)	051190007	Pulaski	11.6	11.7	11.9
Little Rock (Adams Field)	051191004	Pulaski	12.0	11.8	11.7
Little Rock (Doyle Springs Rd)	051191008	Pulaski	12.0	12.1	12.2
Marion	050350005	Crittenden	11.1	11.1	11.2
Stuttgart	050010011	Arkansas	10.9	10.7	10.8
Newport	050670001	Jackson	10.4	10.2	10.3
Springdale	051430005	Washington	10.7	11.0	10.8
Mena	051130002	Polk	10.4	10.8	10.8
Hot Springs	050510003	Garland	10.7	10.8	11.0
El Dorado	051390006	Union	10.9	11.1	11.4
Crossett	050030005	Ashley	10.4	10.6	10.8
Roland	401359021	Sequoyah (OK)	--	11.6[1]	10.9[2]

[1] Based on one year of monitoring data.

[2] Based on two years of monitoring data.

The annual $PM_{2.5}$ design values are greater than 12 µg/m^3 for Little Rock (Doyle Springs Road) for the periods ending in 2011 and 2012.

Table 2-3 lists 24-hour design values for each site for the three three-year periods ending in 2010, 2011, and 2012.

Table 2-3. $PM_{2.5}$ Monitoring Sites and 24-Hour $PM_{2.5}$ Design Values for the Three-Year Periods Ending in 2010, 2011, and 2012

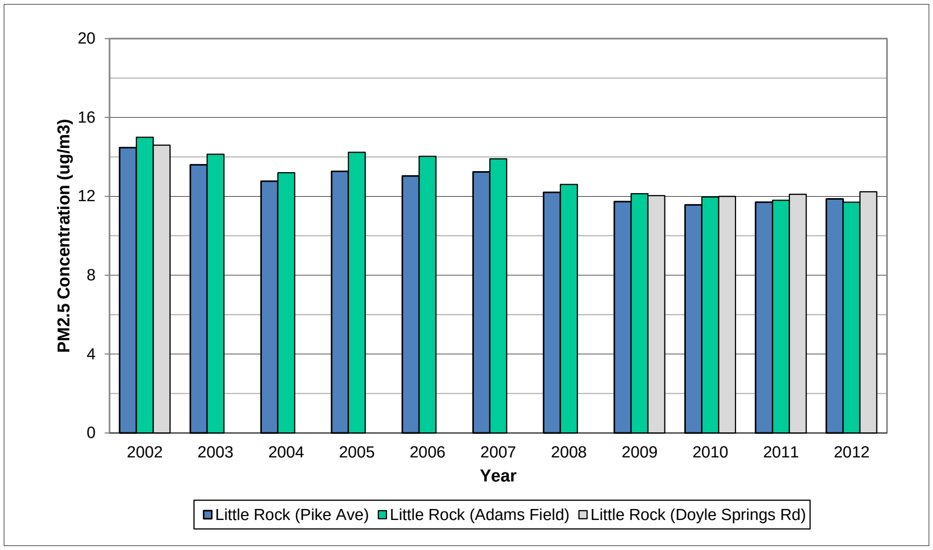
Site Name	ID	County	2008–2010 24-Hr $PM_{2.5}$ Design Value (µg/m^3)	2009–2011 24-Hr $PM_{2.5}$ Design Value (µg/m^3)	2010–2012 24-Hr $PM_{2.5}$ Design Value (µg/m^3)
North Little Rock (Pike Ave)	051190007	Pulaski	24	23	23
Little Rock (Adams Field)	051191004	Pulaski	25	24	25
Little Rock (Doyle Springs Rd)	051191008	Pulaski	25	25	26
Marion	050350005	Crittenden	24	22	23
Stuttgart	050010011	Arkansas	24	22	21
Newport	050670001	Jackson	23	22	22
Springdale	051430005	Washington	22	23	22
Mena	051130002	Polk	21	22	22
Hot Springs	050510003	Garland	21	21	22
El Dorado	051390006	Union	21	22	23
Crossett	050030005	Ashley	21	22	23
Roland	401359021	Sequoyah (OK)	--	23[1]	22[2]

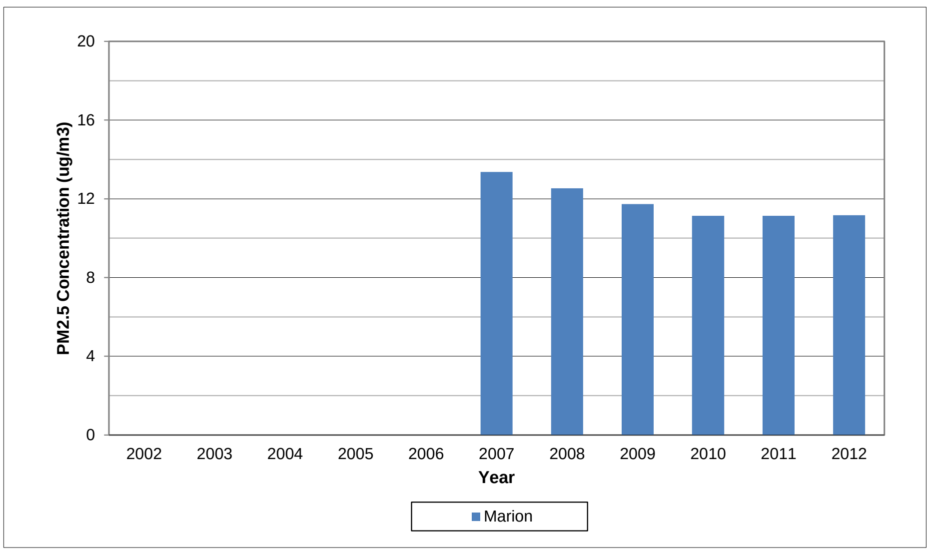
[1] Based on one year of monitoring data.
[2] Based on two years of monitoring data.

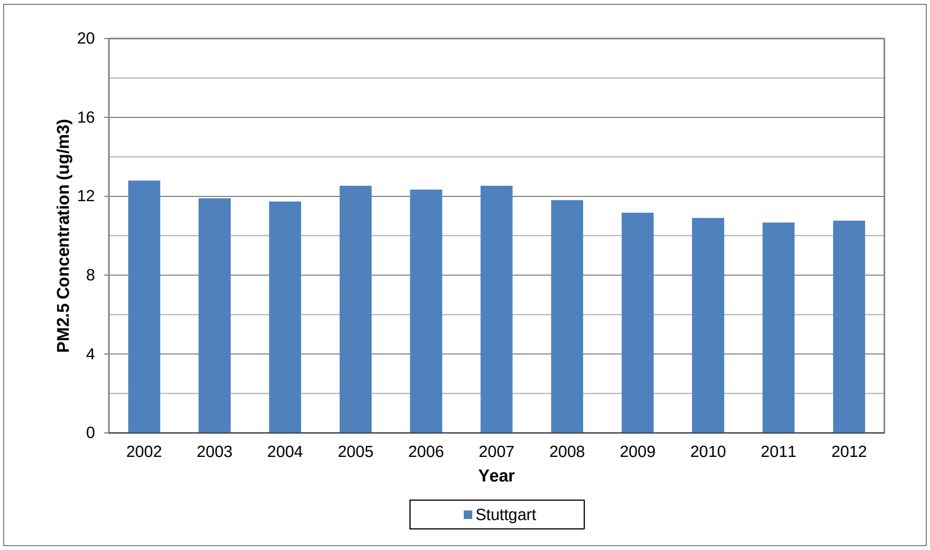
For the three-year period ending in 2012, the annual $PM_{2.5}$ design values are much less than 35 µg/m^3 for all sites and all three periods.

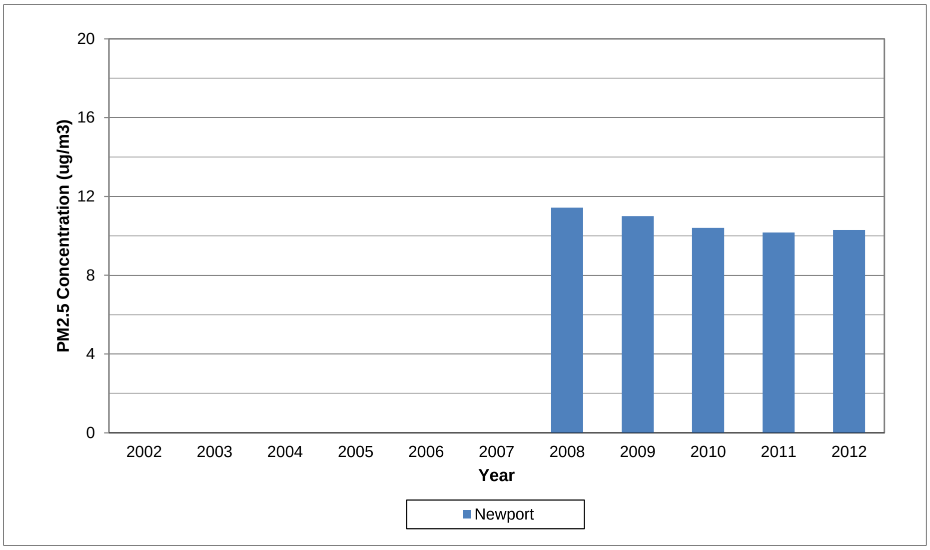
Figure 2-4 displays the annual $PM_{2.5}$ design values and Figure 2-5 displays the 24-hr $PM_{2.5}$ design values for all currently operating monitoring sites with five or more years of data. Data for years with incomplete data and design values based on fewer than three years of data are not included in the displays. Note that the Little Rock sites are grouped together and that the maximum value for any site in the Little Rock area represents the design value for the area.

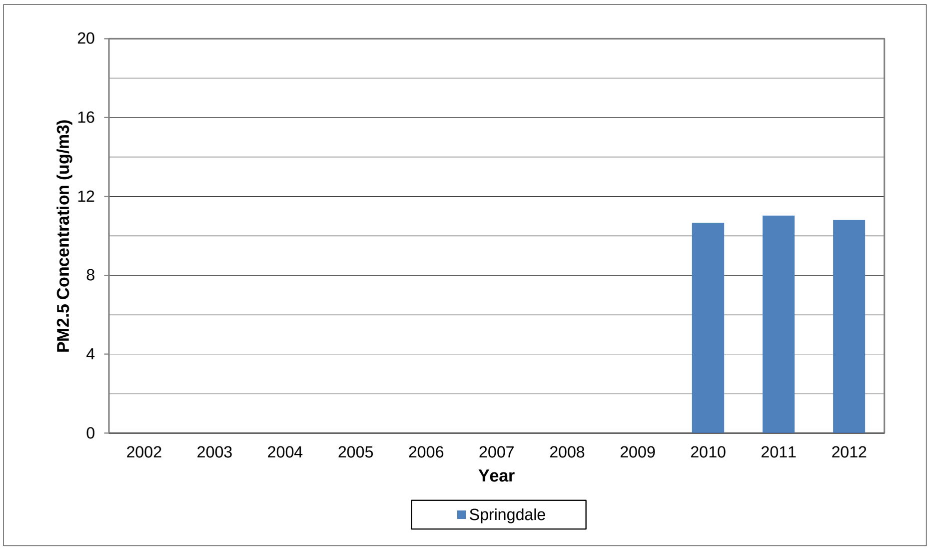
Figure 2-4. Annual $PM_{2.5}$ Design Values ($\mu g/m^3$) for Monitoring Sites within Arkansas

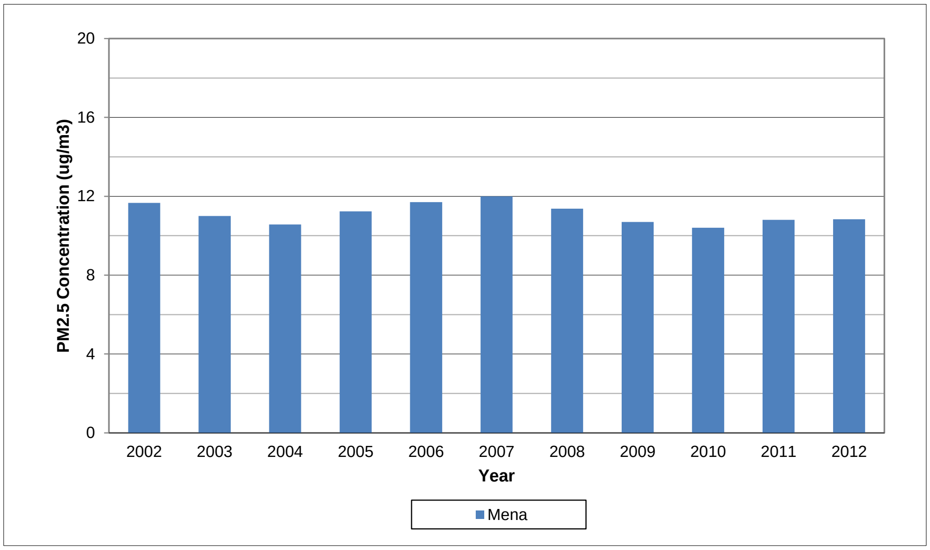


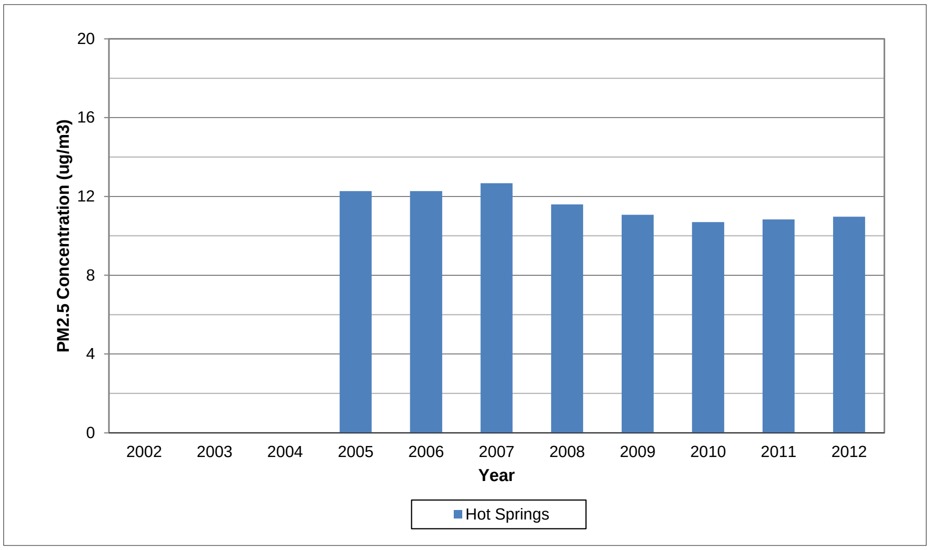


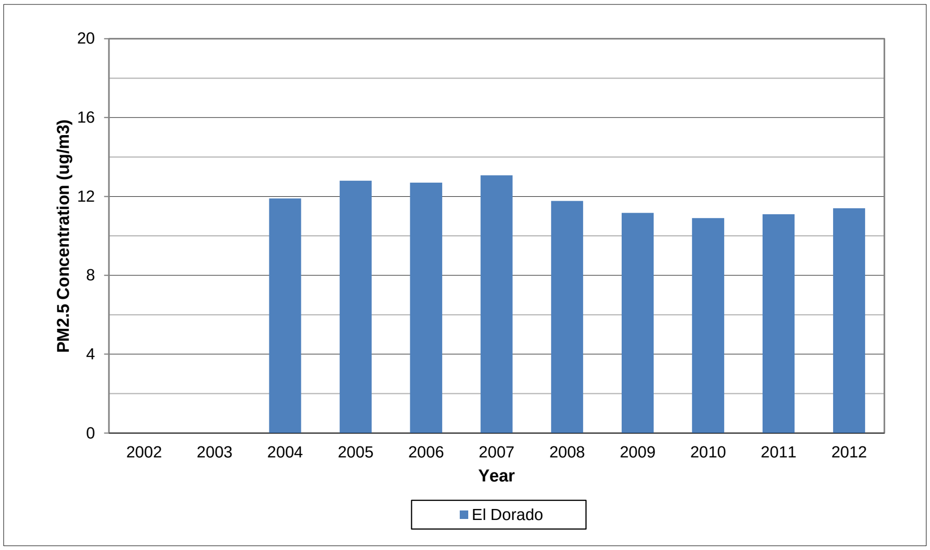

20
16
12
8
4
0
PM2.5 Concentration (ug/m3)
2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012
Year
Stuttgart

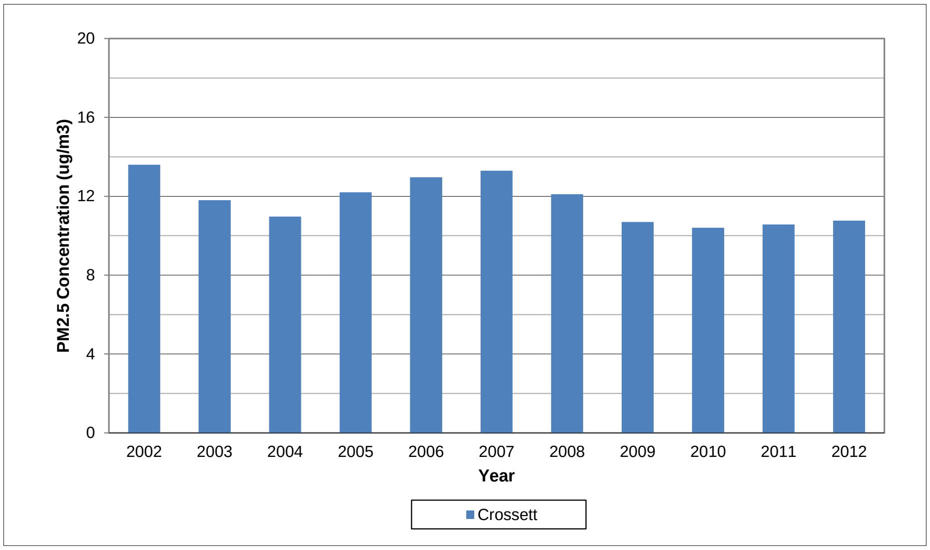

20
16
12
8
4
0
PM2.5 Concentration (ug/m3)
2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012
Year
Newport


20
16
12
8
4
0
PM2.5 Concentration (ug/m3)
2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012
Year
Springdale


PM2.5 Concentration (ug/m3)
20
16
12
8
4
0
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Year
Mena

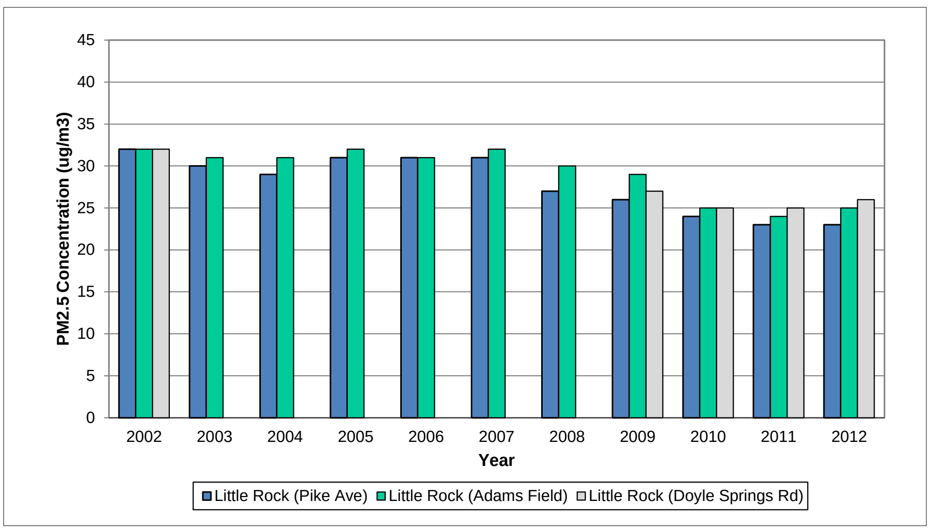

PM2.5 Concentration (ug/m3)
20
16
12
8
4
0
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Year
Hot Springs

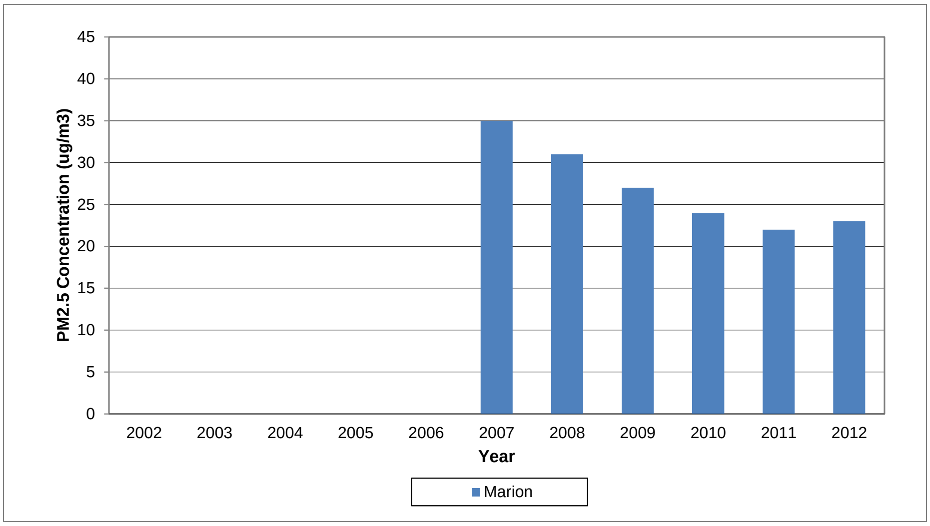

PM2.5 Concentration (ug/m3)
20
16
12
8
4
0
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Year
El Dorado



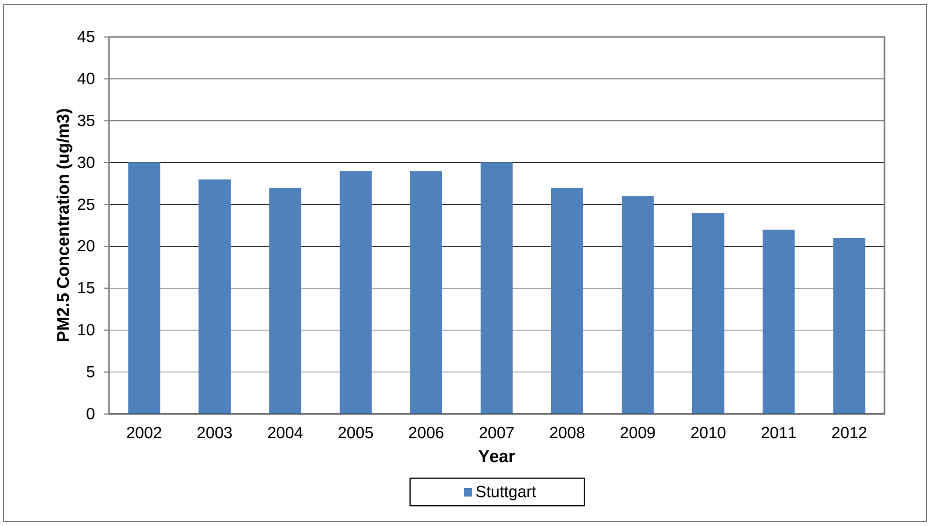
Note: The NAAQS for annual average $PM_{2.5}$ concentration is 12 µg/m^3.

Figure 2-5. 24-Hour $PM_{2.5}$ Design Values (µg/m^3) for Monitoring Sites within Arkansas

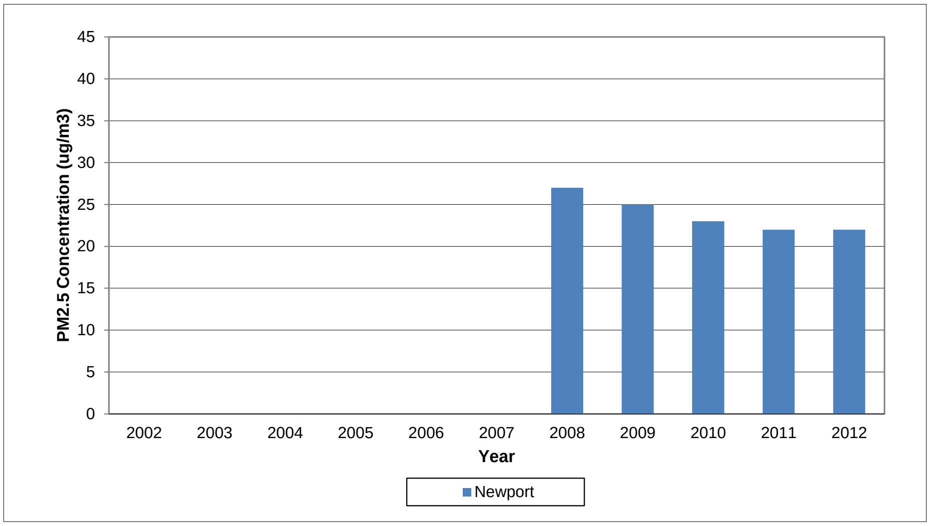




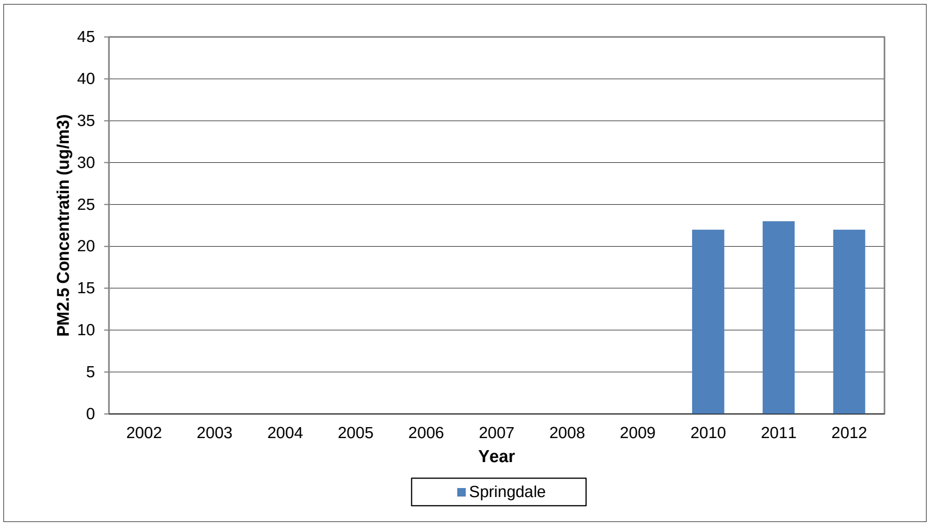
PM2.5 Concentration (ug/m3)
45
40
35
30
25
20
15
10
5
0
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Year
Marion



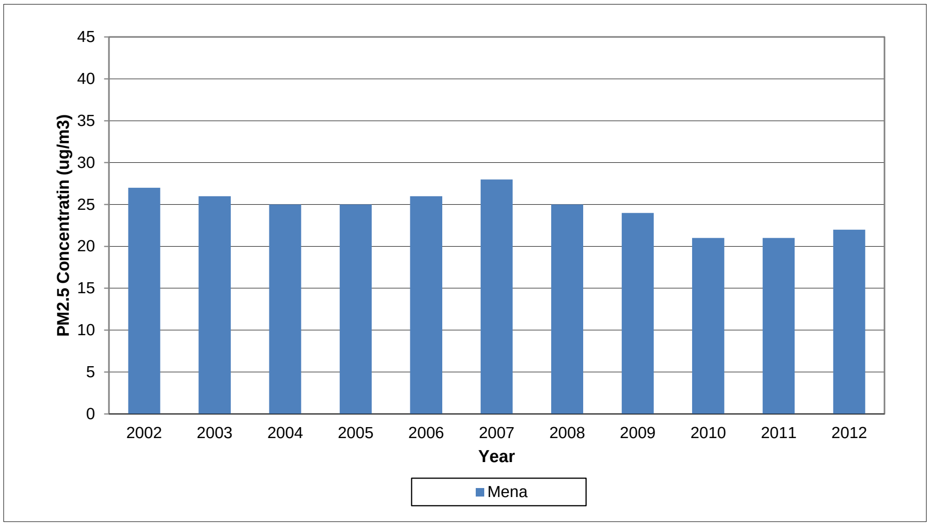
PM2.5 Concentration (ug/m3)
45
40
35
30
25
20
15
10
5
0
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Year
Stuttgart



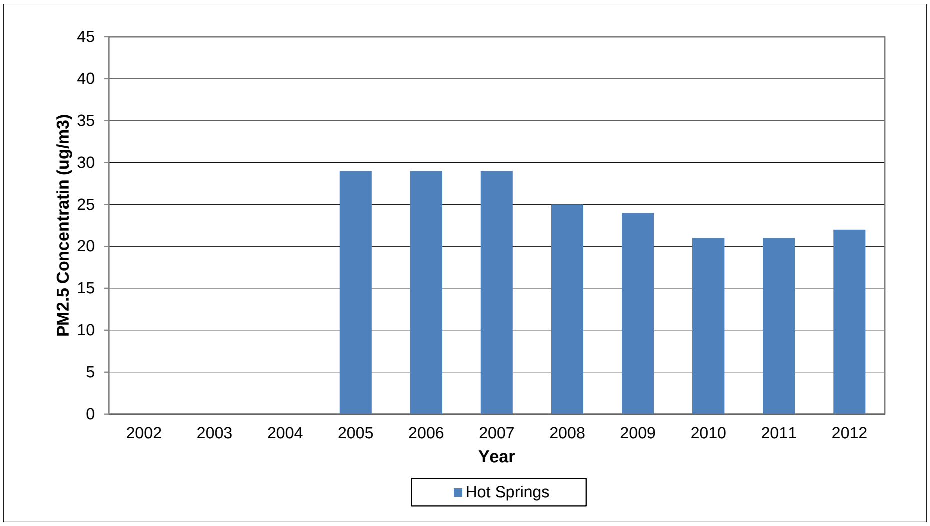
PM2.5 Concentration (ug/m3)
45
40
35
30
25
20
15
10
5
0
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Year
Newport



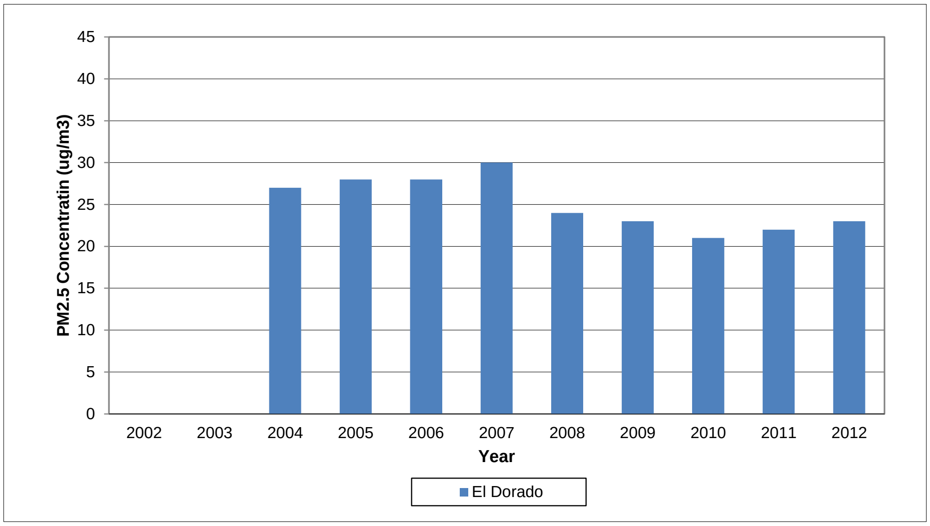
45
40
35
30
25
20
15
10
5
0
PM2.5 Concentratin (ug/m3)
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Year
Springdale

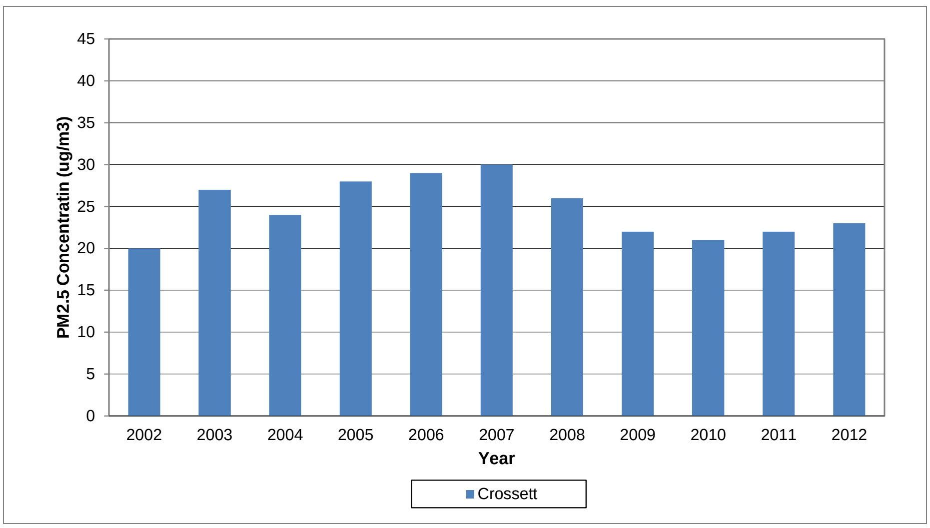


45
40
35
30
25
20
15
10
5
0
PM2.5 Concentratin (ug/m3)
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Year
Mena



45
40
35
30
25
20
15
10
5
0
PM2.5 Concentratin (ug/m3)
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Year
Hot Springs





Note: The NAAQS for 24-hour average $PM_{2.5}$ concentration is 35 µg/m^3.

The design values displayed in Figures 2-4 and 2-5 are based on three years of data. Overall, the data indicate a downward trend in $PM_{2.5}$ concentrations for all sites. However, design values go up and down throughout the eleven-year period. For several of the sites with a full data record, the data indicate a downward trend in design value between 2002 and 2004, an upward trend between 2004 and 2007, and a downward trend between 2007 and 2012. These findings are possibly (even likely) influenced by differences in meteorological and wildfire conditions among the years/periods.

2.1.3 NO_2

NO_2 is a precursor to both ozone and $PM_{2.5}$. In addition, it reacts with water in the respiratory tract to form nitric acid, which is a corrosive irritant. It impairs lung function and can cause respiratory problems including airway inflammation in healthy people, and increased symptoms in people with asthma. Effective April 2010, the 1-hour NO_2 NAAQS requires the three-year average of the 98th-percentile of the annual distribution of daily maximum NO_2 concentration to be less than or equal to 100 ppb (188 µg/m^3). The annual NO_2 NAAQS requires the annual average concentration to be less than or equal to 53 ppb (100 µg/m^3).

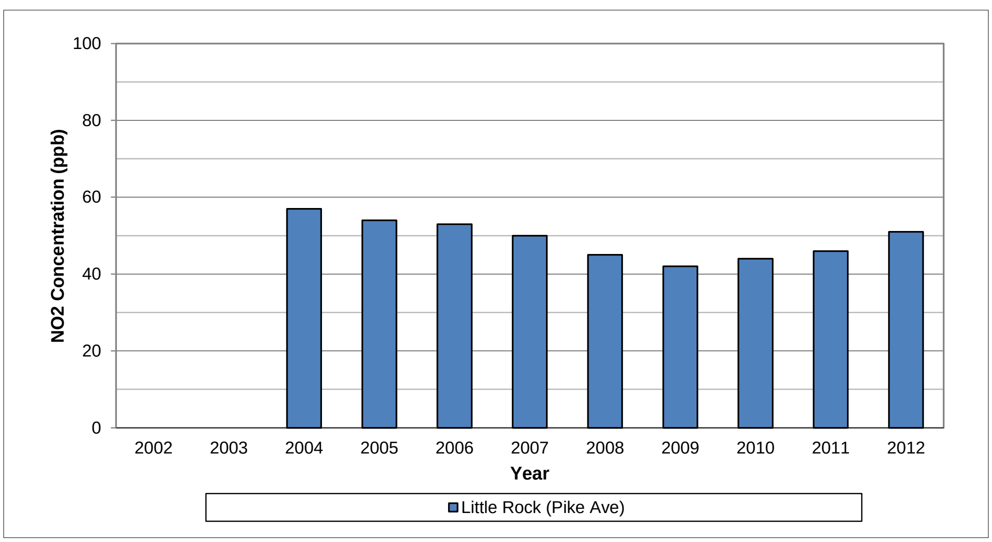
Table 2-4 lists the currently operating NO_2 monitoring sites located within Arkansas and the 1-hour NO_2 design values for each site for the three three-year periods ending in 2010, 2011, and 2012.

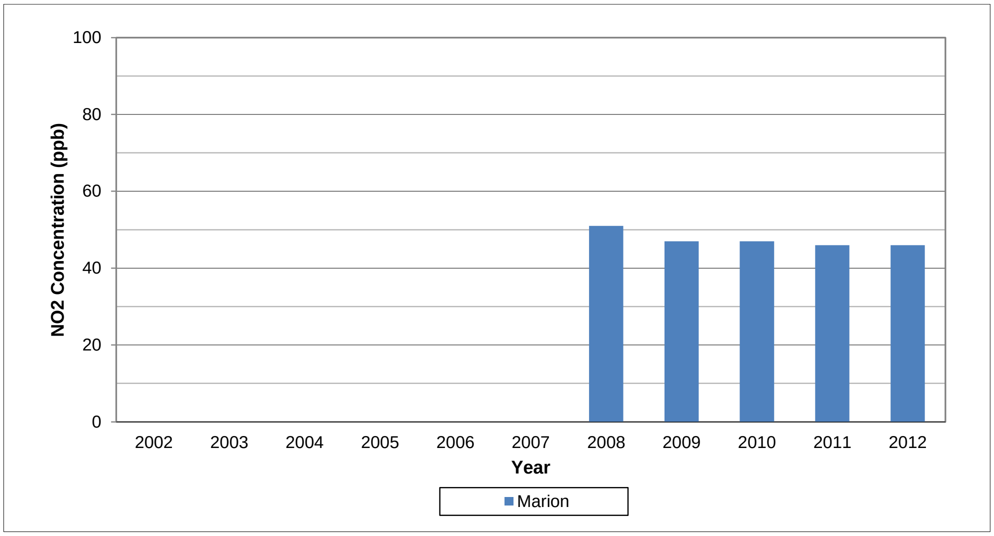
Table 2-4. NO_2 Monitoring Sites and 1-Hour NO_2 Design Values for the Three-Year Periods Ending in 2010, 2011, and 2012

Site Name	ID	County	2008–2010 1-Hour NO_2 Design Value (ppb)	2009–2011 1-Hour NO_2 Design Value (ppb)	2010–2012 1-Hour NO_2 Design Value (ppb)
North Little Rock (Pike Ave)	051190007	Pulaski	44	46	51
Marion	050350005	Crittenden	47	46	46

For all three three-year periods, the 1-hour NO_2 design values are less than 100 ppb for both the North Little Rock (Pike Ave) and Marion sites. The corresponding 98th percentile values for each component year are also less than 100 ppb. Figure 2-6 displays the 1-hour NO_2 design values for these two sites for all years with data beginning with 2002.

Figure 2-6. 1-Hour NO_2 Design Values (ppb) for Monitoring Sites within Arkansas





Note: The NAAQS for 1-hour NO_2 concentration is 100 ppb.

The design values displayed in Figure 2-6 are based on three years of data. For Little Rock, the data indicate a decrease in design value between 2004 and 2009, followed by an increase between 2009 and 2012. The data for Marion show an overall decrease from 2008 to 2009, but a flat trend for the past four design-value periods.

For both sites, the annual average NO_2 values are well below the standard.

2.1.4 SO_2

SO_2 is also a precursor of $PM_{2.5}$ and can contribute to both acid rain and visibility impairment. The primary standard for SO_2 is the 1-hour SO_2 NAAQS which requires the three-year average of the 99th-percentile of the annual distribution of daily maximum SO_2 concentration to be less than or equal to 75 ppb (196 μg/m^3).

Table 2-5 lists the currently operating SO_2 monitoring sites located within Arkansas and the 1-hour SO_2 design values for each site for the three three-year periods ending in 2010, 2011, and 2012.

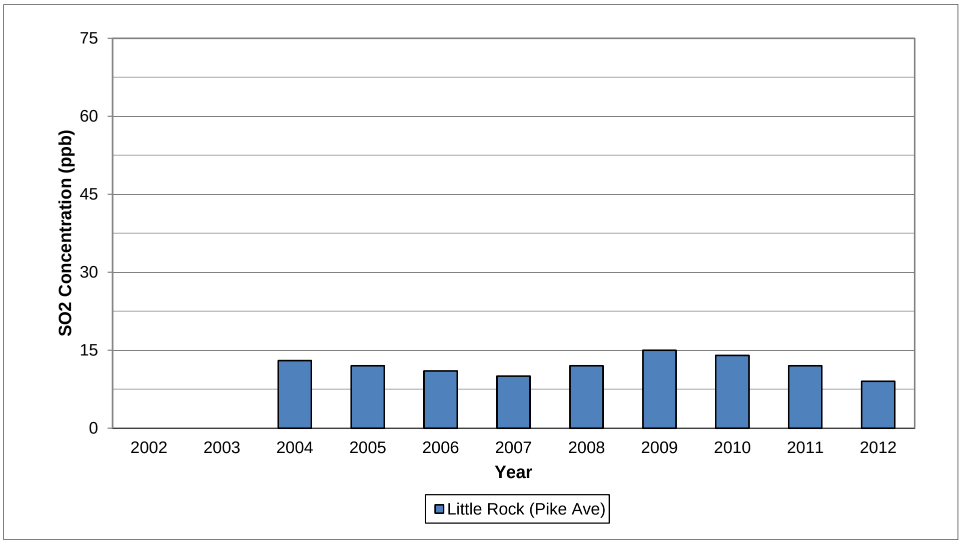
Table 2-5. SO_2 Monitoring Sites and 1-Hour SO_2 Design Values for the Three-Year Periods Ending in 2010, 2011, and 2012

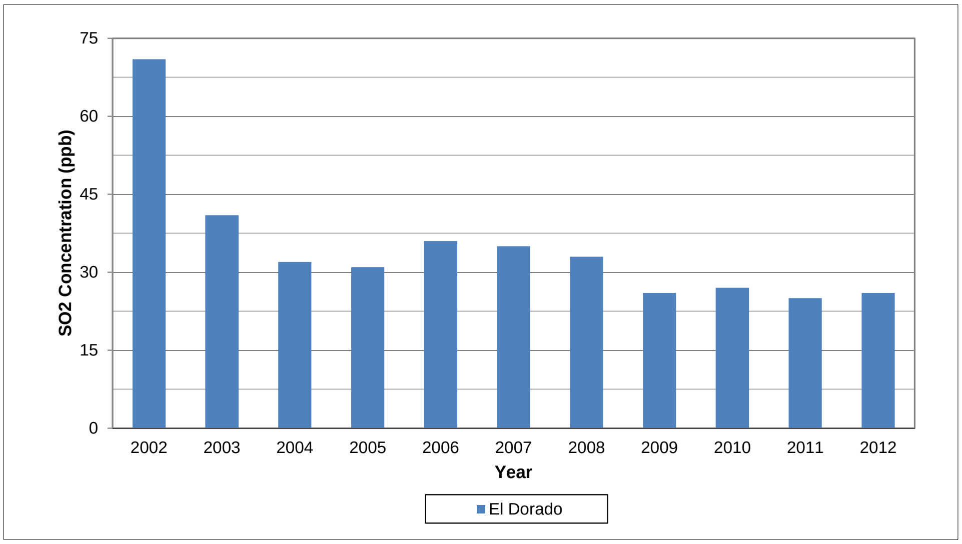
Site Name	ID	County	2008–2010 1-Hour SO_2 Design Value (ppb)	2009–2011 1-Hour SO_2 Design Value (ppb)	2010–2012 1-Hour SO_2 Design Value (ppb)
North Little Rock (Pike Ave)	051190007	Pulaski	14	12	9
El Dorado	051390006	Union	27	25	26

The SO_2 design values are higher for the El Dorado site, compared to the Little Rock site, but much less than 75 ppb for both sites and all three periods. The corresponding 99^{th} percentile values for each component year are also less than 75 ppb.

Figure 2-7 displays the 1-hour SO_2 design values.

Figure 2-7. 1-Hour SO_2 Design Values (ppb) for Monitoring Sites within Arkansas





Note: The NAAQS for 1-hour SO_2 concentration is 75 ppb.

The design values displayed in Figure 2-7 are based on three years of data. For Little Rock, the data indicate a relatively flat tendency between 2004 and 2012. The data for El Dorado show a large drop between 2002 and 2003, followed by a more gradual (and uneven) decrease from 2003 to 2012.

2.1.5 Visibility

Visibility impairment or light extinction can result from the scattering and/or absorption of light by particles in the atmosphere. Coarse and fine particles from both natural and anthropogenic sources can contribute to light extinction. High humidity conditions can also contribute to light extinction and reduced visibility. Visibility is sometimes expressed in terms of deciview units, which vary approximately in proportion to the human response to visibility change. Higher deciview (dv) values correspond to poorer visibility (and a lower visual range).

In 1999, the U.S. EPA promulgated regional haze regulations to prevent “any future, and remedy any existing, impairment of visibility” at 156 designated Class I areas (national parks greater than 6000 acres and wilderness areas greater than 5000 acres). The regional haze rule calls for states to establish “reasonable progress goals” for each Class I area to improve visibility on the 20 percent haziest days and to prevent visibility degradation on the 20 percent clearest days. The national goal is to return visibility to natural background levels by 2064. Using the period 2000 to 2004 as the baseline period, states are to evaluate progress in improving visibility by 2018 and every ten years thereafter. State Implementation Plans (SIPs) for the first phase of the regional haze regulation were due in December 2007. Several Regional Planning Organizations (RPOs) have been developing control strategies to guide states in meeting the regional haze goals.

There are two Class I areas in Arkansas. These are Caney Creek Wilderness and Upper Buffalo Wilderness. Visibility is monitored at these sites as part of the IMPROVE monitoring network. Table 2-6 lists the average visibility (deciviews) for the 20 percent worst visibility days for the periods 2002–2006, 2005–2009, and 2008–2012 for both areas. Deciviews (DV) corresponding to the 2018 goal and estimated natural conditions (EPA, 2003) are also provided.

Table 2-6. Average Visibility for the 20 Percent Worst Days for Class I Areas in Arkansas Based on Data for 2002 through 2012

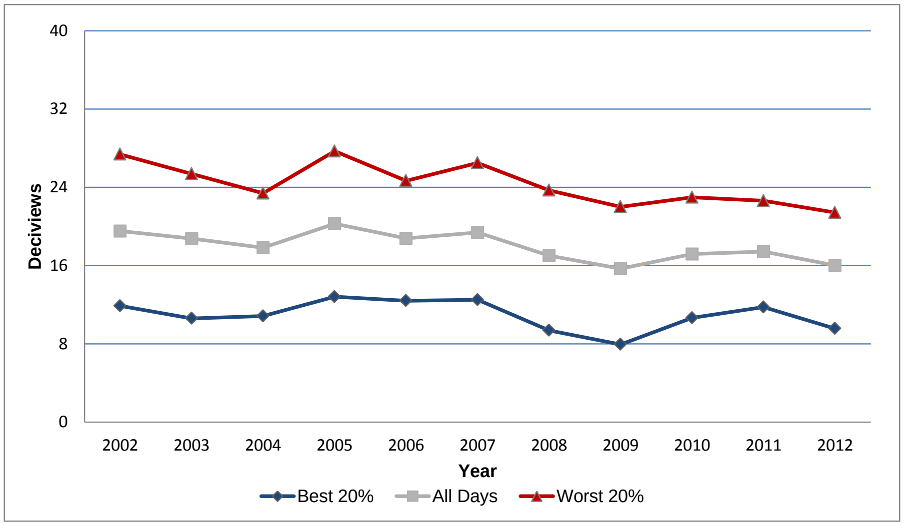
Site Name	ID	County	2002–2006 Average Visibility for 20% Worst Days (dv)	2005–2009 Average Visibility for 20% Worst Days (dv)	2008–2012 Average Visibility for 20% Worst Days (dv)	2018 Glidepath Goal (dv)	Estimated Natural Conditions (dv)
Caney Creek Wilderness	CACR1	Newton	25.7	24.9	22.5	22.9	11.3
Upper Buffalo Wilderness	UPBU1	Union	25.4	24.5	22.9	22.8	11.3

The IMPROVE data indicate that the 2018 goals have been met or nearly met in 2012 and that continued improvement in visibility is needed to achieve the natural condition goals for both areas. As noted above, some measures to reduce regional haze and improve visibility at these and other Class I areas may be under consideration (or being implemented), based on the work conducted by the RPOs.

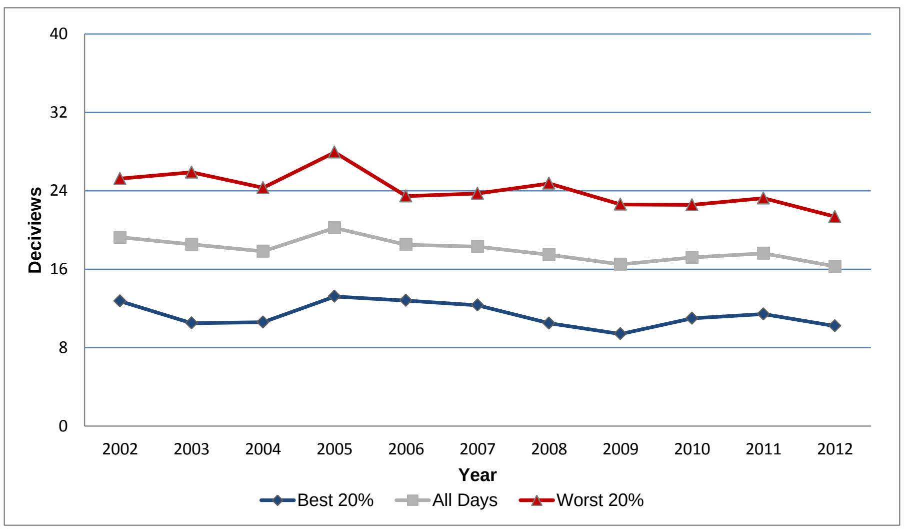
Figure 2-8 displays annual average visibility in deciviews for the 20 percent best days, 20 percent worst days, and all days for each year during the period 2002-2012 for the two IMPROVE sites.

Figure 2-8. Annual Average Visibility (Deciviews) for IMPROVE Monitoring Sites within Arkansas

Caney Creek Wilderness



Upper Buffalo Wilderness



The data for both sites show a slight downward trend (toward improved visibility) for all three categories of days.

2.2 Representativeness of the Simulation Periods

The modeling analysis includes two base years, 2005 and 2008. The meteorological conditions that characterize these two years are representative of the eleven year period from 2002 through 2012. Table 2-7 summarizes the meteorological conditions including temperature, precipitation, and wind information that characterize the Little Rock area, based on meteorological data from the local National Weather Service (NWS) monitoring site for the two years and the multi-year period.

