APPENDIX C-3

LADCO Technical Support Document 2005 and 2009 Emissions Summary Information

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Regional Air Quality Analyses for Ozone, $PM_{2.5}$, and Regional Haze:

Final Technical Support Document

April 25, 2008

States of Illinois, Indiana, Michigan, Ohio, and Wisconsin

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EXECUTIVE SUMMARY

States in the upper Midwest face a number of air quality challenges. More than 50 counties are currently classified as nonattainment for the 8-hour ozone standard and 60 for the fine particle ($PM_{2.5}$) standard (1997 versions). A map of these nonattainment areas is provided in the figure below. In addition, visibility impairment due to regional haze is a problem in the larger national parks and wilderness areas (i.e., Class I areas). There are 156 Class I areas in the U.S., including two in northern Michigan.

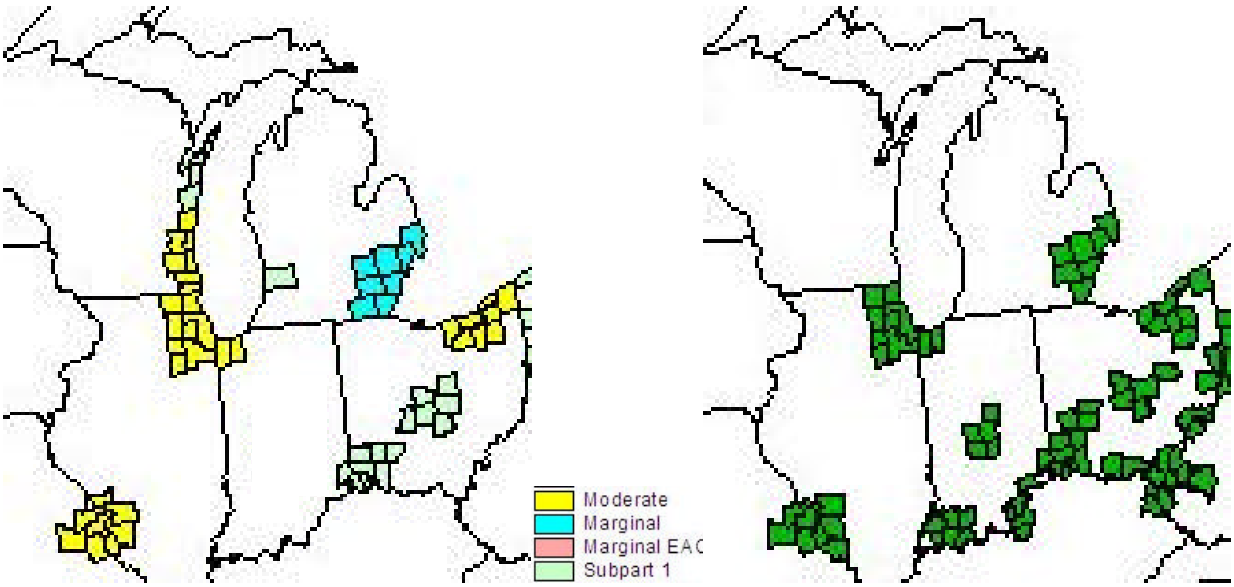


Figure i. Current nonattainment counties for ozone (left) and $PM_{2.5}$ (right)

To support the development of State Implementation Plans (SIPs) for ozone, $PM_{2.5}$, and regional haze in the States of Illinois, Indiana, Michigan, Ohio, and Wisconsin, technical analyses were conducted by the Lake Michigan Air Directors Consortium (LADCO), its member states, and various contractors. The analyses include preparation of regional emissions inventories and meteorological data, evaluation and application of regional chemical transport models, and collection and analysis of ambient monitoring data.

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

Ozone

- Current monitoring data (2005-2007) show about 20 sites in violation of the 8-hour ozone standard of 85 parts per billion (ppb). Historical ozone data show a steady downward trend over the past 15 years, especially since 2001-2003, due likely to federal and state emission control programs.

- Ozone concentrations are strongly influenced by meteorological conditions, with more high ozone days and higher ozone levels during summers with above normal temperatures.