Table 2-7. Summary Meteorological Data for Little Rock for 2005, 2008 and 2002-2012

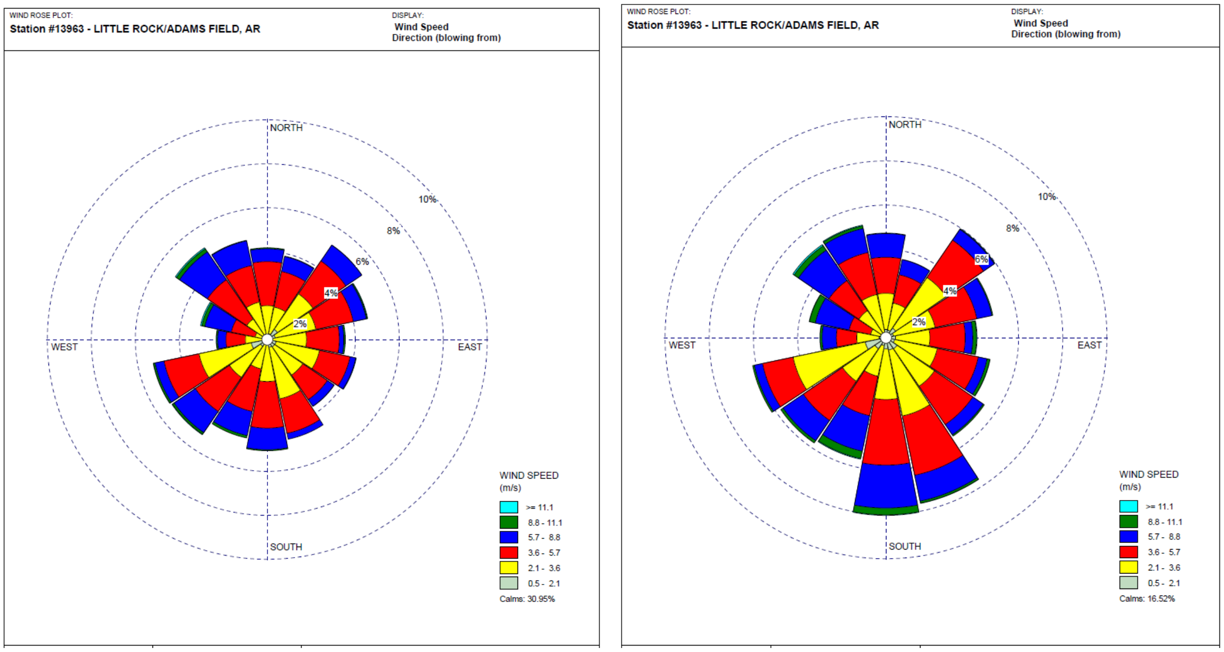
Metric	2005	2008	2002–2012
Mean annual temperature (degrees Fahrenheit)	64.2	62.1	63.4
Mean annual precipitation (inches)	34.6	58.2	49.8
Mean annual wind speed (meters per second)	2.7	3.4	3.1
Prevailing surface wind direction (indicates direction from which the winds are blowing from)	SW	SSW	S

Temperatures were slightly higher than average for 2005 and slightly lower than average for 2008. The total amount of precipitation was lower than average for 2005 and higher than average for 2008. Overall, 2005 was a warmer, dryer year and 2008 was a cooler, wetter year compared to the 2002-2012 multi-year period. Average surface wind speeds were lower than average for 2005 and higher than average for 2008. Predominant wind directions for both 2005 and 2008 include a westerly component and differ slightly from the predominant southerly wind direction that characterizes the multi-year period.

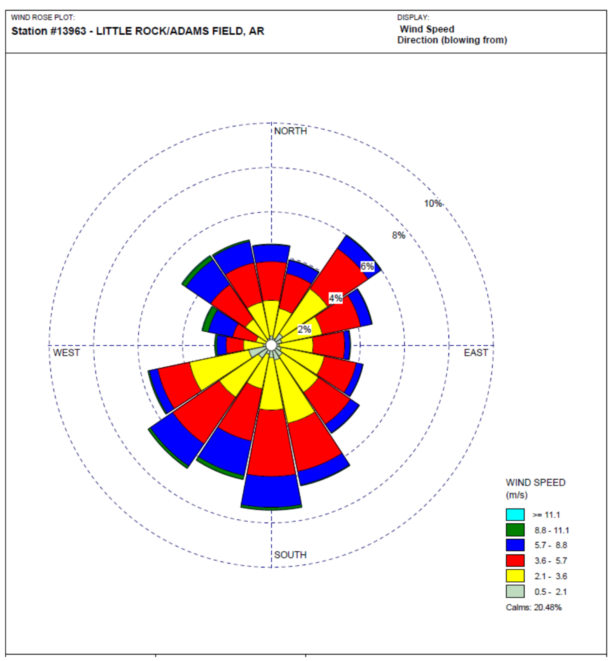
Figure 2-9 illustrates the frequency of observed surface wind speed and wind direction for the Little Rock NWS site for the two years and the multi-year period. In the wind rose diagrams, wind direction is defined as the direction from which the wind is blowing. The length of the bar within that wind-direction sector indicates the frequency of occurrence of a particular wind direction. The shading indicates the distribution of wind speeds.

Figure 2-9. Frequency of Surface Wind Speed and Wind Direction for Little Rock, Arkansas

2005/2008



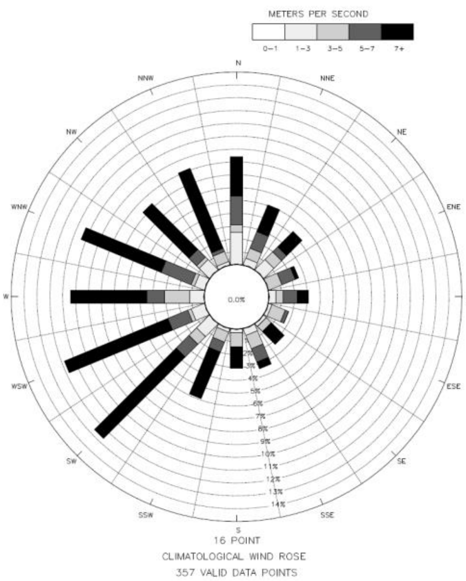
2002-2012

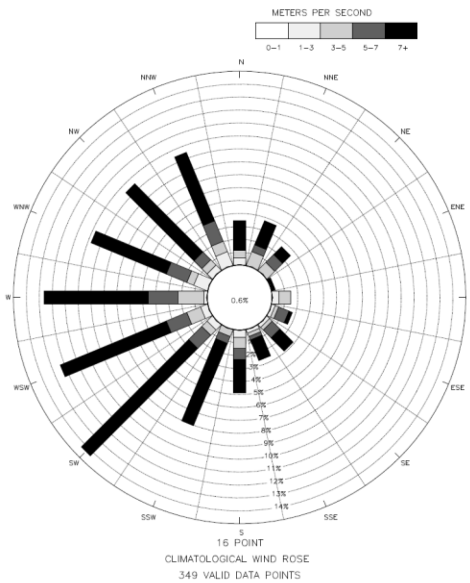


Surface wind directions for both years capture the range of wind directions observed during the full 2002-2012 period. Surface winds for 2005 are characterized by lower wind speeds, a greater incidence of calm winds, and less frequent southerly winds than the full 2002-2012 period. Surface winds for 2008 are characterized by higher wind speeds (and fewer calm periods) than the full period.

Figure 2-10 compares the frequency of observed upper-air wind directions and speeds for the two years and the multi-year period. The upper-air data are for the Little Rock upper-air monitoring site, and are available twice per day, at approximately 0600 and 1800 LST. The plots show data for 850 mb, which is approximately 1500 m above ground level (agl). The upper-air wind data are used here to obtain information about the regional-scale wind directions.

Figure 2-10a. Frequency of 850 mb Wind Speed and Wind Direction for Little Rock, Arkansas: 0600 CST 2005/2008





2002–2012

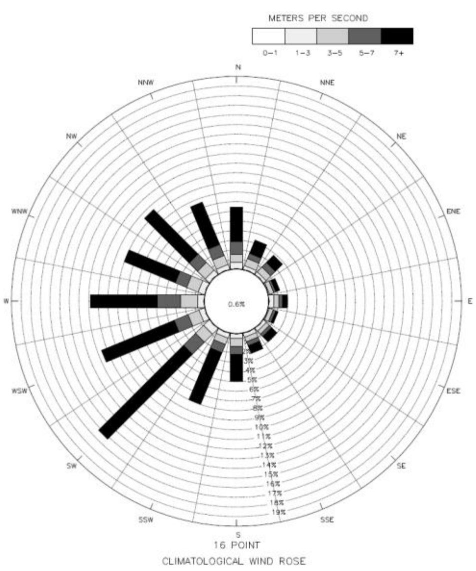
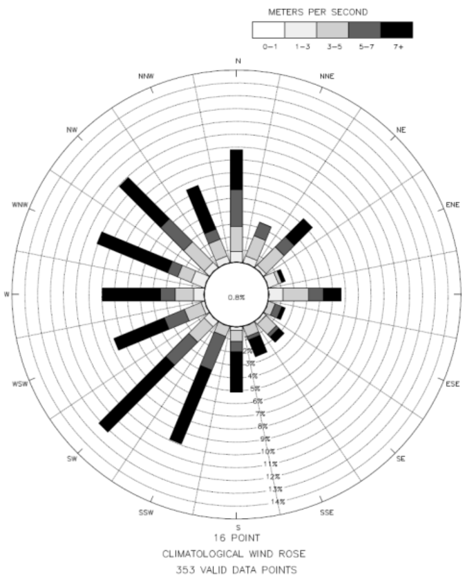
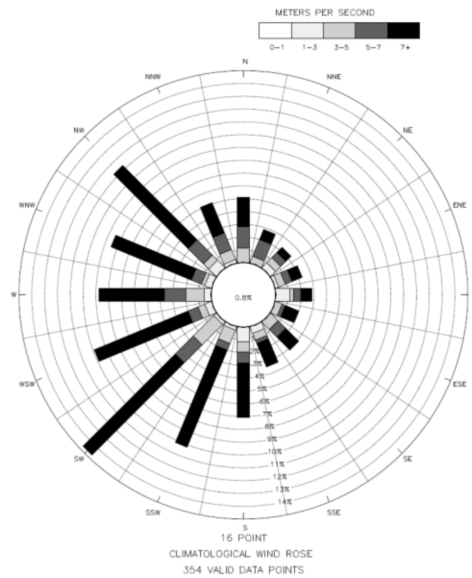
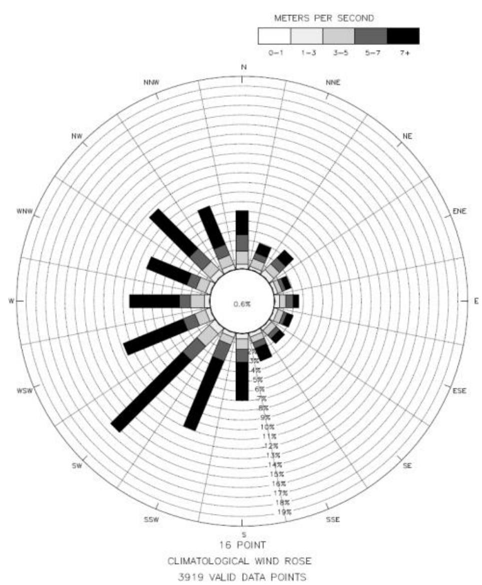


Figure 2-10b. Frequency of 850 mb Wind Speed and Wind Direction for Little Rock, Arkansas: 1800 CST 2005/2008





2002-2012



The upper-air wind directions for both 2005 and 2008 are characterized by a greater frequency of winds from the north and the east, compared to the multi-year period. However, the predominant wind directions (southwesterly to northwesterly) are well represented.

The air quality concentrations that characterize the two modeled years appear to span the range of concentrations measured during the eleven year period from 2002 through 2012. Key air quality metrics for ozone, $PM_{2.5}$, NO_2, and SO_2 for 2005, 2008 and the multi-year period are summarized and compared in Table 2-8. The summary focuses on Little Rock, using data from the Pike Avenue site. The reader is referred to Section 2.2 for information on other monitoring sites.

Table 2-8. Key Air Quality Metrics for the North Little Rock (Pike Ave) Monitoring Site for 2005, 2008 and 2002-2012

Metric	2005	2008	2002–2012 Min/Max/Average		
Ozone					
4th Highest 8-Hour Ozone Concentration (ppb)	86	67	67	86	76
Number of Days with Daily Maximum 8-Hour Ozone Concentrations > 75 ppb	16	0	0	16	4
$PM_{2.5}$					
Annual Average $PM_{2.5}$ Concentration (μg/m^3)	14.7	11.6	10.8	14.7	12.4
98th Percentile 24-Hour $PM_{2.5}$ Concentration (μg/m^3)	39.3	25.6	22.2	39.3	27.1
NO_2					
Annual Average NO_2 Concentration (μg/m^3)	22.6	16.9	16.9	28.2	21.7
98th Percentile 1-Hour NO_2 Concentration (μg/m^3)	101.5	75.2	75.2	116.6	94.6
SO_2					
99th Percentile 1-Hour SO_2 Concentration (μg/m^3)	21.0	36.0	21.0	52.4	31.4

The year 2005 includes the highest overall concentrations for ozone and $PM_{2.5}$, above average concentrations for NO_2, and the lowest overall concentrations for SO_2. The year 2008 includes the lowest overall concentrations for ozone and NO_2, below average (close to median value) concentrations for $PM_{2.5}$, and above average concentrations for SO_2. Together 2005 and 2008 appear to capture both best and worst case air quality conditions for Little Rock, especially for ozone and $PM_{2.5}$.

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3 Air Quality Modeling Methodology

Air quality modeling was used to identify areas with potential ozone, $PM_{2.5}$, SO_2, and NO_2 issues throughout the state, examine the expected changes in these pollutants between the base and future years, and identify areas within the state where additional air quality monitoring may be used to ensure NAAQS compliance. Key components of this modeling analysis included:

- Emission inventory preparation,
- Base-year air quality model application and evaluation (2005 and 2008)
- Future-year air quality model application and assessment (2015).

The primary tools that were used for this assessment include:

- Sparse-Matrix Operator Kernel Emissions (SMOKE) processing tool (version 3.1) for the preparation of model-ready emissions;
- Community Multiscale Air Quality (CMAQ) model (version 5.0) for quantifying the air quality changes for the different scenarios;
- Atmospheric Model Evaluation Tool (AMET) to evaluate the CMAQ modeling results; and
- Modeled Attainment Test Software (MATS) to assess future-year air quality.

These tools are widely used by EPA and others for conducting air quality analysis.

The air quality modeling included an assessment of “current” conditions for two recent historical periods (2005 and 2008). Air quality was then evaluated for the selected future year (2015) by applying the modeling systems using the historical meteorological inputs and estimated emissions for 2015.

The air quality modeling methodology is presented in the remainder of this section. The current- and future-year regional modeling analyses were conducted using emissions data available from EPA and the Arkansas DEQ. Detailed information on the emissions is provided in Section 4 of this document.

3.1 Overview of the CMAQ Modeling System

Version 5.0 of the CMAQ model was used for the statewide modeling analysis. The CMAQ model is a state-of-the-science, regional air quality modeling system that can be used to simulate the physical and chemical processes that govern the formation, transport, and deposition of gaseous and particulate species in the atmosphere (Byun and Ching 1999). The CMAQ tool was designed to improve the understanding of air quality issues (including the physical and chemical processes that influence air quality) and to support the development of effective emission control strategies on both the regional and local scales. The CMAQ model was designed as a “one-atmosphere” model. This concept refers to the ability of the model to dynamically simulate ozone, particulate matter, and other species (such as mercury) in a single simulation. In addition to addressing a variety of pollutants, CMAQ can be applied to a variety of regions (with varying geographical, land-use, and emissions characteristics) and for a range of space and time scales. The latest version of CMAQ includes state-of-the-science advection, dispersion and deposition algorithms, the latest version of the Carbon Bond (CB) chemical mechanism (CB05), and diagnostic tools for assessing source apportionment.

Numerous recent applications of the model, for both research and regulatory air quality planning purposes, have focused on the simulation of ozone and fine particulate matter ($PM_{2.5}$). The CMAQ model was used by EPA to support the development of the Clean Air Interstate Rule (CAIR) (EPA, 2005). It was also used by EPA to support the second prospective analysis of the costs and benefits of the Clean Air Act (CAA) (Douglas et al., 2008) and by ADEQ to support the re-establishment of an Economic Development Zone (EDZ) for Crittenden County (ICF, 2013).

The CMAQ model numerically simulates the physical processes that determine the magnitude, temporal variation, and spatial distribution of the concentrations of ozone and particulate species in the atmosphere and the amount, timing, and distribution of their deposition to the earth's surface. The simulation processes include advection, dispersion (or turbulent mixing), chemical transformation, cloud processes, and wet and dry deposition. The CMAQ science algorithms are described in detail by Byun and Ching (1999).

The CMAQ model requires several different types of input files. Gridded, hourly emission inventories characterize the release of anthropogenic, biogenic, and, in some cases, geogenic emissions from sources within the modeling domain. The emissions represent both low-level and elevated sources and a variety of source categories (including, for example, point, on-road mobile, non-road mobile, area, and biogenic). The amount and spatial and temporal distribution of each emitted pollutant or precursor species are key determinants to the resultant simulated air quality values.

The CMAQ model also requires hourly, gridded input fields of several meteorological parameters including wind, temperature, mixing ratio, pressure, solar radiation, fractional cloud cover, cloud depth, and precipitation. A full list of the meteorological input parameters is provided in Byun and Ching (1999). The meteorological input fields are typically prepared using a data-assimilating prognostic meteorological model, the output of which is processed for input to the CMAQ model using the Meteorology-Chemistry Interface Processor (MCIP). The prescribed meteorological conditions influence the transport, vertical mixing, and resulting distribution of the simulated pollutant concentrations. Certain of the meteorological parameters, such as mixing ratio, can also influence the simulated chemical reaction rates. Rainfall and near-surface meteorological characteristics govern the wet and dry deposition, respectively, of the simulated atmospheric constituents.

Initial and boundary condition (IC/BC) files provide information on pollutant concentrations throughout the domain for the first hour of the first day of the 10-day spin-up period for the simulation, and along the lateral boundaries of the domain for each hour of the simulation. Photolysis rates and other chemistry-related input files supply information needed by the gas-phase and particulate chemistry algorithms.

3.2 CMAQ Application Procedures for the Statewide Modeling Analysis

The CMAQ model was used in this study to examine future-year air quality throughout the State of Arkansas. The air quality modeling methodology is presented in this section.

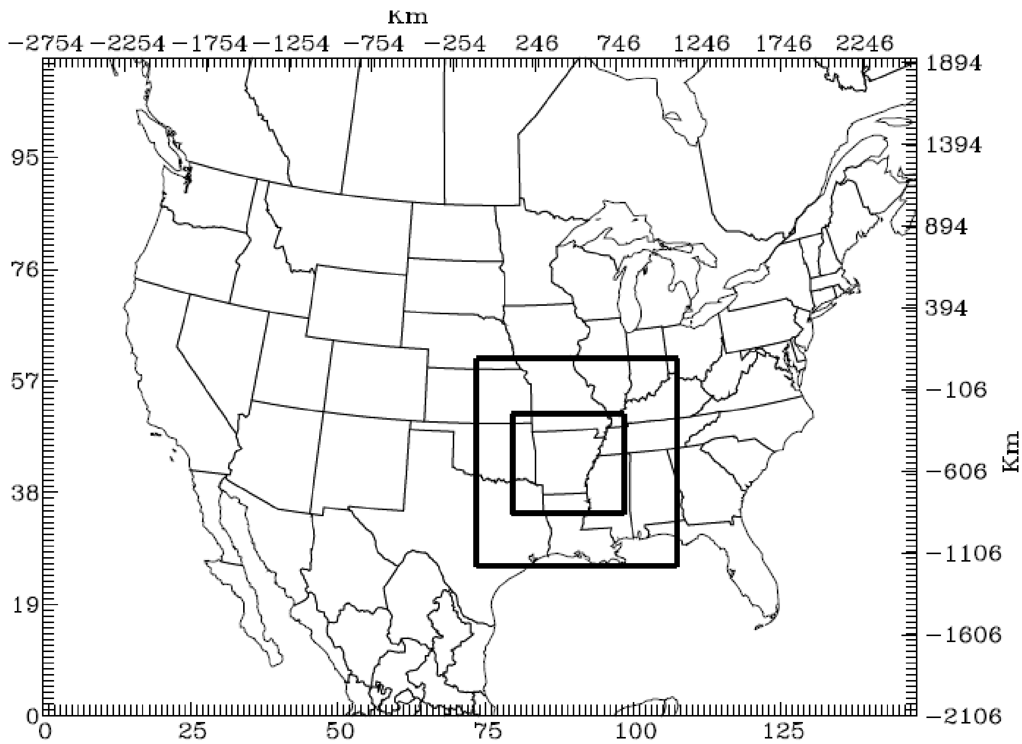
3.3 Modeling Domain

The modeling domain for application of the CMAQ model is presented in Figure 3-1and includes a 36-km resolution outer grid encompassing the continental U.S.; a 12-km resolution intermediate grid; and a 4-km resolution inner grid encompassing Arkansas.

The regional extent of the modeling domain is intended to provide realistic boundary conditions for the area of interest and thus avoid some of the uncertainty introduced in the modeling results through the incomplete and sometimes arbitrary specification of boundary conditions. The use of 4-km grid resolution is consistent with an urban-scale analysis.

The CMAQ domain is further defined by fourteen vertical layers.

Figure 3-1. CMAQ Modeling Domain for the Arkansas Statewide Criteria Pollutant Air Quality Modeling Analysis



3.4 Simulation Period

The two annual simulation periods are 2005 and 2008. These periods were selected due to the availability of emission data and gridded meteorological inputs from EPA.

In running the model, the simulation periods were divided into two parts covering January through June and July through December, respectively. Each part of each simulation also included an additional five start-up simulation days, which were intended to reduce the influence of uncertainties in the initial conditions on the simulation results.

3.5 Modeling Databases

As discussed in the following section, the input files for the application of the CMAQ model were prepared using data and modeling databases obtained from EPA.

3.6 Input Preparation

3.6.1 Emission Inputs

This section summarizes the data, methods, and procedures followed in preparing modeling emission inventories for use in the air quality modeling analysis. Five core regional-scale emission inventories were prepared as part of this study, including a 2005 base-year emission inventory, a 2008 base-year emission inventory, a 2008 current-year inventory, a 2015 future-year baseline emission inventory using 2005 meteorological conditions, and a 2015 future-year baseline inventory using 2008 meteorological conditions. The resulting emissions are presented and summarized in Section 4.

Emissions Data

The CMAQ model requires as input, hourly, gridded criteria pollutant emissions of both anthropogenic and biogenic sources that have been spatially allocated to the appropriate grid cells and chemically speciated for the applicable chemical mechanism used in the model. The modeling inventories were processed and prepared for CMAQ using EPA's Sparse-Matrix Operator Kernel Emissions (SMOKE) software (Version 3.1), with the inline emissions feature.

The 2005 and 2008 base-year emission inventories were prepared based on EPA's National Emission Inventory (NEI), specifically Version 4.2 of the 2005-based modeling platform (EPA, 2005) and EPA's 2008-based platform (2007v5) (EPA, 2012). The NEI includes emission data for the following sectors:

- Electric Generating Unit (EGU) point sources
- Other point sources (non-EGU point)
- Non-point (area) sources
- On-road motor vehicles
- Non-road motor vehicles
- Average-year wildfires and prescribed fires
- Fugitive dust
- Agriculture
- Locomotives and commercial marine except for Category 3 commercial marine vessels
- Category 3 commercial marine vessels
- Canadian, Mexican and offshore emissions for point, non-point and on-road sectors
- Biogenic sources

- Oceanic gaseous chlorine emissions

The SMOKE input files for 2005 and 2008 were obtained from the EPA ftp site.

The gridded surrogates used for spatially allocating anthropogenic emissions and land-use data for preparation of the biogenic emissions for the 12-km grid were extracted from the EPA platform database and the corresponding 12-km grid covering the eastern U.S. The gridded surrogates for the 4-km grid were prepared using the EPA SRGTOOLS and associated database. Land-use data for preparation of the biogenic emissions for the 4-km grid were prepared based on the BELD3 database.

The modeling inventories include the following pollutants: volatile organic compounds (VOC), oxides of nitrogen (NO_x), carbon monoxide (CO), sulfur dioxide (SO_2), fine particulates ($PM_{2.5}$), coarse particulates (PM_{10}), and ammonia (NH_3).

The future-year baseline emission inventories were prepared based on Version 4.2 of the 2005 modeling platform, projected to 2014 (EPA, 2005). The 2014 emissions were used to represent 2015 and no further projection of the emissions was done. The projected EGU emissions were not adjusted for the Cross-State Air Pollution Rule (CSAPR), as this rule was “vacated” in August 2012. Instead, the EGU emissions are consistent with the original Clean Air Interstate Rule (CAIR). In addition, emissions for a new EGU facility (American Electric Power (AEP) Service Corporation’s John W. Turk, Jr. facility) located in southwestern Arkansas were added to the future-year baseline inventory. These data were provided by ADEQ (2012).

Emissions Inventory Preparation Methodology

As noted above, SMOKE version 3.1 was utilized to process the emissions and prepare CMAQ-ready inputs for the base-year (2005 and 2008) and 2015 future-year baseline using source sector files obtained from EPA and updated EGU emissions provided by ADEQ. Emission files were prepared for the 36-, 12- and 4-km resolution grids used in the modeling analysis, and included processing of all source sectors using various SMOKE programs and inputs, and review and quality assurance checks.

The general procedures followed in preparing the modeling inventories, using various programs included with SMOKE, were the following:

- Perform chemical speciation to transform input criteria pollutants into the CB-05 chemical mechanism species, as required by CMAQ.
- Perform temporal distribution to distribute the input annual/monthly emissions into hourly emissions.
- Perform spatial distribution of input emissions to the 36-, 12- and 4-km resolution modeling grids.
- Merge emissions from all source categories into the CMAQ model-ready files.

Quality Assurance Procedures

The emissions inventory processing quality assurance (QA) procedures included the preparation and examination of tabular emissions summaries and graphical display products.

Tabular summaries were used to examine emissions totals for various steps of the emissions processing. Summaries for input emissions are based on the input inventory data: monthly emissions for the on-road and non-road sectors, and annual emissions for other sectors for criteria pollutants. Summaries for the emissions are based on the SMOKE output reports which include daily emissions for each CB-05 species for each sector. The output daily emissions are summed over all days in the year and the CB-05 species are summed for the criteria pollutants. The emissions summaries were made for each scenario by state and sector, and comparisons were made between the input emissions and output emissions for each sector to assure consistency.

In addition to the tabular summaries, various graphical displays were prepared for one day of each month to examine the spatial distribution and temporal variation for each sector and the final merged emissions using a graphical plotting package.

3.6.2 Meteorological Inputs

The 36- and 12-km resolution meteorological input files for the 2005 and 2008 annual simulation periods were originally prepared by EPA using the Pennsylvania State University/National Center for Atmospheric Research (PSU/NCAR) Fifth Generation Mesoscale Model (MM5, version 3.7.4) (EPA, 2009). The model was applied for a 36-km resolution grid covering all of the lower 48 states and major portions of Canada and Mexico and for two 12-km resolution grids covering the eastern and western U.S. (EPA 2009). For the performance evaluation, temperature, wind speed, wind direction, and moisture data were obtained from NOAA's Meteorological Assimilation Data Ingest System (MADIS) and rainfall data were obtained from the National Weather Service's Climate Prediction Center.

The MM5 outputs were postprocessed by EPA for input to CMAQ using the MCIP program. The meteorological fields for the 12-km study domain were extracted from the larger 12-km domain for the eastern U.S. used by EPA. The 12-km meteorological inputs were also used as the basis for the 4-km meteorological fields. Interpolation and reanalysis methods were used to adapt the input files to the 4-km grid. The 12-km fields were interpolated to the 4-km grid. For most parameters, objective analysis (based on bi-linear interpolation) was used to combine the interpolated fields with available observations and thus adjust the 12-km fields to the 4-km grid. Certain parameters such as radiation, rainfall, and land-use-based quantities, which are not expected to exhibit smooth variations in space, were not interpolated and the values used for the 4-km sub-cells were the same as for the encompassing 12-km grid cell.

3.6.3 Other Inputs

All other input files for the application of the CMAQ model were obtained from EPA.

3.7 Model Performance Evaluation

An integral component of all modeling studies is the evaluation of model performance for the base-year (or base-case) simulation. For this study, the CMAQ modeling results were compared with observed data, using a variety of graphical and statistical analysis products.

3.7.1 Air Quality Data

Air quality data for the evaluation of model performance were obtained from EPA's Air Quality System (AQS) database. Ozone, PM_{10}, $PM_{2.5}$, NO_2, SO_2 and CO data for all monitoring sites within the 12- and 4-km grids were obtained and processed for use by AMET. The model performance statistics were calculated using a variety of hourly concentrations, daily maximum 1-hour concentrations, daily maximum 8-hour average concentrations, and 24-hour average concentrations. For consistency with the NAAQS, the evaluation focuses on daily maximum 1-hour concentration for NO_2 and SO_2, daily maximum 8-hour average concentration for ozone, and 24-hour average concentration for $PM_{2.5}$.

3.7.2 Model Performance Evaluation Methodology

The overall objective of a model performance evaluation is to establish that the modeling system can be used reliably to predict the effects of changes in emissions on future-year air quality. This was primarily accomplished by comparing the modeling results with observed data, using a variety of graphical and statistical analysis products. EPA guidance (EPA, 2007) stresses the need to evaluate the model relative to how it will be used in the air quality assessment; that is in simulating the response to changes in emissions. To examine the response of the model to differences in the inputs, the ability of the model to simulate month-to-month differences in concentration levels and patterns, the ability of the model to simulate the concentrations (or at least the frequency distribution of concentrations) associated with different types of meteorological conditions; and the ability of the model to perform consistently and reasonably across a range of concentrations were also examined.

The evaluation focused on the 12- and 4-km resolution grids. Analysis of results for the 12-km resolution grid emphasized representation of the regional-scale concentration levels and patterns, as well as month-to-month variations in regional-scale ozone air quality. A more detailed analysis of the results was performed for the innermost, high-resolution (4-km) grid. This included the analysis of the magnitude and timing of site-specific concentrations and a statistical evaluation. Statistical model performance evaluation focused on ozone, $PM_{2.5}$, NO_2 and SO_2 and statistics were calculated using hourly concentrations, daily maximum 1-hour concentrations, daily maximum 8-hour average concentrations, and 24-hour average concentrations, as appropriate. For extraction of the model output and matching with the station values, concentration information was taken from the grid cell in which the monitoring site is located.

Graphical Analysis to Support Model Performance Evaluation

AMET generates a wide variety of graphical analysis products to facilitate the evaluation of CMAQ model performance. Plots and graphics were used to assess the reasonableness of the results. The graphical analysis included the following:

- Spatial plots of the simulated values were used to qualitatively assess the ability of the model to provide reasonable concentration patterns, consistent with the emissions and seasonal and day-to-day variations in meteorology.
- Bias and error plots were used to graphically display statistical measures of model performance and to identify any spatial patterns or trends in the model performance statistics.

- Concentration time-series plots comparing simulated and observed values at selected monitoring sites were used to determine whether the timing and magnitude of the simulated values match the observations.
- Scatter plots were used to graphically compare the simulated and observed concentrations.

Statistical Analysis to Support Model Performance Evaluation

AMET also calculates a variety of statistical measures to facilitate the evaluation of CMAQ model performance. Table 3-1 summarizes key statistical measures that were used to provide insight into model performance.

Table 3-1. Statistical Measures Used for the CMAQ Model Performance Evaluation for the Statewide Modeling Analysis

Metric	Definition
# of data pairs	The number of observation/simulation data pairs
Mean observation value	The average observed concentration
Mean simulation value	The average simulated concentration
Mean bias	$\left(\frac{1}{N}\right)\sum_{l=1}^{N}(S_l - O_l)$ where N is the number of data pairs, and S_l and O_l are the simulated and observed values at site l, respectively, over a given time interval.
Normalized bias	$\left(\frac{1}{N}\right)\sum_{l=1}^{N}(S_l - O_l)/O_l \cdot 100\%$
Normalized mean bias	$\sum_{l=1}^{N}(S_l - O_l)/ \sum_{l=1}^{N}O_l \cdot 100\%$
Fractional bias	$\left(\frac{1}{N}\right)\sum_{l=1}^{N}(S_l - O_l)/0.5(S_l + O_l)\cdot 100\%$
Mean error	$\left(\frac{1}{N}\right)\sum_{l=1}^{N}\lvert S_l - O_l\rvert$
Normalized error	$\left(\frac{1}{N}\right)\sum_{l=1}^{N}\lvert S_l - O_l\rvert/O_l \cdot 100\%$
Normalized mean error	$\sum_{l=1}^{N}\lvert S_l - O_l\rvert \Big/ \sum_{l=1}^{N}O_l \cdot 100\%$
Fractional error	$\left(\frac{1}{N}\right)\sum_{l=1}^{N}\lvert S_l - O_l\rvert/0.5(S_l + O_l)\cdot 100\%$
Correlation	$\left(N\left(\sum SO\right) - \left(\sum S\right)\left(\sum O\right)\right) \Big/ \sqrt{\left(N\sum S^2 - \left(\sum S\right)^2\right)\left(N\sum O^2 - \left(\sum O\right)^2\right)}$
Index of agreement	A measure of how well the model represents the pattern of perturbation about the mean value; ranges from 0 to 1.

In calculating the statistical measures, AMET pairs the CMAQ model output with the observed data for the appropriate locations and time intervals.

Model Performance Criteria

In keeping with current EPA guidance on model performance evaluation for ozone, a “weight-of-evidence” approach was employed to determine whether model performance is good enough for use in future-year modeling and air quality assessment. In other words, an integrated assessment of the above information was used to document and qualitatively and quantitatively assess whether an acceptable base-case simulation has been achieved.

To the extent practicable, the statistical measures for certain of the pollutants were compared with model performance goals and criteria used for prior studies, as suggested in EPA guidance (EPA, 2007). For ozone, these include recommended ranges for the normalized bias and normalized error from prior (ca. 1990) EPA guidance (these are still widely used for urban- and regional-scale model performance evaluation).

3.7.3 Criteria Pollutant Assessment

The key objectives of this modeling study were to identify potential ozone, $PM_{2.5}$, SO_2, and NO_2 issues throughout the State of Arkansas, examine the expected changes in these pollutants between the base and future years, and identify areas within the state where additional air quality monitoring may be used to ensure compliance with existing NAAQS.

This was accomplished by first examining the changes in simulated concentration between the future year and base or current year in order to examine the magnitude and extent of the simulated decreases in concentration and to identify any areas with increases in concentration. The difference plots reference the form of the standard and averaging period(s) (e.g., 1-hour NO_2 and SO_2, 8-hour average ozone, and 24-hour and annual average $PM_{2.5}$) appropriate for each pollutant. Tabular summaries of the concentrations and differences for monitoring sites and any grid locations with an increase in concentration of any of the pollutants between the base and future years were also prepared.

Note that, for consistency with the 2015 emissions, the 2008 simulation was first rerun with “current-year” emissions, in which the anthropogenic emissions were consistent with 2005 and 2015 in terms of methodology, but the biogenic emissions were consistent with the 2008 meteorological conditions. The “current year” modeling results were used as the basis for the criteria pollutant assessment for 2008.

Next, the procedures outlined in EPA guidance on the use of models for attainment demonstration purposes (EPA, 2007) were applied. The guidance specifically addresses ozone and $PM_{2.5}$, but the same procedures were applied for all of the criteria pollutants considered in the analysis. This methodology is based on relative (rather than absolute) use of the modeling results, and relies on the ability of the air quality modeling system to simulate the change in concentration due to changes in emissions, but not necessarily its ability to simulate exact values for future-year concentrations. For each air quality metric, a future-year estimated design value (FDV) is calculated using the “current-year” design value and the future-year and base-year modeling results.

The current-year design value for each pollutant and monitoring site within Arkansas was calculated in accordance with the form of the standard for that pollutant. For this analysis (which is not an attainment demonstration) the current-year design values were based on data for 2005 through 2008. This was done to represent the emissions base year (2005), the meteorological base years (2005 and 2008), and to allow a direct comparison of the projected future-year design values for the two simulation pairs. Calculation of the current year design values differs among the pollutants and the procedures outlined in the guidance document were followed. Additional detail for each pollutant is provided in Section 6.

The current-year design value for each site was then multiplied by a relative response factor (RRF), which is defined as ratio of the future-year to base-year simulated concentration in the vicinity of the monitoring site. The resulting value is referred to as the future-year design value or FDV. The methodology has additional layers of complexity for multi-species pollutants such as $PM_{2.5}$; these are carefully outlined in the guidance document and were accounted for this in this analysis. The resulting values were compared with the NAAQS. The analysis was conducted for both base-year/future-year simulation pairs. For ozone and $PM_{2.5}$, the MATS software was used to estimate the FDVs for 2015. For NO_2 and SO_2, which are not accommodated in MATS, the same procedures were applied using custom software. Tabular summaries comparing the DVs and FDVs and assessing compliance relative to the NAAQS were prepared.

This analysis also examined future-year attainment for locations without monitoring sites. The current-year design value for the unmonitored area was set equal to the value for the nearest monitoring site or to an interpolated value based on several neighboring sites. Additional detail for each site and pollutant is provided in Section 6.

4 Emission Inventories

The modeling emission inventories for the base-year (2005 and 2008) and future-year baseline (2015) are summarized in this section.

Tables 4-1 through 4-4 summarize the base-year (2005 and 2008) and future-year (2015) emissions used for the CMAQ modeling. These tables summarize anthropogenic emissions by source sector and pollutant for the 36-km grid, the 12-km grid, the 4-km grid, and the State of Arkansas. Emissions totals are provided for the following species: VOC, NO_x, SO_2, CO, and $PM_{2.5}$. The units are thousand tons per year (thousand tpy).

Table 4-1. Base-Year (2005 and 2008) and Future-Year Baseline (2015) Emissions for the Arkansas Statewide Criteria Pollutant Modeling Analysis: 36-km Grid

Source Sector	2005 Base Year				
	VOC (thousand tpy)	NO_x (thousand tpy)	SO_2 (thousand tpy)	CO (thousand tpy)	$PM_{2.5}$ (thousand tpy)
EGU Point	45	3,726	10,372	603	496
Non-EGU Point	1,292	2,218	2,077	3,209	431
Non-Point (Area)	8,959	1,885	1,248	16,054	2,793
Non-Road	3,497	3,881	420	19,979	253
On-Road Mobile	6,144	8,841	172	43,350	297
Total	19,938	20,552	14,289	83,195	4,270

Source Sector	2008 Base Year				
	VOC (thousand tpy)	NO_x (thousand tpy)	SO_2 (thousand tpy)	CO (thousand tpy)	$PM_{2.5}$ (thousand tpy)
EGU Point	42	3,363	9,152	705	330
Non-EGU Point	1,048	2,078	1,589	2,940	410
Non-Point (Area)	8,638	1,453	524	20,310	2,659
Non-Road	2,494	3,349	256	18,046	232
On-Road Mobile	3,202	7,430	39	37,278	283
Total	15,424	17,672	11,559	79,279	3,915

Source Sector	2015 Future-Year Baseline				
	VOC (thousand tpy)	NO_x (thousand tpy)	SO_2 (thousand tpy)	CO (thousand tpy)	$PM_{2.5}$ (thousand tpy)
EGU Point	45	2,089	7,155	717	423
Non-EGU Point	1,152	2,014	1,639	3,025	409
Non-Point (Area)	8,506	1,818	1,157	15,637	2,745
Non-Road	2,325	2,896	74	14,340	175
On-Road Mobile	2,283	4,808	26	28,133	166
Total	14,311	13,625	10,051	61,852	3,917

Table 4-2. Base-Year (2005 and 2008) and Future-Year Baseline (2015) Emissions for the Arkansas Statewide Criteria Pollutant Modeling Analysis: 12-km Grid

Source Sector	2005 Base Year				
	VOC (thousand tpy)	NO_x (thousand tpy)	SO_2 (thousand tpy)	CO (thousand tpy)	$PM_{2.5}$ (thousand tpy)
EGU Point	18	1,254	3,809	327	158
Non-EGU Point	506	736	717	926	162
Non-Point (Area)	1,919	435	355	3,465	729
Non-Road	694	1,149	107	4,245	65
On-Road Mobile	1,364	2,214	47	9,881	73
Total	4,500	5,788	5,035	18,844	1,186

Source Sector	2008 Base Year				
	VOC (thousand tpy)	NO_x (thousand tpy)	SO_2 (thousand tpy)	CO (thousand tpy)	$PM_{2.5}$ (thousand tpy)
EGU Point	18	1,185	3,422	374	89
Non-EGU Point	390	658	544	781	151
Non-Point (Area)	2,336	408	111	5,171	736
Non-Road	665	867	61	3,917	54
On-Road Mobile	770	1,901	11	8,895	68
Total	4,179	5,019	4,149	19,137	1,098

Source Sector	2015 Future-Year Baseline				
	VOC (thousand tpy)	NO_x (thousand tpy)	SO_2 (thousand tpy)	CO (thousand tpy)	$PM_{2.5}$ (thousand tpy)
EGU Point	17	711	3,387	225	171
Non-EGU Point	458	673	563	885	145
Non-Point (Area)	1,567	367	273	3,009	672
Non-Road	451	863	16	2,881	44
On-Road Mobile	504	1,150	6	6,037	36
Total	2,997	3,764	4,245	13,036	1,078

Table 4-3. Base-Year (2005 and 2008) and Future-Year Baseline (2015) Emissions for the Arkansas Statewide Criteria Pollutant Modeling Analysis: 4-km Grid

Source Sector	2005 Base Year				
	VOC (thousand tpy)	NO_x (thousand tpy)	SO_2 (thousand tpy)	CO (thousand tpy)	$PM_{2.5}$ (thousand tpy)
EGU Point	3	241	499	185	15
Non-EGU Point	116	137	73	196	33
Non-Point (Area)	402	94	61	818	169
Non-Road	156	212	17	792	12
On-Road Mobile	247	403	8	1,845	13
Total	924	1,087	658	3,837	242

Source Sector	2008 Base Year				
	VOC (thousand tpy)	NO_x (thousand tpy)	SO_2 (thousand tpy)	CO (thousand tpy)	$PM_{2.5}$ (thousand tpy)
EGU Point	4	220	471	172	11
Non-EGU Point	80	133	52	146	21
Non-Point (Area)	482	81	25	1,530	197
Non-Road	152	154	7	733	10
On-Road Mobile	148	361	2	1,742	12
Total	866	949	557	4,323	252

Source Sector	2015 Future-Year Baseline				
	VOC (thousand tpy)	NO_x (thousand tpy)	SO_2 (thousand tpy)	CO (thousand tpy)	$PM_{2.5}$ (thousand tpy)
EGU Point	4	169	482	56	17
Non-EGU Point	100	122	67	188	32
Non-Point (Area)	379	90	60	793	166
Non-Road	103	158	1	555	8
On-Road Mobile	92	217	1	1,110	6
Total	679	756	610	2,703	230

Table 4-4. Base-Year (2005 and 2008) and Future-Year Baseline (2015) Emissions for the Arkansas Statewide Criteria Pollutant Modeling Analysis: State of Arkansas

Source Sector	2005 Base Year				
	VOC (thousand tpy)	NO_x (thousand tpy)	SO_2 (thousand tpy)	CO (thousand tpy)	$PM_{2.5}$ (thousand tpy)
EGU Point	0	35	66	4	2
Non-EGU Point	35	36	13	65	11
Non-Point (Area)	125	24	28	298	45
Non-Road	37	63	6	227	4
On-Road Mobile	44	106	2	510	3
Total	242	265	115	1,105	65

Source Sector	2008 Base Year				
	VOC (thousand tpy)	NO_x (thousand tpy)	SO_2 (thousand tpy)	CO (thousand tpy)	$PM_{2.5}$ (thousand tpy)
EGU Point	1	38	72	4	1
Non-EGU Point	27	37	14	40	6
Non-Point (Area)	153	21	5	619	75
Non-Road	35	49	2	208	3
On-Road Mobile	47	94	1	521	3
Total	264	240	95	1,392	89

Source Sector	2015 Future-Year Baseline				
	VOC (thousand tpy)	NO_x (thousand tpy)	SO_2 (thousand tpy)	CO (thousand tpy)	$PM_{2.5}$ (thousand tpy)
EGU Point	1	38	102	13	4
Non-EGU Point	32	32	12	63	11
Non-Point (Area)	120	23	27	296	45
Non-Road	26	45	0	179	3
On-Road Mobile	24	57	0	331	2
Total	202	195	142	882	63

Total base-year (2005 and 2008) and future-year baseline anthropogenic emissions for the 4-km grid and State of Arkansas, excluding CO, are graphically displayed and compared in Figure 4-1 and Figure 4-2, respectively.

Figure 4-1. Base-Year (2005 and 2008) and Future-Year Baseline (2015) Emissions Totals for the Arkansas Statewide Criteria Pollutant Modeling Analysis: 4-km Grid

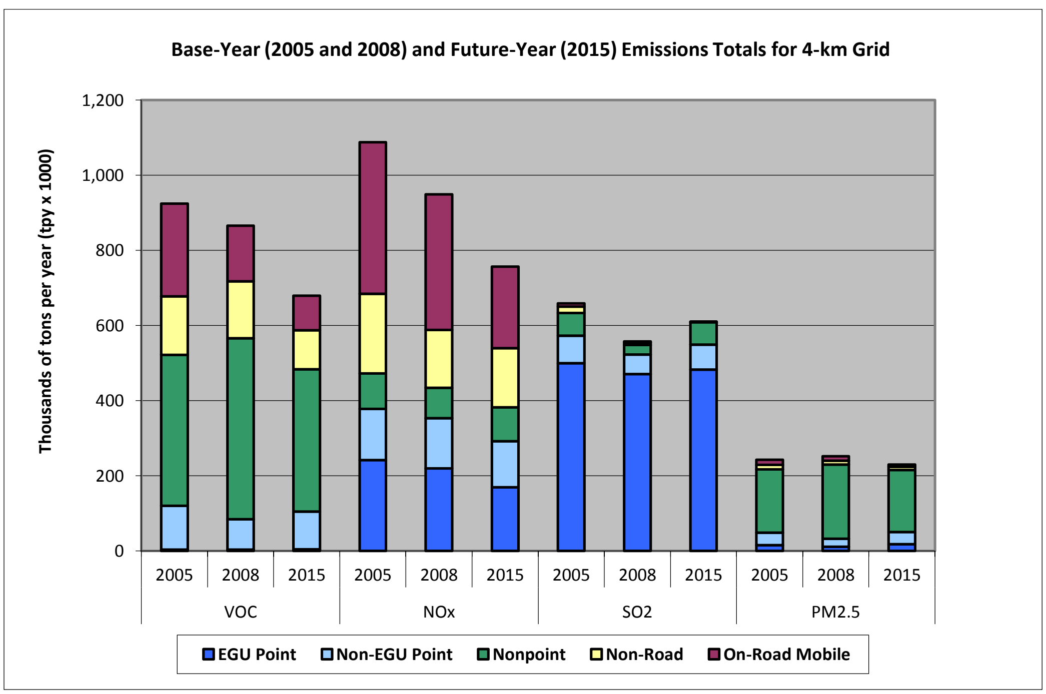
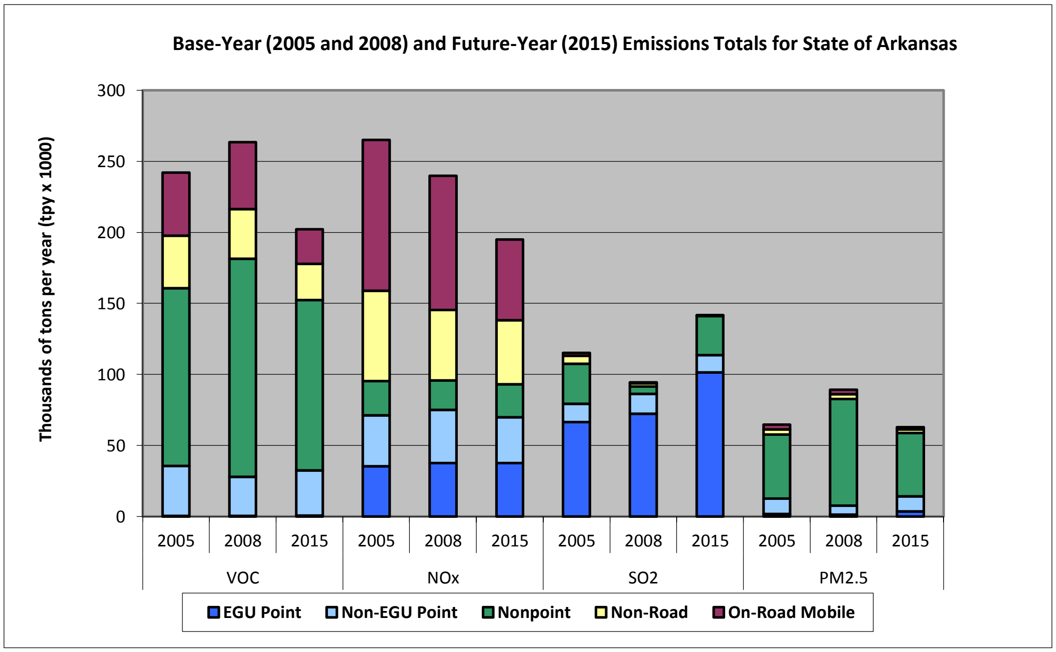


Figure 4-2. Base-Year (2005 and 2008) and Future-Year Baseline (2015) Emissions Totals for the Arkansas Statewide Criteria Pollutant Modeling Analysis: State of Arkansas



For the 4-km grid, overall anthropogenic VOC emissions are 27 percent lower, and both NO_x and CO emissions are 30 percent lower for 2015 compared to 2005. These changes reflect expected future emission reductions due to on-road mobile fleet turnover and the use of cleaner fuels; the introduction and use of cleaner non-road engines, fuel, and other equipment; and the mandated reductions in EGU emissions. For SO_2 in the 4-km grid, the emissions 2015 emissions are slightly lower than the 2005 emissions, but for the State of Arkansas, SO_2 emissions are higher in 2015 compared to 2005, mainly due to large increases in emissions from EGU's. The 2008 reflect some decreases compared to 2005, but also some increases. Note that these are not directly comparable, due to differences in fire emissions (this mostly affects primary $PM_{2.5}$) and other emissions that are affected by meteorology. There are also some methodological changes in the way EPA estimated the emissions between 2005 and 2008. As discussed in Section 6, the 2008 emissions were used for the base-year model performance for that period, but "current-year" emissions, consistent with 2005, were used for the future-year projections.

Table 4-5 presents a summary of EGU emissions for 2005 and 2015 for State of Arkansas sources. The emissions for the large power plants reflect expected growth in electricity demand as well as controls imposed by the CAIR legislation. For example, there are a few new sources that have come on line since 2005 and there are a number of small "generic units" in 2015 that have been added to the Arkansas inventory, reflecting expected future demands in electricity throughout the state. The NO_x emissions for most of the existing sources increase slightly, but there is a decrease in emissions at the Entergy White Bluff plant, likely reflecting CAIR controls. Because Arkansas is identified as one of the states that CAIR imposes NO_x controls only on, to reduce ozone concentrations, no controls are imposed on SO_2 emissions, and there is a significant increase in SO_2 emissions estimated for 2015 for the larger EGU's.

Table 4-5. Base-Year (2005) and Future-Year Baseline (2015) EGU Emissions for the Arkansas Statewide Criteria Pollutant Modeling Analysis: State of Arkansas

County	Facility Name	2005 Base Case				
		VOC (tpy)	NO_x (tpy)	SO_2 (tpy)	CO (tpy)	$PM_{2.5}$ (tpy)
Benton	SWEPCO-Flint Creek Power Plant	63	4,628	8,228	529	253
Craighead	City Water Light Plant City of Jonesboro	7	27	21	11	5
Franklin	Thomas B Fitzhugh Generating Station	8	147	185	48	3
Hempstead	CTI-Arkansas Electric Cooperative	1	5	0	0	0
Hot Spring	KGen-Hot Spring LLC	1	34	1	47	0
Hot Spring	Lake Catherine	8	204	1	29	0
Independence	Entergy Ark-Independence	179	13,174	22,367	1,487	695
Jefferson	Entergy Ark-White Bluff	178	16,263	34,890	1,481	682
Jefferson	Pine Bluff Entergy Center	3	250	4	21	30
Lafayette	Entergy Ark-Couch	3	112	0	40	0
Ouachita	John L McClellan Generating Station	3	212	461	12	1
Phillips	Entergy Ark-Ritchie	0	1	0	1	0
Pulaski	Entergy Ark-Lynch	0	0	0	0	0
Pulaski	Entergy Ark-Mabelvale	0	0	0	0	0
Union	Union Power Station-El Dorado	21	211	6	427	1
Woodruff	Carl Bailey	5	138	220	40	18
Total		**480**	**35,408**	**66,385**	**4,173**	**1,688**

County	Facility Name	2015 Future-Year Baseline				
		VOC (tpy)	NO_x (tpy)	SO_2 (tpy)	CO (tpy)	$PM_{2.5}$ (tpy)
Arkansas	STEC-S LLC	3	96	28	119	4
Benton	Generic Unit	0	1	0	4	0
Benton	SWEPCO-Flint Creek Power Plant	72	5,446	16,287	599	422
Bradley	Potlatch Southern Wood Products	5	138	40	171	6
Clay	Generic Unit	0	1	0	5	0
Clay	Municipal Light	0	5	0	0	0
Craighead	City Water Light Plant City of Jonesboro	2	92	0	70	0
Franklin	Thomas B Fitzhugh Generating Station	2	138	0	99	0
Greene	Paragould Reciprocating	0	37	0	1	0
Greene	Paragould Turbine	0	0	0	0	0
Hempstead	CTI-Arkansas Electric Cooperative	0	9	0	15	0
Hempstead	John W. Turk Jr.	23	1,334	2,103	3,950	615
Hot Spring	Hot Spring Power Project	1	6	0	42	0
Hot Spring	KGen-Hot Spring LLC	4	19	0	144	0
Independence	Entergy Ark-Independence	222	14,189	32,958	2,609	1,163
Jefferson	Entergy Ark-White Bluff	206	14,090	48,351	2,420	1,067
Jefferson	Pine Bluff Entergy Center	8	172	0	303	1
Mississippi	Dell Power Station	3	56	0	128	0
Mississippi	Plum Point Energy	76	1,091	1,746	636	256
Phillips	Entergy Ark-Ritchie	0	2	0	0	0
Pulaski	Wrightsville Power Facility	9	306	0	349	1
Union	Union Power Station-El Dorado	26	450	0	1,026	2
Washington	Harry D Mattison Power Plant	0	3	0	6	0
Total		**662**	**37,681**	**101,513**	**12,695**	**3,537**

As noted earlier, a key component of the emission processing is the spatial allocation of the emissions to each grid cell or point-source location in the modeling domain. To illustrate the spatial distribution of emissions throughout the modeling domain, spatial plots of low-level anthropogenic VOC and NO_x emissions and biogenic VOC emissions for the 4-km grid for 15 July (representing a typical summer day) are displayed in Figure 4-3 through Figure 4-5. The anthropogenic emissions are for the 2015 future-year baseline. The spatial distribution of emissions for the base years (not shown) is similar to that for the future-year baseline.

The anthropogenic VOC emissions are associated mainly with population centers scattered throughout the domain, with the highest emissions occurring in the Memphis, Little Rock and Jackson areas. The

NO_x emissions are similarly associated with population centers, but reflect emissions associated with the various transportation modes and corridors that are running through the area including the Interstate highways, state highways, railways, and waterways. The biogenic VOC emissions are associated with the various types of vegetation growing in the region including hardwood and softwood forests and agricultural crops located in eastern Arkansas and along the Mississippi River delta.

Figure 4-3. Spatial Distribution of Future-Year Baseline (2015) Low-Level Anthropogenic Emissions for the 4-km Modeling Grid for the Arkansas Statewide Criteria Pollutant Modeling Analysis: VOC

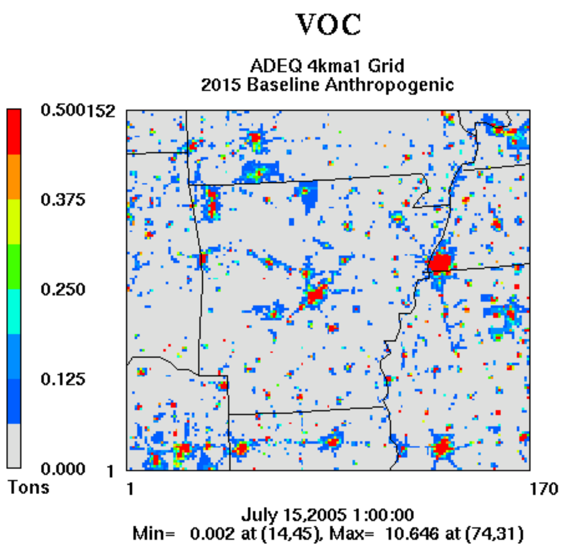


Figure 4-4. Spatial Distribution of Future-Year Baseline (2015) Low-Level Anthropogenic Emissions for the 4-km Modeling Grid for the Arkansas Statewide Criteria Pollutant Modeling Analysis: NO_x

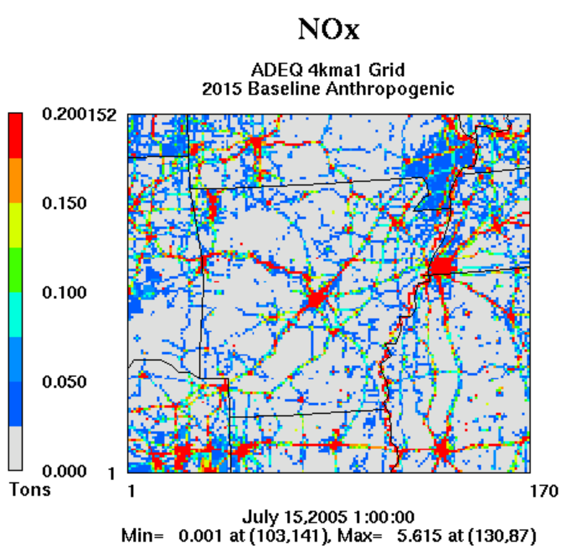
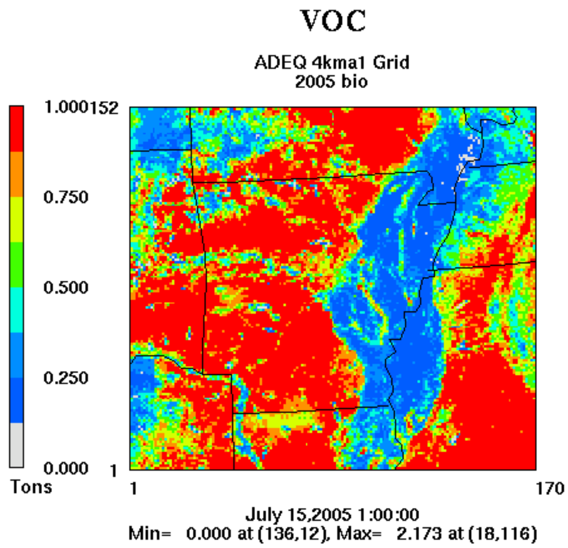


Figure 4-5. Spatial Distribution of Biogenic Emissions for the 4-km Modeling Grid for the Arkansas Statewide Criteria Pollutant Modeling Analysis: VOC



5 Base-Year Modeling Results

The base-year modeling effort included the application of CMAQ for the 2005 and 2008 annual simulation periods and the evaluation of model performance.

5.1 2005 Simulation Period

CMAQ model performance for the base-year simulation for 2005 is summarized in the remainder of this section.

5.1.1 Summary of Model Performance for Ozone

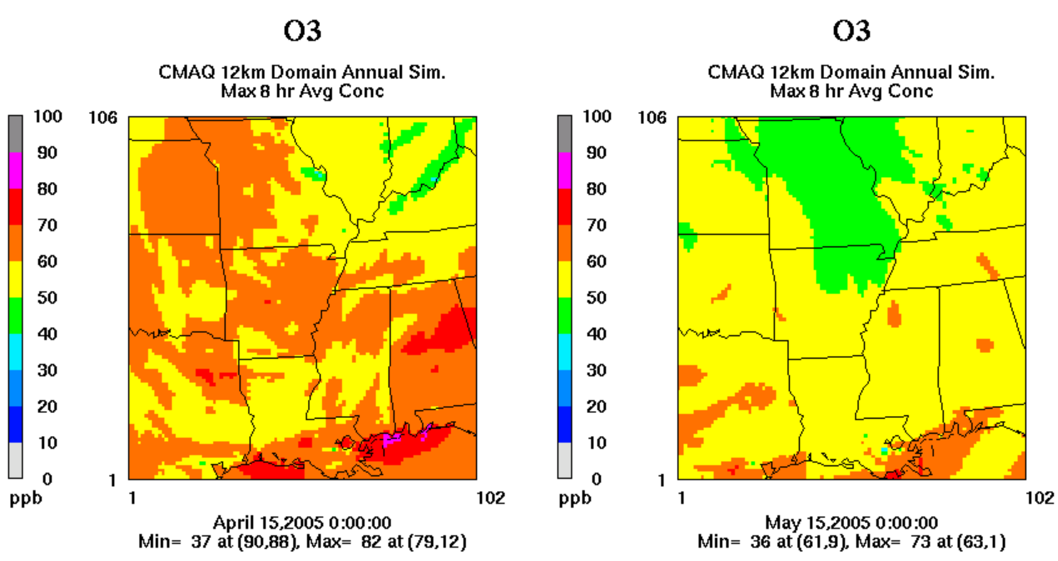
CMAQ model performance for ozone focused on the typical ozone season months of April through October and is summarized in the remainder of this section.

12-km Grid

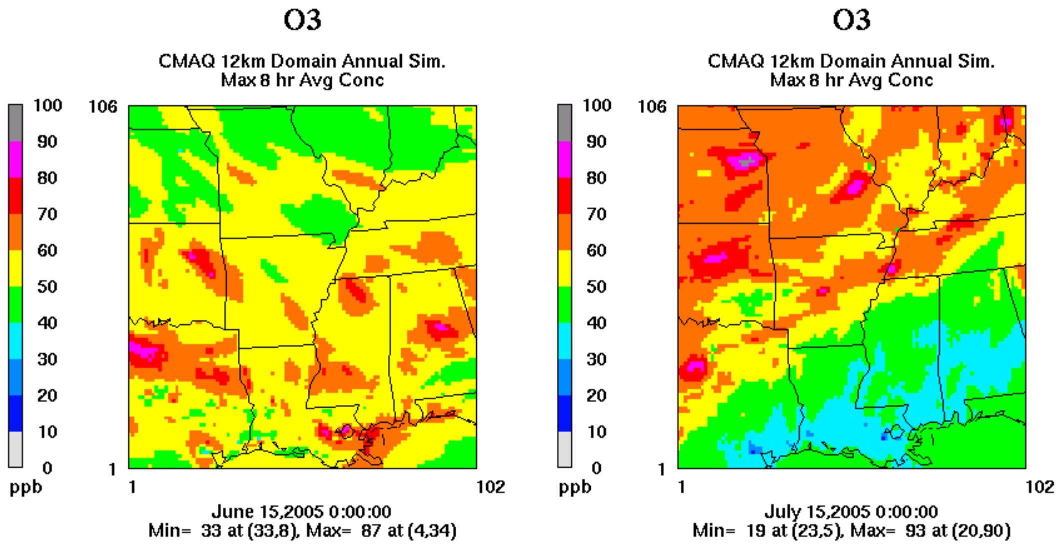
Spatial Concentration Patterns

Spatial plots of the simulated ozone concentration patterns for the 12-km grid for selected days throughout the simulation period were plotted and examined. Figure 5-1 illustrates the simulated ozone concentration patterns for the 15th of each month (April – October). Consistent with the NAAQS for ozone, daily maximum 8-hour average ozone concentration is displayed. The units are parts per billion (ppb).

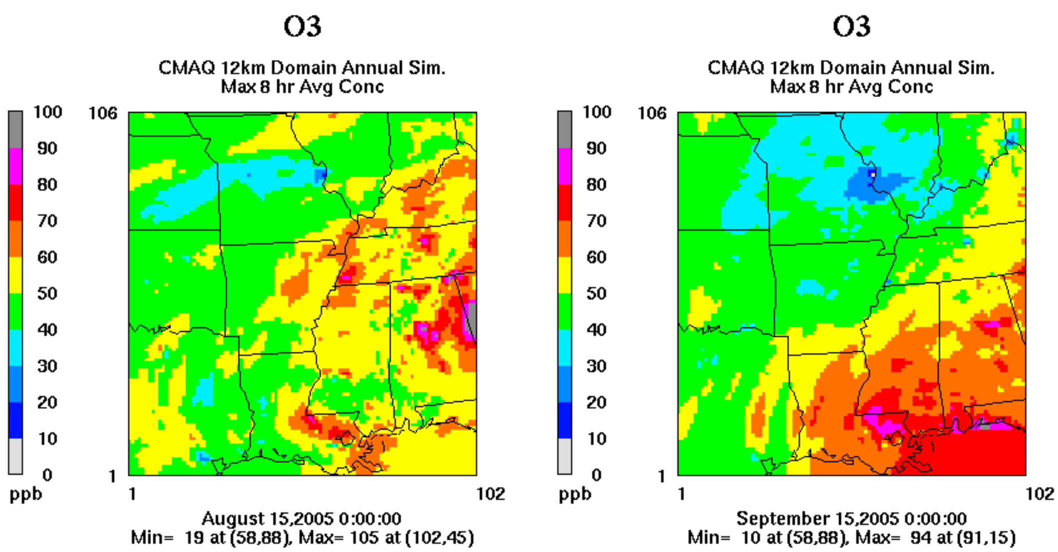
Figure 5-1. Simulated Daily Maximum 8-Hour Ozone Concentration (ppb) for Selected Days for the CMAQ 12-km Grid
April 15/May 15



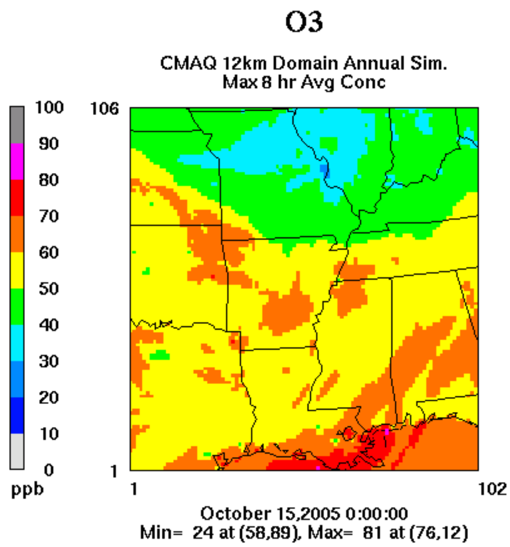
June 15/July 15



August 15/September 15



October 15

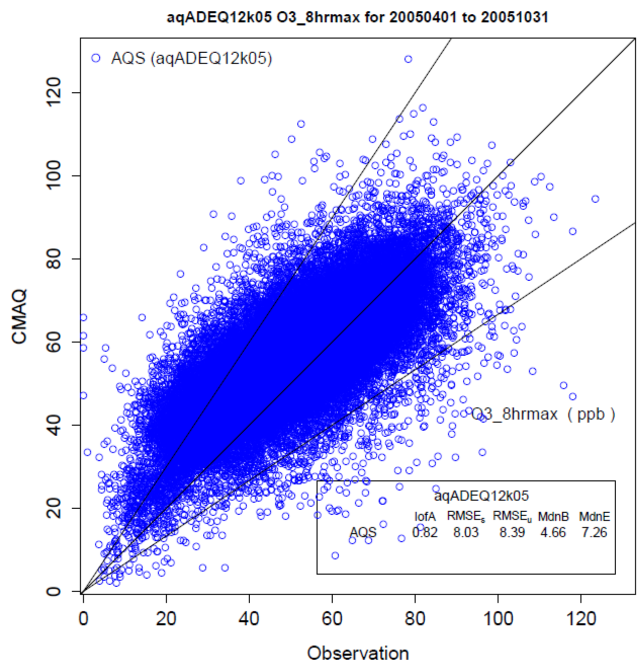


The plots depict a wide range of ozone concentration patterns for the selected days and illustrate the regional nature of ozone. Among the selected days, the simulated 8-hour average ozone concentrations are highest over Arkansas for the middle days of April, July, and October, exceeding 80 ppb on July 15. Maximum 8-hour average concentrations for the 12-km grid range from 73 to 105 ppb for the selected days.

Comparison of Simulated and Observed Concentrations

A scatter plot comparing simulated and observed daily maximum 8-hour ozone concentrations for the 12-km grid for April through October is presented in Figure 5-2. The scatter plot provides a visual representation of how well the simulated values match the observations, and can reveal biases toward over- or underestimation of the observed values. Also included on the scatter plot is some statistical information further summarizing model performance. Note that these statistical measures are calculated using the 8-hour average ozone concentrations. The solid lines on the plot are for visual reference and are drawn with slopes of 1:1 (center), 1.5:1 (upper), and 1:1.5 (lower).

Figure 5-2. Comparison of Simulated and Observed Daily Maximum 8-Hour Average Ozone Concentration (ppb) for the 12-km Grid (April through October)



There is a general tendency for CMAQ to overestimate the 8-hour average ozone concentrations, especially for observed values within the range of 20 to 60 ppb. However, the higher concentrations are well simulated and there is good correlation overall as indicated by an index of agreement of 0.82.

Statistical Measures of Model Performance

Summary metrics and statistical measures calculated using hourly ozone concentrations for the 12-km grid are presented in Table 5-1. The recommended ranges for the normalized bias and normalized error shown in this table are no longer a part of current EPA guidance but are still widely used for urban- and regional-scale model performance evaluations (EPA, 2007). A lower bound of 40 ppb was used in calculating the normalized bias and error statistics.

Table 5-1. Summary Model Performance Statistics for Ozone for the 12-km Modeling Grid

Metric	Apr	May	Jun	Jul	Aug	Sep	Oct	Apr–Oct	Goal
Number of Data Pairs	85,545	91,156	80,095	68,630	66,587	61,934	38,690	492,931	
Mean Observed (ppb)	51.9	54.1	57.1	55.2	55.3	56.9	52.1	54.7	
Mean Simulated (ppb)	48	50.2	53.9	54.9	56.1	56.0	49.3	52.5	
Mean Bias (ppb)	-3.9	-3.8	-3.2	-0.3	0.9	-1.0	-2.7	-2.2	
Normalized Bias (%)	-7.0	-6.4	-4.9	0.7	3.1	-1.0	-4.6	-3.2	**± 15**
Normalized Mean Bias (%)	-7.5	-7.1	-5.6	-0.5	1.5	-1.7	-5.3	-4.0	
Fractional Bias (%)	-11.2	-10.8	-9.5	-3.4	-2.1	-5.7	-9.4	-7.7	
Mean Error (ppb)	8.7	9.4	10.4	10.4	11.8	10.9	10.1	10.2	

Normalized Error (%)	17.1	18.0	19.1	19.8	22.4	20.1	20.0	19.3	**≤ 35**
Normalized Mean Error (%)	16.7	17.4	18.3	18.9	21.4	19.1	19.5	18.6	
Fractional Error (%)	20.5	21.3	22.0	21.0	23.8	22.3	23.0	21.8	
Correlation (unitless)	0.51	0.52	0.59	0.51	0.46	0.57	0.49	0.54	
Index of Agreement (unitless)	0.66	0.68	0.74	0.70	0.66	0.73	0.66	0.70	

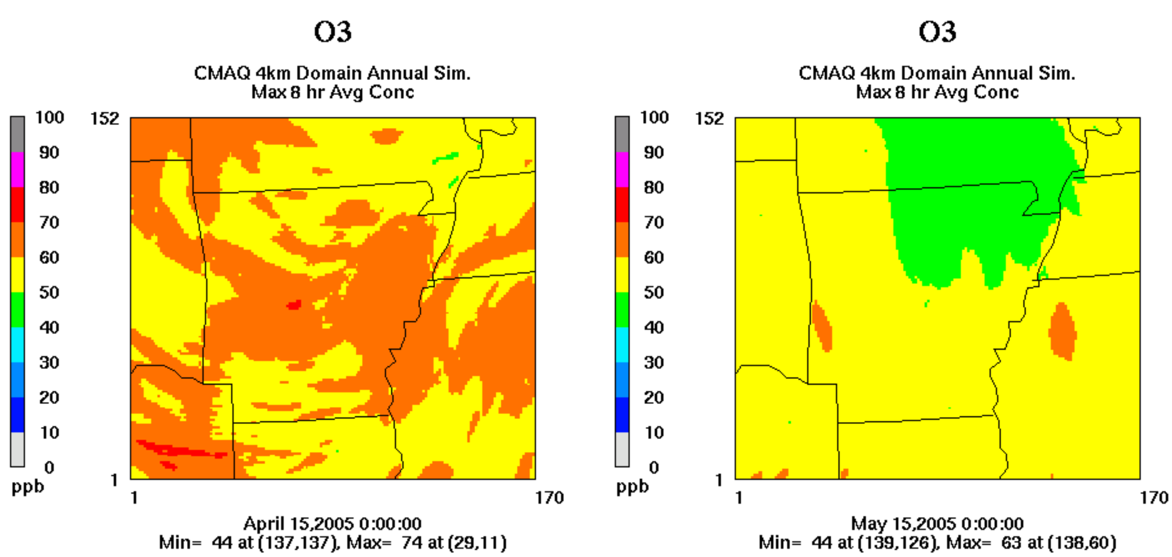
The statistical measures indicate very good agreement, on average, between the simulated and observed concentrations for all months. The normalized bias is within ±15 percent and the normalized error is well within 35 percent for all months. Using a lower bound value of 60 ppb for the calculation of the statistics, the normalized mean bias for the multi-month period (April- October) is -7.6 percent and the normalized mean error is 14.6 percent, indicating some underestimation of the higher ozone values but also very good model performance.

Ozone Model Performance for the 4-km Grid

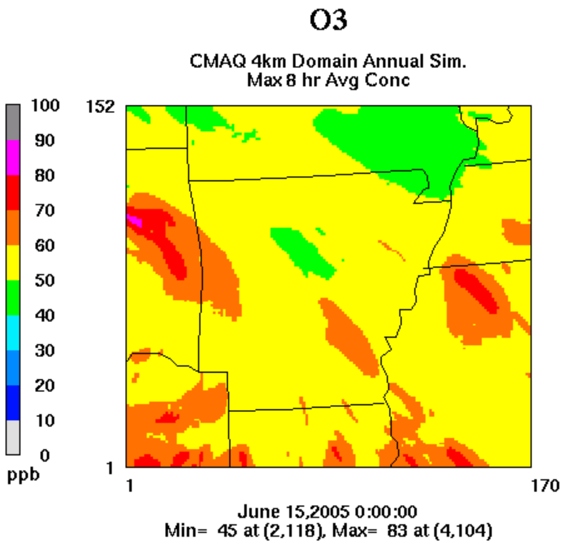
Spatial Concentration Patterns

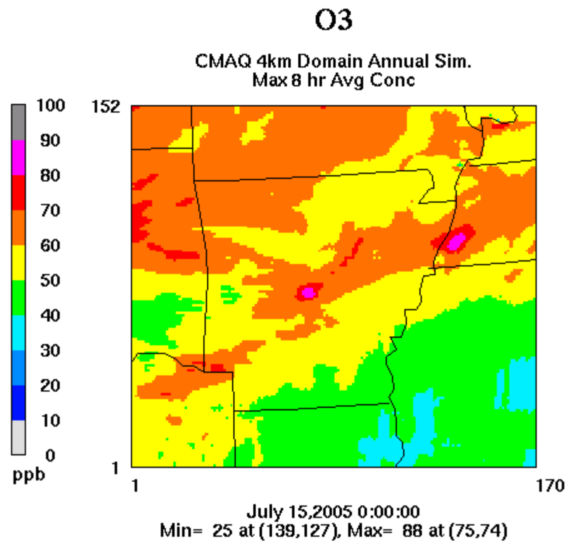
Spatial plots of the simulated ozone concentration patterns for the 4-km grid for selected days throughout the simulation period were plotted and examined. Figure 5-3 illustrates the daily maximum 8-hour average ozone concentration patterns for the 15th of each month (April – October). Units are parts per billion (ppb).

Figure 5-3. Simulated Daily Maximum 8-Hour Ozone Concentration (ppb) for Selected Days for the CMAQ 4-km Grid
April 15/May 15

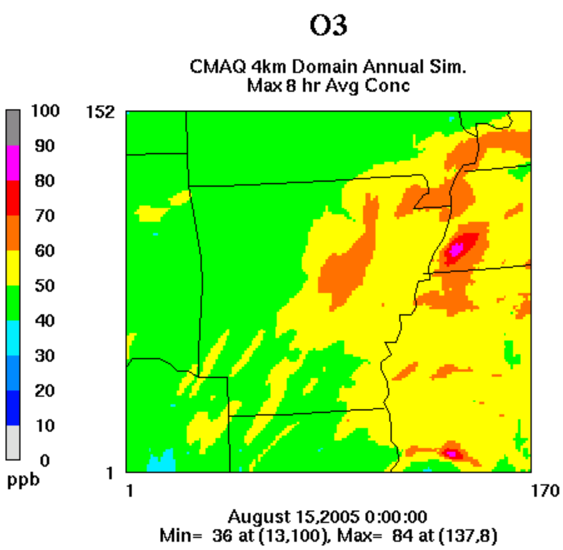


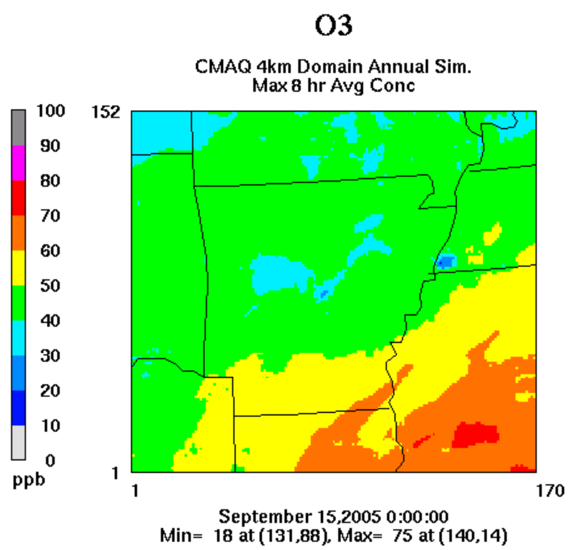
June 15/July 15



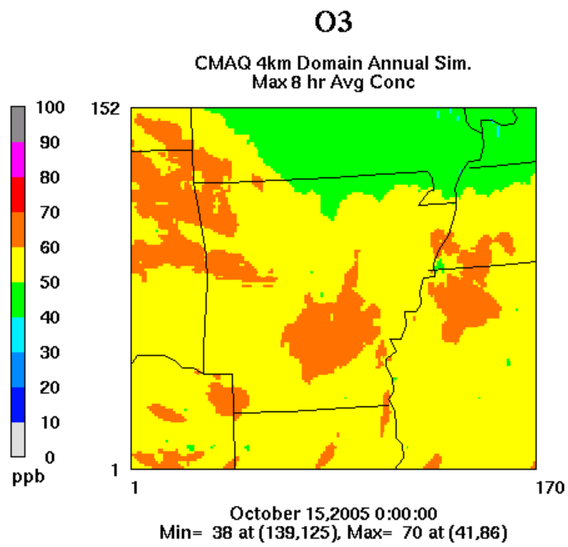


August 15/September 15





October 15

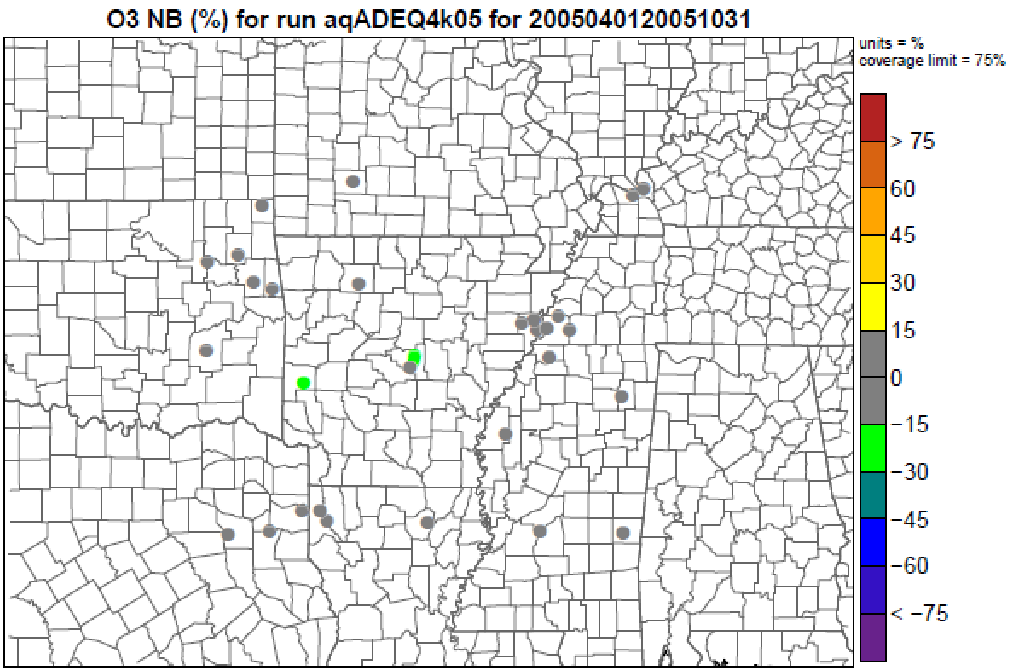


For many of the selected days, the simulated ozone concentration patterns indicate moderate to high ozone concentrations over at least a portion of Arkansas. Higher concentrations are more widespread across the state on April 15 and July 15. Among the selected days, the highest simulated concentration occurs near Little Rock on July 15. On this day the simulated daily maximum 8-hour ozone concentration is 88 ppb.

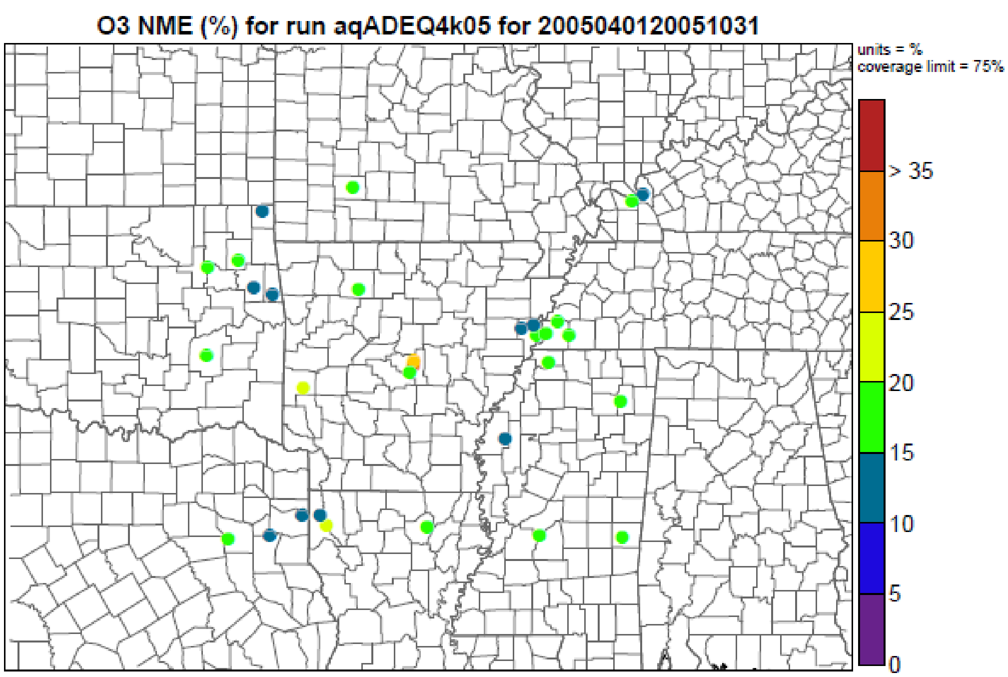
Figure 5-4 depicts the average bias and error for all sites in the 4-km modeling grid, based on daily maximum 8-hour ozone concentrations for the ozone season months (April through October). For the normalized bias, gray shaded circles indicate that the bias is within ± 15 percent; blue and green shading indicates underestimation of the observed concentrations and yellow, orange, and red shading indicates overestimation. For the normalized mean error, blue and green shading represent the smaller errors, while red indicates an error greater than 35 percent. A lower bound of 40 ppb was used in calculating the normalized bias and error statistics. Note that the plotted area is slightly larger than the 4-km grid, but that information is presented only for sites within the 4-km grid.

Figure 5-4. Normalized Bias (%) and Normalized Mean Error (%) Based on Daily Maximum 8-Hour Average Simulated and Observed Ozone Concentrations for April through October for the CMAQ 4-km Grid

Normalized Bias



Normalized Mean Error

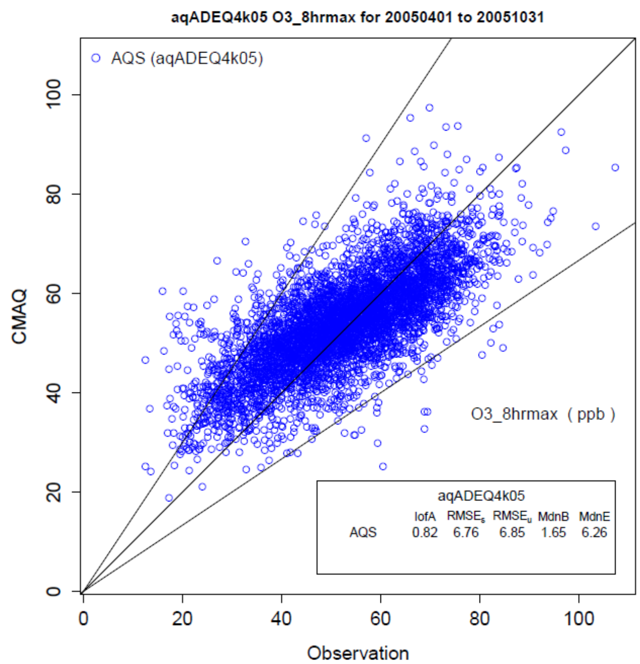


Model performance is consistent throughout the 4-km grid (i.e., there do not appear to be any distinct differences in model performance within the region covered by the grid). For most monitoring sites, the normalized bias is within ± 15 percent (as indicated by the gray shading). The normalized mean error is less than 35 percent for all sites and months.

Comparison of Simulated and Observed Concentrations

A scatter plot comparing simulated and observed daily maximum 8-hour ozone concentrations for the 4-km grid for April through October is presented in Figure 5-5. Again, note that the statistical measures given on the plot are calculated using the 8-hour average ozone concentrations.

Figure 5-5. Comparison of Simulated and Observed Daily Maximum 8-Hour Average Ozone Concentration (ppb) for the 4-km Grid (April through October)



There is a slight tendency for CMAQ to overestimate the lower concentrations and underestimate the higher concentrations, but there is good correlation overall as indicated by an index of agreement of 0.82.

Statistical Measures of Model Performance

Summary metrics and statistical measures calculated using hourly ozone concentrations for the 4-km grid are presented in Table 5-2. A lower bound of 40 ppb was used in calculating the normalized bias and error statistics.

Table 5-2. Summary Model Performance Statistics for Ozone for the 4-km Modeling Grid

Metric	Apr	May	Jun	Jul	Aug	Sep	Oct	Apr-Oct	Goal
Number of Data Pairs	9,580	10,931	10,031	8,982	8,994	8,580	5,937	63,035	
Mean Observed (ppb)	51.5	54.0	57.6	54.0	54.4	57.2	52.4	54.5	
Mean Simulated (ppb)	47.3	49.2	52.0	52.0	53.6	52.8	47.5	50.7	
Mean Bias (ppb)	-4.1	-4.8	-5.6	-2.0	-0.7	-4.4	-4.9	-3.8	
Normalized Bias (%)	-7.2	-8.3	-8.9	-2.7	0.0	-7.2	-8.7	-6.1	**± 15**
Normalized Mean Bias (%)	-8.0	-8.9	-9.7	-3.7	-1.3	-7.7	-9.3	-7.0	
Fractional Bias (%)	-10.6	-11.6	-12.8	-6.6	-3.9	-10.8	-12.4	-9.8	
Mean Error (ppb)	8.1	8.9	9.7	9.9	10.3	9.6	9.3	9.4	
Normalized Error (%)	15.9	16.5	17.2	18.9	19.6	17.4	17.9	17.6	**≤ 35**
Normalized Mean Error (%)	15.7	16.1	16.9	18.4	18.9	16.9	17.7	17.2	
Fractional Error (%)	18.6	19.2	20.4	20.7	21.0	20.0	20.7	20.0	
Correlation (unitless)	0.49	0.56	0.63	0.47	0.45	0.61	0.54	0.55	
Index of Agreement (unitless)	0.65	0.70	0.75	0.65	0.65	0.74	0.68	0.70	

The statistical measures for the 4-km grid also show underestimation of ozone for most months. The normalized bias is within ±15 percent and the normalized error is well within 35 percent for all months and for the ozone season. Using a lower-bound value of 60 ppb, the normalized mean bias for the multi-month period (April- October) is –11.1 percent and the normalized mean error is 15.4 percent, also within the model performance goals.

5.1.2 Summary of Model Performance for $PM_{2.5}$

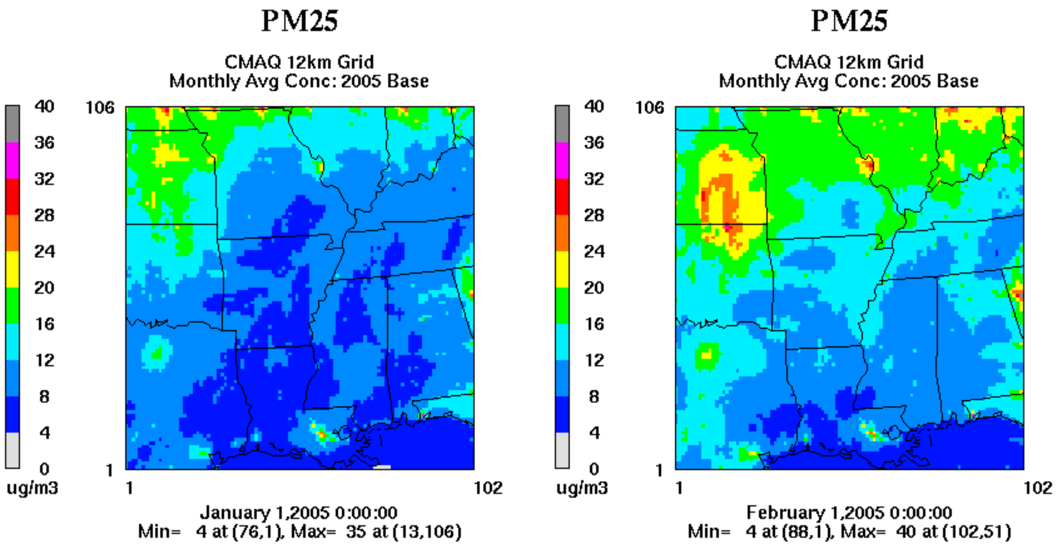
12-km Grid

Spatial Concentration Patterns

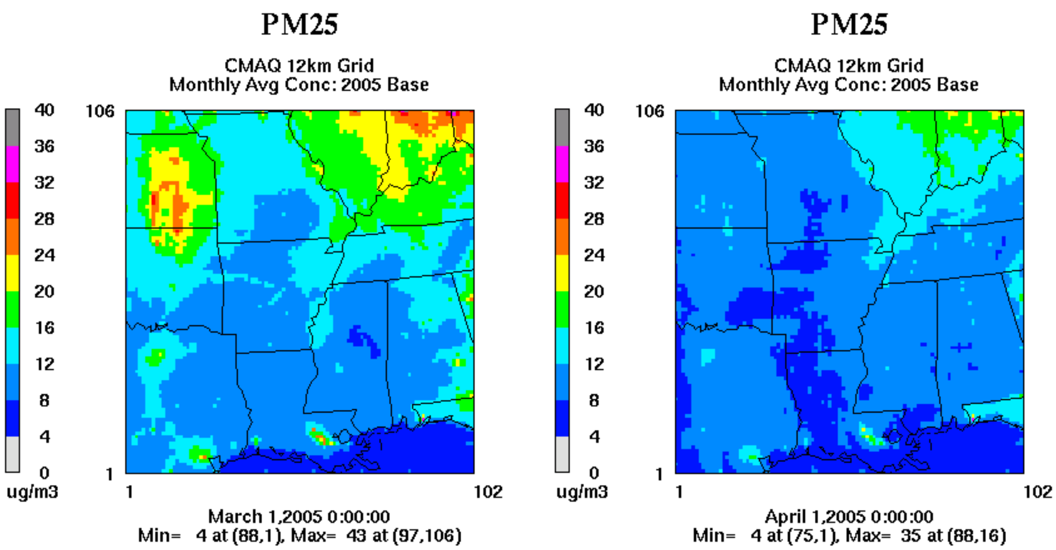
Spatial plots of the monthly average simulated $PM_{2.5}$ concentration patterns for the 12-km grid are illustrated in Figure 5-6. The units are micrograms per cubic meter ($\mu g/m^3$).

Figure 5-6. Simulated Monthly Average $PM_{2.5}$ Concentration ($\mu g/m^3$) for the CMAQ 12-km Grid

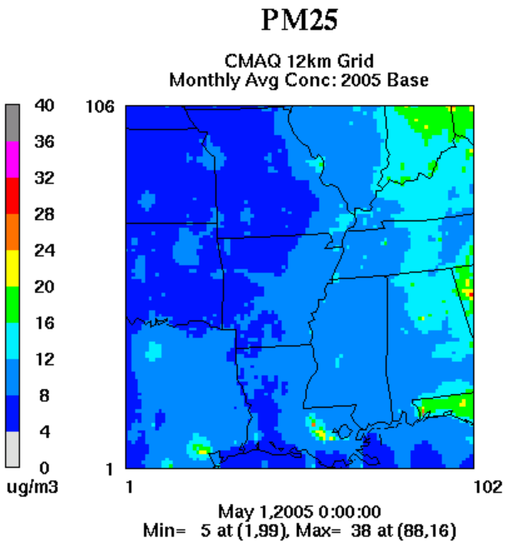
January/February

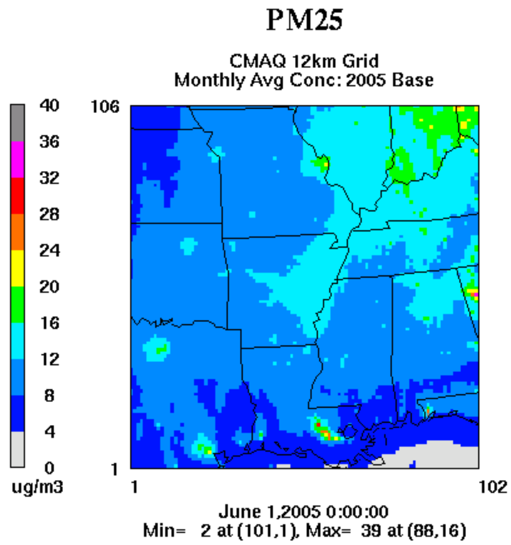


March/April

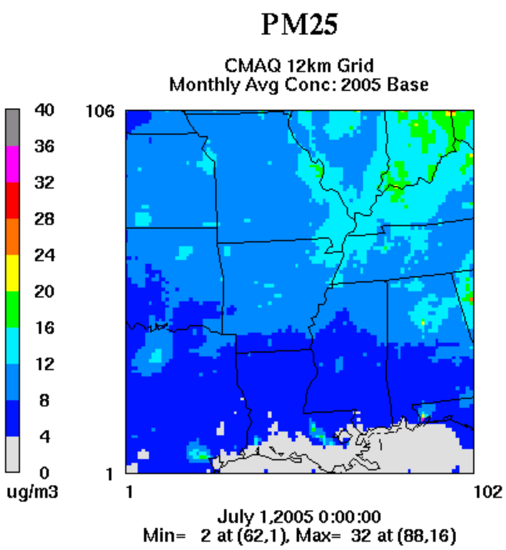


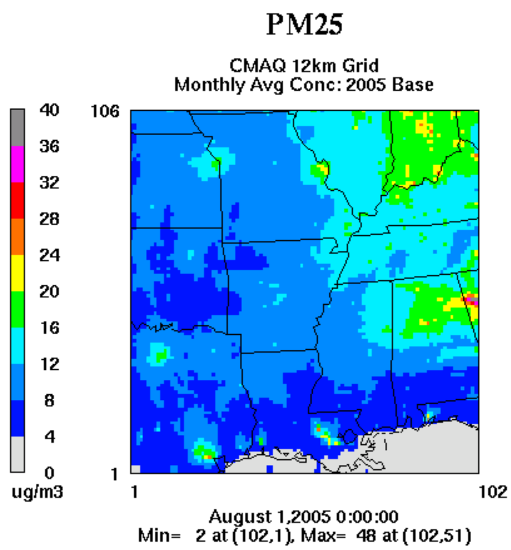
May/June



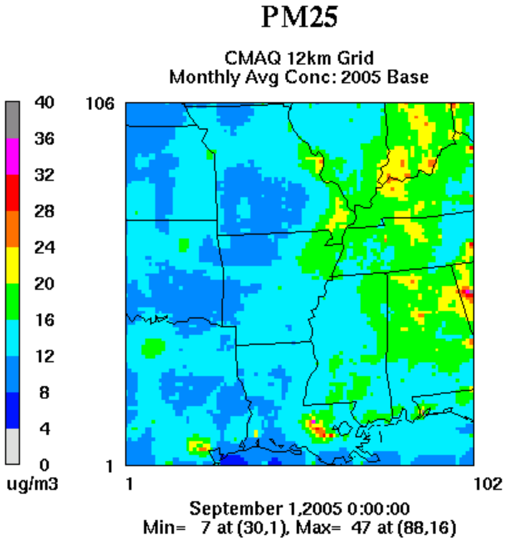


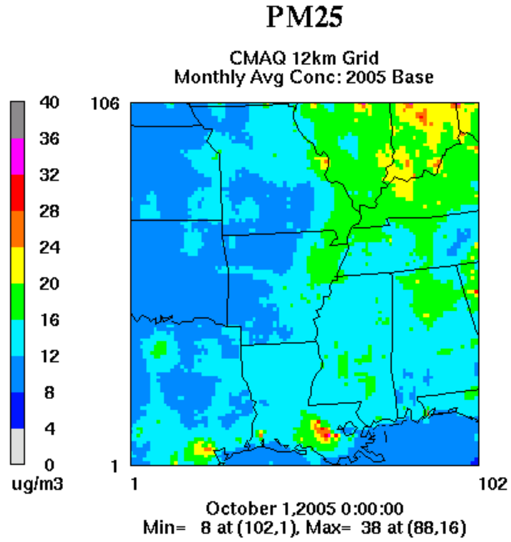
July/August



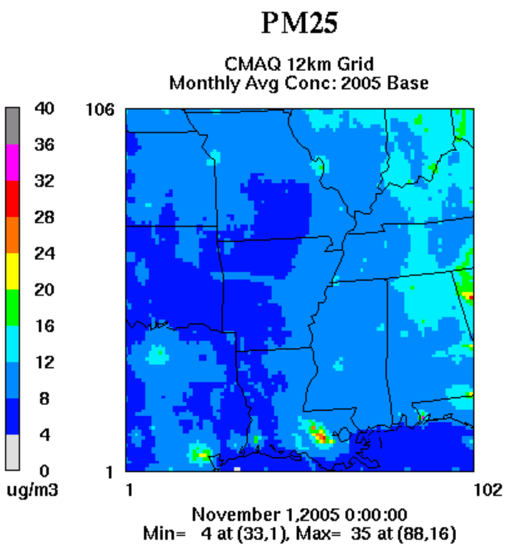


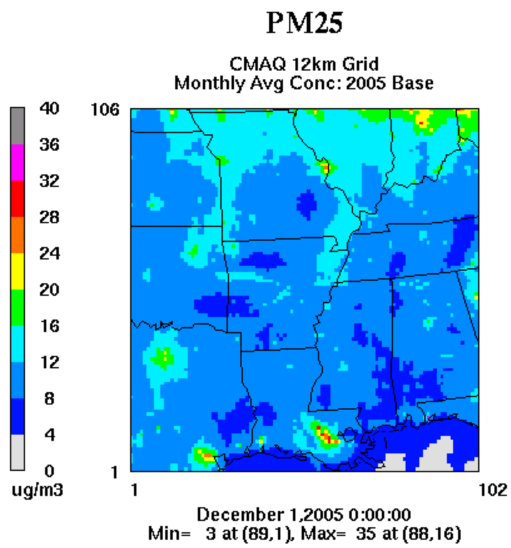
September/October





November/December

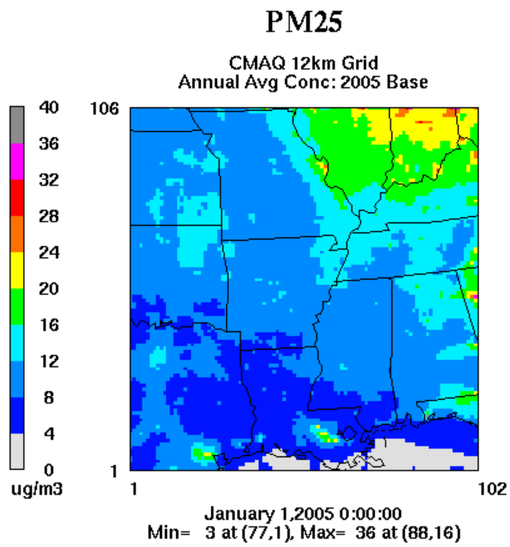




For most months, the simulated monthly average $PM_{2.5}$ concentrations over Arkansas are within the range of 4 to 16 µg/m^3. For September and October, the model results indicate localized areas of higher $PM_{2.5}$ (in the 16 to 20 µg/m^3 range) over the northwest portion of the state.