- Inter- and intra-regional transport of ozone and ozone precursors affects many portions of the five states, and is the principal cause of nonattainment in some areas far from population or industrial centers.

$PM_{2.5}$

- Current monitoring data (2005-2007) show 30 sites in violation of the annual $PM_{2.5}$ standard of 15 ug/m^3. Nonattainment sites are characterized by an elevated regional background (about 12 – 14 ug/m^3) and a significant local (urban) increment (about 2 – 3 ug/m^3). Historical $PM_{2.5}$ data show a slight downward trend since deployment of the $PM_{2.5}$ monitoring network in 1999.

- $PM_{2.5}$ concentrations are also influenced by meteorology, but the relationship is more complex and less well understood compared to ozone.

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

Haze

- Current monitoring data (2000-2004) show visibility levels in the Class I areas in northern Michigan are on the order of 22 – 24 deciviews. The goal of EPA's visibility program is to achieve natural conditions, which is about 12 deciviews for these Class I areas, by the year 2064.

- Visibility impairment is dominated by sulfate and nitrate.

Air quality models were applied to support the regional planning efforts. Two base years were used in the modeling analyses: 2002 and 2005. Basecase modeling was conducted to evaluate model performance (i.e., assess the model's ability to reproduce observed concentrations). This exercise was intended to build confidence in the model prior to its use in examining control strategies. Model performance for ozone and $PM_{2.5}$ was found to be generally acceptable.

Future year strategy modeling was conducted to determine whether existing ("on the books") controls would be sufficient to provide for attainment of the standards for ozone and $PM_{2.5}$ and if not, then what additional emission reductions would be necessary for attainment. Based on the modeling and other supplemental analyses, the following general conclusions can be made:

- Existing controls are expected to produce significant improvement in ozone and $PM_{2.5}$ concentrations and visibility levels.

- The choice of the base year affects the future year model projections. A key difference between the base years of 2002 and 2005 is meteorology. 2002 was more ozone conducive than 2005. The choice of which base year to use as the basis for the SIP is a policy decision (i.e., how much safeguard to incorporate).

- Modeling suggests that most sites are expected to meet the current 8-hour ozone standard by the applicable attainment date, except for sites in western Michigan and, possibly, in eastern Wisconsin and northeastern Ohio.

- Modeling suggests that most sites are expected to meet the current $PM_{2.5}$ standard by the applicable attainment date, except for sites in Detroit, Cleveland, and Granite City.

  The regional modeling for $PM_{2.5}$ does not include air quality benefits expected from local controls. States are conducting local-scale analyses and will use these results, in conjunction with the regional-scale modeling, to support their attainment demonstrations for $PM_{2.5}$.

- These findings of residual nonattainment for ozone and $PM_{2.5}$ are supported by current (2005 – 2007) monitoring data which show significant nonattainment in the region (e.g., peak ozone design values on the order of 90 – 93 ppb, and peak $PM_{2.5}$ design values on the order of 16 - 17 ug/m^3). It is unlikely that sufficient emission reductions will occur in the next couple of years to provide for attainment at all sites.

- Attainment at most sites by the applicable attainment date is dependent on actual future year meteorology (e.g., if the weather conditions are consistent with [or less severe than] 2005, then attainment is likely) and actual future year emissions (e.g., if the emission reductions associated with the existing controls are achieved, then attainment is likely). If either of these conditions is not met, then attainment may be less likely.

- Modeling suggests that the new $PM_{2.5}$ 24-hour standard and the new lower ozone standard will not be met at several sites, even by 2018, with existing controls.

- Visibility levels in a few Class I areas in the eastern U.S. are expected to be greater than (less improved than) the uniform rate of visibility improvement values in 2018 based on existing controls, including those in northern Michigan and some in the northeastern U.S. Visibility levels in many other Class I areas in the eastern U.S. are expected to be less than (more improved than) the uniform rate of visibility improvement values in 2018. These results, along with information on the costs of compliance, time necessary for compliance, energy and non air quality environmental impacts of compliance, and remaining useful life of existing sources, should be considered by the states in setting reasonable progress goals for regional haze.

Section 1.0 Introduction

This Technical Support Document summarizes the final air quality analyses conducted by the Lake Michigan Directors Consortium (LADCO)[1] and its contractors to support the development of State Implementation Plans (SIPs) for ozone, fine particles ($PM_{2.5}$), and regional haze in the States of Illinois, Indiana, Michigan, Ohio, and Wisconsin. The analyses include preparation of regional emissions inventories and meteorological modeling data for two base years (2002 and 2005), evaluation and application of regional chemical transport models, and analysis of ambient monitoring data.

Two aspects of the analyses should be emphasized. First, a regional, multi-pollutant approach was taken in addressing ozone, $PM_{2.5}$, and haze for technical reasons (e.g., commonality in precursors, emission sources, atmospheric processes, transport influences, and geographic areas of concern), and practical reasons (e.g., more efficient use of program resources). Furthermore, EPA has consistently encouraged multi-pollutant planning in its rule for the haze program (64 FR 35719), and its implementation guidance for ozone (70 FR 71663) and $PM_{2.5}$ (72 FR 20609). Second, a weight-of-evidence approach was taken in considering the results of the various analyses (i.e., two sets of modeling results -- one for a 2002 base year and one for a 2005 base year -- and ambient data analyses) in order to provide a more robust assessment of expected future year air quality.

The report is organized in the following sections. This Introduction provides an overview of regulatory requirements and background information on regional planning. Section 2 reviews the ambient monitoring data and presents a conceptual model of ozone, $PM_{2.5}$, and haze for the region. Section 3 discusses the air quality modeling analyses, including development of the key model inputs (emissions inventory and meteorological data), and basecase model performance evaluation. A modeled attainment demonstration for ozone and $PM_{2.5}$ is presented in Section 4, along with relevant data analyses considered as part of the weight-of-evidence determination. Section 5 documents the reasonable progress assessment for regional haze, along with relevant data analyses considered as part of the weight-of-evidence determination. Finally, key study findings are reviewed and summarized in Section 6.

1.1 SIP Requirements

For ozone, EPA promulgated designations on April 15, 2004 (69 FR 23858, April 30, 2004). In the 5-state region, more than 100 counties were designated as nonattainment.[2] The designations became effective on June 15, 2004. SIPs for ozone were due no later than three years from the effective date of the nonattainment designations (i.e., by June 2007). The attainment date for ozone varies as a function of nonattainment classification. For the region, the attainment dates are either June 2007 (marginal nonattainment areas), June 2009 (basic nonattainment areas), or June 2010 (moderate nonattainment areas).

[1] A sub-entity of LADCO, known as the Midwest Regional Planning Organization (MRPO), is responsible for the regional haze activities of the multi-state organization.

[2] Based on more recent air quality data, many counties in Indiana, Michigan, and Ohio were subsequently redesignated as attainment. As of December 31, 2007, there are 53 counties designated as nonattainment in the region.

For $PM_{2.5}$, EPA promulgated designations on December 17, 2004 (70 FR 944, January 5, 2005). In the 5-state region, 70 counties were designated as nonattainment.[3] The designations became effective on April 5, 2005. SIPs for $PM_{2.5}$ are due no later than three years from the effective date of the nonattainment designations (per section 172(b) of the Clean Air Act) (i.e., by April 2008) and for haze no later than three years after the date on which the Administrator promulgated the $PM_{2.5}$ designations (per the Omnibus Appropriations Act of 2004) (i.e., by December 2007). The applicable attainment date for $PM_{2.5}$ nonattainment areas is five years from the date of the nonattainment designation (i.e., by April 2010).

For haze, the Clean Air Act sets "as a national goal the prevention of any future, and the remedying of any existing, impairment of visibility in Class I areas which impairment results from manmade air pollution." There are 156 Class I areas, including two in northern Michigan: Isle Royale National Park and Seney National Wildlife Refuge[4]. EPA's visibility rule (64 FR 35714, July 1, 1999) requires reasonable progress in achieving "natural conditions" by the year 2064. As noted above, the first regional haze SIP was due in December 2007 and must address the initial 10-year implementation period (i.e., reasonable progress by the year 2018). SIP requirements (pursuant to 40 CFR 51.308(d)) include setting reasonable progress goals, determining baseline conditions, determining natural conditions, providing a long-term control strategy, providing a monitoring strategy (air quality and emissions), and establishing BART emissions limitations and associated compliance schedule.