Figure 5-7 displays the annual average simulated $PM_{2.5}$ concentration pattern for the 12-km grid.

Figure 5-7. Simulated Annual Average $PM_{2.5}$ Concentration (µg/m^3) for the CMAQ 12-km Grid

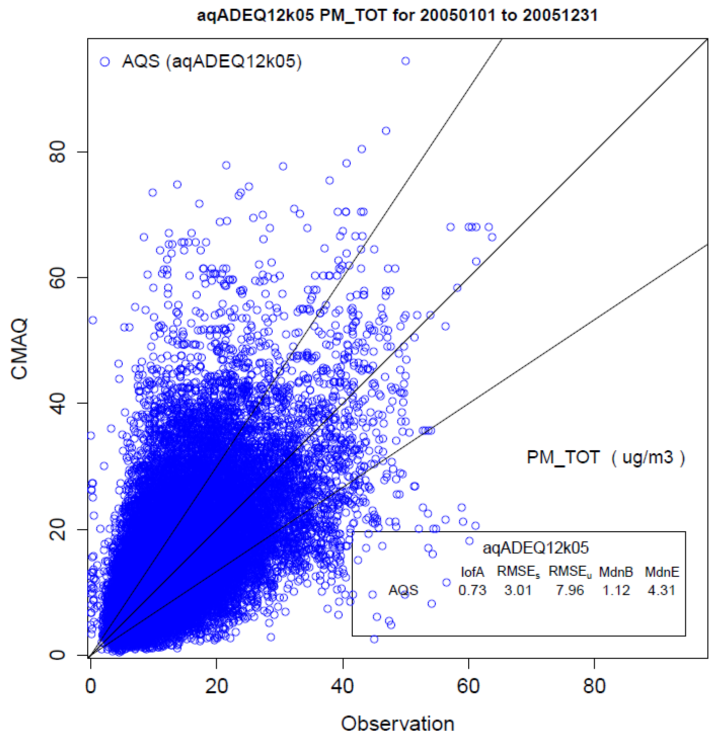


The simulated annual average concentrations range from about 4 to 16 ppb over Arkansas and across most of the 12-km grid, with higher $PM_{2.5}$ concentrations (greater than 16 µg/m^3) over Kentucky, Illinois, Indiana, Ohio, and several other isolated areas. The maximum simulated annual average $PM_{2.5}$ concentration is 36 µg/m^3 and is located along the Gulf Coast (near Pensacola).

Comparison of Simulated and Observed Concentrations

Scatter plots comparing simulated and observed 24-hour $PM_{2.5}$ concentrations for AQS sites within the 12-km grid for the annual simulation period are presented in Figure 5-8.

Figure 5-8. Comparison of Simulated and Observed 24-Hour Average $PM_{2.5}$ Concentration ($\mu g/m^3$) for the 12-km Grid (All Months)



The scatter plot indicates an overall tendency for the model to overestimate observed annual average $PM_{2.5}$ concentrations within the 12-km grid.

Statistical Measures of Model Performance

Summary metrics and statistical measures calculated using 24-hr $PM_{2.5}$ concentrations for the 12-km grid are presented in Table 5-3. The recommended ranges for the fractional bias and fractional error are based on Boylan (2005) and are widely used for regional-scale model performance evaluation for $PM_{2.5}$. No lower bound was applied in calculating the statistics.

Table 5-3. Summary Model Performance Statistics for $PM_{2.5}$ for the 12-km Modeling Grid

Metric	Jan–Mar	Apr–Jun	Jul–Sep	Oct–Dec	Annual	Goal
Number of Data Pairs	7,685	7,867	7,202	6,964	29,718	
Mean Observed (ppb)	12.3	14.1	17.6	12.5	14.1	
Mean Simulated (ppb)	17.1	14.3	16.2	16.7	16.0	
Mean Bias (ppb)	4.8	0.1	1.4	4.1	1.9	
Fractional Bias (%)	25.8	-0.4	-13.9	24.8	9.0	**± 60**
Mean Error (ppb)	7.0	5.2	5.9	6.0	6.0	
Fractional Error (%)	45.9	36.1	38.7	40.7	40.3	**≤ 75**
Correlation (unitless)	0.60	0.57	0.65	0.61	0.57	
Index of Agreement (unitless)	0.67	0.75	0.80	0.69	0.73	

On average, $PM_{2.5}$ concentrations are overestimated for the first and fourth quarters (the cooler months of the year), slightly overestimated for the second quarter, and underestimated for third quarter. On an annual basis, this results in a slight to moderate overestimation and overall better model performance for the warmer months when observed $PM_{2.5}$ concentrations are relatively high. The statistical measures for fractional bias and fractional error are well within the model performance goals for all periods.

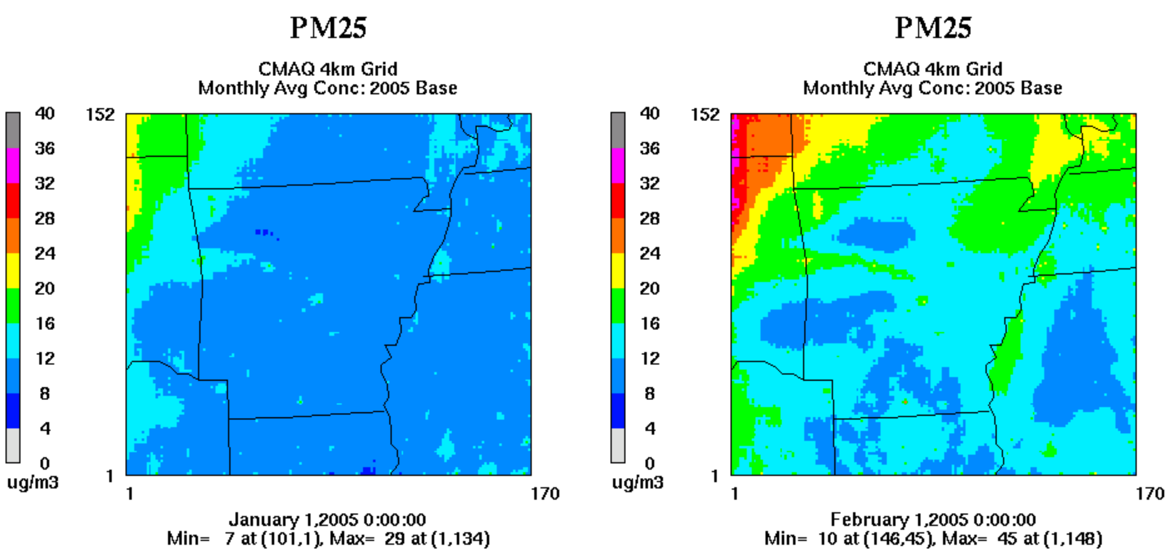
4-km Grid

Spatial Concentration Patterns

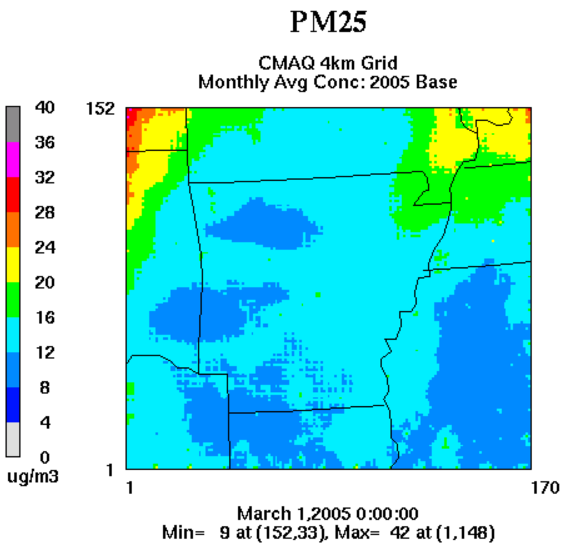
Spatial plots of the monthly average simulated $PM_{2.5}$ concentration patterns for the 4-km grid are illustrated in Figure 5-9. The units are micrograms per cubic meter (µg/m^3).

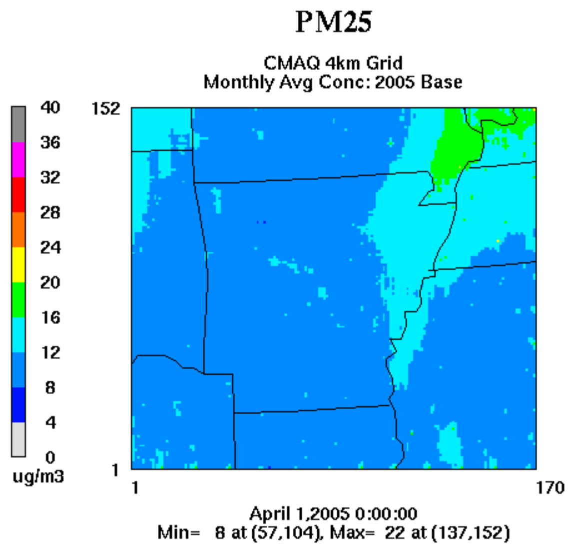
Figure 5-9. Simulated Monthly Average $PM_{2.5}$ Concentration (µg/m^3) for the CMAQ 4-km Grid

January/February

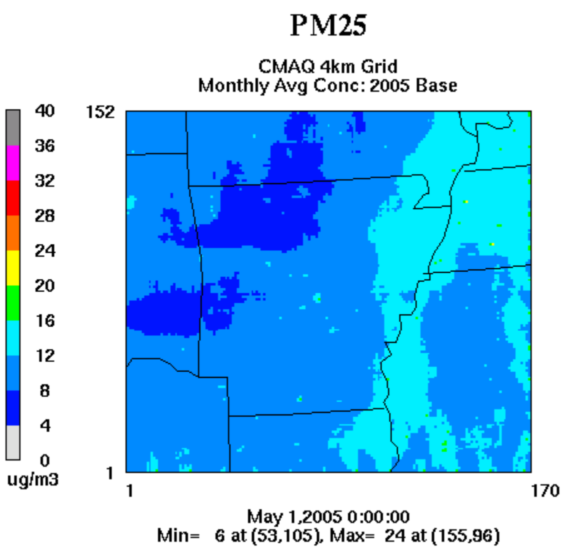


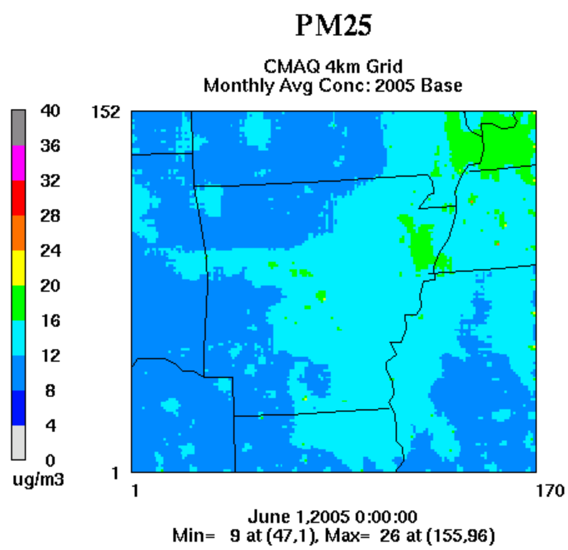
March/April



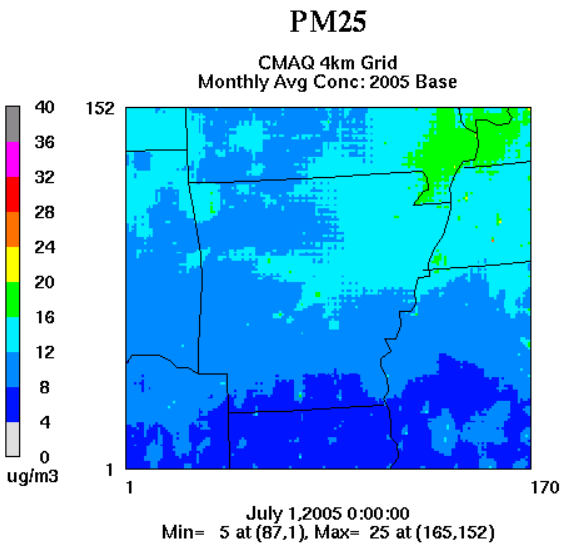


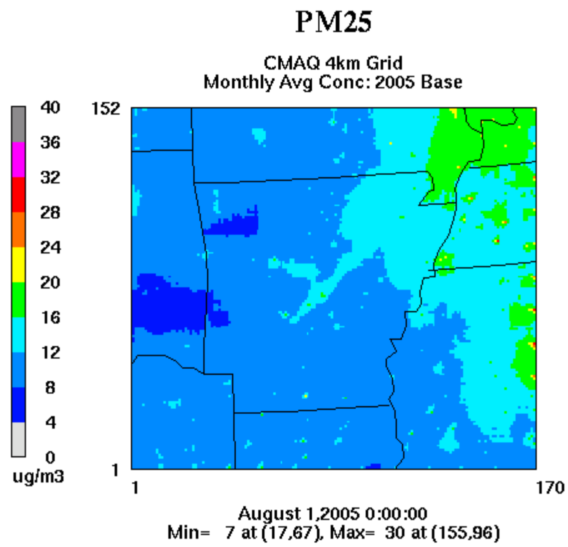
May/June



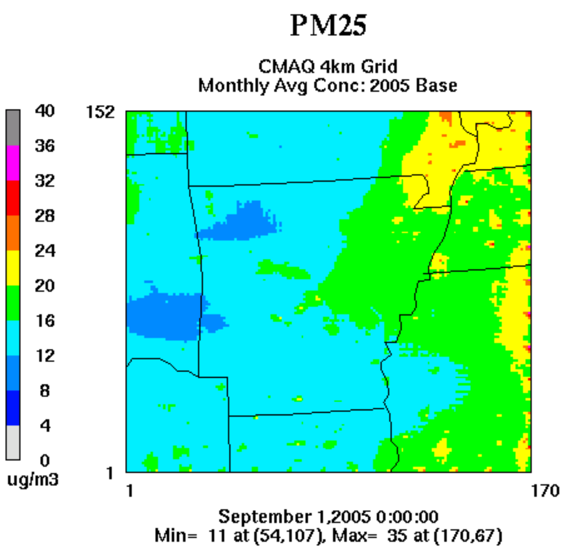


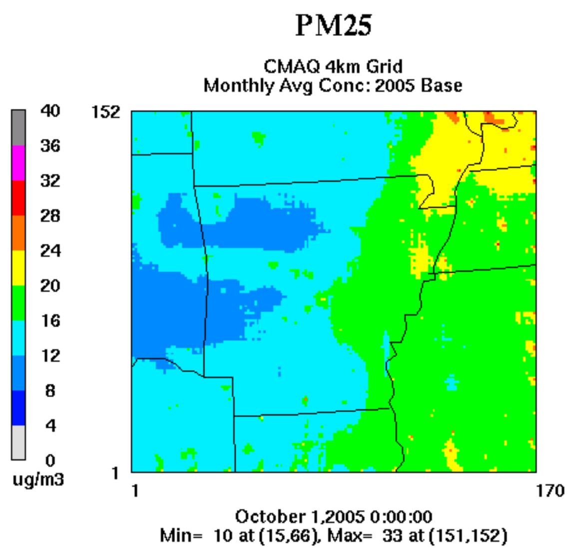
July/August



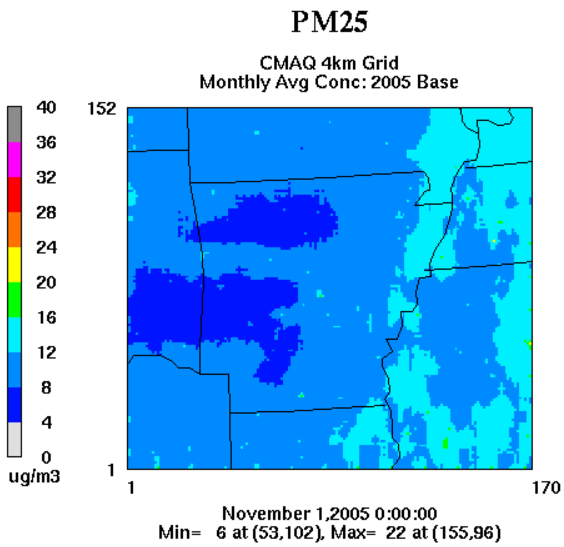


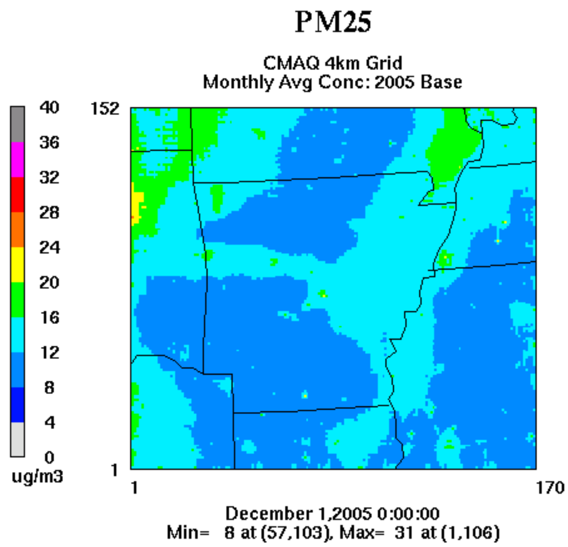
September/October





November/December

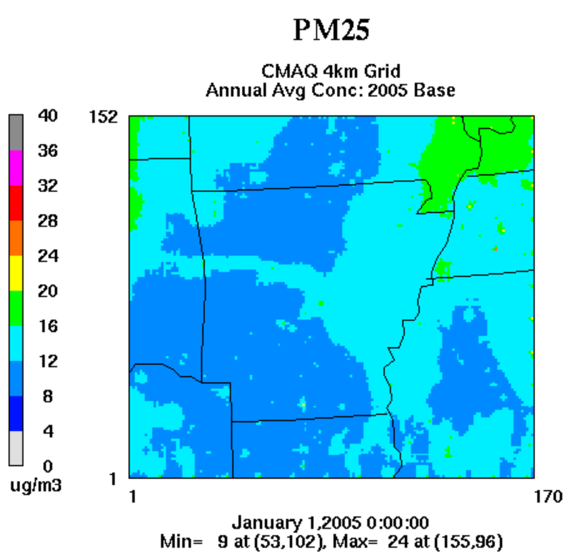




For most months, the simulated monthly average $PM_{2.5}$ concentrations over Arkansas are generally within the range of 4 to 16 µg/m^3. Somewhat higher concentrations (in the 16 to 24 µg/m^3 range) are simulated in the northern part of the state for February, in the northeastern part of the state for September, in the eastern part of the state for October.

Figure 5-10 displays the annual average simulated $PM_{2.5}$ concentration pattern for the 4-km grid.

Figure 5-10. Simulated Annual Average $PM_{2.5}$ Concentration (µg/m^3) for the CMAQ 4-km Grid

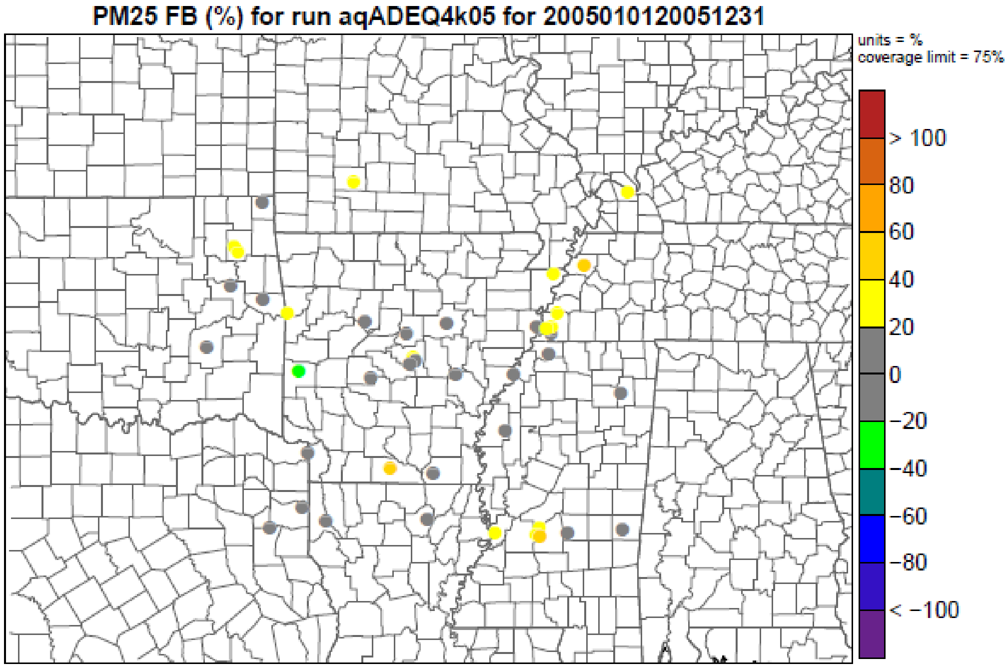


The simulated annual average $PM_{2.5}$ concentrations are less than 16 µg/m^3 throughout the state, with the exception of a few localized areas, including Little Rock.

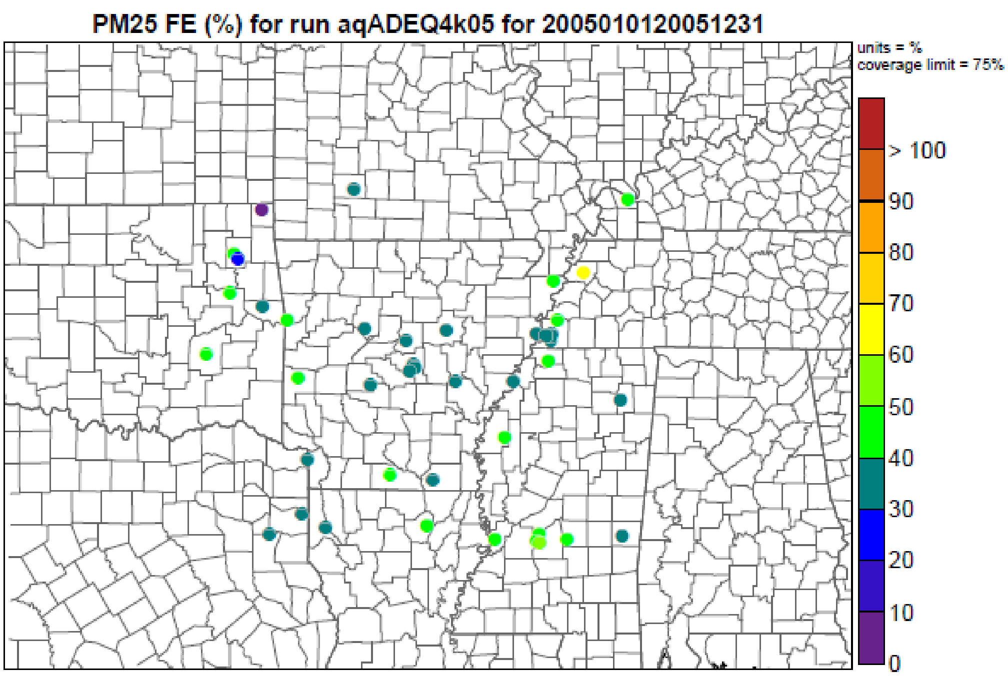
Because the observed $PM_{2.5}$ concentrations can be quite small and there is no accepted minimum threshold, fractional bias and error are better suited to characterizing model performance. To illustrate the agreement between the simulated and observed values, Figure 5-11 depicts the fractional bias and fractional error statistics for the 4-km modeling domain. The statistics are calculated using 24-hour average $PM_{2.5}$ concentrations and are calculated using data for the annual simulation period. Again, each monitoring site is represented by a circle and the shading of the circle provides information about how well the 24-hour observed $PM_{2.5}$ concentrations are represented by the simulation results, on average. For the fractional bias, gray shaded circles indicate that the fraction bias is within ± 20 percent and, in general, values within ±60 percent (lighter colors) correspond to acceptable model performance. Blue and green shading indicates underestimation of the observed concentrations and yellow, orange, and red shading indicates overestimation. For the fractional error, blue and green shading represent the smaller errors, while red indicates an error greater than 100 percent. Values less than 75 percent are considered to represent reasonable model performance for $PM_{2.5}$.

Figure 5-11. Fractional Bias (%) and Fractional Error (%) Based on 24-Hour Average Simulated and Observed $PM_{2.5}$ Concentrations for CMAQ 4-km Grid (All Months)

Fractional Bias



Fractional Error

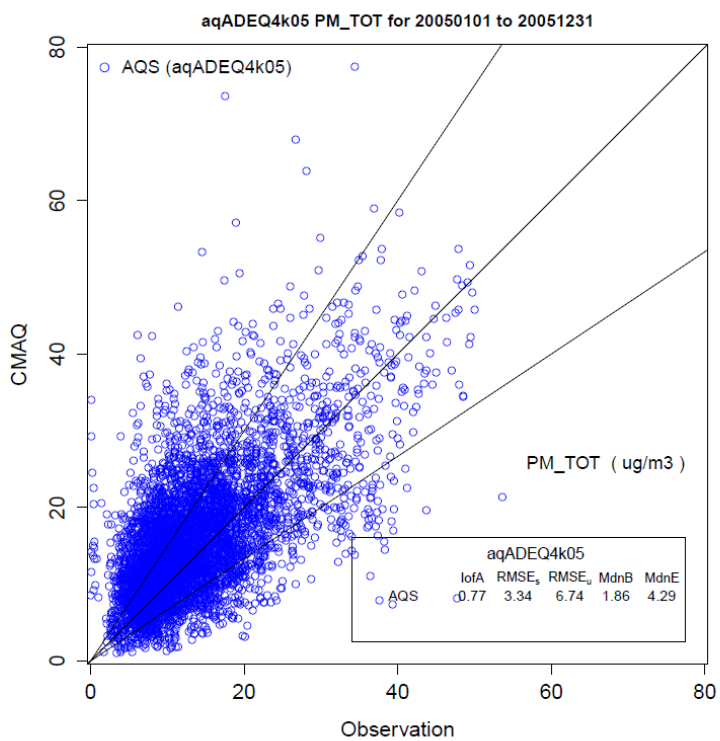


The fractional bias is within the range of -40 to 60 percent for all sites located within the 4-km grid (as indicated by the green, gray, and yellow, and orange shading) and within the range of -40 to 40 percent for all but three sites (in orange). The three sites with a greater amount of overestimation are located in northwestern Tennessee, southern Arkansas, and central Mississippi; thus no regional overestimation patterns are evident. The fractional error is less than 70 percent for all sites. Some of the best performance (teal shading) is over Arkansas.

Comparison of Simulated and Observed Concentrations

Scatter plots comparing simulated and observed 24-hour $PM_{2.5}$ concentrations for AQS sites within the 4-km grid for the annual simulation period are presented in Figure 5-12.

Figure 5-12. Comparison of Simulated and Observed 24-Hour Average $PM_{2.5}$ Concentration ($\mu g/m^3$) for the 4-km Grid (All Months)



The scatter plot shows fairly good agreement between the simulated and observed $PM_{2.5}$ concentrations and a slight tendency for overestimation.

Statistical Measures of Model Performance

Summary metrics and statistical measures calculated using 24-hr $PM_{2.5}$ concentrations for the 4-km grid are presented in Table 5-4. The recommended ranges for the fractional bias and fractional error are based on Boylan (2005) and are widely used for regional-scale model performance evaluation for $PM_{2.5}$. No lower bound was applied in calculating the statistics.

Table 5-4. Summary Model Performance Statistics for $PM_{2.5}$ for the 4-km Modeling Grid

Metric	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Annual	Goal
Number of Data Pairs	1,307	1,341	1,282	1,312	5,242	
Mean Observed (ppb)	10.6	14.5	18.1	12.5	13.9	
Mean Simulated (ppb)	16.6	14.9	16.5	16.7	16.2	
Mean Bias (ppb)	6.0	0.5	-1.6	4.2	2.3	
Fractional Bias (%)	40.0	4.1	-13.9	28.1	14.7	**± 60**
Mean Error (ppb)	7.3	4.4	4.9	5.7	5.6	
Fractional Error (%)	52.5	30.3	32.3	40.4	38.8	**≤ 75**
Correlation (unitless)	0.51	0.74	0.76	0.64	0.62	
Index of Agreement (unitless)	0.56	0.86	0.86	0.72	0.77	

Performance is similar to that for the 12-km grid. On average, $PM_{2.5}$ concentrations are overestimated for the first and fourth quarters, slightly overestimated for the second quarter, and underestimated for third quarter. On an annual basis, this results in a slight to moderate overestimation. Model performance is best for the warmer months when observed $PM_{2.5}$ concentrations are relatively high. The statistical measures for fractional bias and fractional error are well within the model performance goals for all periods.

5.1.3 Summary of Model Performance for PM_{10}, NO_x, SO_2 and CO

Model performance for PM_{10}, NO_x, SO_2 and CO was examined with emphasis on quarterly and annual average concentrations. Observed concentrations of these criteria pollutants are generally expected to represent local rather than regional scale concentrations. This is due to the fact that these pollutants are directly emitted into the atmosphere and also because the monitoring sites are typically located in urban areas and near roadways. A grid-based model like CMAQ may not be able to capture the sub grid-scale variations in concentration reflected in the data that are due to local emissions sources and thus may not agree with the observed data unless the data are representative of the area encompassed by a grid cell. Thus, model performance for these species was examined only for the 4-km grid.

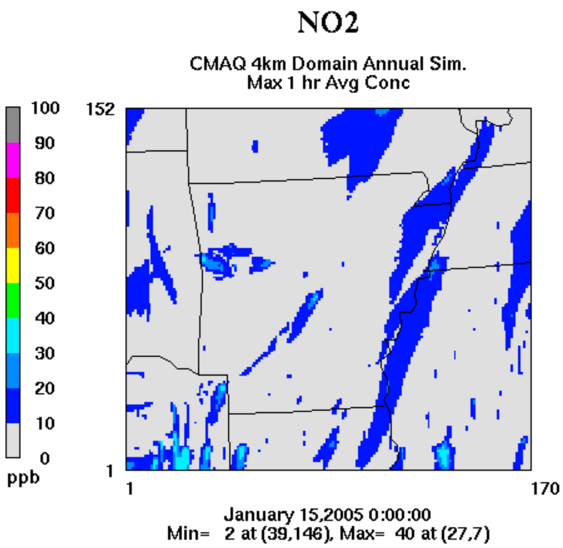
4-km Grid

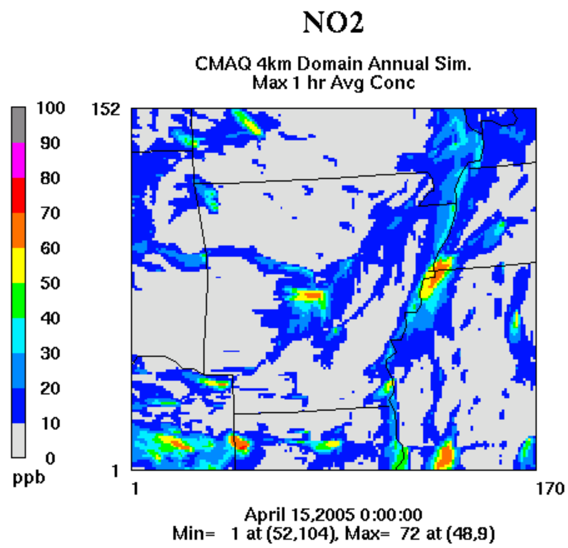
Spatial Concentration Patterns for NO_2 and SO_2

Spatial plots of the simulated NO_2 and SO_2 concentration patterns for the 4-km grid for selected days throughout the simulation period were plotted and examined. Figures 5-13 and 5-14 illustrate the daily maximum 1-hour average NO_2 concentration patterns and daily maximum 1-hour average SO_2 concentration patterns, respectively, for the 15th of January, April, July, and October (one day per quarter). These are provided primarily as a point of reference for the difference plots presented in Section 6. Units are parts per billion (ppb).

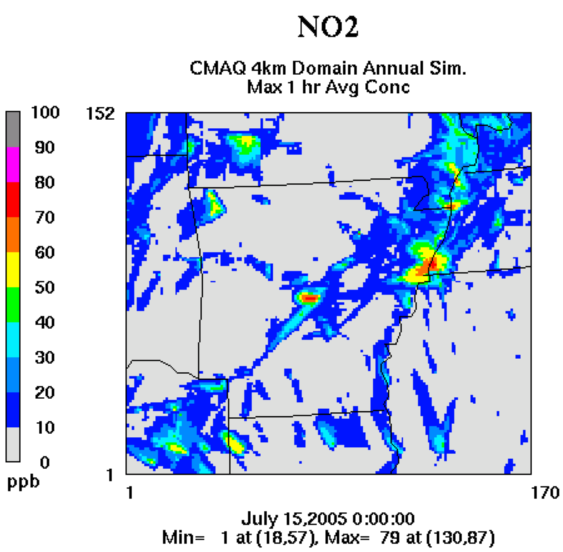
Figure 5-13. Simulated Daily Maximum 1-NO_2 Concentration (ppb) for Selected Days for the CMAQ 4-km Grid

January 15/April 15





July 15/October 15



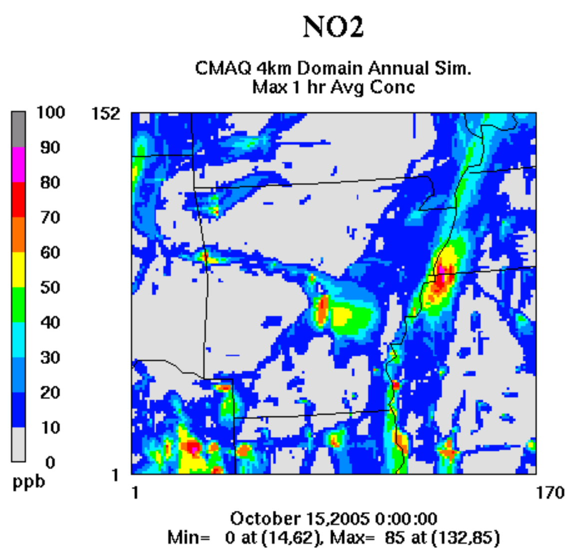
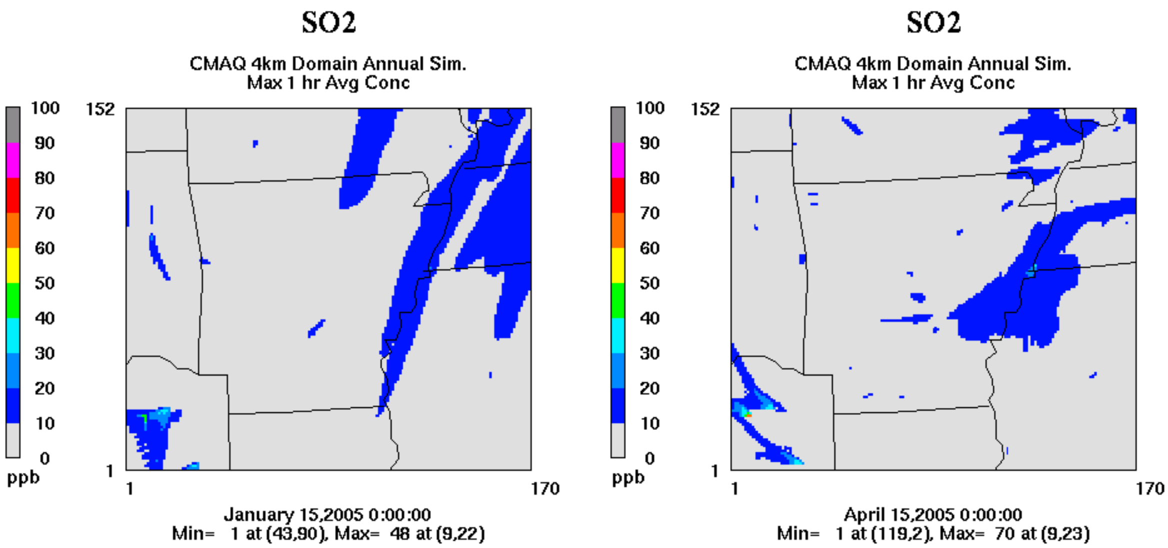
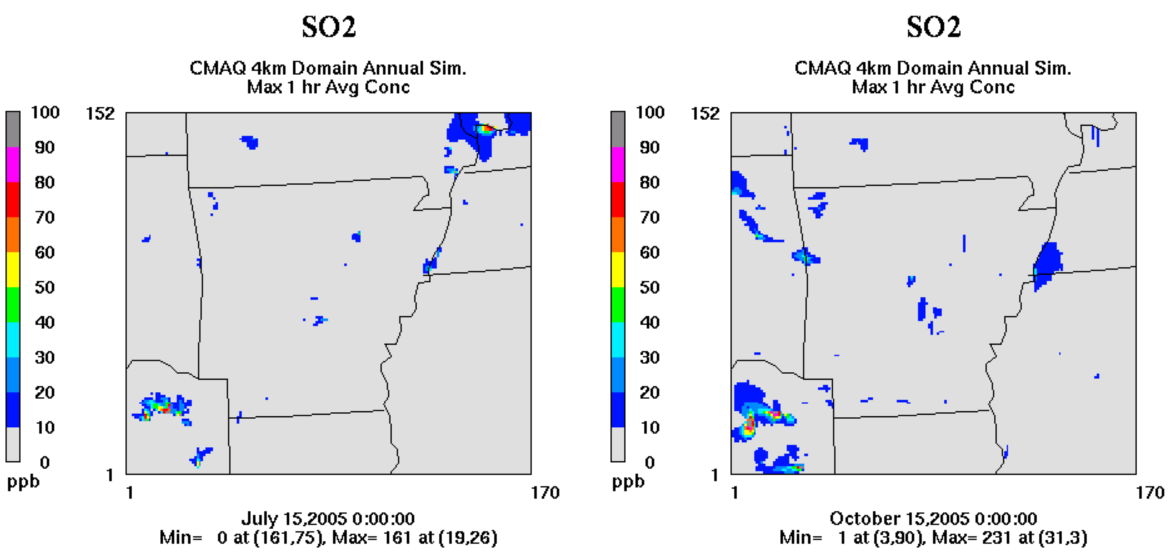


Figure 5-14. Simulated Daily Maximum 1-SO_2 Concentration (ppb) for Selected Days for the CMAQ 4-km Grid

January 15/April 15



July 15/October 15

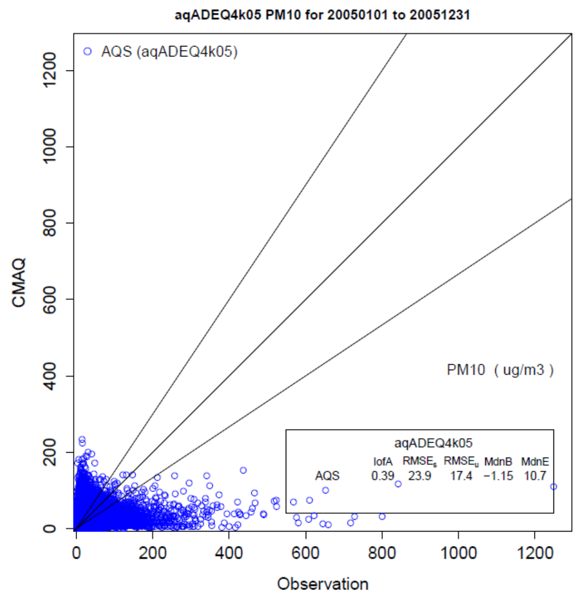


Simulated NO_2 concentrations are highest over and downwind of Memphis, Little Rock, and other urban areas. SO_2 concentrations are low throughout Arkansas, with some areas of high SO_2 in southern Illinois and northeastern Texas.

Comparison of Simulated and Observed Concentrations

Scatter plots comparing simulated and observed 24-hour PM_{10} concentrations for AQS sites within the 4-km grid for the annual simulation period are presented in Figure 5-15. Units for PM_{10} are µg/m^3.

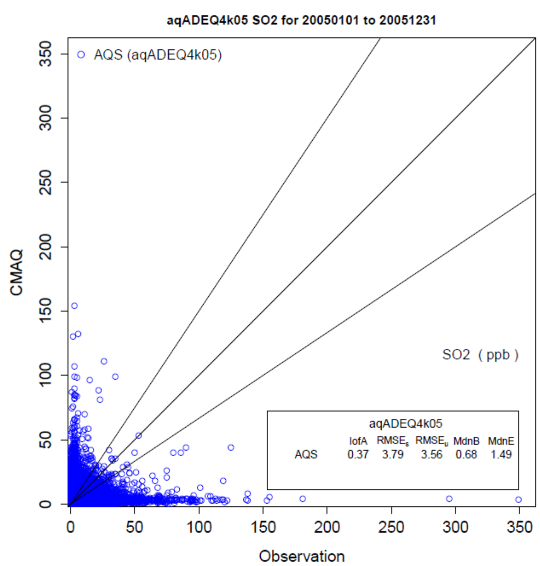
Figure 5-15. Comparison of Simulated and Observed 24-Hour Average PM_{10} Concentration ($\mu g/m^3$) for the 4-km Grid (All Months)



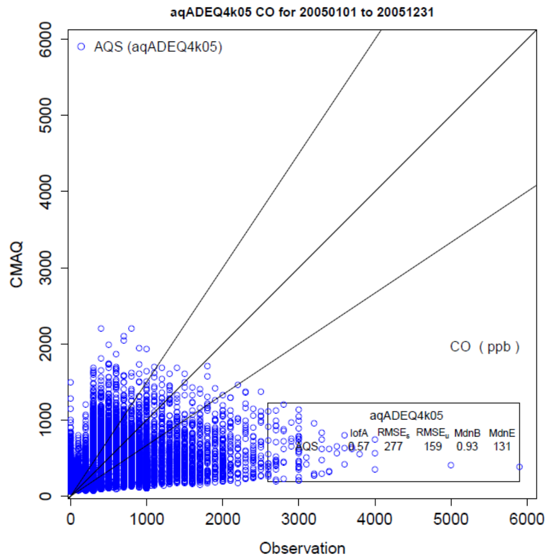
Scatter plots comparing simulated and observed hourly NO_x, SO_2, and CO concentrations for AQS sites within the 4-km grid for the annual simulation period are presented in Figure 5-16. Units for the gaseous species are ppb.

Figure 5-16. Comparison of Simulated and Observed Hourly Average NO_2, SO_2, and CO Concentrations (ppb) for the 4-km Grid (All Months)

NO_2/SO_2



CO



As expected, agreement between the simulated and observed values is not very good. PM_{10} concentrations are mostly underestimated, but there is a lot of scatter about the 1:1 line. High observed values tend to be underestimated while the low observed values are both under- and overestimated. Model performance for 1-hour NO_2, SO_2, and CO concentrations is characterized by a good deal of scatter about the 1:1 line and a tendency for overestimation of NO_2, and underestimation of CO.

Statistical Measures of Model Performance

Summary metrics and statistical measures for all months for PM_{10}, NO_x, and SO_2 for the 4-km grid are presented in Table 5-5. No lower bound was applied in calculating the statistics; fractional bias and error are emphasized.

Table 5-5. Summary Model Performance Statistics for PM_{10}, NO_2, SO_2 and CO for the 4-km Modeling Grid

Metric	PM_{10} (μg/m^{3})	NO_2 (ppb)	SO_2 (ppb)	CO (ppb)
Number of Data Pairs	3,758	82,062	180,525	55,333
Mean Observed (ppb)	23	8.0	2.4	308
Mean Simulated (ppb)	24.7	10.0	3.2	254
Mean Bias (ppb)	1.7	2.0	0.8	-53.5
Fractional Bias (%)	9.3	-4.4	4.8	-8.8
Mean Error (ppb)	14.3	5.7	2.6	205
Fractional Error (%)	55.8	63.8	75.2	65.6

The statistics suggest better model performance than the scatter plots. A fractional bias within ±67 percent indicates that the simulated values are, on average, within a factor of two of the observed values. This is achieved for all four pollutants. However, as indicated by the scatter plots and confirmed by the larger errors, the relatively low bias values for PM_{10}, NO_2, SO_2, and CO are due to a mix of under and overestimation and not necessarily to good model performance. The fractional error values are nonetheless within the goals established for $PM_{2.5}$.

5.2 2008 Simulation Period

CMAQ model performance for the base-year simulation for 2008 is summarized in the remainder of this section.

5.2.1 Summary of Model Performance for Ozone

CMAQ model performance for ozone focused on the typical ozone season months of April through October and is summarized in the remainder of this section.

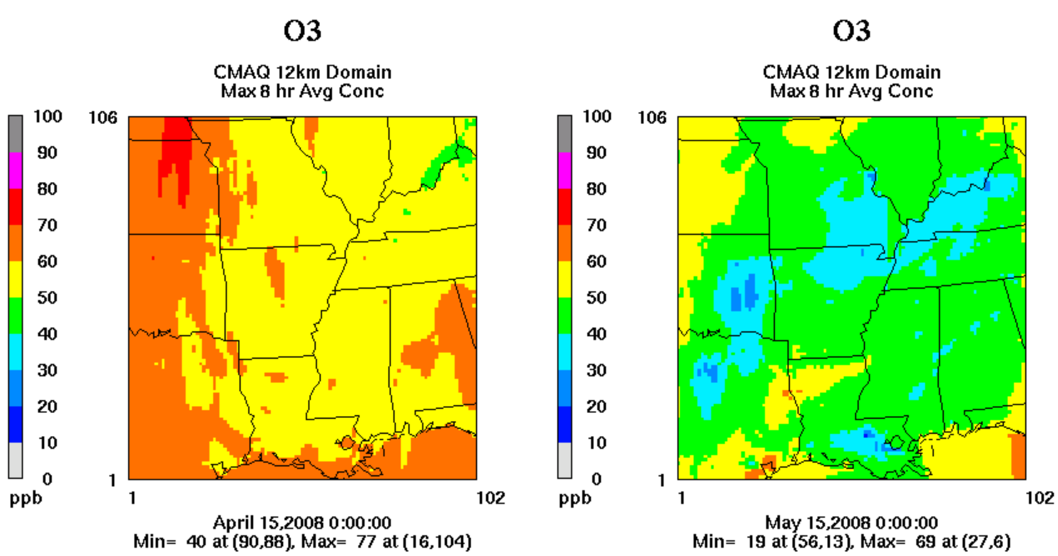
12-km Grid

Spatial Concentration Patterns

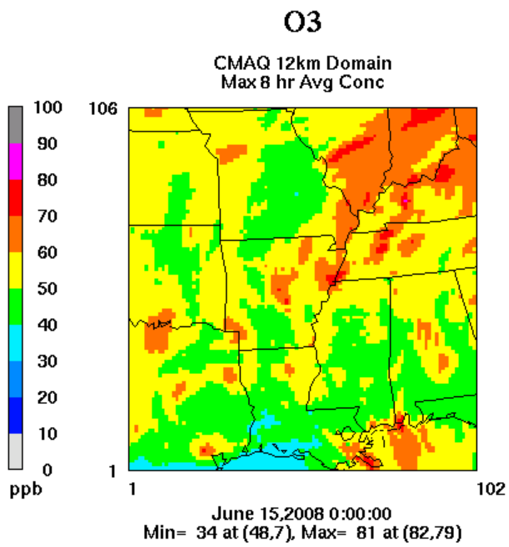
Spatial plots of the simulated ozone concentration patterns for the 12-km grid for selected days throughout the simulation period were plotted and examined. Figure 5-17 illustrates the simulated ozone concentration patterns for the 15th of each month (April – October). Consistent with the NAAQS for ozone, daily maximum 8-hour average ozone concentration is displayed. The units are parts per billion (ppb).

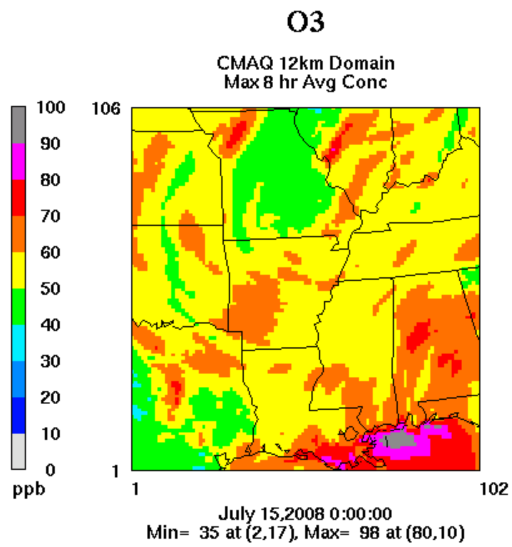
Figure 5-17. Simulated Daily Maximum 8-Hour Ozone Concentration (ppb) for Selected Days for the CMAQ 12-km Grid

April 15/May 15

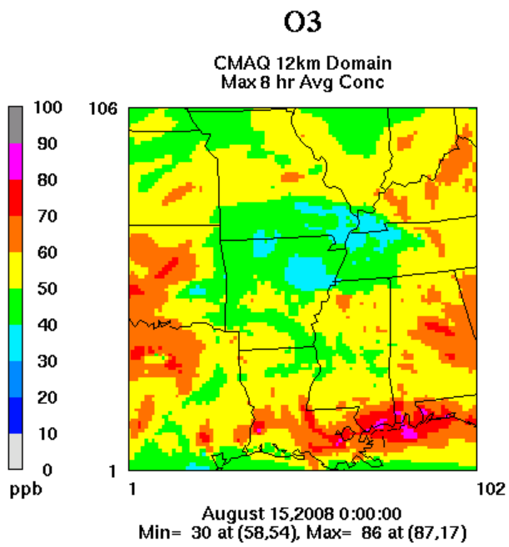


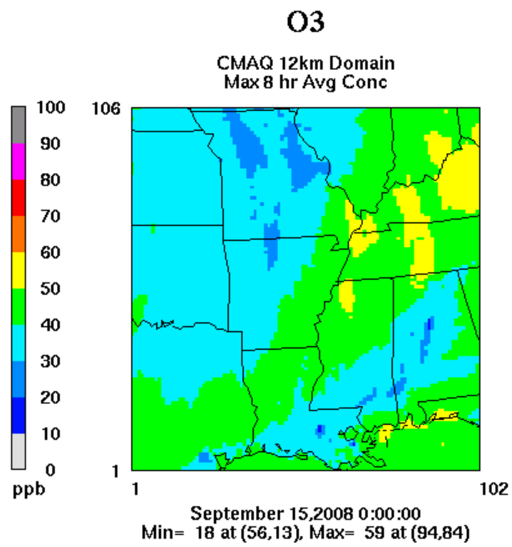
June 15/July 15



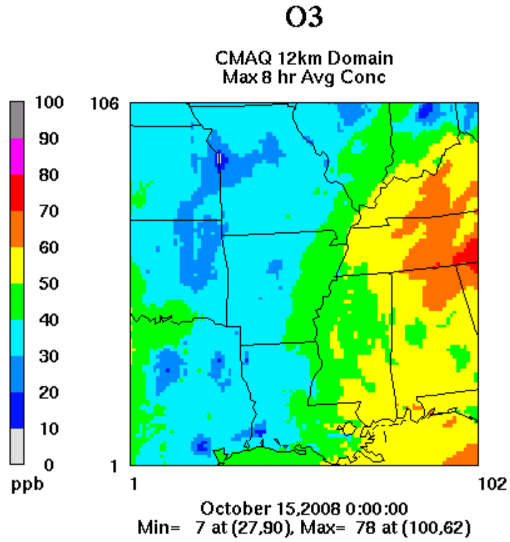


August 15/September 15





October 15

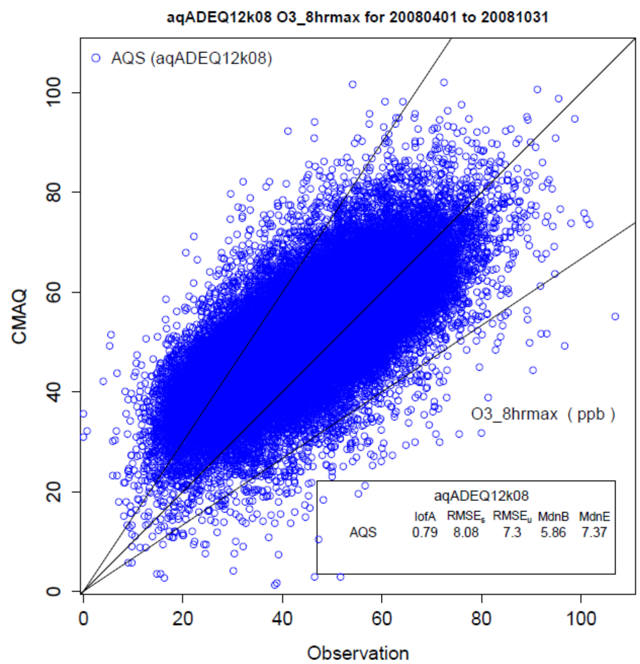


The plots depict a wide range of ozone concentration patterns for the selected days and illustrate the regional nature of ozone and potential transport patterns. Among the selected days, the simulated 8-hour average ozone concentrations are highest over Arkansas for the middle days of April, June, and July. Maximum 8-hour average concentrations for the 12-km grid range from 59 to 98 ppb for the selected days, overall slightly lower than for the 2005 annual simulation period.

Comparison of Simulated and Observed Concentrations

A scatter plot comparing simulated and observed daily maximum 8-hour ozone concentrations for the 12-km grid for April through October is presented in Figure 5-18. The scatter plot provides a visual representation of how well the simulated values match the observations, and can reveal biases toward over- or underestimation of the observed values. Also included on the scatter plot is some statistical information further summarizing model performance. Note that these statistical measures are calculated using the 8-hour average ozone concentrations.

Figure 5-18. Comparison of Simulated and Observed Daily Maximum 8-Hour Average Ozone Concentration (ppb) for the 12-km Grid (April through October)



There is a general tendency for CMAQ to overestimate the 8-hour average ozone concentrations, especially for observed values within the range of 20 to 40 ppb. Higher concentrations are well simulated and there is good correlation overall as indicated by an index of agreement of 0.79.

Statistical Measures of Model Performance

Summary metrics and statistical measures calculated using hourly ozone concentrations for the 12-km grid are presented in Table 5-6. The recommended ranges for the normalized bias and normalized error shown in this table are no longer a part of current EPA guidance but are still widely used for urban- and regional-scale model performance evaluations (EPA, 2007). A lower bound of 40 ppb was used in calculating the normalized bias and error statistics.

Table 5-6. Summary Model Performance Statistics for Ozone for the 12-km Modeling Grid

Metric	Apr	May	Jun	Jul	Aug	Sep	Oct	Apr-Oct	Goal
Number of Data Pairs	71,699	76,484	53,128	60,778	56,356	40,801	34,978	394,224	
Mean Observed (ppb)	50.7	50.6	51.7	53.0	51.7	52.0	49.6	51.4	
Mean Simulated (ppb)	48.9	46.7	49.5	52.9	53.4	53.1	48.6	50.2	
Mean Bias (ppb)	-1.8	-3.9	-2.2	-0.1	1.7	1.5	-1.1	-1.1	
Normalized Bias (%)	-2.7	-7.2	-3.7	0.6	4.1	2.7	-1.6	-1.6	**± 15**
Normalized Mean Bias (%)	-3.5	-7.7	-4.3	-0.3	3.2	2.2	-2.2	-2.2	
Fractional Bias (%)	-5.6	-10.7	-7.6	-3.3	0.0	-0.9	-4.6	-5.1	
Mean Error (ppb)	7.8	8.6	9.3	9.9	10.4	9.3	7.9	9.0	
Normalized Error (%)	15.7	17.3	18.6	19.5	20.8	18.7	16.2	18.1	**≤ 35**
Normalized Mean Error (%)	15.3	16.9	18.0	18.7	20.1	17.9	15.9	17.5	
Fractional Error (%)	17.3	19.7	20.6	20.8	21.6	19.9	17.8	19.7	
Correlation (unitless)	0.49	0.49	0.52	0.52	0.47	0.55	0.49	0.51	
Index of Agreement (unitless)	0.67	0.64	0.68	0.69	0.65	0.70	0.66	0.68	

The statistical measures indicate very good agreement, on average, between the simulated and observed concentrations for all months. The normalized bias is well within ±15 percent and the normalized error is well within 35 percent for all months. Using a lower bound value of 60 ppb for the calculation of the statistics, the normalized mean bias for the multi-month period (April- October) is -7.3 percent and the normalized mean error is 13.6 percent, indicating some underestimation of the higher ozone values but also very good model performance.

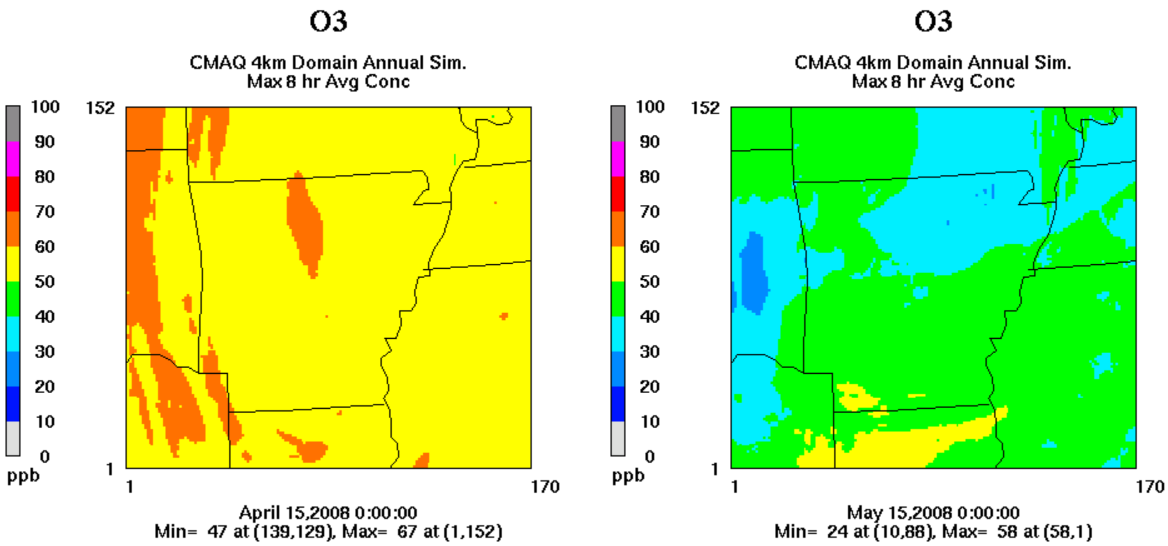
Ozone Model Performance for the 4-km Grid

Spatial Concentration Patterns

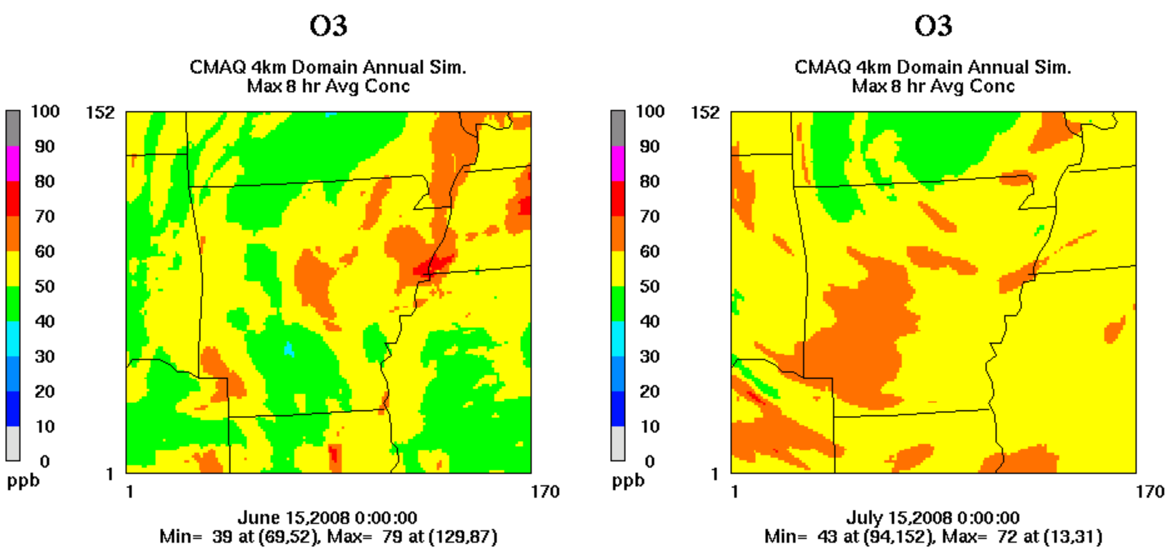
Spatial plots of the simulated ozone concentration patterns for the 4-km grid for selected days throughout the simulation period were plotted and examined. Figure 5-19 illustrates the daily maximum 8-hour average ozone concentration patterns for the 15th of each month (April – October). Units are parts per billion (ppb).

Figure 5-19. Simulated Daily Maximum 8-Hour Ozone Concentration (ppb) for Selected Days for the CMAQ 4-km Grid

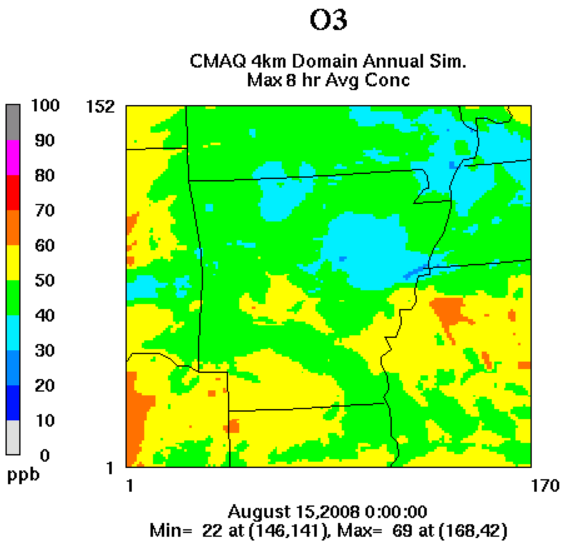
April 15/May 15

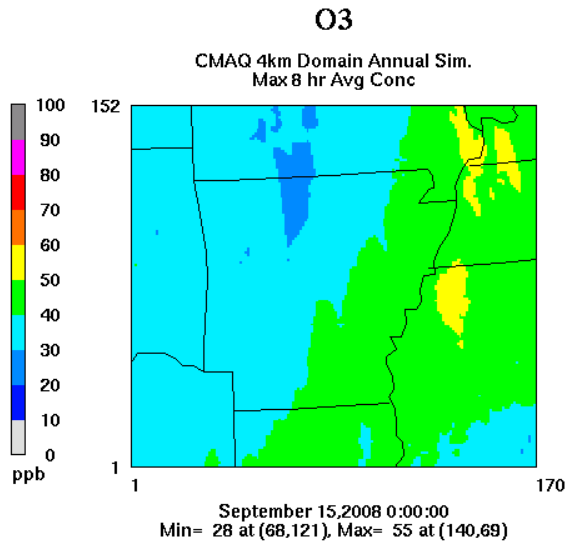


June 15/July 15

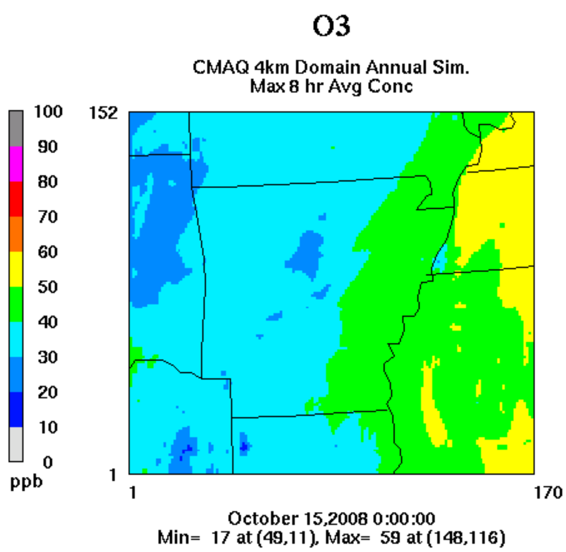


August 15/September 15





October 15

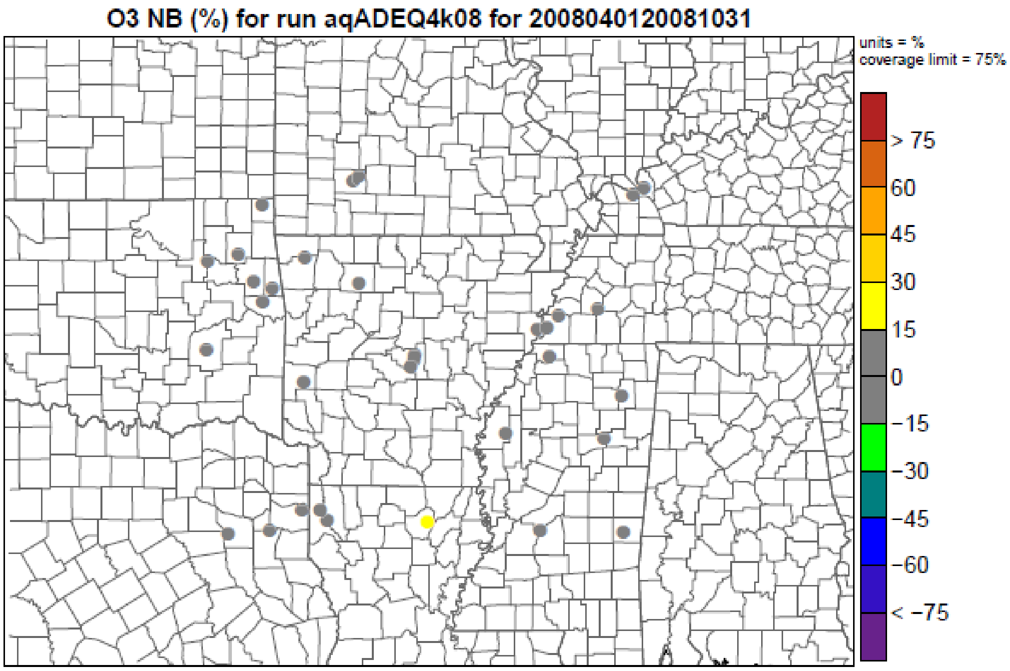


Simulated ozone concentrations over Arkansas for the selected days are mostly in the low to moderate range (40 to 60 ppb). Among the selected days, the highest simulated concentration (79 ppb) occurs near Memphis (Crittenden County) on July 15. Overall, the plots reflect the relatively low ozone concentrations that characterized the 2008 simulation period.

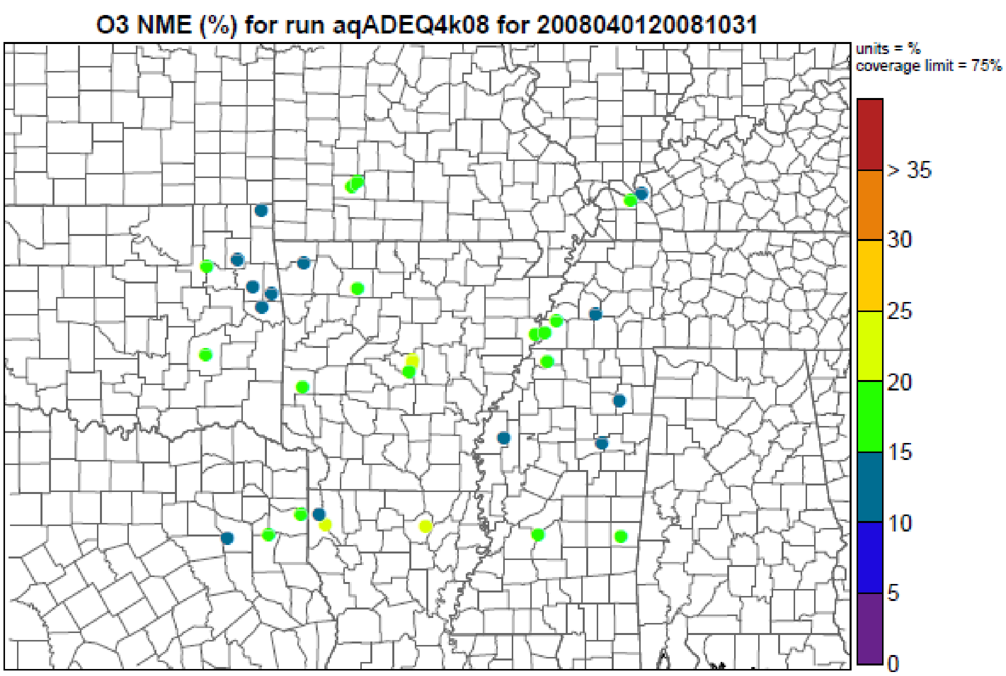
Figure 5-20 depicts the average bias and error for all sites in the 4-km modeling grid, based on daily maximum 8-hour ozone concentrations for the ozone season months (April through October). For the normalized bias, gray shaded circles indicate that the bias is within ± 15 percent; blue and green shading indicates underestimation of the observed concentrations and yellow, orange, and red shading indicates overestimation. For the normalized mean error, blue and green shading represent the smaller errors, while red indicates an error greater than 35 percent. A lower bound of 40 ppb was used in calculating the normalized bias and error statistics. Note that the plotted area is slightly larger than the 4-km grid, but that information is presented only for sites within the 4-km grid.

Figure 5-20. Normalized Bias (%) and Normalized Mean Error (%) Based on Daily Maximum 8-Hour Average Simulated and Observed Ozone Concentrations for April through October for the CMAQ 4-km Grid

Normalized Bias



Normalized Mean Error

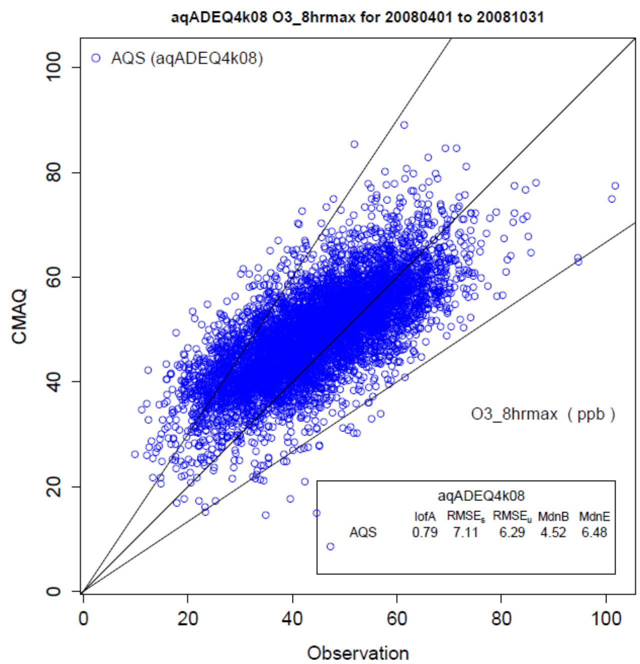


Model performance is consistently good throughout the 4-km grid and no distinct spatial patterns emerge. For all but one monitoring site, the normalized bias is within ± 15 percent (as indicated by the gray shading). The normalized mean error is less than 35 percent (actually less than 25 percent) for all sites and months.

Comparison of Simulated and Observed Concentrations

A scatter plot comparing simulated and observed daily maximum 8-hour ozone concentrations for the 4-km grid for April through October is presented in Figure 5-21. Again, note that the statistical measures given on the plot are calculated using the 8-hour average ozone concentrations.

Figure 5-21. Comparison of Simulated and Observed Daily Maximum 8-Hour Average Ozone Concentration (ppb) for the 4-km Grid (April through October)



There is a slight tendency for CMAQ to overestimate the lower concentrations and underestimate the highest concentrations, but there is good agreement overall as indicated by an index of agreement of 0.79.

Statistical Measures of Model Performance

Summary metrics and statistical measures calculated using hourly ozone concentrations for the 4-km grid are presented in Table 5-7. A lower bound of 40 ppb was used in calculating the normalized bias and error statistics.

Table 5-7. Summary Model Performance Statistics for Ozone for the 4-km Modeling Grid

Metric	Apr	May	Jun	Jul	Aug	Sep	Oct	Apr-Oct	Goal
Number of Data Pairs	9,527	9,099	5,747	8,406	7,148	4,451	5,125	49,503	
Mean Observed (ppb)	49.7	50.1	50.5	52.6	50.3	5.2	48.6	50.5	
Mean Simulated (ppb)	47.9	45.6	47.2	51.1	50.3	51.2	46.0	48.4	
Mean Bias (ppb)	-1.8	-4.5	-3.3	-1.6	0.0	0.0	-2.6	-2.1	
Normalized Bias (%)	-2.9	-8.2	-5.6	-2.1	0.5	0.8	-5.1	-3.5	**± 15**
Normalized Mean Bias (%)	-3.6	-8.9	-6.5	-3.0	0.1	0.0	-5.4	-4.1	
Fractional Bias (%)	-5.0	-11.1	-8.7	-5.3	-3.5	-1.6	-7.5	-6.4	
Mean Error (ppb)	7.0	6.4	8.6	9.1	9.6	7.8	6.8	8.2	
Normalized Error (%)	14.2	16.5	17.1	17.8	19.7	15.8	14.1	16.5	**≤ 35**
Normalized Mean Error (%)	14.0	16.4	17.0	17.2	19.1	15.3	13.9	16.2	
Fractional Error (%)	15.3	18.7	19.0	19.2	21.3	16.5	15.8	18.1	
Correlation (unitless)	0.48	0.42	0.49	0.49	0.47	0.51	0.51	0.48	
Index of Agreement (unitless)	0.67	0.60	0.66	0.68	0.63	0.70	0.66	0.66	

The statistical measures for the 4-km grid show underestimation of ozone for most months, with the exception of August and September. The normalized bias is well within ±15 percent and the normalized error is well within 35 percent for all months and for the ozone season. Using a lower-bound value of 60 ppb, the normalized mean bias for the multi-month period (April- October) is –10.7 percent and the normalized mean error is 14.4 percent, also within the model performance goals.

5.2.2 Summary of Model Performance for $PM_{2.5}$

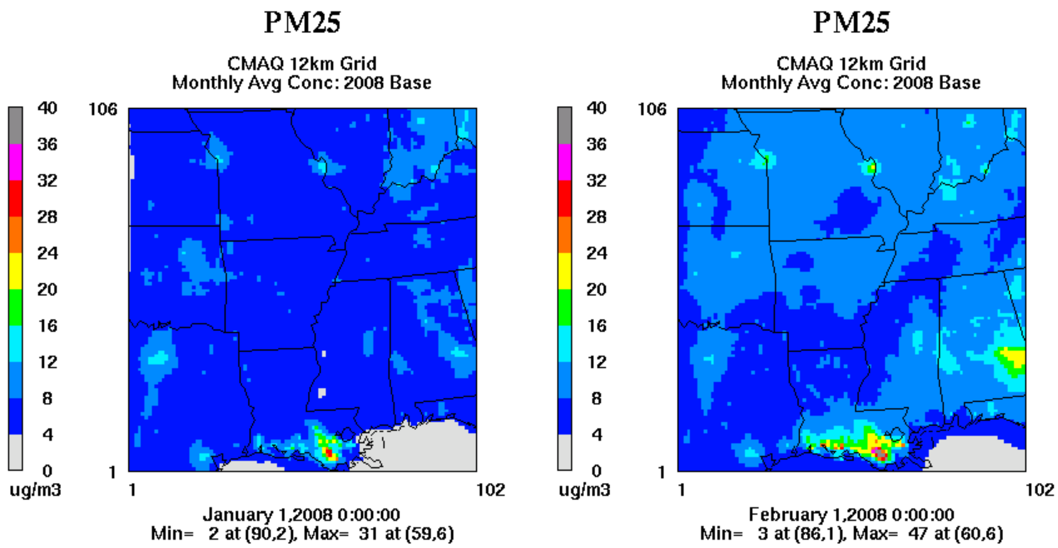
12-km Grid

Spatial Concentration Patterns

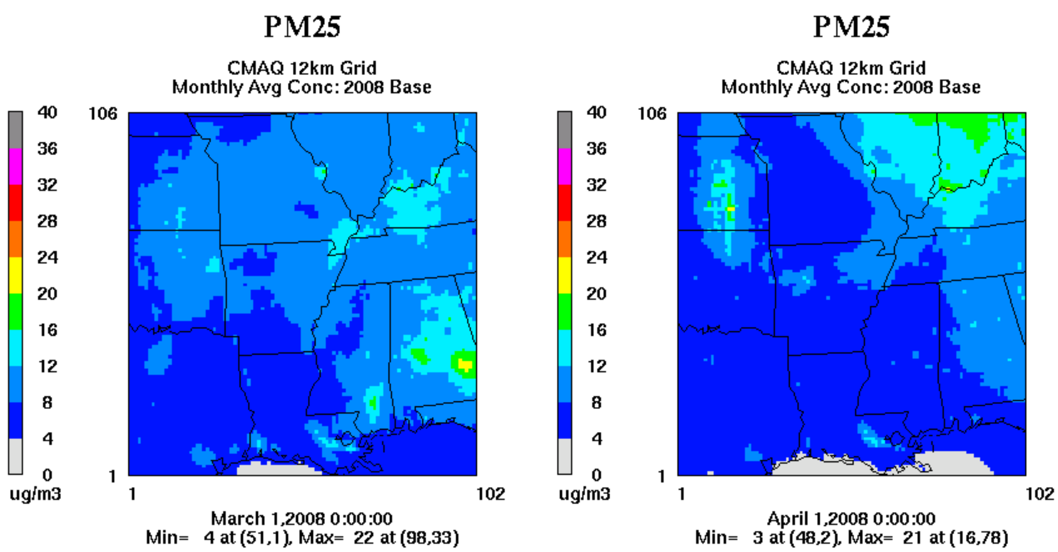
Spatial plots of the monthly average simulated $PM_{2.5}$ concentration patterns for the 12-km grid are illustrated in Figure 5-22. The units are micrograms per cubic meter (µg/m^3).

Figure 5-22. Simulated Monthly Average $PM_{2.5}$ Concentration ($\mu g/m^3$) for the CMAQ 12-km Grid

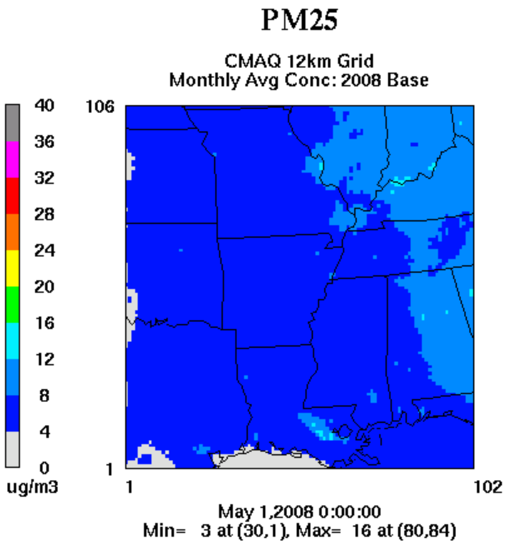
January/February

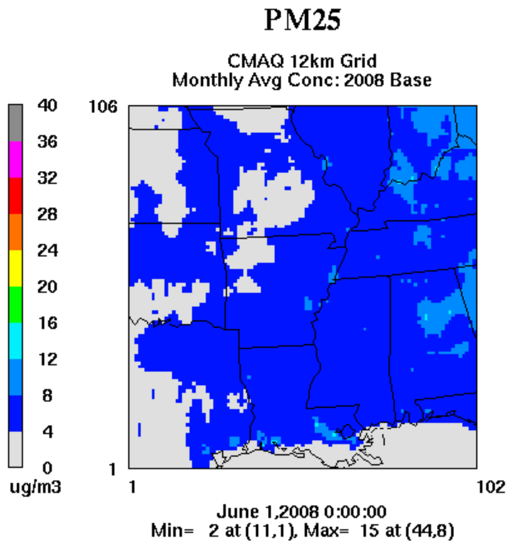


March/April

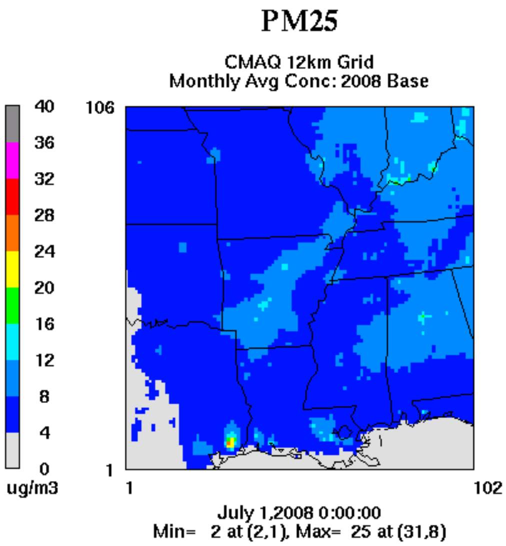


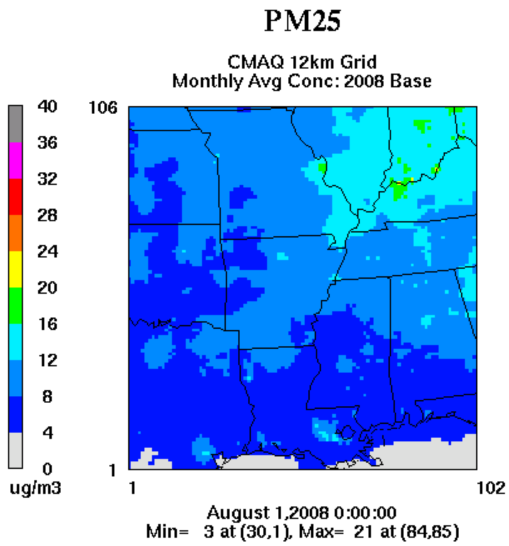
May/June



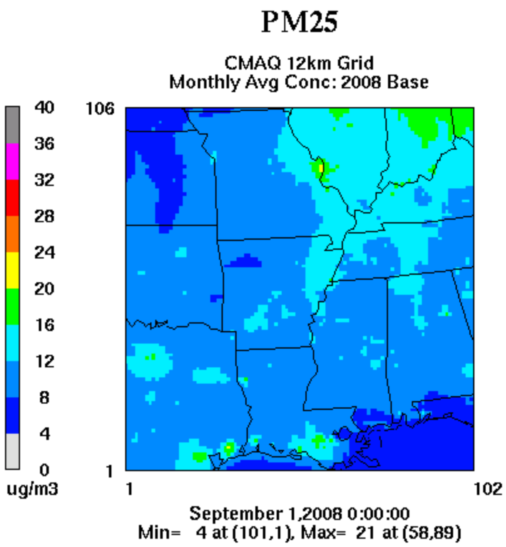


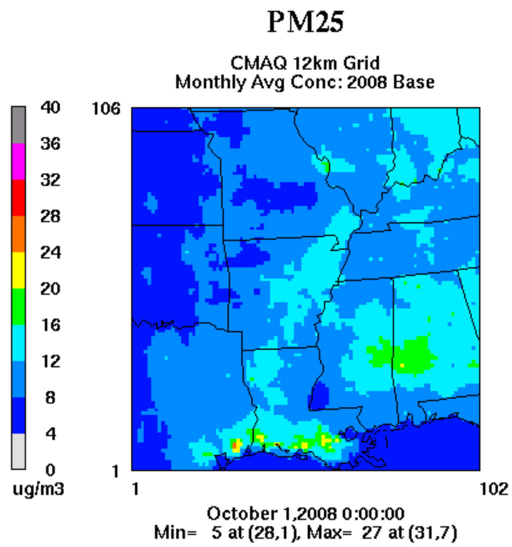
July/August



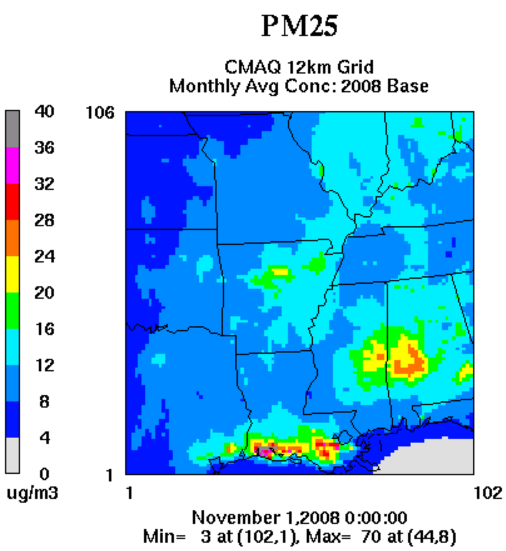


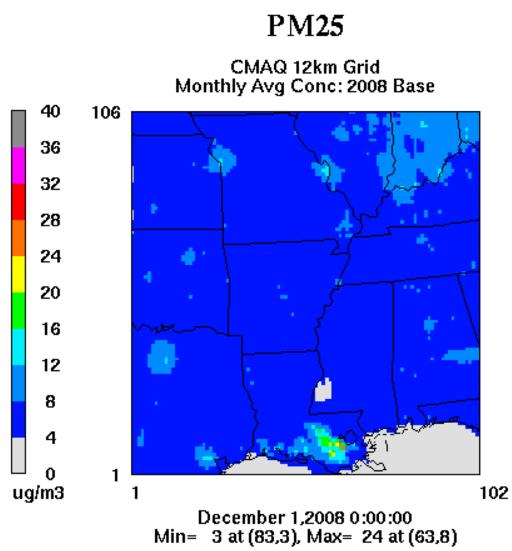
September/October





November/December

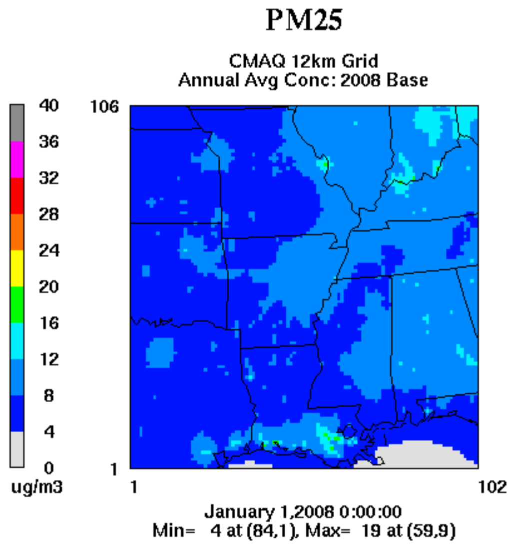




For most months, the simulated monthly average $PM_{2.5}$ concentrations over Arkansas are low – in some cases less than 8 μg/m^3 and in most cases less than 12 μg/m^3. The simulated concentrations are highest for September, October and November. For November, concentrations greater than 20 μg/m^3 occur over the north-central and northeastern portions of the state.

Figure 5-23 displays the annual average simulated $PM_{2.5}$ concentration pattern for the 12-km grid.

Figure 5-23. Simulated Annual Average $PM_{2.5}$ Concentration (µg/m^3) for the CMAQ 12-km Grid

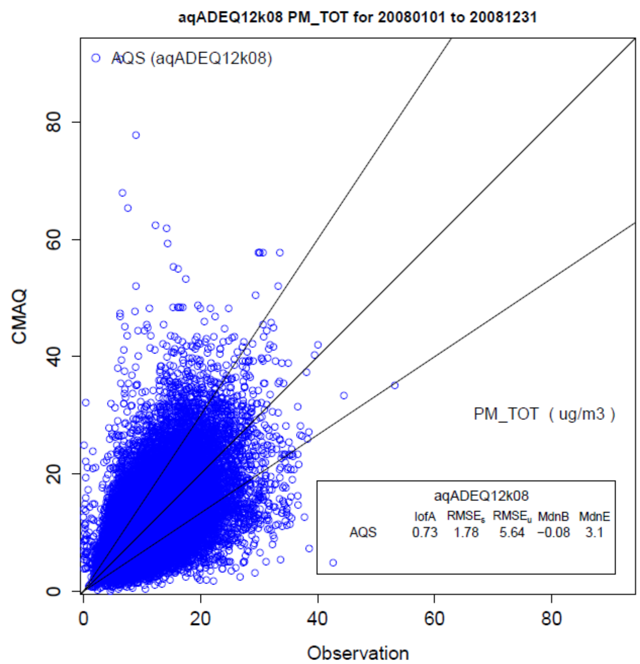


The simulated annual average concentrations range from about 4 to 12 µg/m^3 over Arkansas and across most of the 12-km grid. The maximum simulated annual average $PM_{2.5}$ concentration is only 19 µg/m^3 and is located along the coast of Louisiana.

Comparison of Simulated and Observed Concentrations

Scatter plots comparing simulated and observed 24-hour $PM_{2.5}$ concentrations for AQS sites within the 12-km grid for the annual simulation period are presented in Figure 5-24.

Figure 5-24. Comparison of Simulated and Observed 24-Hour Average $PM_{2.5}$ Concentration ($\mu g/m^3$) for the 12-km Grid (All Months)



The scatter plot indicates both over and underestimation of the observed annual average $PM_{2.5}$ concentrations within the 12-km grid, but overall good correlation as indicated by an index of agreement of 0.73.

Statistical Measures of Model Performance

Summary metrics and statistical measures calculated using 24-hr $PM_{2.5}$ concentrations for the 12-km grid are presented in Table 5-8. The recommended ranges for the fractional bias and fractional error are based on Boylan (2005) and are widely used for regional-scale model performance evaluation for $PM_{2.5}$. No lower bound was applied in calculating the statistics.

Table 5-8. Summary Model Performance Statistics for $PM_{2.5}$ for the 12-km Modeling Grid

Metric	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Dec	Annual	Goal
Number of Data Pairs	6,717	6,363	6,526	6,511	26,135	
Mean Observed (ppb)	10.7	11.0	14.6	10.3	11.6	
Mean Simulated (ppb)	11.6	10.0	12.5	13.4	11.9	
Mean Bias (ppb)	0.9	-1.0	-2.1	3.0	0.2	
Fractional Bias (%)	3.7	-13.9	-18.7	21.2	-1.8	**± 60**
Mean Error (ppb)	4.0	3.8	4.8	4.4	4.3	
Fractional Error (%)	35.1	36.8	37.7	36.2	36.4	**≤ 75**
Correlation (unitless)	0.55	0.50	0.58	0.70	0.56	
Index of Agreement (unitless)	0.71	0.69	0.74	0.75	0.73	

On average, $PM_{2.5}$ concentrations are overestimated for first and fourth quarters and underestimated for the second and third quarters. The lowest bias and error values and thus the best model performance are achieved for the first quarter, when observed $PM_{2.5}$ concentrations are relatively low. The statistical measures for fractional bias and fractional error are well within the model performance goals for all periods.

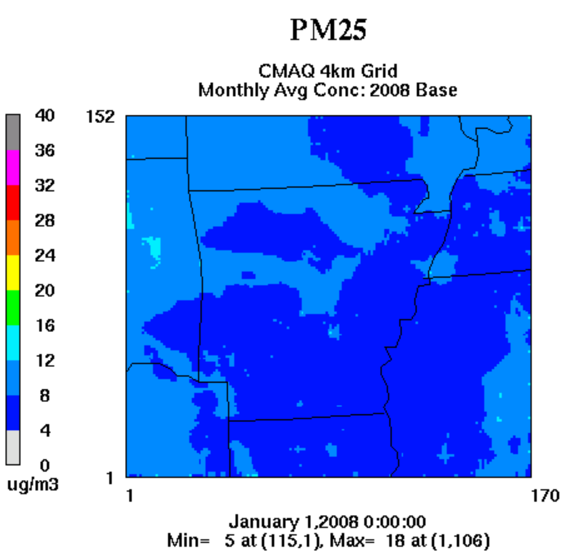
4-km Grid

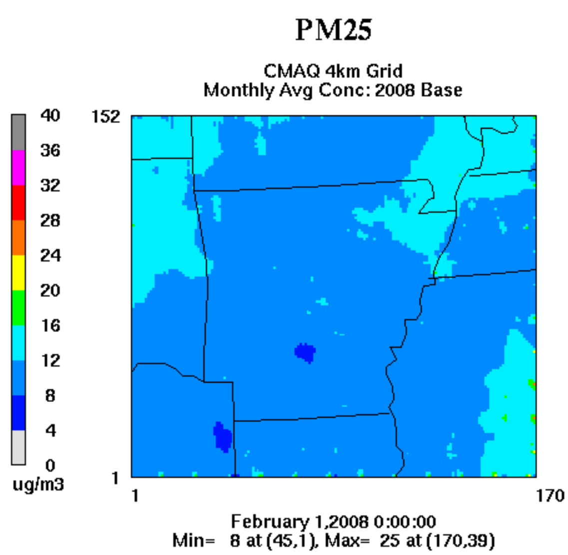
Spatial Concentration Patterns

Spatial plots of the monthly average simulated $PM_{2.5}$ concentration patterns for the 4-km grid are illustrated in Figure 5-25. The units are micrograms per cubic meter (μg/m^3).

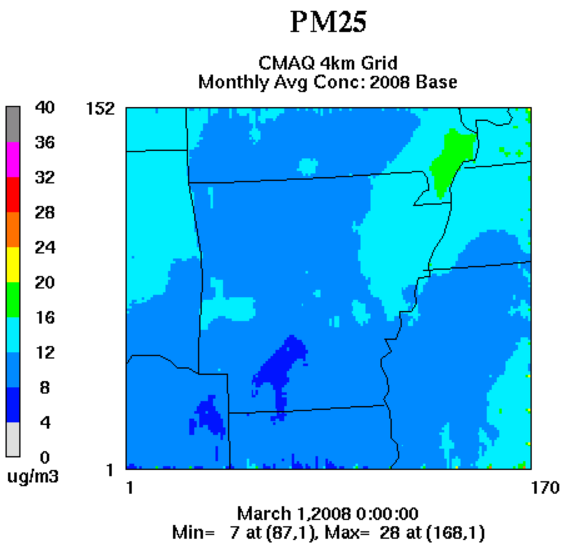
Figure 5-25. Simulated Monthly Average $PM_{2.5}$ Concentration (μg/m^3) for the CMAQ 4-km Grid

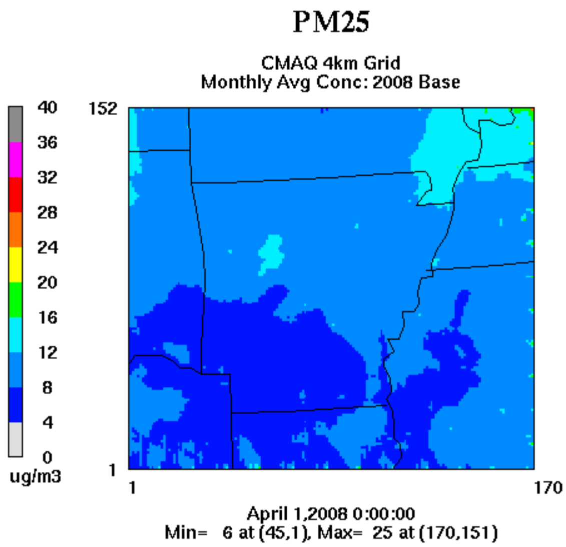
January/February



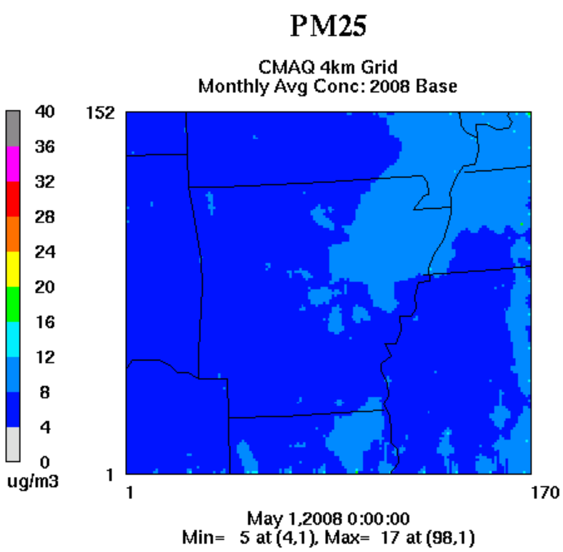


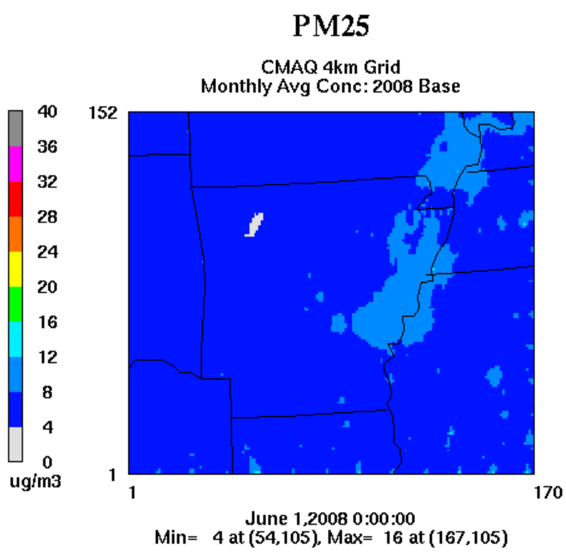
March/April



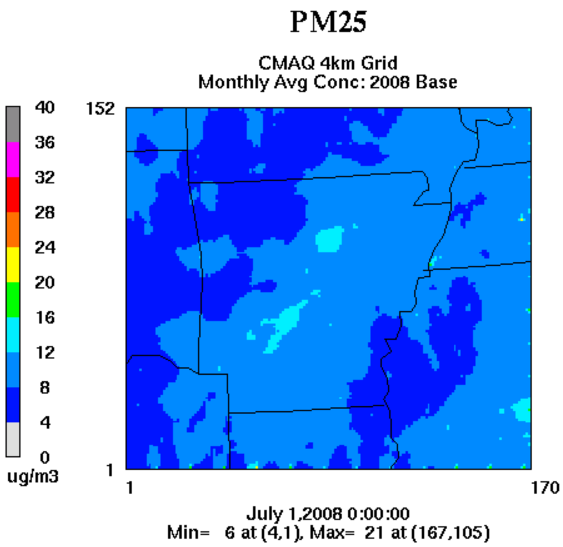


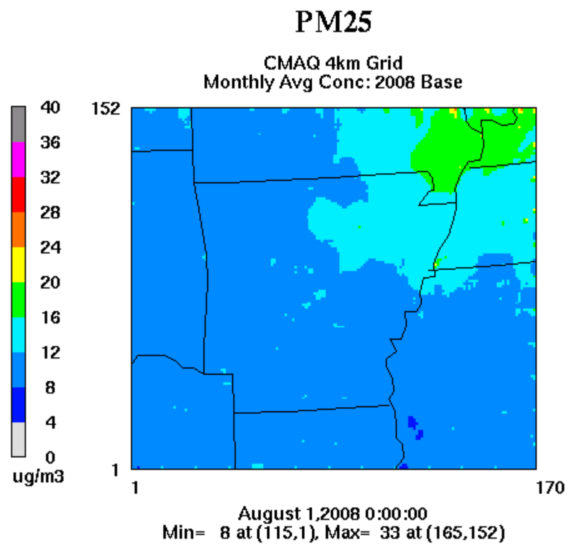
May/June



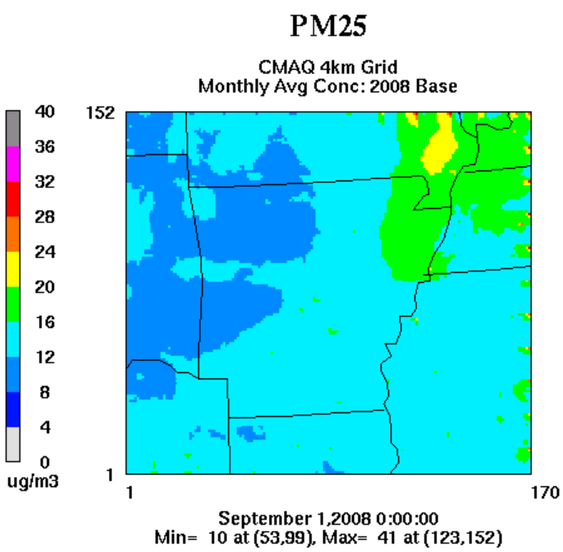


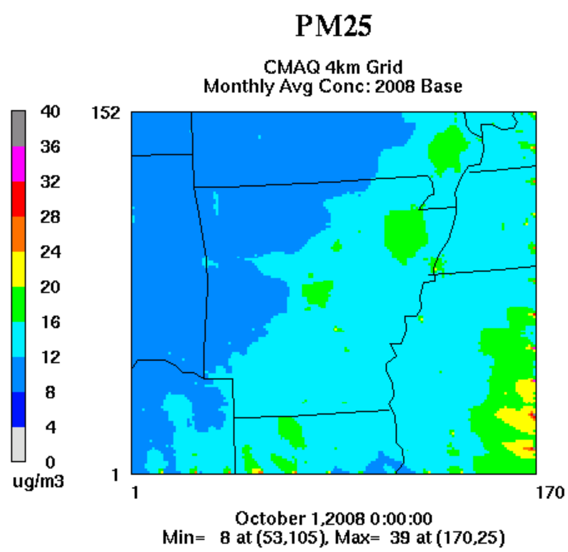
July/August



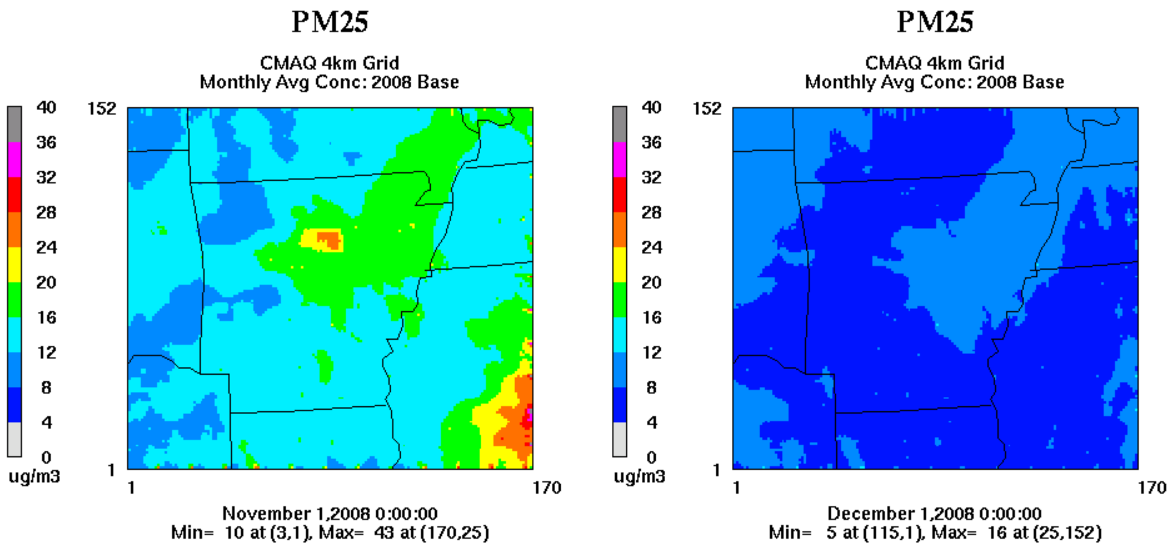


September/October





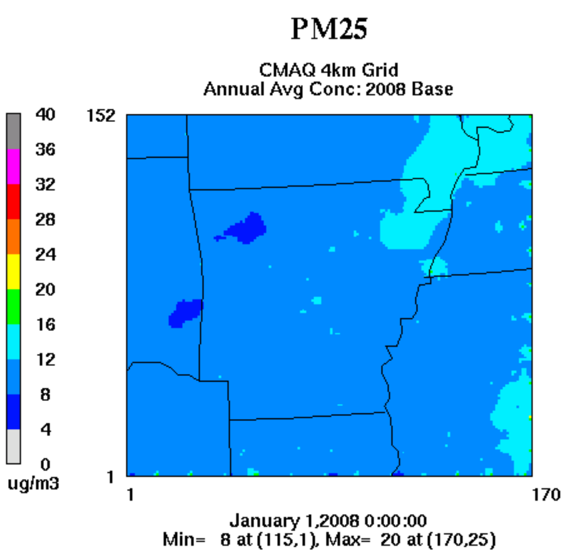
November/December



For most months, the simulated monthly average $PM_{2.5}$ concentrations over Arkansas are generally within the range of 4 to 16 µg/m^3. A few months (May, June, and December) are characterized by lower concentrations. September, October, and November have somewhat higher concentrations (with maximum values in the 16 to 28 µg/m^3 range).

Figure 5-26 displays the annual average simulated $PM_{2.5}$ concentration pattern for the 4-km grid.

Figure 5-26. Simulated Annual Average $PM_{2.5}$ Concentration (µg/m^3) for the CMAQ 4-km Grid

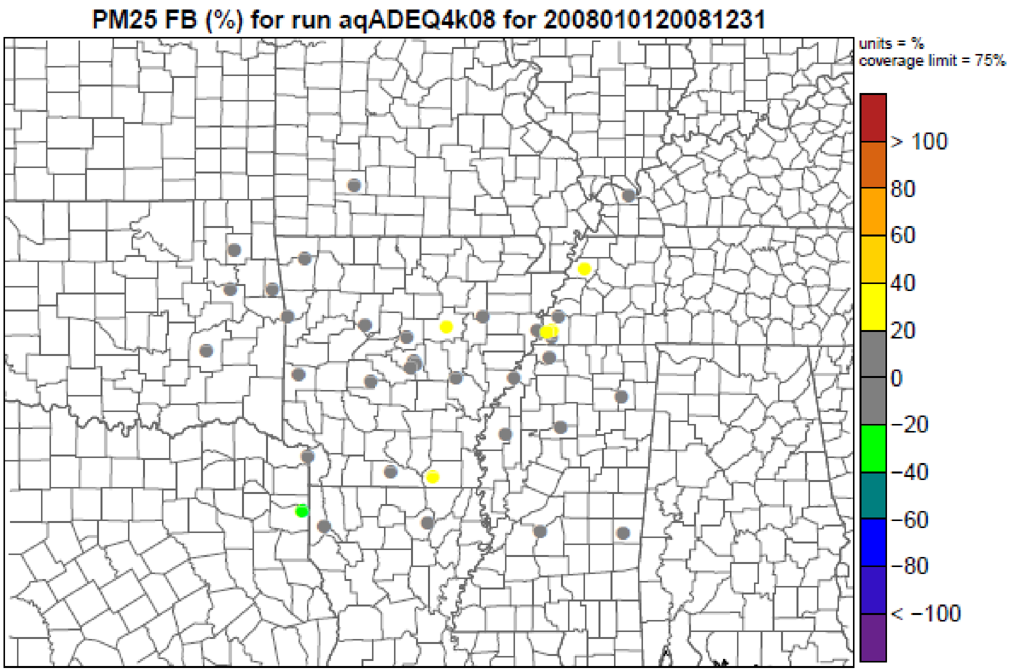


The simulated annual average $PM_{2.5}$ concentrations for 2008 are less than 16 µg/m^3 throughout the state of Arkansas. The highest concentrations occur near Little Rock and Memphis, and in the northeast portion of the state.

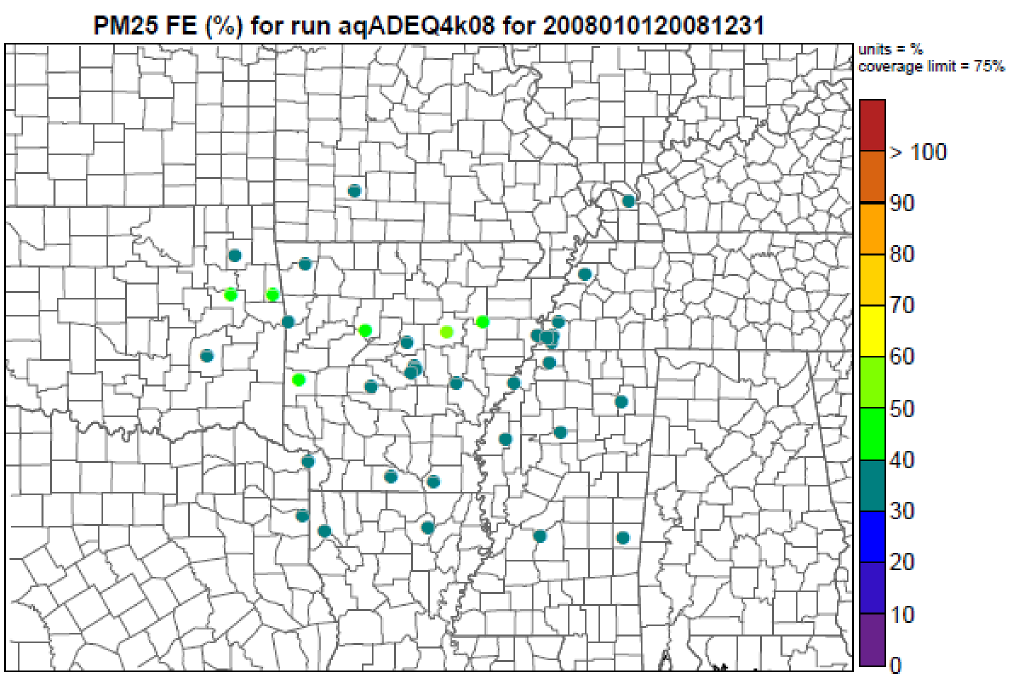
To illustrate the agreement between the simulated and observed values, Figure 5-27 depicts the fractional bias and fractional error statistics for the 4-km modeling domain. The statistics are calculated using 24-hour average $PM_{2.5}$ concentrations and are calculated using data for the annual simulation period. Again, each monitoring site is represented by a circle and the shading of the circle provides information about how well the 24-hour observed $PM_{2.5}$ concentrations are represented by the simulation results, on average. For the fractional bias, gray shaded circles indicate that the fractional bias is within ± 20 percent and, in general, values within ±60 percent (lighter colors) correspond to acceptable model performance. Blue and green shading indicates underestimation of the observed concentrations and yellow, orange, and red shading indicates overestimation. For the fractional error, blue and green shading represent the smaller errors, while red indicates an error greater than 100 percent. Values less than 75 percent are considered to represent reasonable model performance for $PM_{2.5}$.

Figure 5-27. Fractional Bias (%) and Fractional Error (%) Based on 24-Hour Average Simulated and Observed $PM_{2.5}$ Concentrations for CMAQ 4-km Grid (All Months)

Fractional Bias



Fractional Error

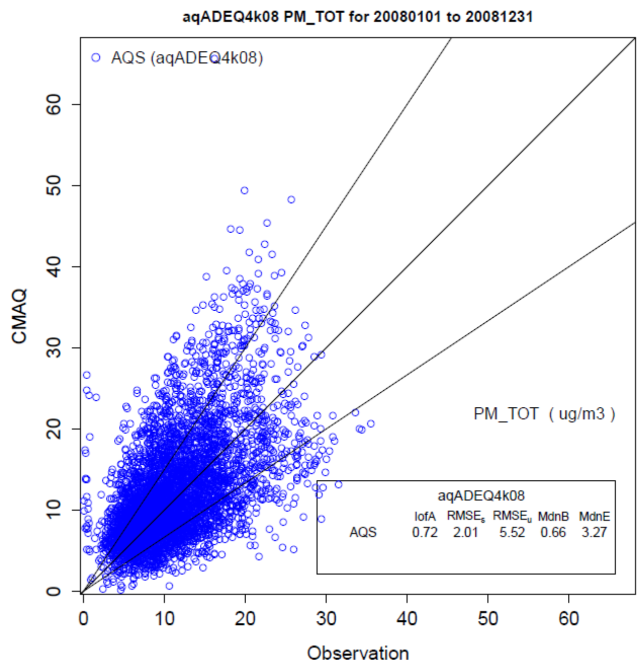


The fractional bias is within the range of -40 to 40 percent (as indicated by the green, gray and yellow shading) and the fractional error is less than 60 percent for all sites.

Comparison of Simulated and Observed Concentrations

Scatter plots comparing simulated and observed 24-hour $PM_{2.5}$ concentrations for AQS sites within the 4-km grid for the annual simulation period are presented in Figure 5-28.

Figure 5-28. Comparison of Simulated and Observed 24-Hour Average $PM_{2.5}$ Concentration ($\mu g/m^3$) for the 4-km Grid (All Months)



The scatter plot shows a tendency for overestimation but otherwise fairly good agreement between the simulated and observed $PM_{2.5}$ concentrations.

Statistical Measures of Model Performance

Summary metrics and statistical measures calculated using 24-hr $PM_{2.5}$ concentrations for the 4-km grid are presented in Table 5-9. The recommended ranges for the fractional bias and fractional error are based on Boylan (2005) and are widely used for regional-scale model performance evaluation for $PM_{2.5}$. No lower bound was applied in calculating the statistics.

Table 5-9. Summary Model Performance Statistics for $PM_{2.5}$ for the 4-km Modeling Grid

Metric	Jan–Mar	Apr–Jun	Jul–Sep	Oct–Dec	Annual	Goal
Number of Data Pairs	1,258	1,161	1,201	1,174	4,794	
Mean Observed (ppb)	9.5	10.4	14.8	10.5	11.3	
Mean Simulated (ppb)	11.6	9.4	13.3	14.8	12.3	
Mean Bias (ppb)	2.2	-1.0	-1.5	4.2	1.0	
Fractional Bias (%)	19.9	-11.0	-16.0	31.4	6.2	**± 60**
Mean Error (ppb)	3.9	3.1	5.1	5.4	4.4	
Fractional Error (%)	36.7	32.9	38.2	42.5	37.6	**≤ 75**
Correlation (unitless)	0.51	0.51	0.55	0.67	0.54	
Index of Agreement (unitless)	0.66	0.70	0.72	0.71	0.72	

On average, $PM_{2.5}$ concentrations are overestimated for the 4-km grid for the first and fourth quarters and underestimated for the second and third quarters. Thus, model performance is a bit inconsistent throughout the simulation period. Overestimation during the winter months was also noted for the 2005 simulation period. The fractional bias and error values are well within the model performance goals for all periods.

5.2.3 Summary of Model Performance for PM_{10}, NO_x, SO_2 and CO

Model performance for PM_{10}, NO_x, SO_2 and CO was examined with emphasis on quarterly and annual average concentrations. Observed concentrations of these criteria pollutants are generally expected to represent local rather than regional scale concentrations. This is due to the fact that these pollutants are directly emitted into the atmosphere and also because the monitoring sites are typically located in urban areas and near roadways. A grid-based model like CMAQ may not be able to capture the sub grid-scale variations in concentration reflected in the data that are due to local emissions sources and thus may not agree with the observed data unless the data are representative of area encompassed by a grid cell. Thus, model performance for these species was examined only for the 4-km grid.

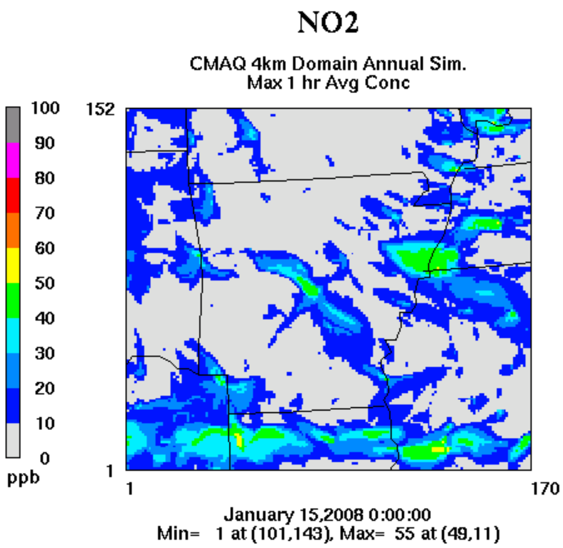
4-km Grid

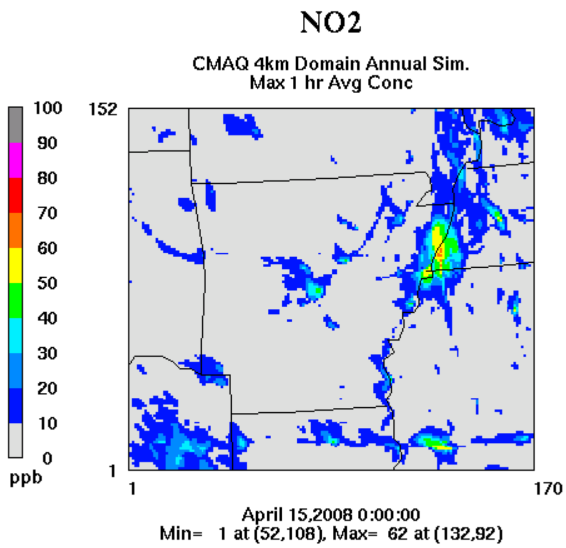
Spatial Concentration Patterns for NO_2 and SO_2

Spatial plots of the simulated NO_2 and SO_2 concentration patterns for the 4-km grid for selected days throughout the simulation period were plotted and examined. Figures 5-29 and 5-30 illustrate the daily maximum 1-hour average NO_2 concentration patterns and daily maximum 1-hour average SO_2 concentration patterns, respectively, for the 15th of January, April, July, and October (one day per quarter). These are provided primarily as a point of reference for the difference plots presented in Section 6. Units are parts per billion (ppb).

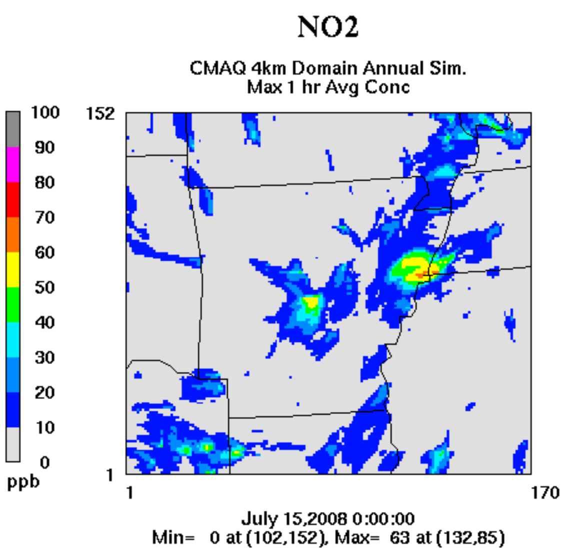
Figure 5-29. Simulated Daily Maximum 1-NO_2 Concentration (ppb) for Selected Days for the CMAQ 4-km Grid

January 15/April 15





July 15/October 15



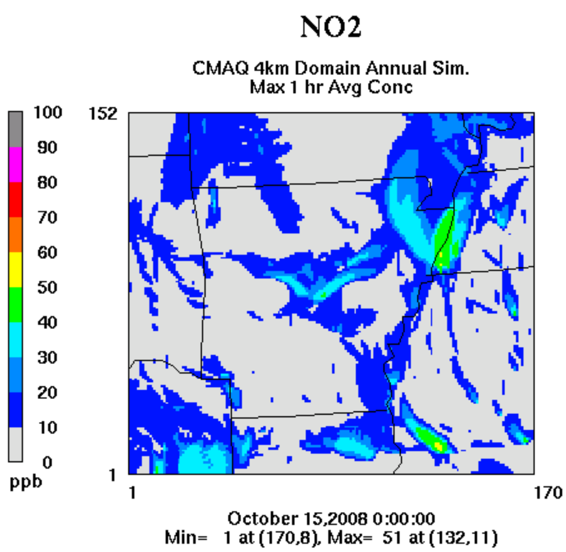
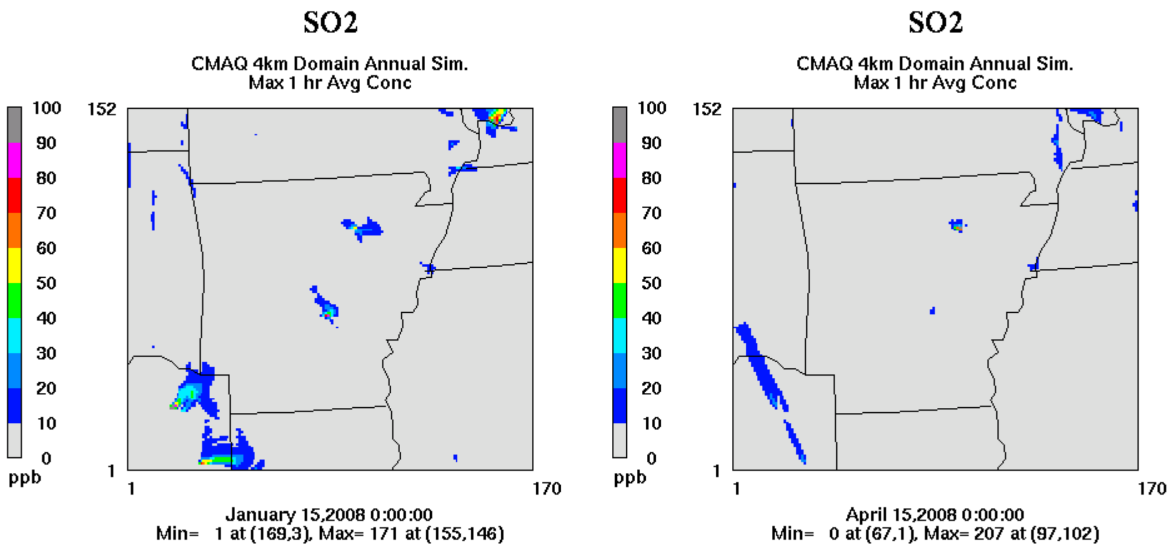
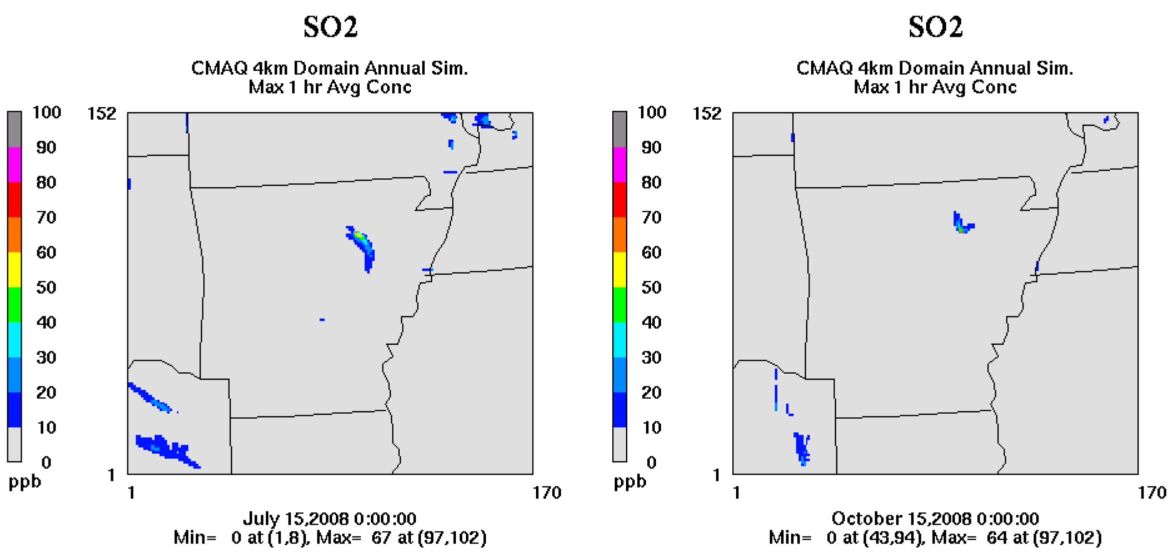


Figure 5-30. Simulated Daily Maximum 1-SO_2 Concentration (ppb) for Selected Days for the CMAQ 4-km Grid

January 15/April 15



July 15/October 15

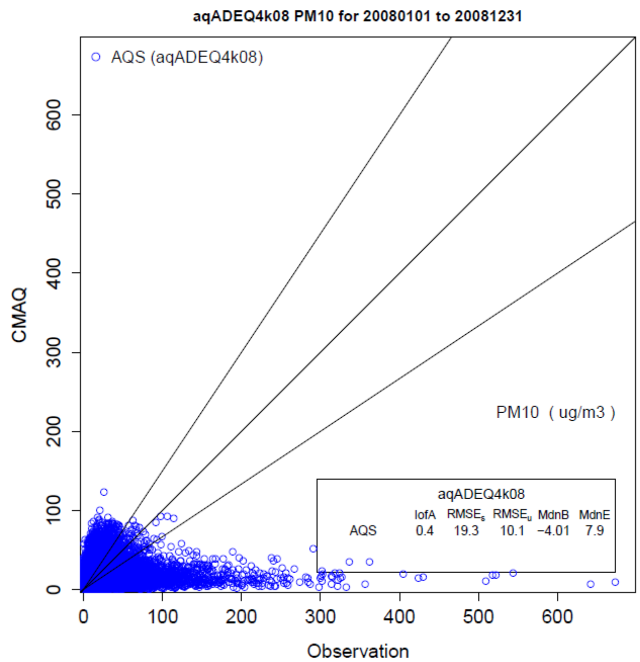


As for 2005, the simulated NO_2 concentrations for 2008 are highest over and downwind of Memphis, Little Rock, and (in some cases) other urban areas. There are a couple of areas of high SO_2 concentrations within Arkansas, as well as in southern Illinois and northeastern Texas. The majority of these areas are located downwind of various EGUs or other large industrial sources. For example, the high SO_2 "plumes" in northeastern Arkansas (near Batesville), depicted in the monthly plots, are from the FutureFuel Chemical Co. source, the former Eastman Chemical Co. facility. The FutureFuel facility started operations in 2006 and for 2008 was the largest non-EGU SO_2 source in the state with SO_2 emission levels of 2,881 tons per year.

Comparison of Simulated and Observed Concentrations

Scatter plots comparing simulated and observed 24-hour PM_{10} concentrations for AQS sites within the 4-km grid for the annual simulation period are presented in Figure 5-31. Units for PM_{10} are µg/m^3.

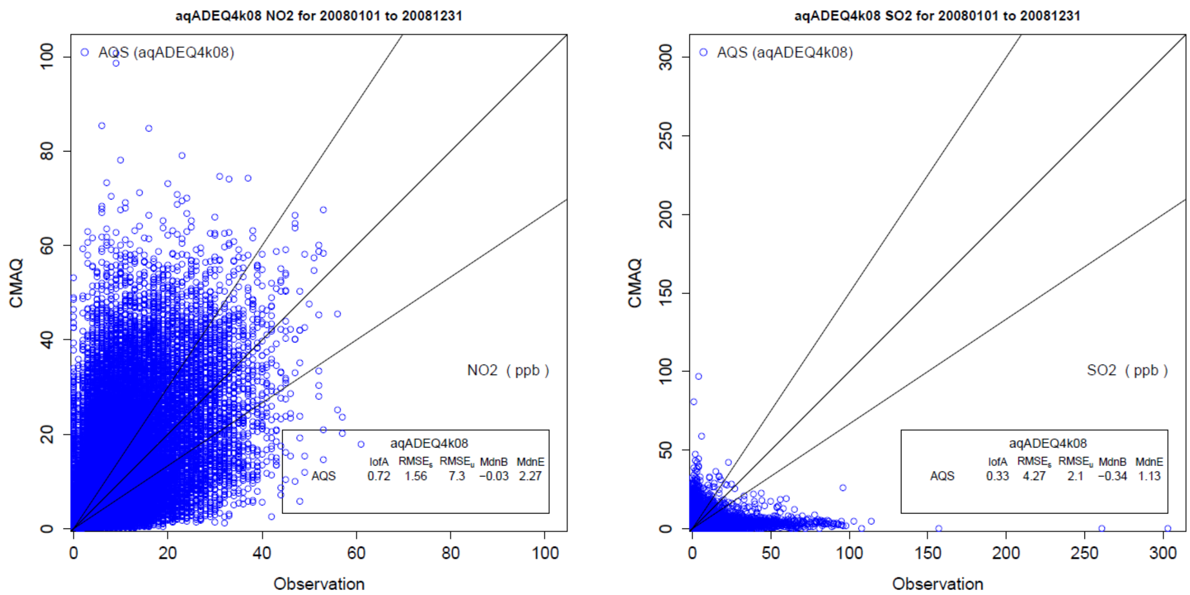
Figure 5-31. Comparison of Simulated and Observed 24-Hour Average PM_{10} Concentration (µg/m^3) for the 4-km Grid (All Months)



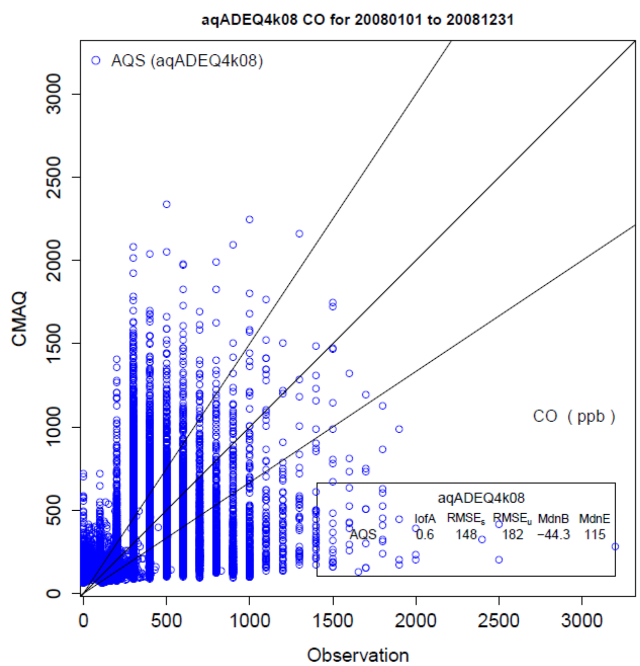
Scatter plots comparing simulated and observed hourly NO_x, SO_2, and CO concentrations for AQS sites within the 4-km grid for the annual simulation period are presented in Figure 5-32. Units for the gaseous species are ppb.

Figure 5-32. Comparison of Simulated and Observed Hourly Average NO_2, SO_2, and CO Concentrations (ppb) for the 4-km Grid (All Months)

NO_2/SO_2



CO



PM_{10} concentrations are mostly underestimated, but there is a lot of scatter about the 1:1 line. The higher PM_{10} concentrations are consistently underestimated while the low observed values are both under- and overestimated. Model performance for 1-hour NO_2, SO_2, and CO concentrations is characterized by a good deal of scatter about the 1:1 line and a tendency for overestimation of NO_2, and underestimation of SO_2 and CO.

Statistical Measures of Model Performance

Summary metrics and statistical measures for PM_{10}, NO_x, and SO_2 for the 4-km grid are presented in Table 5-10. No lower bound was applied in calculating the statistics; fractional bias and error are emphasized.

Table 5-10. Summary Model Performance Statistics for PM_{10}, NO_2, SO_2 and CO for the 4-km Modeling Grid

Metric	PM_{10} (µg/m$^{3)}$	NO_2 (ppb)	SO_2 (ppb)	CO (ppb)
Number of Data Pairs	3,148	83,448	130,236	34,383
Mean Observed (ppb)	18.6	6.4	3.6	309
Mean Simulated (ppb)	15.1	7.8	1.6	264
Mean Bias (ppb)	-3.6	1.4	-0.9	-45.3
Fractional Bias (%)	-19.7	-3.2	-54.2	-8.1
Mean Error (ppb)	10.1	4.5	2.3	162
Fractional Error (%)	57.9	62.2	91.0	58.3

Overall, the errors for these pollutants are somewhat worse than for the 2005 simulation period. For all pollutants, the simulated values are, on average, within a factor of two of the observed values. The fractional error values are large and do not indicate a great deal of skill in replicating the observed concentrations.

6 Future-Year Modeling Results

The future-year modeling and criteria pollutant assessment results are presented in this section. The following summary of the future-year modeling results is based on the modeling results for the 4-km grid and focuses on changes in pollutant concentrations throughout the State of Arkansas and design values and design-value-related metrics at monitoring sites and unmonitored areas throughout the state.

Note that, for consistency with the 2015 emissions, the 2008 simulation was first rerun with "current-year" emissions, in which the anthropogenic emissions were consistent with 2005 and 2015 in terms of methodology, but the biogenic emissions were consistent with the 2008 meteorological conditions. The "current year" modeling results were used as the basis for the criteria pollutant assessment for 2008, as presented in the remainder of this section.

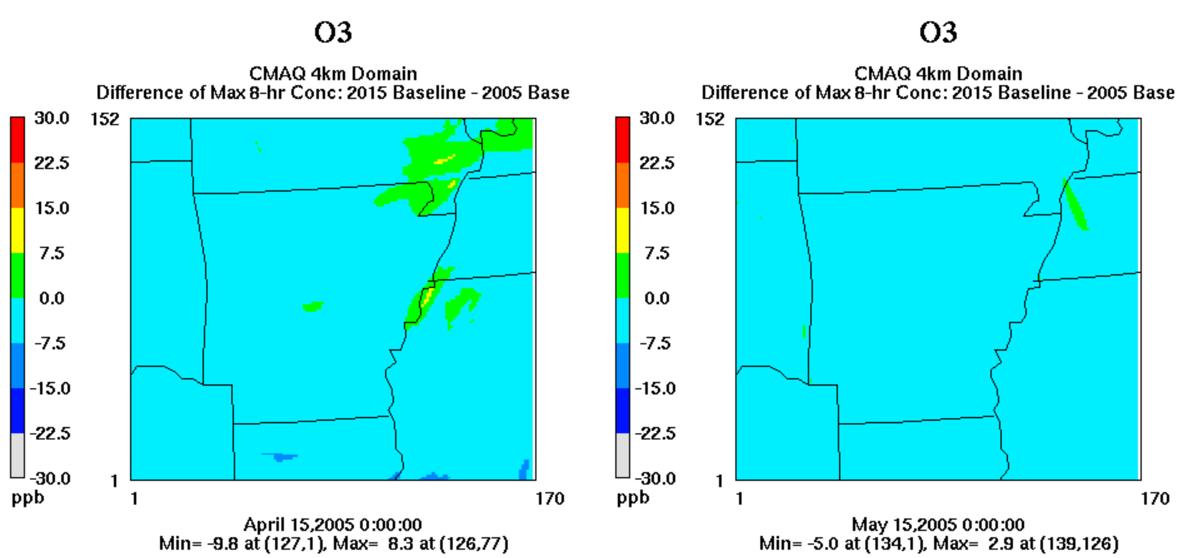
6.1 Overview of Future-Year Modeling Results

6.1.1 Ozone

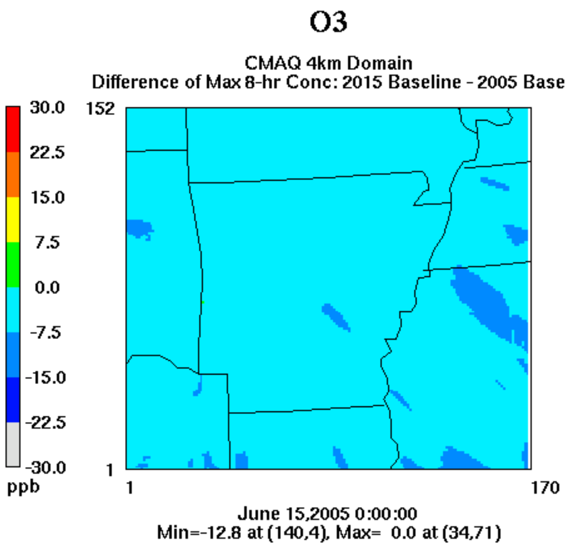
Figures 6-1 and 6-2 illustrate the difference in daily maximum 8-hour average ozone concentration for the 4-km grid and the 15th of each month (April – October) for the 2005/2015 and 2008/2015 simulation pairs. The differences are calculated as future year minus base year, specifically 2015 minus 2005 in Figure 6-1 and 2015 minus 2008 in Figure 6-2. The units are ppb. The date and time given on these and all subsequent difference plots refer to the meteorological base year and start hour for the selected day or averaging period. The minimum and maximum difference values for any location within the domain are also provided, along with their grid cell (x,y) locations.

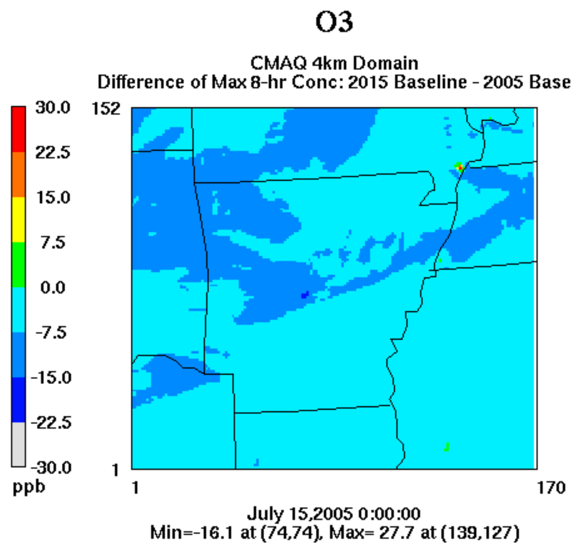
Figure 6-1. Difference in Simulated Daily Maximum 8-Hour Ozone Concentration (ppb) for Selected Days for the CMAQ 4-km Grid: 2015 - 2005

April 15/May 15

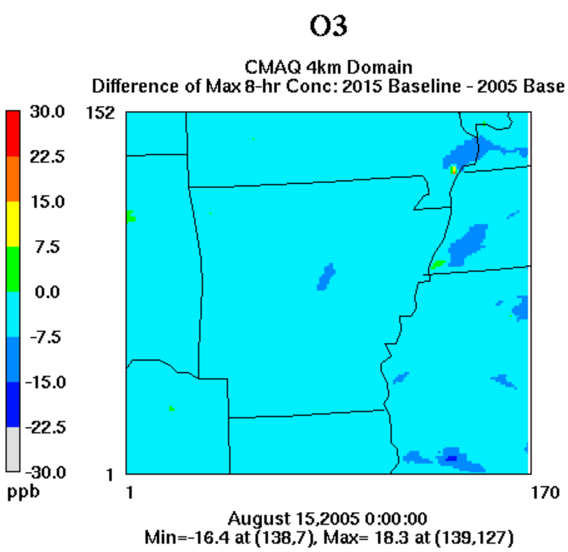


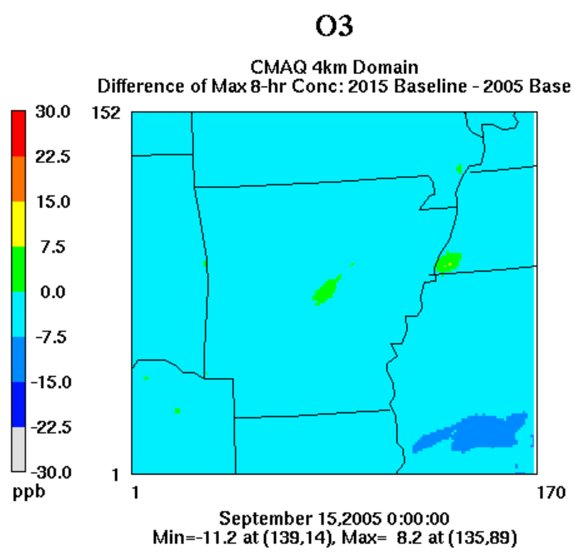
June 15/July 15





August 15/September 15





October 15

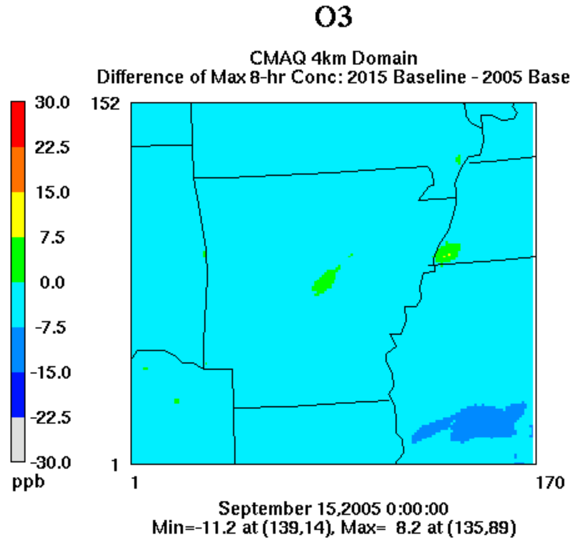
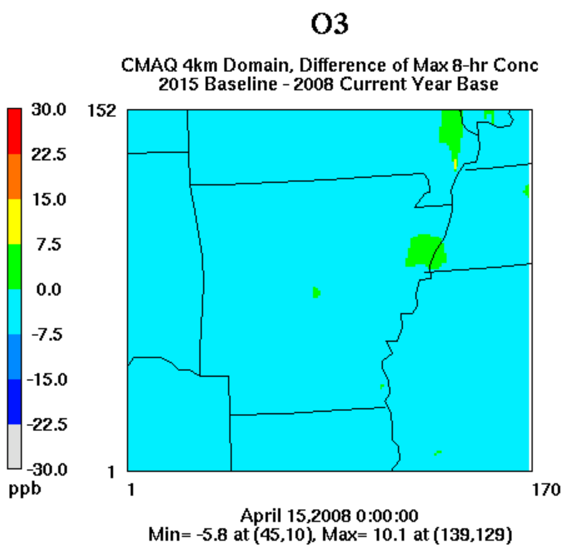
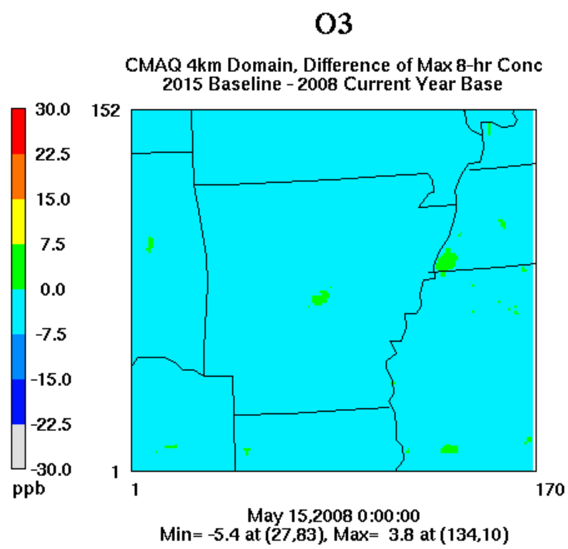


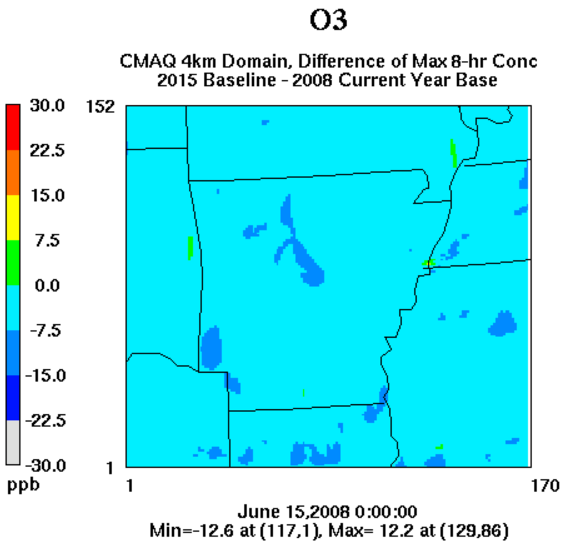
Figure 6-2. Difference in Simulated Daily Maximum 8-Hour Ozone Concentration (ppb) for Selected Days for the CMAQ 4-km Grid: 2015 - 2008

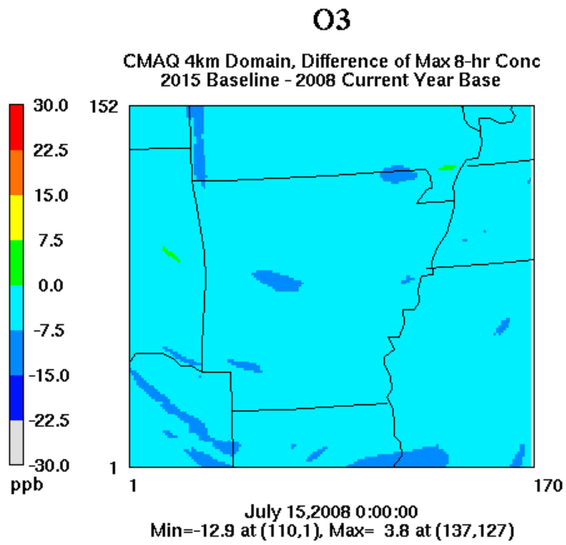
April 15/May 15



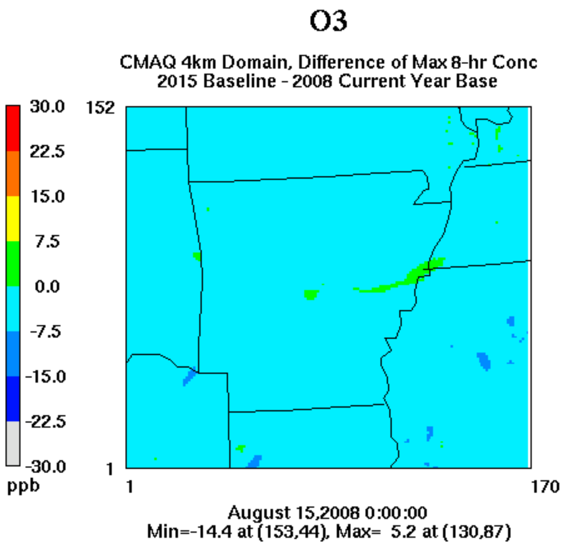


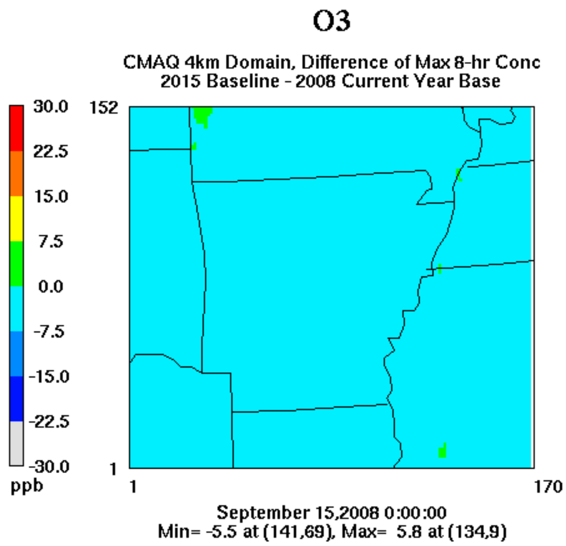
June 15/July 15



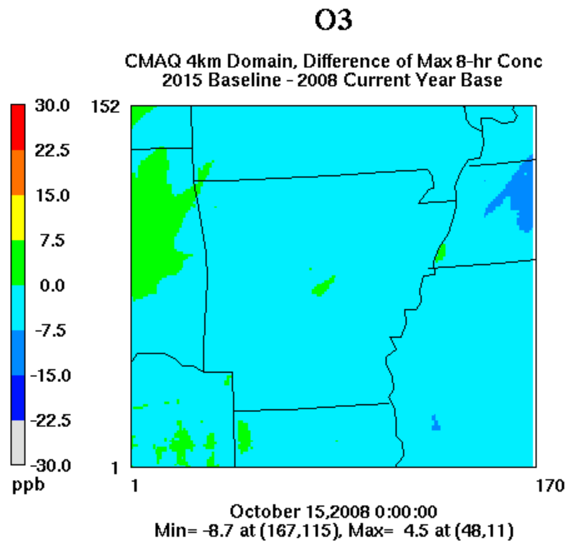


August 15/September 15





October 15



The plots show a mix of small increases and decreases in daily maximum 8-hour ozone concentrations for the selected days. The largest decreases for the selected days range from -5.0 to -16.4 ppb for the 2005/2015 simulation pair, and from -5.4 to -14.4 ppb for the 2008/2015 simulation pair. There are a few days (for example, July 15, 2005) for which the decreases over Arkansas are as much as 15 ppb.

Based on the CMAQ results, Table 6-1 summarizes the 4th high 8-hour ozone concentration (a key NAAQS related metric) for the base- and future-year simulations. Included in the table are the simulated concentrations and differences in simulated concentration for current ozone monitoring sites and any grid locations with an increase in the value of a key NAAQS metric (for any criteria pollutant) between the base and future year. The three unmonitored locations listed in Table 6-1 represent grid cells where the NAAQS-relevant concentration of any criteria pollutant (in this case SO_2) is higher for 2015 compared to both base years.

Table 6-1. Simulated 4th High Daily Maximum 8-Hour Ozone Concentration (ppb) for Monitoring Sites and Selected Unmonitored Locations within Arkansas

Site/Location	County	2005/2015 4th High 8-Hr Ozone (ppb)			2008/2015 4th High 8-Hr Ozone (ppb)		
		2005 Base Year	2015 Future Year	Diff-erence	2008 Current Year	2015 Future Year	Diff-erence
North Little Rock (Pike Ave)	Pulaski	76.3	65.7	-10.5	70.9	64.0	-6.9
North Little Rock Airport	Pulaski	74.3	66.0	-8.3	79.2	68.1	-11.2
Little Rock (Doyle Springs Rd)	Pulaski	80.3	69.3	-11.0	70.9	64.9	-6.0
Marion	Crittenden	89.8	75.4	-14.4	70.3	62.9	-7.4
Deer	Newton	66.4	59.1	-7.3	64.2	57.6	-6.6
Springdale	Washington	72.7	63.8	-8.9	69.6	59.7	-9.9
Fayetteville	Washington	74.8	65.2	-9.6	65.5	58.1	-7.4
Mena	Polk	65.8	59.7	-6.2	64.2	58.9	-5.3
Arkadelphia	Clark	75.7	65.7	-9.9	70.2	62.5	-7.7
Unmonitored 1	Benton	69.7	61.9	-7.7	71.3	65.2	-6.0
Unmonitored 2	Jefferson	70.4	62.4	-8.0	69.3	62.0	-7.3
Unmonitored 3	Independence	72.8	63.9	-8.9	66.3	58.1	-8.3

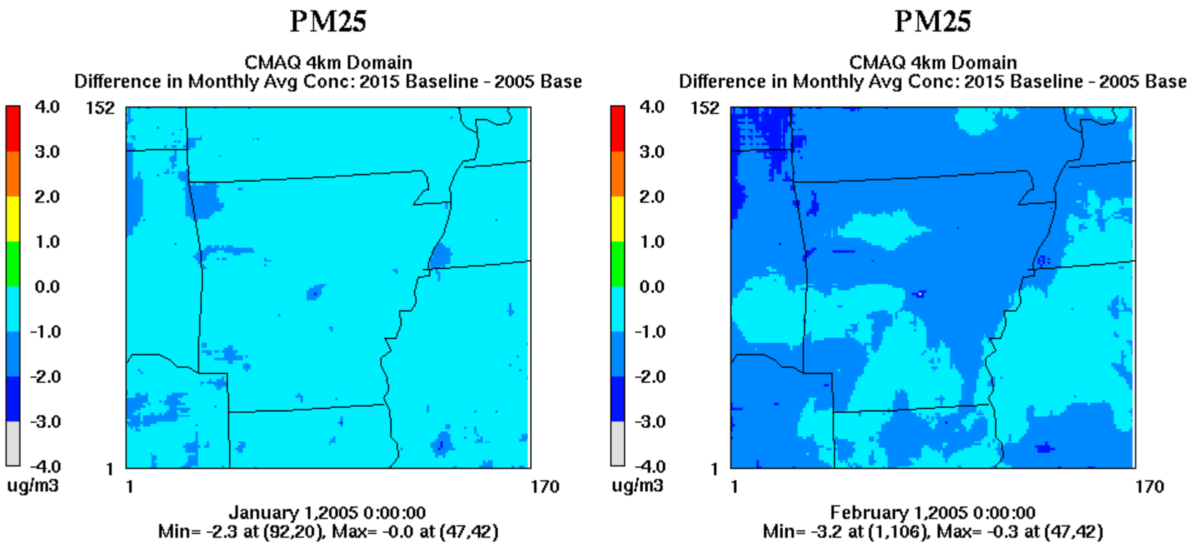
For the 2005/2015 simulation pair, the simulated 4th high 8-hour ozone concentration is lower for 2015 for all ozone monitoring sites and all locations in the 4 km grid. The average decrease is 9.2 ppb (9.6 ppb when only actual monitoring sites are included). Similarly, for the 2008/2015 simulation pair the simulated 4th high 8-hour ozone concentration is lower for 2015 for all ozone monitoring sites and all locations in the 4 km grid. The average decrease is 7.5 ppb (7.6 ppb when only actual monitoring sites are included).

6.1.2 $PM_{2.5}$

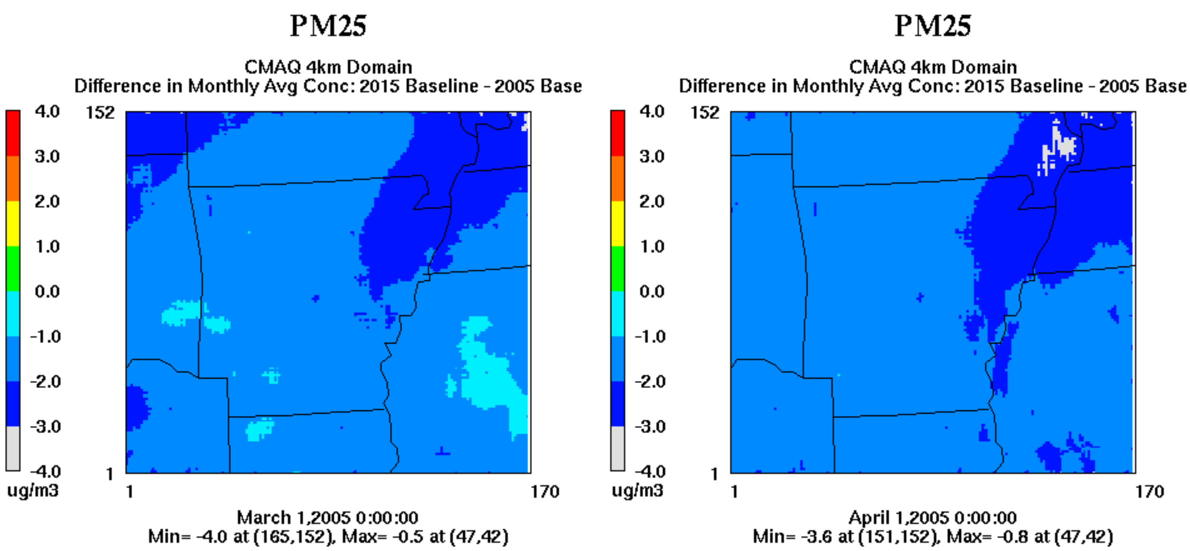
Figures 6-3 and 6-4 illustrate the difference in monthly average simulated $PM_{2.5}$ concentration for the 4-km grid for the 2005/2015 and 2008/2015 simulation pairs. The differences are calculated as future year minus base year, specifically 2015 minus 2005 in Figure 6-3 and 2015 minus 2008 in Figure 6-4. The units are $\mu g/m^3$.

Figure 6-3. Difference in Simulated Monthly Average 24-Hour $PM_{2.5}$ Concentration ($\mu g/m^3$) for the CMAQ 4-km Grid: 2015 - 2005

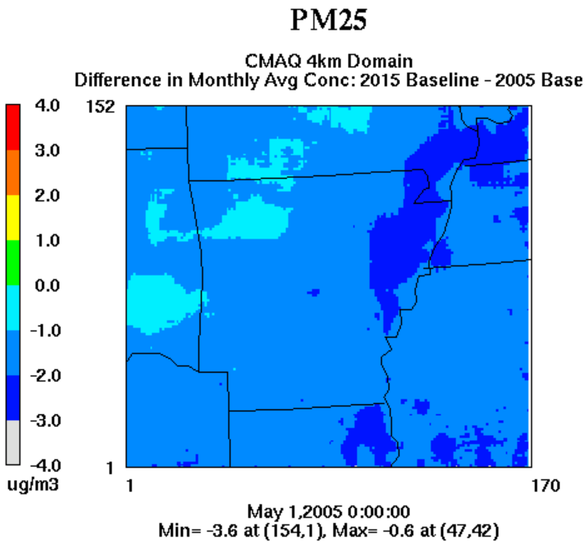
January/February

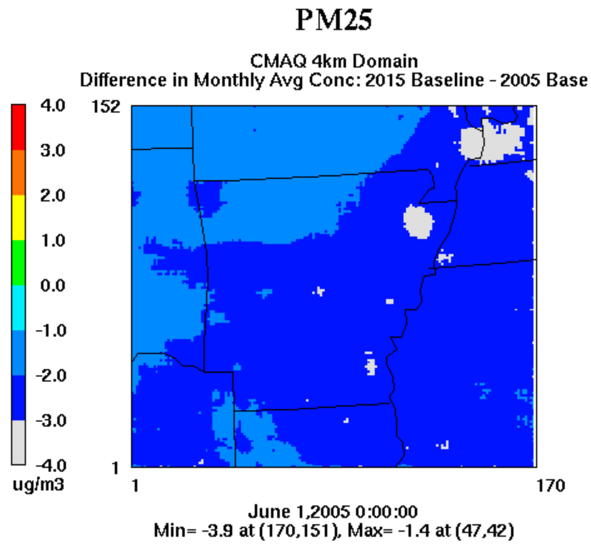


March/April

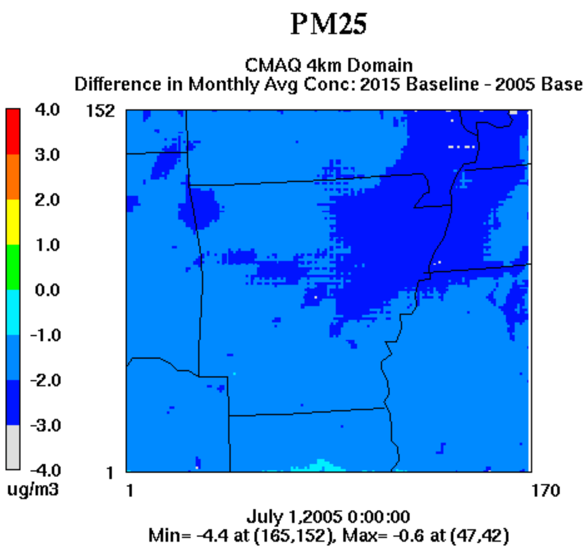


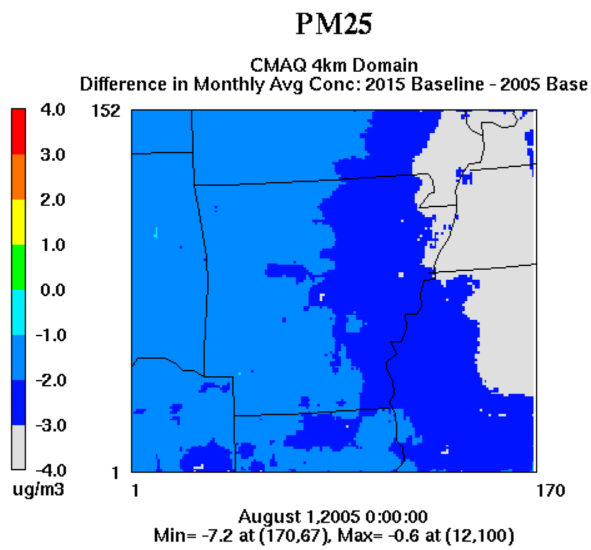
May/June



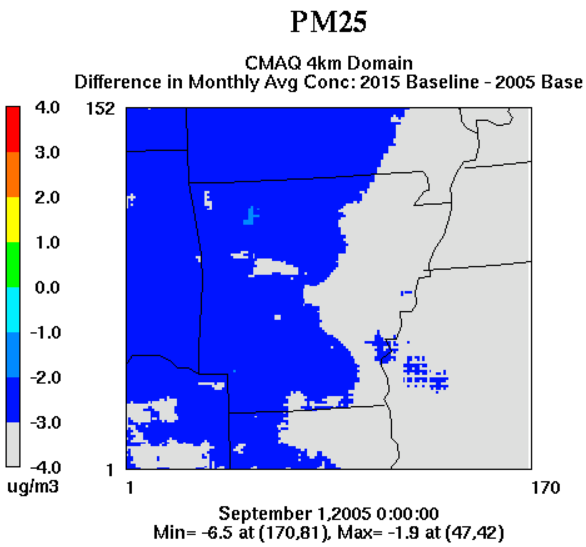


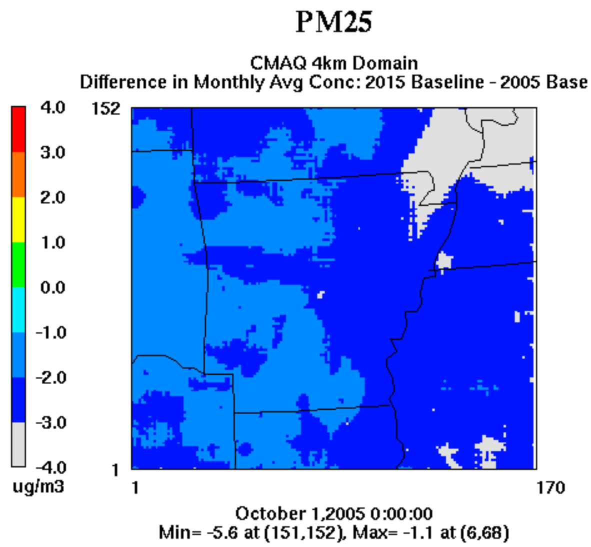
July/August



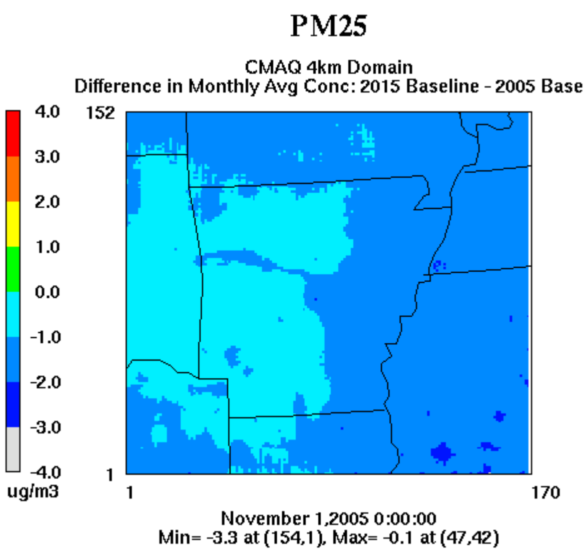


September/October





November/December



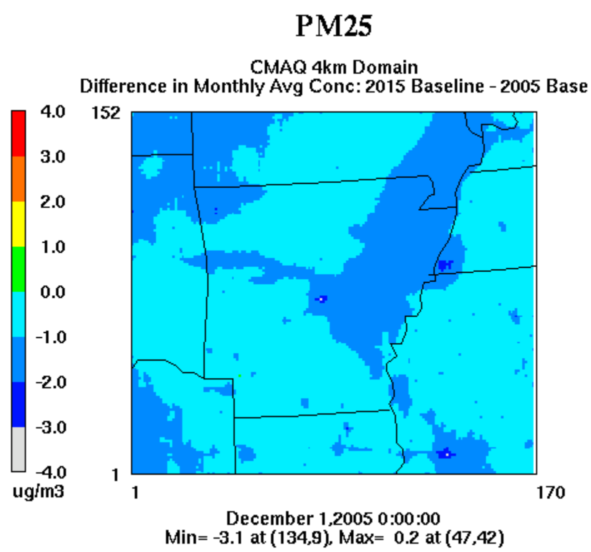
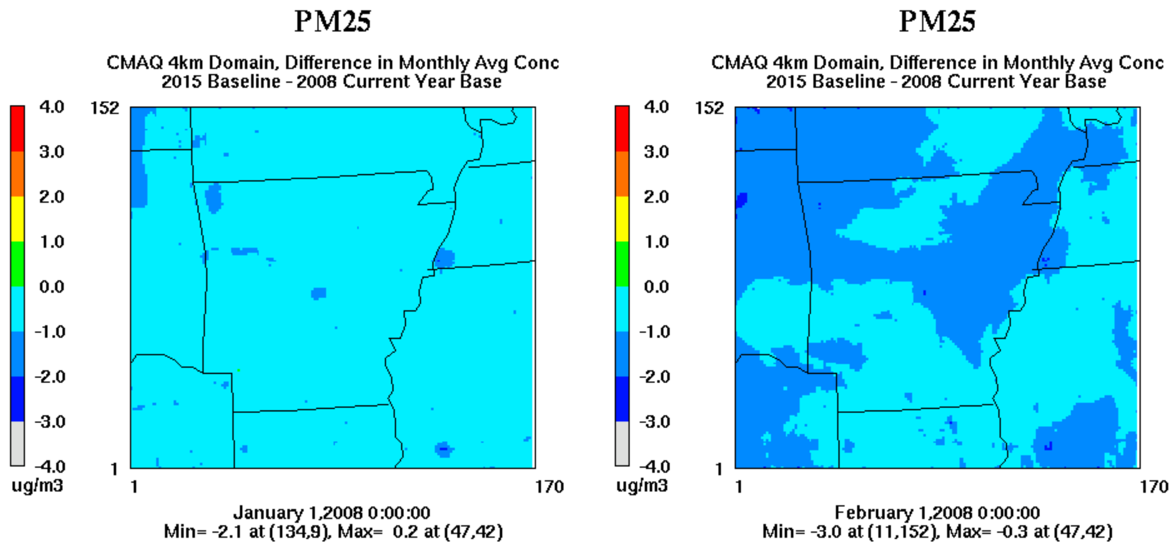
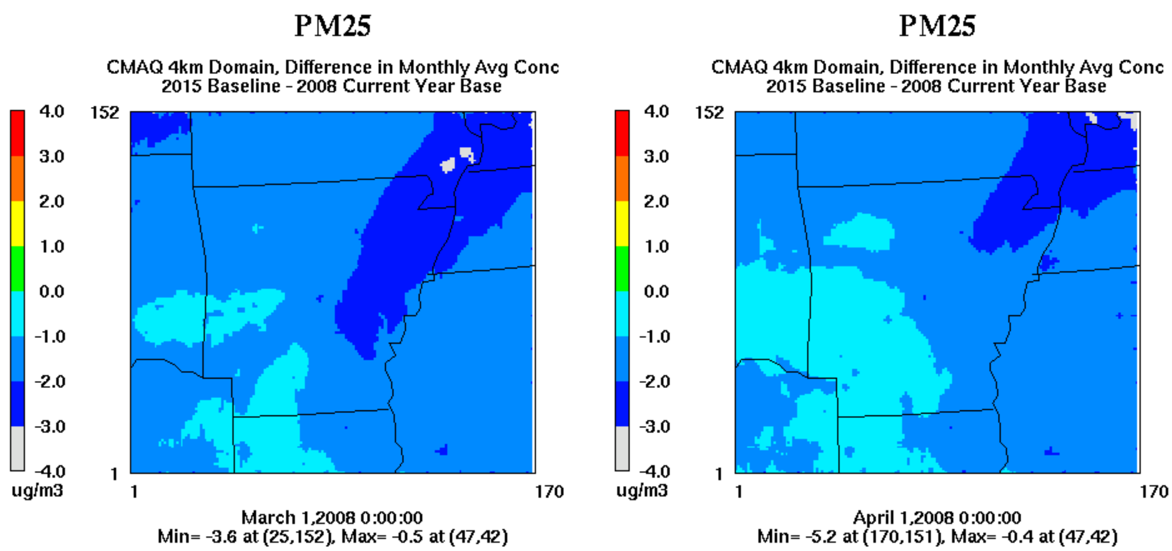


Figure 6-4. Difference in Simulated Monthly Average 24-Hour $PM_{2.5}$ Concentration ($\mu g/m^3$) for the CMAQ 4-km Grid: 2015 - 2005

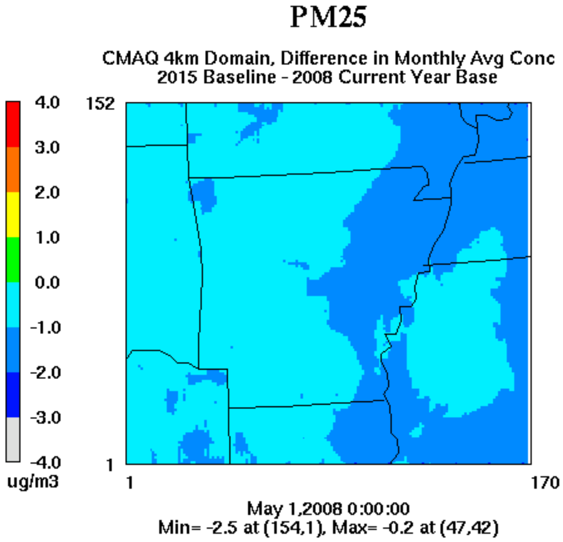
January/February

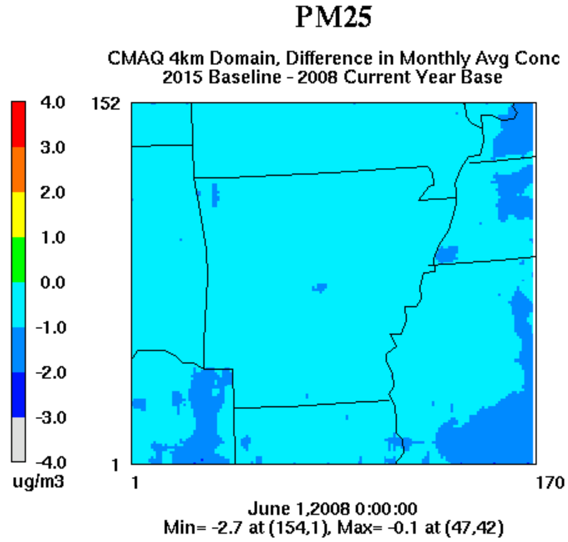


March/April

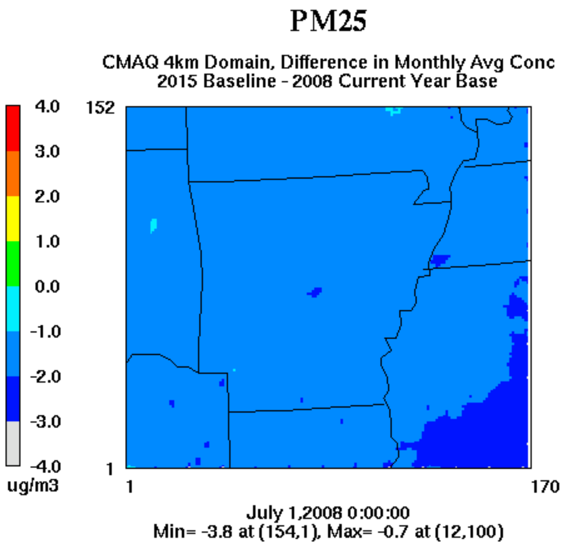


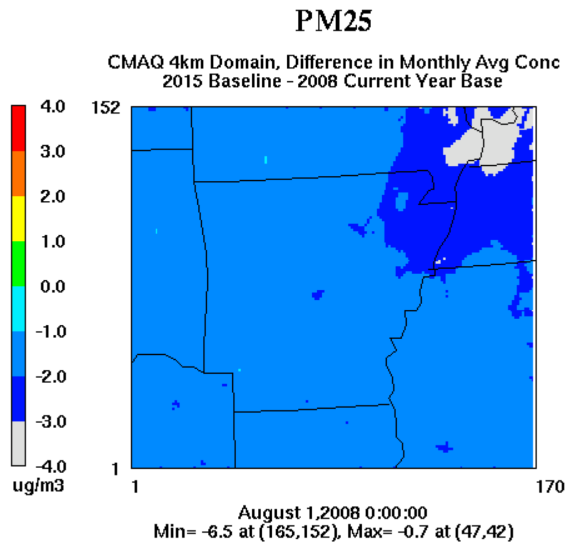
May/June



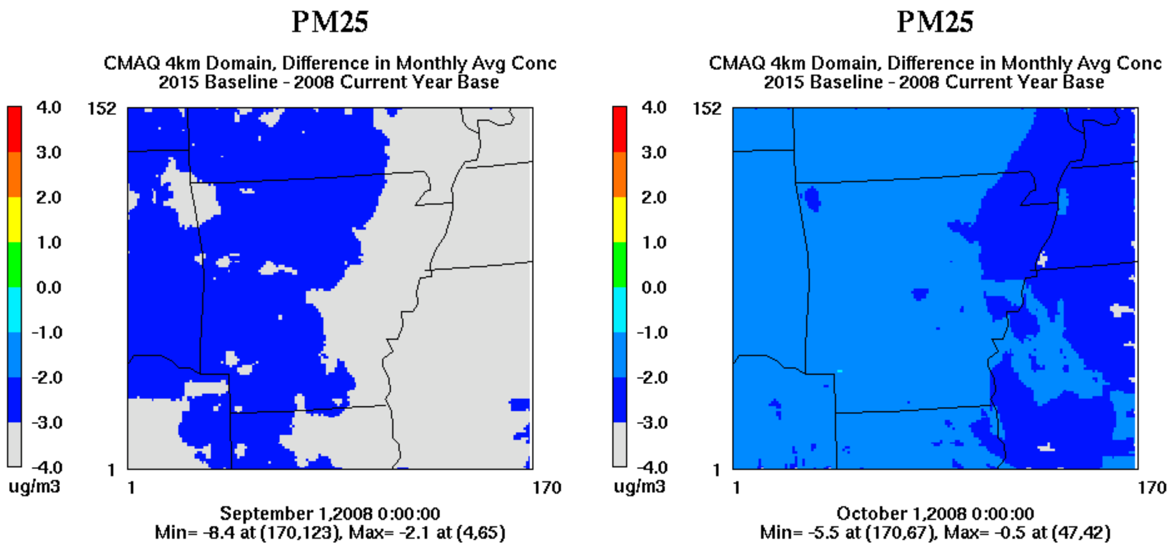


July/August

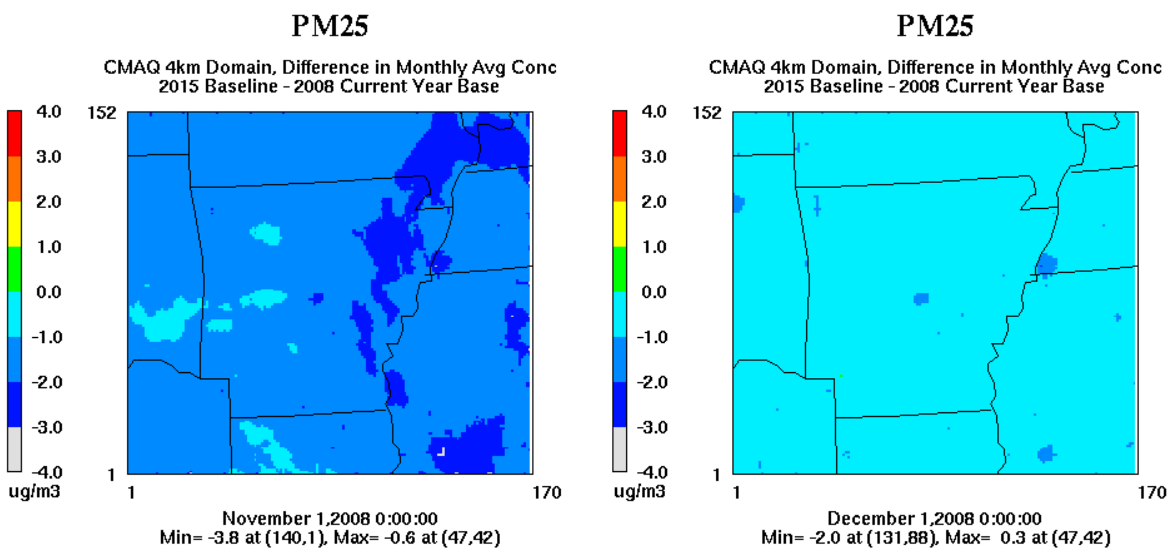




September/October



November/December



The plots show consistent decreases in $PM_{2.5}$ between 2005 and 2015 and 2008 and 2015 for the selected days. The largest decreases for the selected days range from -2.3 to -7.2 µg/m^3 for the 2005/2015 simulation pair, and from -2.0 to -8.4 for the 2008/2015 simulation pair.

Table 6-2 summarizes the 8th high 24-hour $PM_{2.5}$ concentration (one of the two key NAAQS related metrics for $PM_{2.5}$) for the base- and future-year simulations. Included in the table are the simulated concentrations and differences in simulated concentration for current $PM_{2.5}$ monitoring sites and any grid locations with an increase in the value of a key NAAQS metric between the base and future year. The three unmonitored locations listed in Table 6-2 represent grid cells where the NAAQS-relevant concentration of any pollutant (in this case SO_2) is higher for 2015 than the base years.

Table 6-2. Simulated 8th High 24-Hour $PM_{2.5}$ Concentration ($\mu g/m^3$) for Monitoring Sites and Selected Unmonitored Locations within Arkansas

Site/Location	County	2005/2015 8th High 24-Hr $PM_{2.5}$ ($\mu g/m^3$)			2008/2015 8th High 24-Hr $PM_{2.5}$ ($\mu g/m^3$)		
		2005 Base Year	2015 Future Year	Diff-erence	2008 Current Year	2015 Future Year	Diff-erence
North Little Rock (Pike Ave)	Pulaski	37.6	30.2	-7.4	31.1	25.1	-6.0
Little Rock (Adams Field)	Pulaski	33.5	28.4	-5.1	29.0	23.6	-5.4
Little Rock (Doyle Springs Rd)	Pulaski	41.0	33.4	-7.6	34.1	27.0	-7.1
Marion	Crittenden	37.6	31.8	-5.8	32.3	25.6	-6.7
Stuttgart	Arkansas	35.5	29.9	-5.6	31.8	25.7	-6.1
Newport	Jackson	36.2	29.8	-6.4	33.9	27.7	-6.2
Springdale	Washington	33.1	30.1	-3.0	27.5	24.8	-2.7
Mena	Polk	26.0	21.7	-4.3	22.8	19.0	-3.8
Hot Springs	Garland	27.3	23.6	-3.7	24.8	19.9	-4.9
El Dorado	Union	28.8	24.7	-4.1	26.8	22.6	-4.2
Crossett	Ashley	27.3	23.6	-3.7	24.8	19.9	-4.9
Roland	Sequoyah (OK)	33.6	30.1	-3.5	26.7	23.8	-2.9
Unmonitored 1	Benton	32.6	27.5	-5.1	26.5	23.0	-3.5
Unmonitored 2	Jefferson	38.3	32.7	-5.6	31.3	26.4	-4.9
Unmonitored 3	Independence	36.3	30.5	-5.8	32.8	26.3	-6.5

For the 2005/2015 simulation pair, the simulated 98th percentile 24-hr $PM_{2.5}$ concentration is lower for all $PM_{2.5}$ monitoring sites and all locations. The average decrease is 5.1 $\mu g/m^3$ (5.0 $\mu g/m^3$ when only actual monitoring sites are included). Similarly, for the 2008/2015 simulation pair, this metric is lower for all monitoring sites and all locations. The average decrease is 5.1 $\mu g/m^3$ (both with and without the pseudo sites).

Figures 6-5 and 6-6 illustrate the difference in annual average simulated $PM_{2.5}$ concentration for the 4-km grid for the 2005/2015 and 2008/2015 simulation pairs. The units are $\mu g/m^3$.

Figure 6-5. Difference in Simulated Annual Average $PM_{2.5}$ Concentration ($\mu g/m^3$) for the CMAQ 4-km Grid: 2015 - 2005

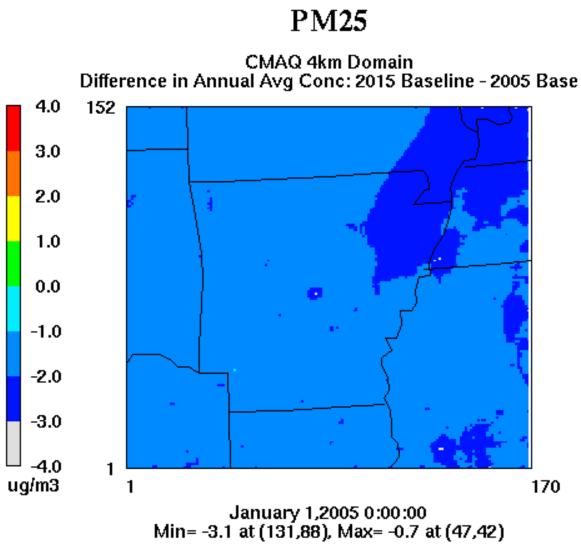
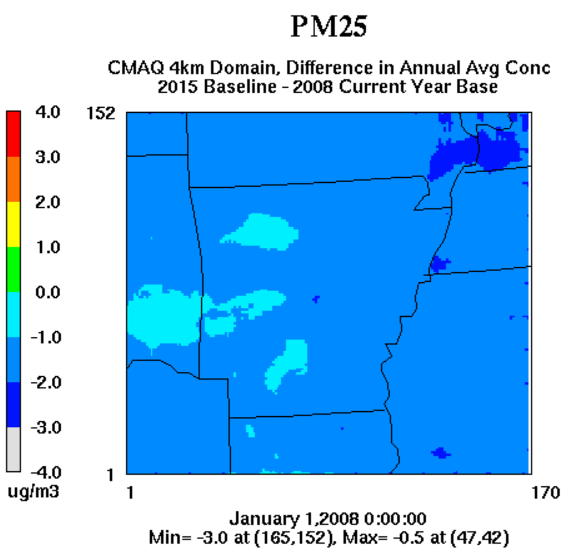


Figure 6-6. Difference in Simulated Annual Average $PM_{2.5}$ Concentration ($\mu g/m^3$) for the CMAQ 4-km Grid: 2015 - 2008



The annual difference plots also show a regional decrease in $PM_{2.5}$ between the base/current and future years, averaged over all simulation days. The magnitude of the decreases is similar (-0.7 to -3.2 ppb for the 2005/2015 simulation pair and -0.5 to -3.0 ppb for the 2008/2015 simulation pair), but the difference patterns are different for the two years. Decreases of 1 ppb or more are more widespread for the 2005/2015 simulation pair.

Table 6-3 summarizes the annual average $PM_{2.5}$ concentration for the base-/current- and future-year simulations. Included in the table are the simulated concentrations and differences in simulated concentration for current $PM_{2.5}$ monitoring sites and any grid locations with an increase in the value of this metric between the base and future year. The three unmonitored locations listed in Table 6-3 represent grid cells where the NAAQS-relevant concentration of any pollutant (in this case SO_2) is higher for 2015, compared to both base years.

Table 6-3. Simulated Annual Average $PM_{2.5}$ Concentration ($\mu g/m^3$) for Monitoring Sites and Selected Unmonitored Locations within Arkansas

Site/Location	County	2005/2015 Annual Average $PM_{2.5}$ ($\mu g/m^3$)			2008/2015 Annual Average $PM_{2.5}$ ($\mu g/m^3$)		
		2005 Base Year	2015 Future Year	Difference	2008 Current Year	2015 Future Year	Difference
North Little Rock (Pike Ave)	Pulaski	15.5	12.8	-2.7	13.1	11.0	-2.1
Little Rock (Adams Field)	Pulaski	13.4	11.5	-1.9	11.3	9.8	-1.5
Little Rock (Doyle Springs Rd)	Pulaski	16.7	14.1	-2.6	13.7	11.7	-2.0
Marion	Crittenden	14.8	12.6	-2.2	13.0	11.3	-1.7
Stuttgart	Arkansas	13.2	11.2	-2.0	11.7	10.1	-1.6
Newport	Jackson	14.2	12.1	-2.1	12.4	10.7	-1.7
Springdale	Washington	13.1	11.4	-1.7	11.1	9.6	-1.5
Mena	Polk	10.1	8.8	-1.3	8.7	7.6	-1.1
Hot Springs	Garland	11.2	9.7	-1.5	9.4	8.2	-1.2
El Dorado	Union	12.3	10.7	-1.6	10.5	9.2	-1.3
Crossett	Ashley	11.2	9.7	-1.5	9.4	8.2	-1.2
Roland	Sequoyah (OK)	13.5	11.9	-1.6	11.1	9.8	-1.3
Unmonitored 1	Benton	13.7	12.0	-1.7	11.8	10.2	-1.6
Unmonitored 2	Jefferson	14.8	12.8	-2.0	12.2	10.7	-1.5
Unmonitored 3	Independence	14.4	12.4	-2.0	12.3	10.7	-1.6

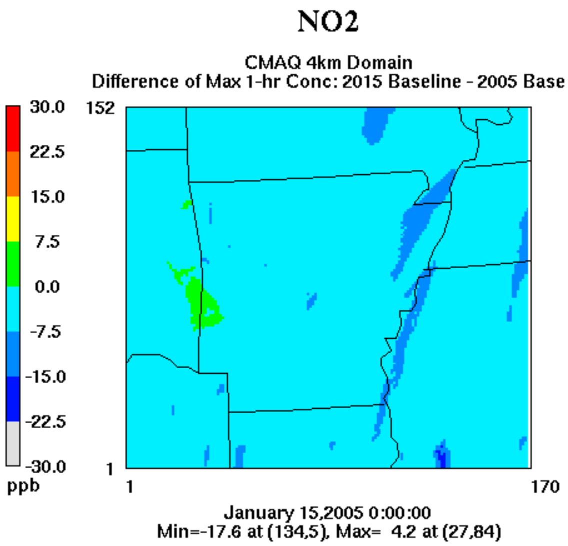
For the 2005/2015 simulation pair, the simulated annual average $PM_{2.5}$ concentration is lower for all $PM_{2.5}$ monitoring sites and all locations. The average decrease is 1.9 $\mu g/m^3$ (both with and without the pseudo sites). Similarly, this metric is lower for the 2008/2015 simulation pair for all monitoring sites and all locations. The average decrease is 1.5 $\mu g/m^3$ (both with and without the pseudo sites).

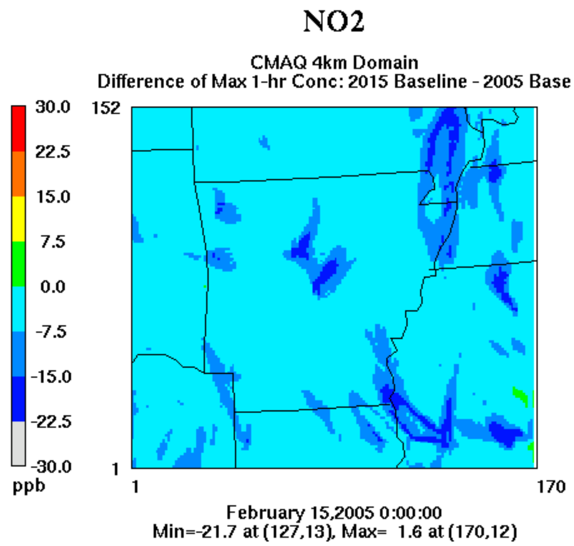
6.1.3 NO_2

Figures 6-7 and 6-8 illustrate the difference in daily maximum 1-hour average NO_2 concentration for the 4-km grid and the 15th of each month for the 2005/2015 and 2008/2015 simulation pairs. The units are ppb.

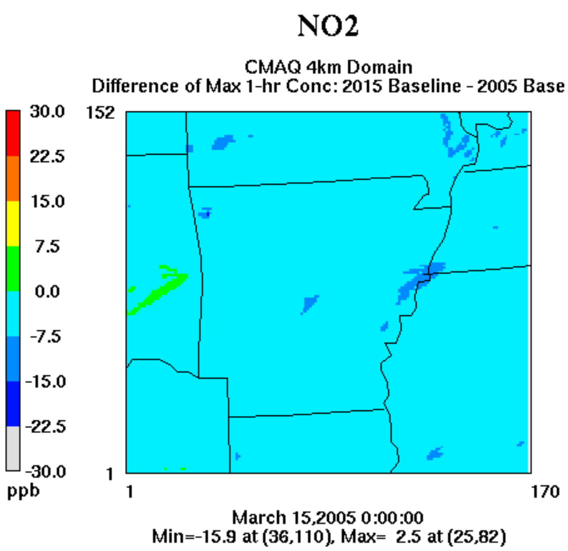
Figure 6-7. Difference in Simulated Monthly Average 1-Hour NO_2 Concentration (ppb) for the CMAQ 4-km Grid: 2015 - 2005

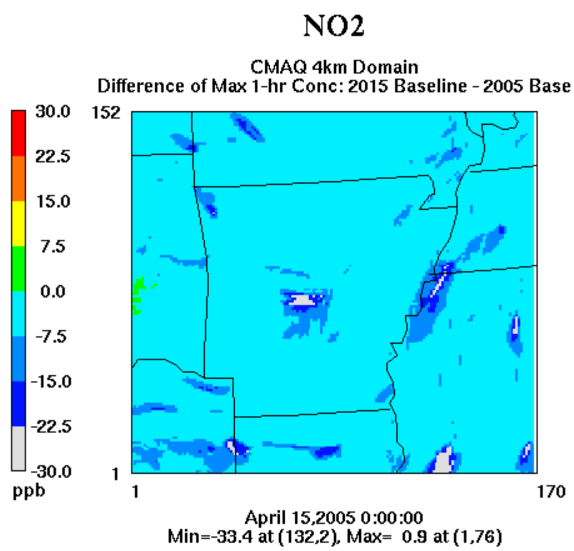
January/February



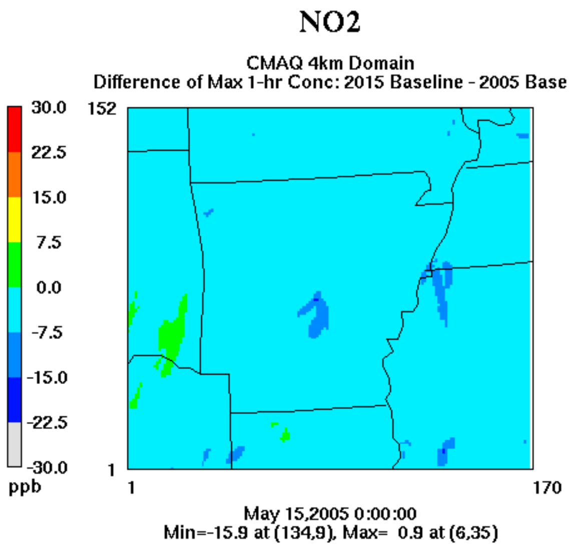


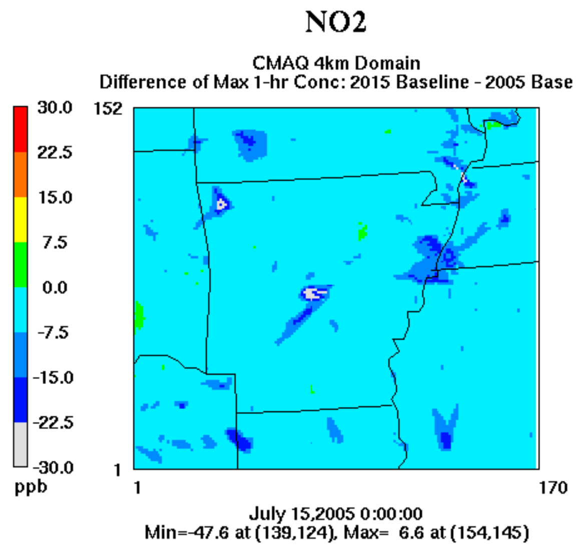
March/April



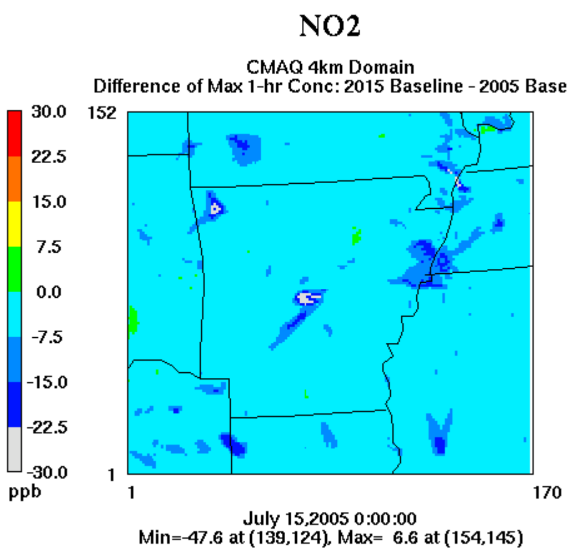


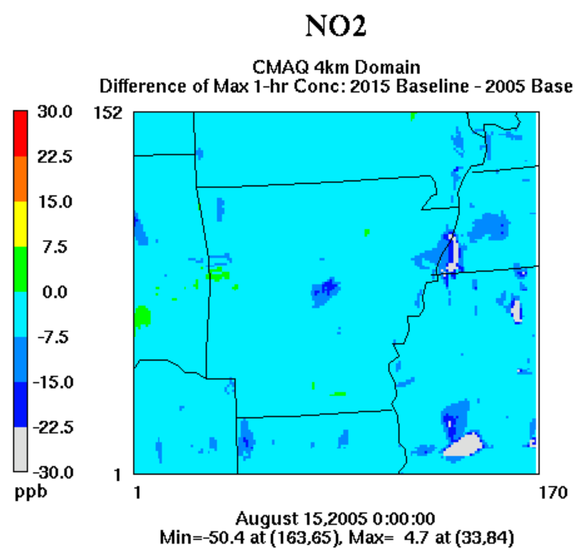
May/June



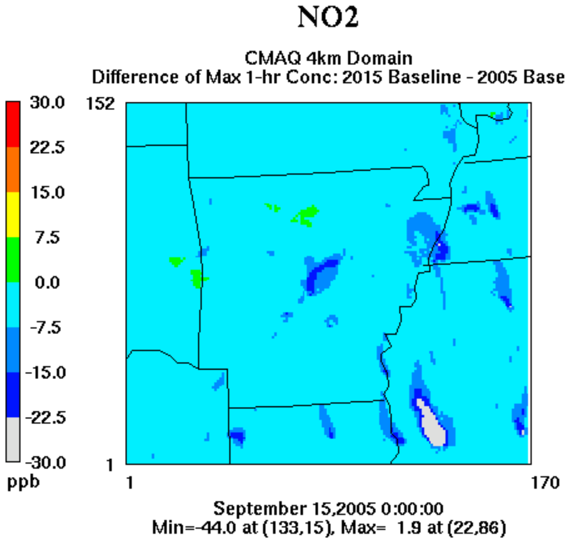


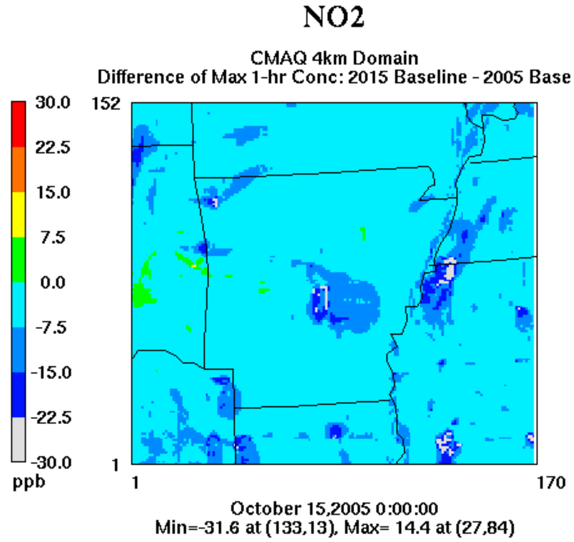
July/August



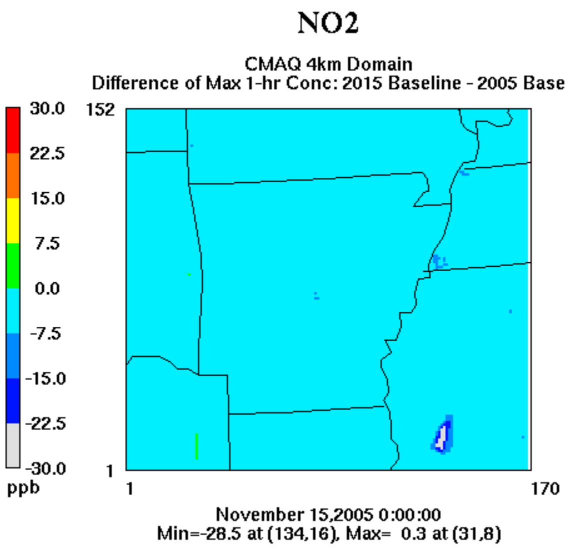


September/October





November/December



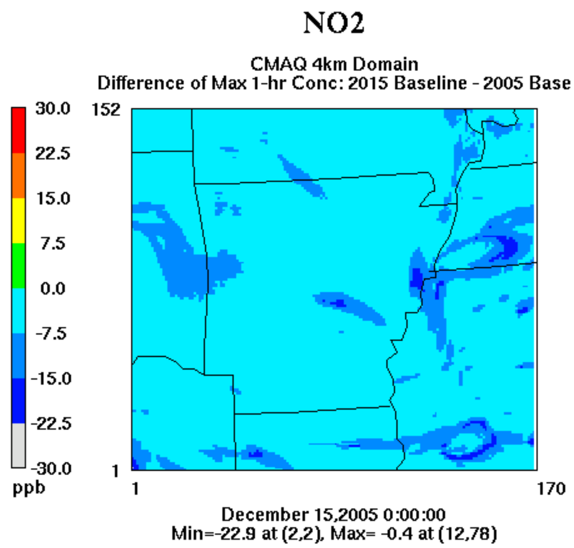
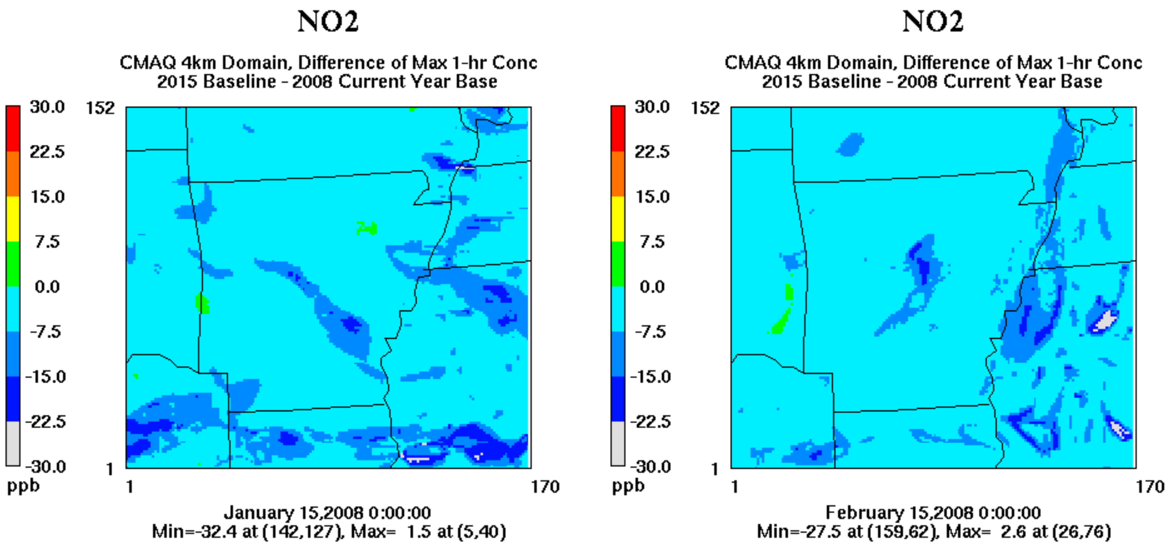
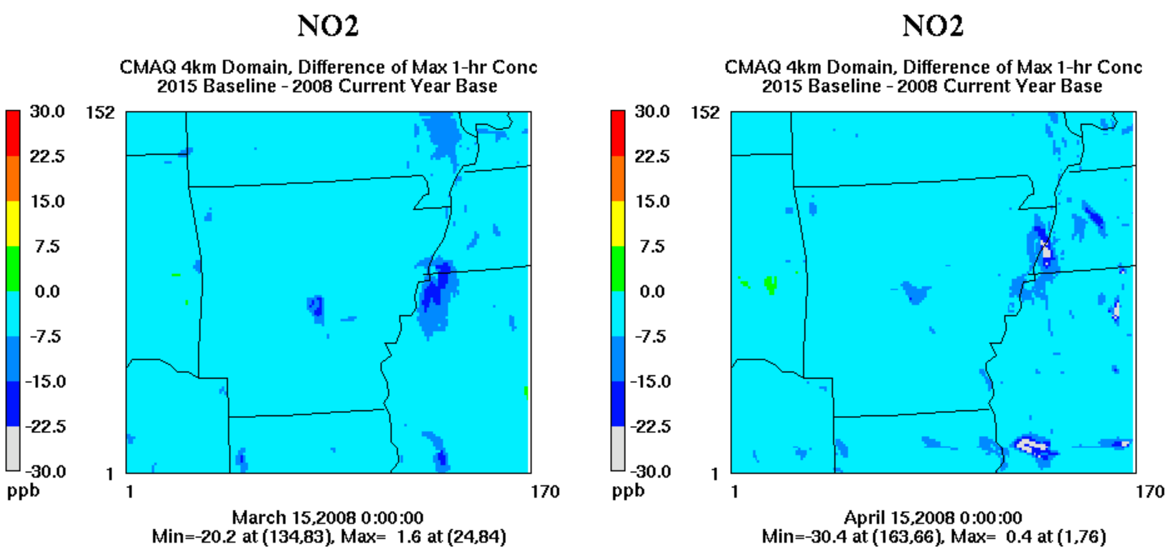


Figure 6-8. Difference in Simulated Monthly Average 1-Hour NO_2 Concentration (ppb) for the CMAQ 4-km Grid: 2015 - 2008

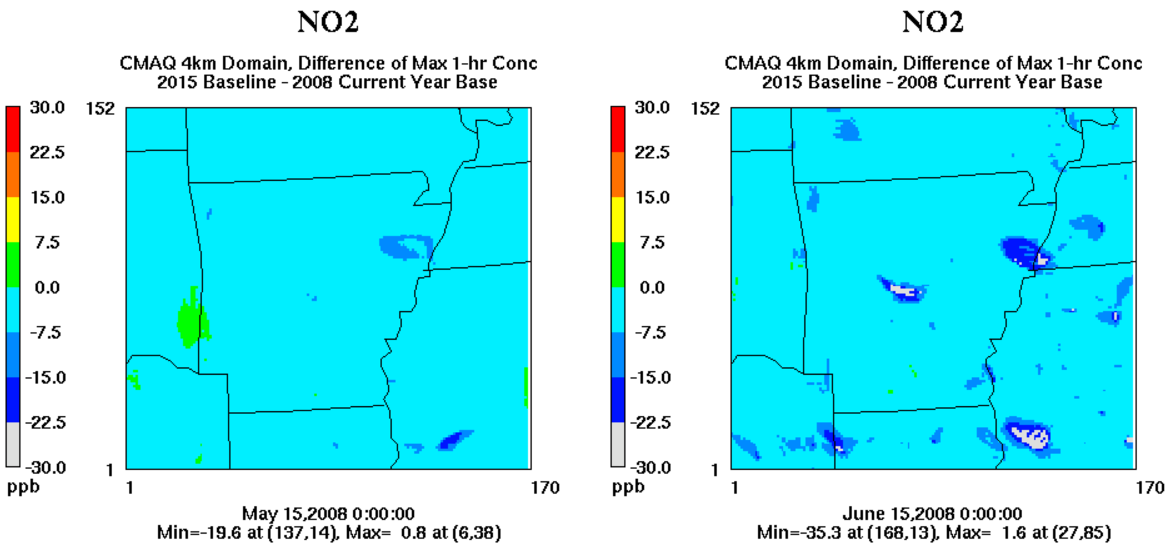
January/February



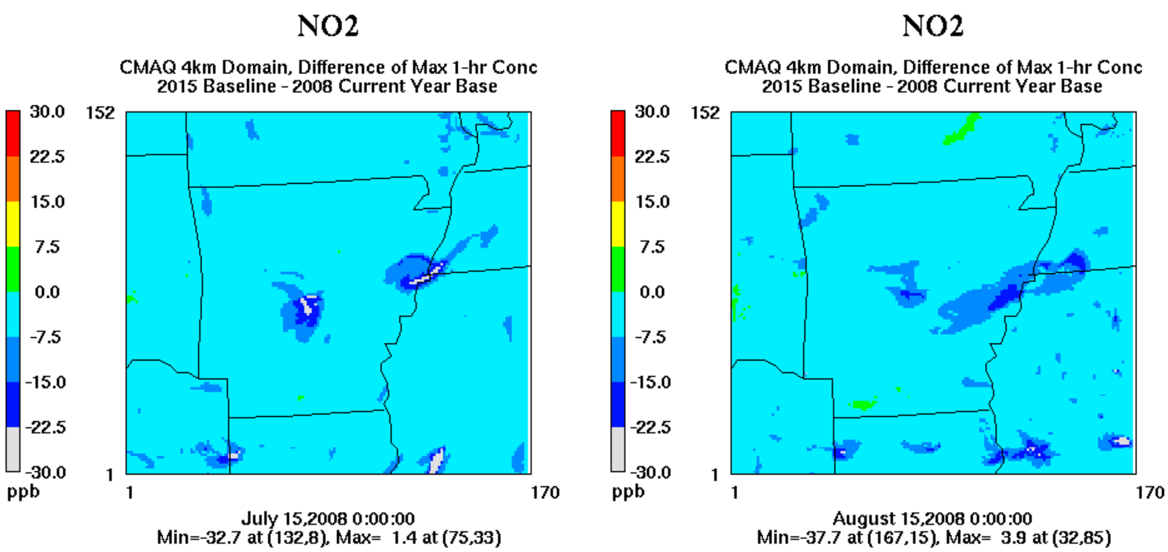
March/April



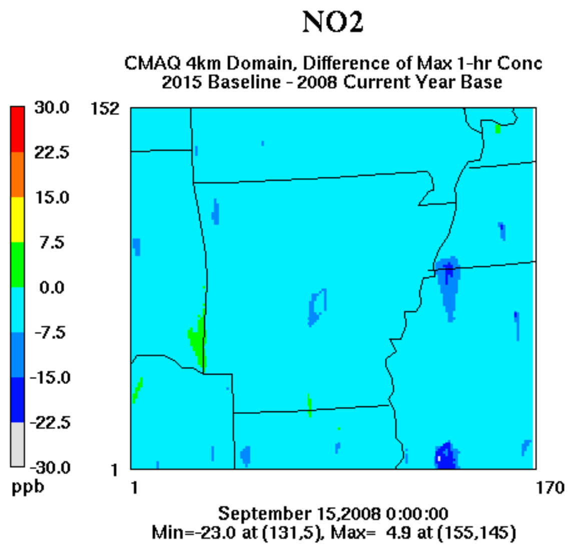
May/June

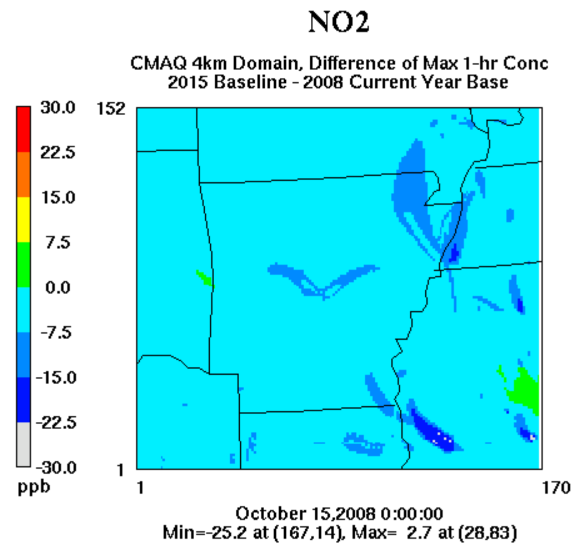


July/August

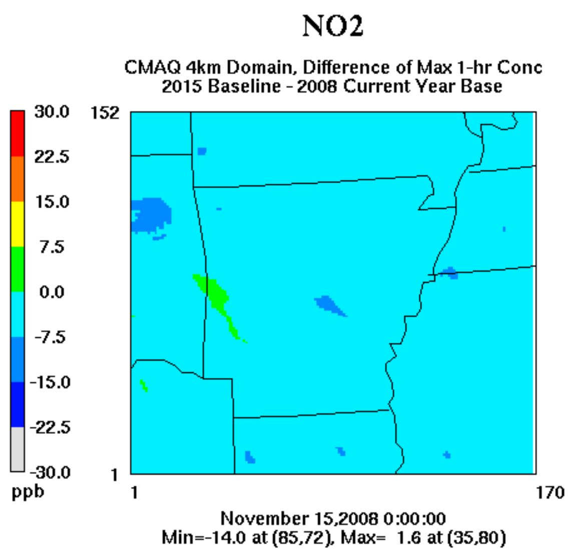


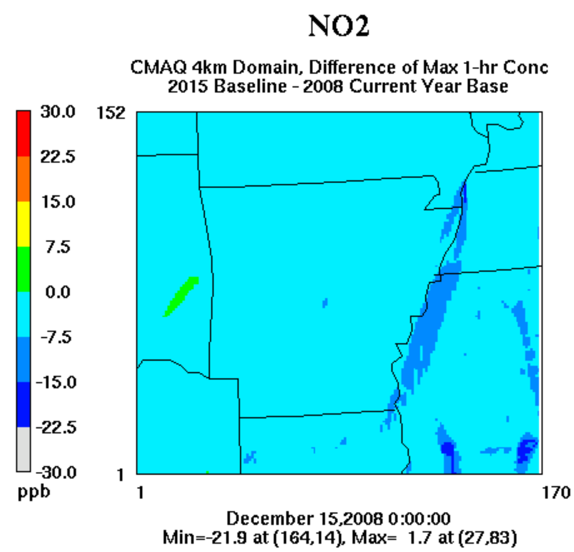
September/October





November/December





For NO_2, the plots show a mix of increases and decreases between both simulation pairs. The decreases are greater in magnitude and more widespread than the increases.

Table 6-4 summarizes the 8th high daily maximum 1-hour NO_2 concentration (equivalent to the 98th percentile value as used in the NAAQS) for the base- and future-year simulations. Included in the table are the simulated concentrations and differences in simulated concentration for current NO_2 monitoring sites and any grid locations with an increase in the value of this metric between the base and future year. The three unmonitored locations listed in Table 6-4 represent grid cells where the NAAQS-relevant concentration of any pollutant (in this case SO_2) is higher for 2015, compared to both base years.

Table 6-4. Simulated 8th High Daily Maximum 1-Hour NO_2 Concentration (ppb) for Monitoring Sites and Selected Unmonitored Locations within Arkansas

Site/Location	County	2005/2015 8th High 1-Hr NO_2 (ppb)			2008/2015 8th High 1-Hr NO_2 (ppb)		
		2005 Base Year	2015 Future Year	Diff-erence	2008 Current Year	2015 Future Year	Diff-erence
North Little Rock (Pike Ave)	Pulaski	66.0	50.3	-15.7	72.5	57.4	-19.4
Marion	Crittenden	71.8	55.8	-16.0	73.1	58.1	-15.0
Unmonitored 1	Benton	32.8	22.3	-10.5	27.4	18.8	-8.6
Unmonitored 2	Jefferson	49.0	42.7	-6.3	43.4	28.7	-14.7
Unmonitored 3	Independence	30.5	28.4	-2.1	26.3	19.5	-6.8

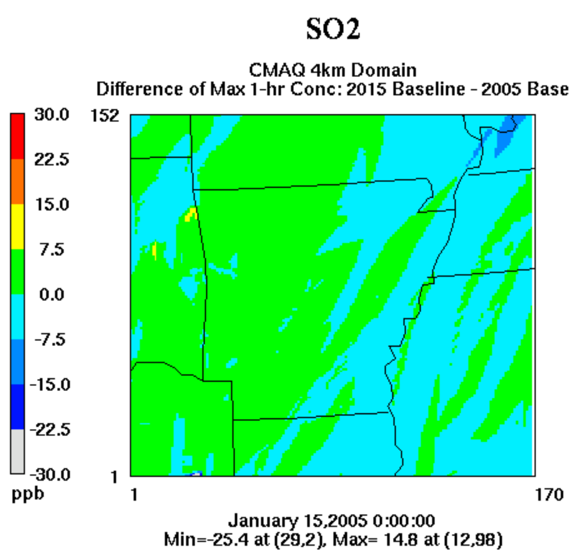
For the 2005/2015 simulation pair, the 8th high daily maximum 1-hour NO_2 concentration is lower for all monitoring sites. The average decrease is 10.1 ppb (15.9 ppb when only actual monitoring sites are included). This metric is also lower for the 2008/2015 simulation pair for all monitoring sites. The average decrease is 12.9 ppb (17.2 ppb when only actual monitoring sites are included).

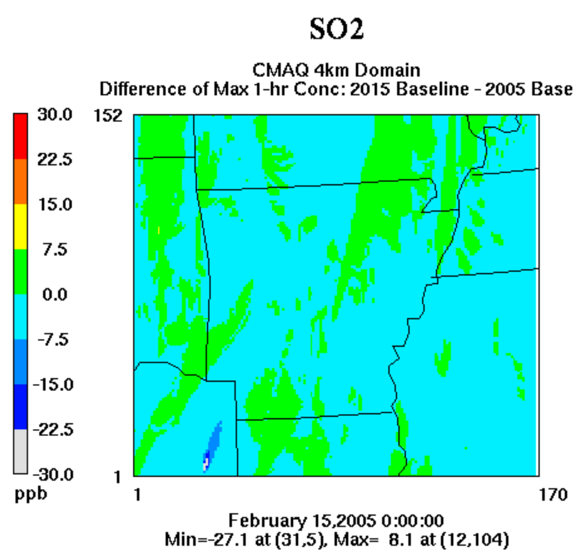
6.1.4 SO_2

Figures 6-9 and 6-10 illustrate the difference in daily maximum 1-hour average SO_2 concentration for the 4-km grid and the 15th of each month for the 2005/2015 and 2008/2015 simulation pairs. The units are ppb.

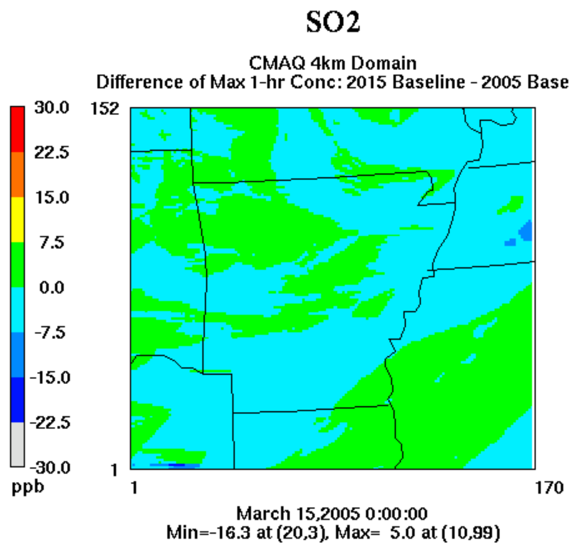
Figure 6-9. Difference in Simulated Monthly Average 1-Hour SO_2 Concentration (ppb) for the CMAQ 4-km Grid: 2015 - 2005

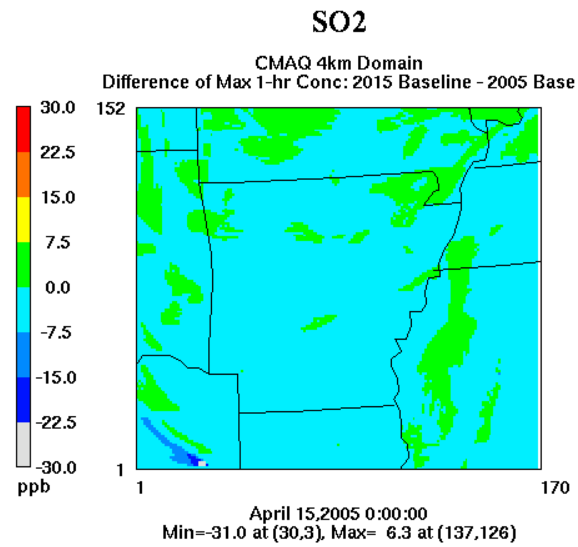
January/February



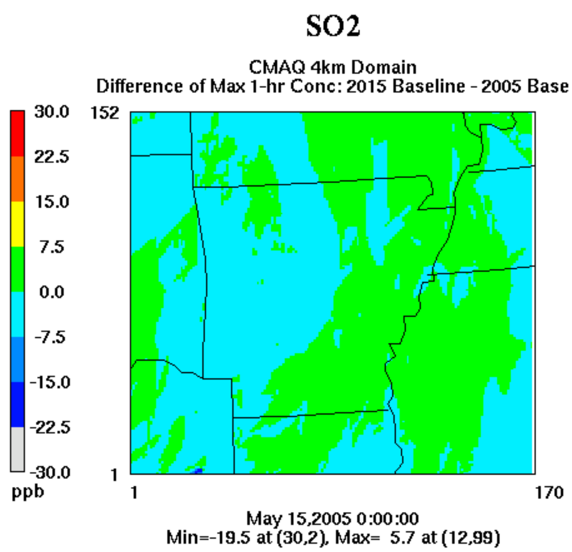


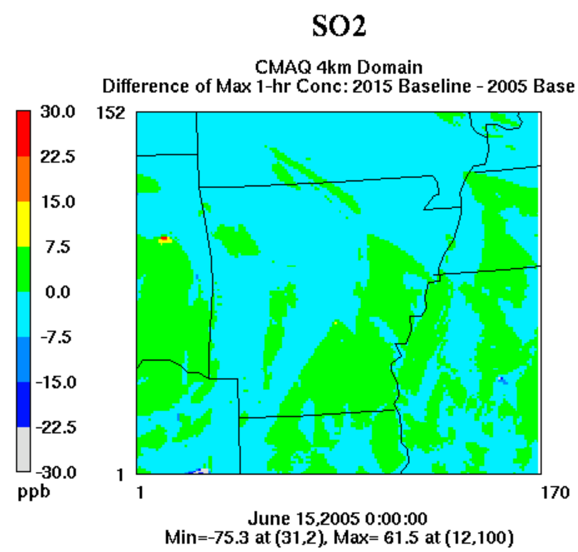
March/April



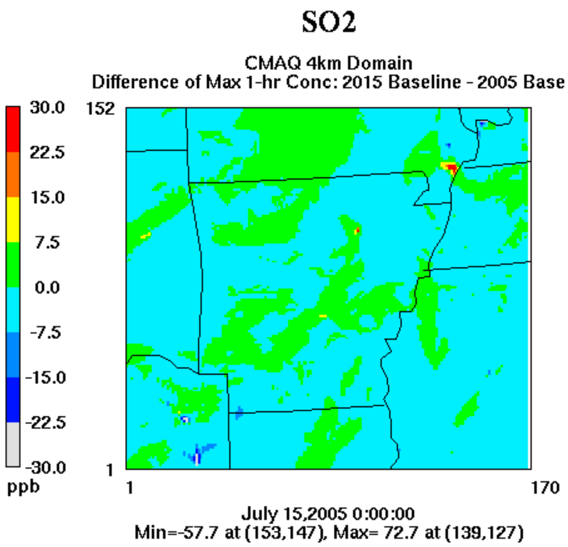


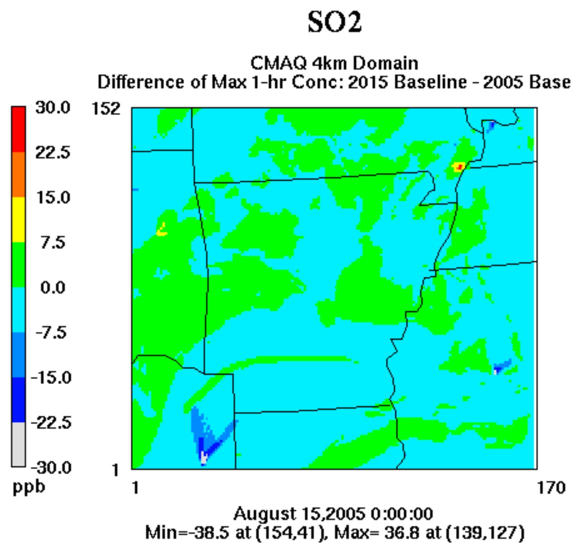
May/June



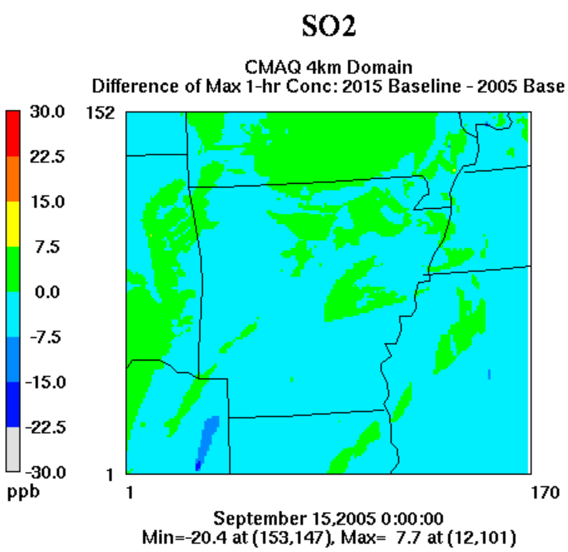


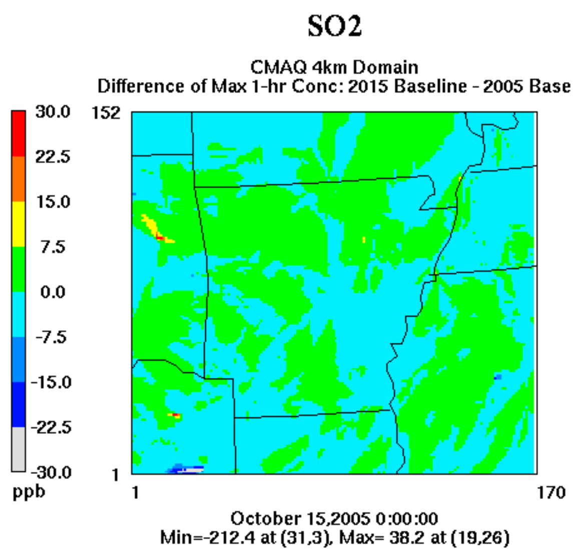
July/August





September/October





November/December

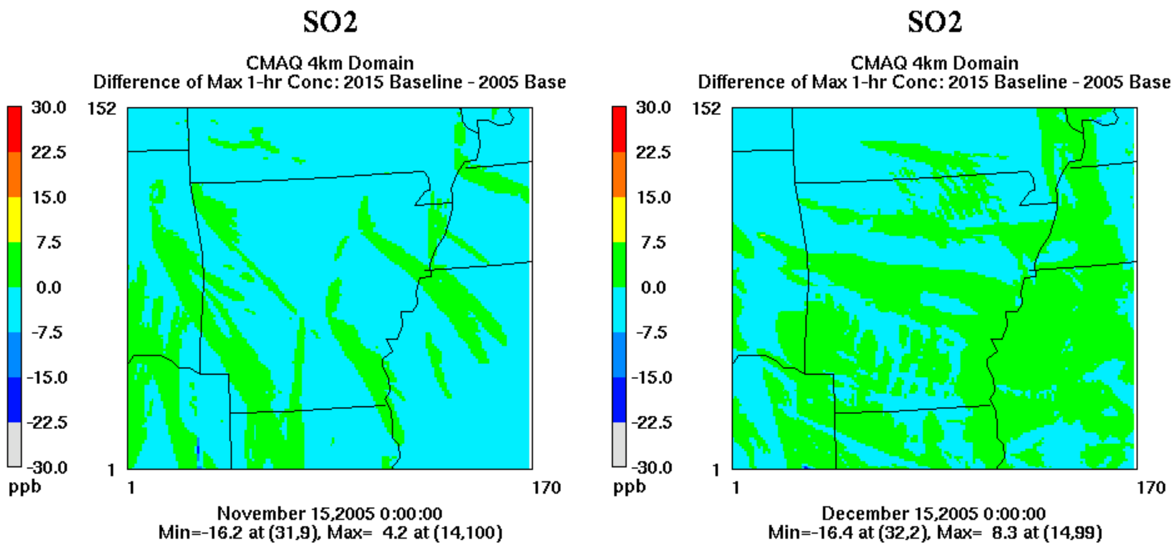
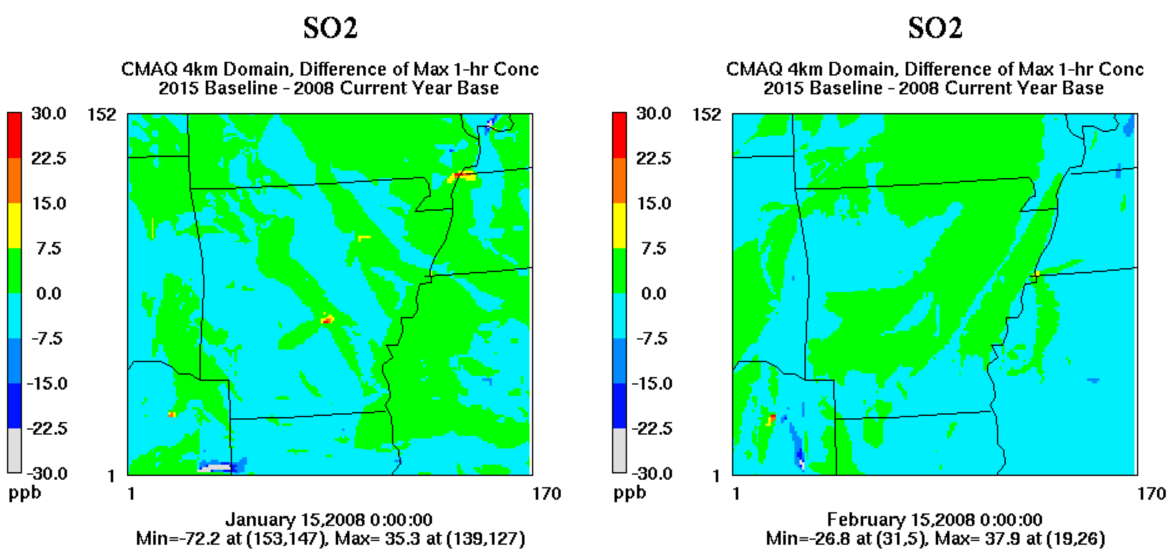
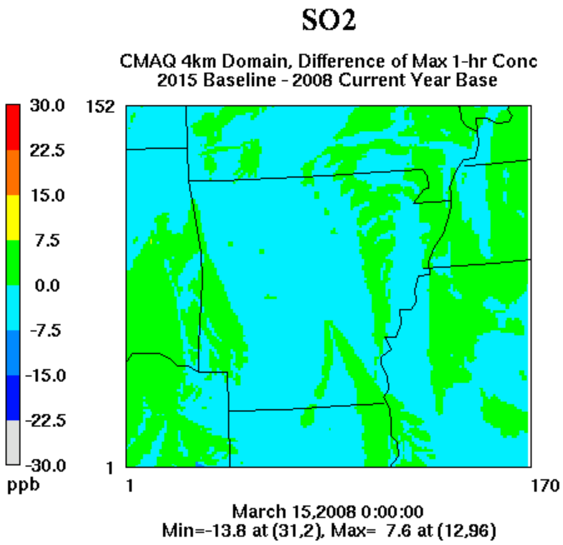


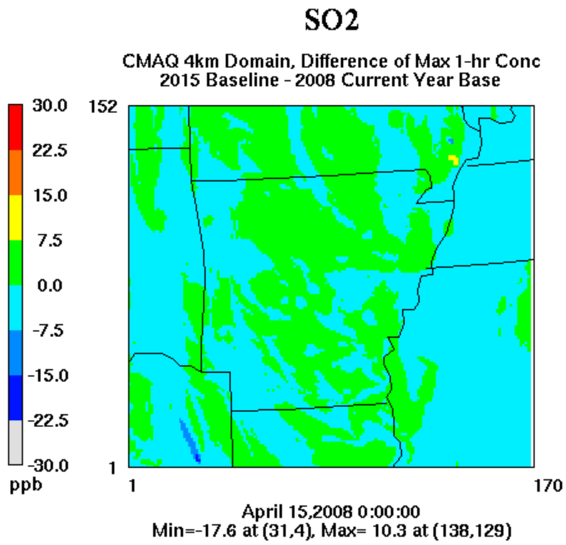
Figure 6-10. Difference in Simulated Monthly Average 1-Hour SO_2 Concentration (ppb) for the CMAQ 4-km Grid: 2015 - 2008

January/February

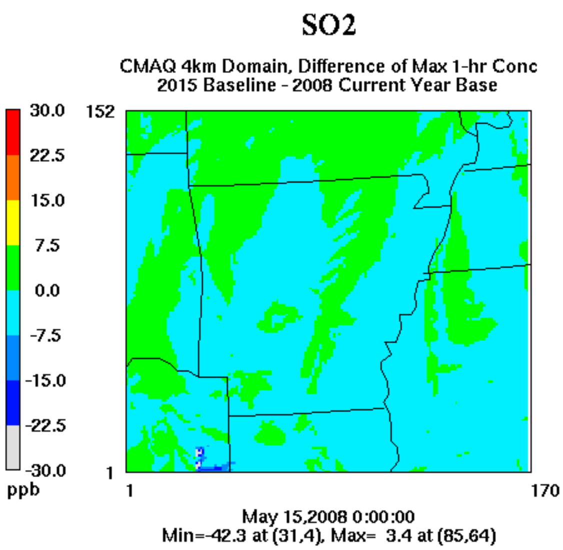


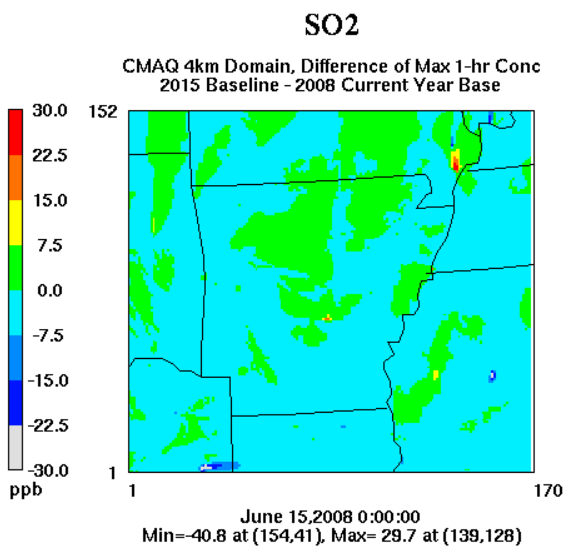
March/April



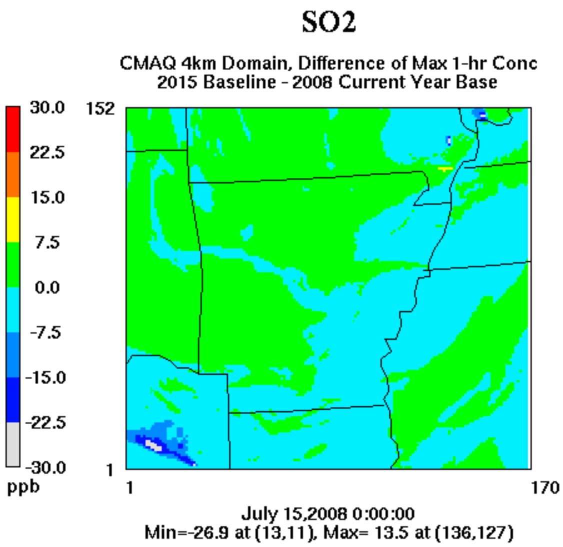


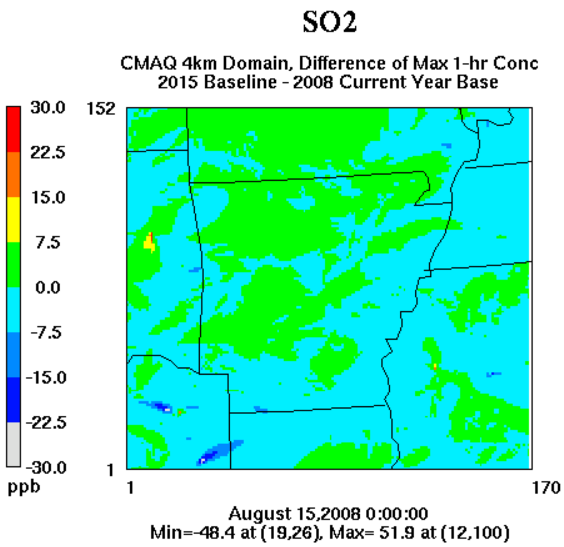
May/June



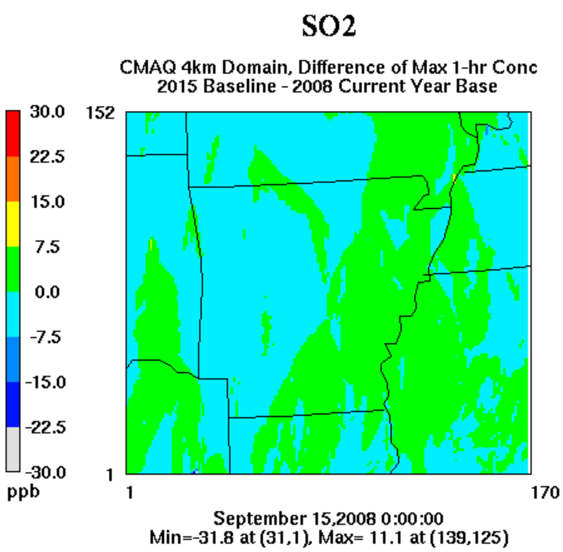


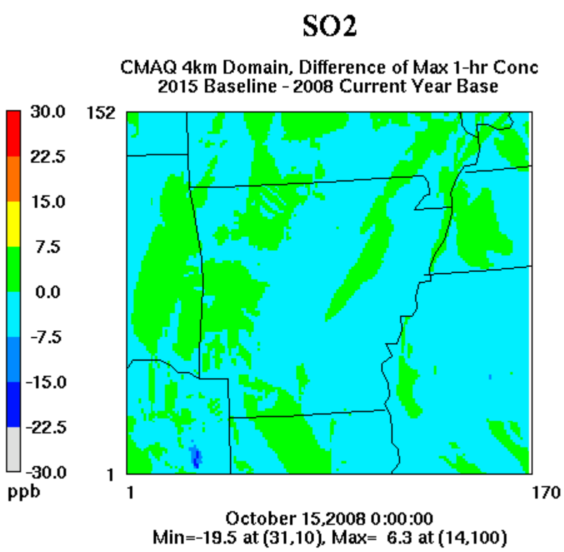
July/August



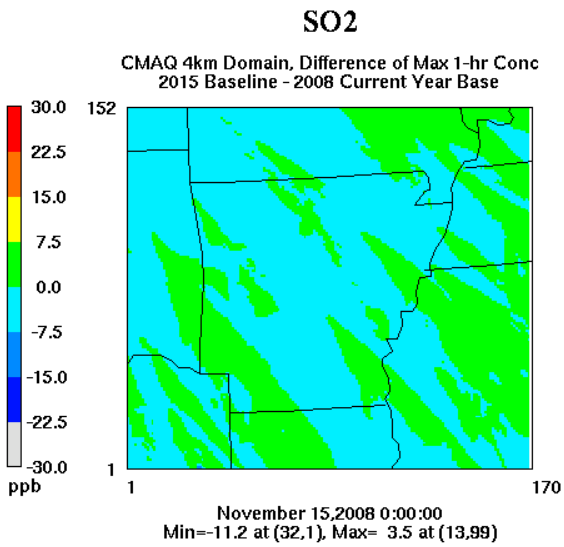


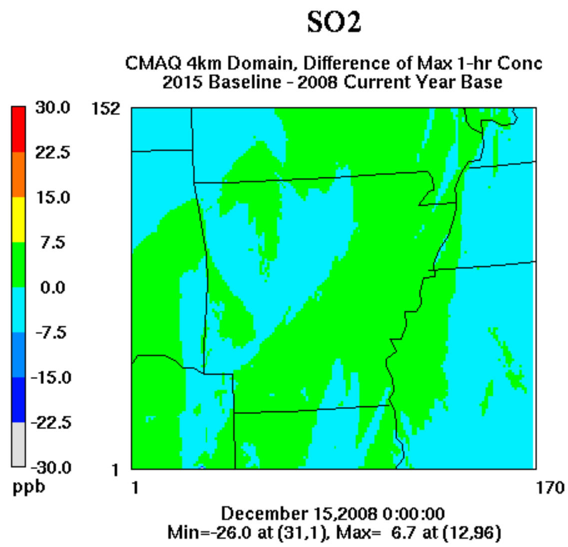
September/October





November/December





For SO_2, the difference plots show a mix of increases and decreases between 2005 and 2015 and between 2008 and 2015. For most of the selected days, the decreases are larger in magnitude than the increases, but the increases tend to be more widespread.

Table 6-5 summarizes the 4th high daily maximum 1-hour SO_2 concentration (equivalent to the 99th percentile value as used in the NAAQS) for the base- and future-year simulations. Included in the table are the simulated concentrations and differences in simulated concentration for current monitoring sites and any grid locations with an increase in the value of this metric between the base and future year. There are three primary areas of increase within the state and the unmonitored locations represent the grid cells with the maximum increase for each of these areas.

Table 6-5. Simulated 4th High Daily Maximum 1-Hour SO_2 Concentration (ppb) for Monitoring Sites and Selected Unmonitored Locations within Arkansas

Site/Location	County	2005/2015 4th High 1-Hour SO_2 (ppb)			2008/2015 4th High 1-Hour SO_2 (ppb)		
		2005 Base Year	2015 Future Year	Diff-erence	2008 Current Year	2015 Future Year	Diff-erence
North Little Rock (Pike Ave)	Pulaski	18.6	15.4	-3.2	15.3	13.6	-1.7
Marion	Crittenden	16.4	19.8	3.4	21.3	24.0	2.7
El Dorado	Union	13.5	12.3	-1.2	10.2	9.6	-0.6
Unmonitored 1	Benton	26.8	43.6	16.8	31.7	46.8	15.1
Unmonitored 2	Jefferson	77.1	109.0	31.9	59.3	84.0	24.7
Unmonitored 3	Independence	55.3	77.7	22.4	38.1	54.1	16.0

For both simulation pairs, the 4th high daily maximum 1-hour SO_2 concentration is lower for 2015 for the current SO_2 monitoring site locations but higher for 2015 for a number of grid cells including one non-SO_2 monitoring site (Marion). The greatest increases are 31.7 ppb for 2005/2015 and 24.7 ppb for 2008/2015 and occur at the Jefferson County pseudo site location.

6.2 Criteria Pollutant Assessment

To complete the criteria pollutant assessment, the MATS software was applied using the base-/current-year and future-year modeling results and was used to estimate future-year design values at both monitored and unmonitored locations throughout the state. The MATS input parameters were set to the EPA-recommended default values. “Monitored” data (current year design values) for both new monitoring sites (that were not operational during the base year period) and the unmonitored locations relied on data for the nearest monitoring site or were estimated using inverse-distance-weighted interpolation of the data from multiple nearby monitoring sites.

6.2.1 Ozone

Table 6-6 summarizes the modeled attainment test results for 8-hour ozone. The current-year design values used for this summary were calculated as the average of the design values for the two overlapping three-year periods that include the modeled years (2005-2007 and 2006-2008). This is not an attainment demonstration and the data for these years were used in order to represent the emissions base year (2005) and the meteorological base years (2005 and 2008), and to allow a direct comparison of the projected future-year design values for the two simulation pairs. The current-year design values are based on the data contained with the MATS database and are calculated within MATS.

Table 6-6. Estimated Future-Year 8-Hour Ozone Design Values (ppb) for Monitoring Sites and Selected Unmonitored Locations within Arkansas

Site/Location	County	2005/2015 8-Hr Ozone Design Values (ppb)			2008/2015 8-Hr Ozone Design Values (ppb)		
		Current Year DV	Future Year DV	Diff-erence	Current Year DV	Future Year DV	Diff-erence
North Little Rock (Pike Ave)	Pulaski	77	66	-11	77	68	-9
North Little Rock Airport	Pulaski	81	70	-11	81	71	-10
Little Rock (Doyle Springs Rd)	Pulaski	71	61	-10	71	62	-9
Marion	Crittenden	85	74	-11	85	77	-8
Deer	Newton	71	62	-9	71	63	-8
Springdale	Washington	61*	53	-8	61*	54	-7
Fayetteville	Washington	66	57	-9	66	57	-9
Mena	Polk	74	66	-8	74	67	-7
Arkadelphia	Clark	64*	56	-8	64*	57	-7
Unmonitored 1	Benton	61*	55	-6	61*	55	-6
Unmonitored 2	Jefferson	77*	68	-9	77*	69	-8
Unmonitored 3	Independence	76*	67	-9	76*	67	-9

Note: The NAAQS for 8-hour average ozone concentration is 75 ppb. * Current Year DV is estimated.

Ozone design values for 2015 are estimated to be 6 to 11 ppb lower than the current-year value for the 2005/2015 simulation pair, and 6 to 10 ppb lower for the 2008/2015 simulation pair. The average reduction is 9 ppb for the 2005/2015 simulation pair and 8 ppb for the 2008/2015 simulation pair. Although the current-year design values are the same, there are differences in the estimated future-year design values for many of the sites. For Marion, for example, the estimated future-year design value is 74 ppb for the 2005/2015 simulation pair and 77 ppb for the 2008/2015 simulation pair. One could interpret these results to mean that the 8-hour ozone design value for 2015 for the Marion site is estimated to be in the range of 74 to 77 ppb. For reference, the 2010-2012 design value is 79 ppb and the 2011-2013 design value is currently expected to be 75 ppb (although the data for 2013 have not been finalized). The differences in the results reflect the difference in the response of the model to changes in emissions under different meteorological conditions. The estimated future-year design values for the remaining sites are all well below the NAAQS and range from 53 to 70 ppb for the 2005/2015 simulation pair and from 54 to 71 for the 2008/2015 simulation pair.

6.2.2 $PM_{2.5}$

Table 6-7 summarizes the modeled attainment test results for 24-hour $PM_{2.5}$. The current-year design values used for this summary are calculated as the average of the design values for the two overlapping three-year periods that include the modeled years (2005-2007 and 2006-2008). For each three-year period, the design value is calculated as the three-year average of the 98th percentile 24-hour $PM_{2.5}$

concentration for each of the years. The current-year design values are based on the data contained with the MATS database and are calculated within MATS.

Table 6-7. Estimated Future-Year 24-Hour $PM_{2.5}$ Design Values ($\mu g/m^3$) for Monitoring Sites and Selected Unmonitored Locations within Arkansas

Site/Location	County	2005/2015 24-Hr $PM_{2.5}$ Design Values ($\mu g/m^3$)			2008/2015 24-Hr $PM_{2.5}$ Design Values ($\mu g/m^3$)		
		Current Year DV	Future Year DV	Diff-erence	Current Year DV	Future Year DV	Diff-erence
North Little Rock (Pike Ave)	Pulaski	29.1	24.7	-4.4	29.1	25.3	-3.8
Little Rock (Adams Field)	Pulaski	30.9	26.1	-4.8	30.9	26.3	-4.6
Little Rock (Doyle Springs Rd)	Pulaski	29.5	24.9	-4.6	29.5	25.1	-4.4
Marion	Crittenden	32.8	25.7	-7.1	32.8	27.0	-5.8
Stuttgart	Arkansas	28.1	23.0	-5.1	28.1	24.0	-4.1
Newport	Jackson	30.5	25.1	-5.4	30.5	24.5	-6.0
Springdale	Washington	26.7	23.6	-3.1	26.7	21.5	-5.2
Mena	Polk	26.3	21.9	-4.4	26.3	22.6	-3.7
Hot Springs	Garland	27.2	22.3	-4.9	27.2	22.8	-4.4
El Dorado	Union	27.0	22.5	-4.5	27.0	23.3	-3.7
Crossett	Ashley	27.7	23.5	-4.2	27.7	24.1	-3.6
Roland	Sequoyah (OK)	26.5	23.0	-3.5	26.5	21.4	-5.1
Unmonitored 1	Benton	26.7	23.0	-3.7	26.7	20.9	-5.8
Unmonitored 2	Jefferson	29.5	24.9	-4.6	29.5	24.5	-5.0
Unmonitored 3	Independence	30.0	25.1	-4.9	30.0	24.2	-5.8

Note: The NAAQS for 24-hour average $PM_{2.5}$ is 35 $\mu g/m^3$. * Current Year DV is estimated.

Estimated daily $PM_{2.5}$ design values are lower than the current-year values by approximately 3 to 7 $\mu g/m^3$ for the 2005/2015 simulation pair and approximately 3.5 to 6 $\mu g/m^3$ for the 2008/2015 simulation pair. Again, the differences in the results reflect the difference in the response of the model to changes in emissions under different meteorological conditions. In both cases, the greatest reduction is simulated to occur at the Marion site in Crittenden County. The resulting future-year design values are all lower than the NAAQS.

Table 6-8 summarizes the modeled attainment test results for annual $PM_{2.5}$. The current-year design values used for this summary are calculated as the average of the design values for the two overlapping three-year periods that include the modeled years (2005-2007 and 2006-2008). For each three-year period, the design value is calculated as the three-year average of the annual average $PM_{2.5}$ concentration for each of the three years. The current-year design values are based on the data contained with the MATS database and calculated within MATS.

Table 6-8. Estimated Future-Year Annual Average $PM_{2.5}$ Design Values ($\mu g/m^3$) for Monitoring Sites and Selected Unmonitored Locations within Arkansas

Site/Location	County	2005/2015 Annual $PM_{2.5}$ Design Values ($\mu g/m^3$)			2008/2015 Annual $PM_{2.5}$ Design Values ($\mu g/m^3$)		
		Current Year DV	Future Year DV	Diff-erence	Current Year DV	Future Year DV	Diff-erence
North Little Rock (Pike Ave)	Pulaski	12.7	11.0	-1.7	12.7	11.1	-1.6
Little Rock (Adams Field)	Pulaski	13.2	11.5	-1.7	13.2	11.7	-1.5
Little Rock (Doyle Springs Rd)	Pulaski	13.2	11.5	-1.7	13.2	11.7	-1.5
Marion	Crittenden	12.9	11.1	-1.8	12.9	11.3	-1.6
Stuttgart	Arkansas	12.2	10.7	-1.5	12.2	10.9	-1.3
Newport	Jackson	12.6	10.7	-1.9	12.6	10.9	-1.7
Springdale	Washington	11.9	10.3	-1.6	11.9	10.3	-1.6
Mena	Polk	11.7	10.4	-1.3	11.7	10.5	-1.2
Hot Springs	Garland	12.1	10.8	-1.3	12.1	11.0	-1.1
El Dorado	Union	12.4	10.9	-1.5	12.4	11.1	-1.3
Crossett	Ashley	12.7	11.2	-1.5	12.7	11.4	-1.3
Roland	Sequoyah (OK)	11.8	10.3	-1.5	11.8	10.4	-1.4
Unmonitored 1	Benton	11.9	10.3	-1.6	11.9	10.3	-1.6
Unmonitored 2	Jefferson	12.9	11.2	-1.7	12.9	11.3	-1.6
Unmonitored 3	Independence	12.8	11.1	-1.7	12.8	11.1	-1.7

Note: The NAAQS for annual average $PM_{2.5}$ is 12 $\mu g/m^3$. * Current Year DV is estimated.

Estimated annual $PM_{2.5}$ design values are lower than the current-year values by approximately 1 to 2 $\mu g/m^3$ for both simulation pairs. In both cases, the greatest reductions are simulated to occur at the Newport site in Jackson County. The resulting future-year design values are all lower than the NAAQS.

6.2.3 NO_2

MATS does not accommodate NO_2. The results presented in this section were calculated using the MATS procedures, but in this case the procedures were applied manually within spreadsheets containing the model output for NO_2.

Table 6-9 summarizes the modeled attainment test results for 1-hour NO_2. For this summary, the current-year design value is calculated as the average design value for the two periods 2005-2007 and 2006-2008, where the design value for each of these periods is the three-year average of the of 98th percentile daily maximum 1-hour NO_2 concentration for each of the three years. The current-year design values were calculated manually, based on observed data.

Table 6-9. Estimated Future-Year 1-Hour NO_2 Design Values (ppb) for Monitoring Sites and Selected Unmonitored Locations within Arkansas

Site/Location	County	2005/2015 1-Hr NO_2 Design Values (ppb)			2008/2015 1-Hr NO_2 Design Values (ppb)		
		Current Year DV	Future Year DV	Diff-erence	Current Year DV	Future Year DV	Diff-erence
North Little Rock (Pike Ave)	Pulaski	47.5	35.5	-12.0	47.5	38.4	-9.1
Marion	Crittenden	52.0	38.6	-13.4	52.0	42.6	-9.4
Unmonitored 1	Benton	52.0	30.8	-21.2	52.0	34.0	-18.0
Unmonitored 2	Jefferson	52.0	42.0	-10.0	52.0	37.7	-14.3
Unmonitored 3	Independence	52.0	41.4	-10.6	52.0	35.7	-16.3

Note: The NAAQS for 1-hour average NO_2 is 100 ppb. * Current Year DV is estimated.

Future-year NO_2 design values are estimated to be lower than the current-year values by approximately 12 to 13 ppb at the monitoring sites and by approximately 10 to 20 ppb at the unmonitored locations for the 2005/2015 simulation pair. The differences are approximately 9 ppb at the monitoring sites and 14 to 18 ppb at the unmonitored locations for the 2008/2015 simulation pair. The estimated future-year design values for all locations range from about 30 to 40 ppb (well below the NAAQS).

6.2.4 SO_2

MATS also does not accommodate SO_2. The results presented in this section were calculated using the MATS procedures, but in this case the procedures were applied manually within spreadsheets containing the model output for SO_2.

Table 6-10 summarizes the modeled attainment test results for 1-hour SO_2. For this summary, the current-year design value is the average design value for the two periods 2005-2007 and 2006-2008, where the design value for each of these periods is the three-year average of the of 99^{th} percentile daily maximum 1-hour SO_2 concentration for each of the three years. The current-year design values were calculated manually, based on observed data.

Table 6-10. Estimated Future-Year 1-Hour SO_2 Design Values (ppb) for Monitoring Sites and Selected Unmonitored Locations within Arkansas

Site/Location	County	2005/2015 1-Hr SO_2 Design Values (ppb)			2008/2015 1-Hr SO_2 Design Values (ppb)		
		Current Year DV	Future Year DV	Diff-erence	Current Year DV	Future Year DV	Diff-erence
North Little Rock (Pike Ave)	Pulaski	11.0	8.5	-2.5	11.0	9.9	-1.1
Marion	Crittenden	20.2*	24.4	4.2	20.2*	26.1	5.9
El Dorado	Union	34.0	29.7	-4.3	34.0	32.0	-2.0
Unmonitored 1	Benton	20.9*	35.9	15.0	20.9*	33.3	12.4
Unmonitored 2	Jefferson	16.3*	23.2	6.9	16.3*	22.7	6.4
Unmonitored 3	Independence	18.1*	26.0	7.9	18.1*	25.6	7.5

Note: The NAAQS for 1-hour average SO_2 is 75 ppb. * Current Year DV is estimated.

For both simulation pairs, SO_2 design values are estimated to be lower than the current-year values at the actual monitoring sites and higher at the unmonitored locations. Despite the increases all estimated future-year design values are below the NAAQS.

6.2.5 Visibility

MATS was also applied for visibility, focusing on the two Class I areas in Arkansas. Table 6-11 summarizes the modeled attainment test results for visibility – first for the 20 percent best visibility days and then for the 20 percent worst visibility days. The current year design values are based on the best and worst visibility days for the four-year period 2005-2008. The units are deciviews (dV).

Table 6-11a. Estimated Future-Year Visibility (dV) for IMPROVE Monitoring Sites within Arkansas: 20 Percent Best Days

Site/Location	County	2005/2015 Visibility Values (dV)			2008/2015 Visibility Values (dV)		
		Current Year DV	Future Year DV	Diff-erence	Current Year DV	Future Year DV	Diff-erence
Caney Creek Wilderness	Newton	12.2	11.7	-0.5	12.2	11.6	-0.6
Upper Buffalo Wilderness	Union	12.3	11.6	-0.7	12.3	11.7	-0.6

Table 6-11b. Estimated Future-Year Visibility (dV) for IMPROVE Monitoring Sites within Arkansas: 20 Percent Worst Days

Site/Location	County	2005/2015 Visibility Values (dV)			2008/2015 Visibility Values (dV)		
		Current Year DV	Future Year DV	Diff-erence	Current Year DV	Future Year DV	Diff-erence
Caney Creek Wilderness	Newton	26.3	23.9	-2.4	26.3	24.0	-2.3
Upper Buffalo Wilderness	Union	26.7	24.5	-2.2	26.7	24.6	-2.1

The CMAQ/MATS modeling results indicate an improvement in visibility at the two Class I sites, on both the 20 percent best and worst days between the current-year period and 2015.

7 References

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