1.2 Organization

LADCO was established by the States of Illinois, Indiana, Michigan, and Wisconsin in 1989. The four states and EPA signed a Memorandum of Agreement (MOA) that initiated the Lake Michigan Ozone Study (LMOS) and identified LADCO as the organization to oversee the study. Additional MOAs were signed by the States in 1991 (to establish the Lake Michigan Ozone Control Program), January 2000 (to broaden LADCO's responsibilities), and June 2004 (to update LADCO's mission and reaffirm the commitment to regional planning). In March 2004, Ohio joined LADCO. LADCO consists of a Board of Directors (i.e., the State Air Directors), a technical staff, and various workgroups. The main purposes of LADCO are to provide technical assessments for and assistance to its member states, and to provide a forum for its member states to discuss regional air quality issues.

MRPO is a similar entity led by the five LADCO States and involves the federally recognized tribes in Michigan and Wisconsin, EPA, and Federal Land Managers (i.e., National Park Service, U.S. Fish & Wildlife Agency, and U.S. Forest Service). In October 2000, the States of Illinois, Indiana, Michigan, Ohio, and Wisconsin signed an MOA that established the MRPO. An operating principles document for MRPO, which describe the roles and responsibilities of states, tribes, federal agencies, and stakeholders, was issued in March 2001. MRPO has a similar purpose as LADCO, but is focused on visibility impairment due to regional haze in the Federal Class I areas located inside the borders of the five states, and the impact of emissions from the five states on visibility impairment due to regional haze in the Federal Class I areas located outside the borders of the five states. MRPO works cooperatively with the Regional Planning Organizations (RPOs) representing other parts of the country. The RPOs sponsored several

[3] USEPA subsequently adjusted the final designations, which resulted in 63 counties in the region being designated as nonattainment (70 FR 19844, April 15, 2005).

[4] Although Rainbow Lake in northern Wisconsin is also a Class I area, the visibility rule does not apply because the Federal Land Manager determined that visibility is not an air quality related value there.

joint projects and, with assistance by EPA, maintain regular contact on technical and policy matters.

1.3 Technical Work: Overview

To ensure the reliability and effectiveness of its planning process, LADCO has made data collection and analysis a priority. More than $7M in RPO grant funds were used for special purpose monitoring, preparing and improving emissions inventories, and conducting air quality analyses[5]. An overview of the technical work is provided below.

Monitoring: Numerous monitoring projects were conducted to supplement on-going state and local air pollution monitoring. These projects include rural monitoring (e.g., comprehensive sampling in the Seney National Wildlife Refuge and in Bondville, IL); urban monitoring (e.g., continuation of the St. Louis Supersite); aloft (aircraft) measurements; regional ammonia monitoring; and organic speciation sampling in Seney, Bondville, and five urban areas.

Emissions: Baseyear emissions inventories were prepared for 2002 and 2005. States provided point source and area source emissions data, and MOBILE6 input files and mobile source activity data. LADCO and its contractors developed the emissions data for other source categories (e.g., select nonroad sources, ammonia, fires, and biogenics) and processed the data for input into an air quality model. To support control strategy modeling, future year inventories were prepared. The future years of interest include 2008 (planning year to address the 2009 attainment year for basic ozone nonattainment ares), 2009 (planning year to address the 2010 attainment year for $PM_{2.5}$ and moderate ozone nonattainment areas), 2012 (planning to address a 2013 alternative attainment date), and 2018 (first milestone year for regional haze).

Air Quality Analyses: The weight-of-evidence approach relies on data analysis and modeling. Air quality data analyses were used to provide both a conceptual model (i.e., a qualitative description of the ozone, $PM_{2.5}$, and regional haze problems) and supplemental information for the attainment demonstration. Given uncertainties in emissions inventories and modeling, especially for $PM_{2.5}$, these data analyses are a necessary part of the overall technical support.

Modeling includes baseyear analyses for 2002 and 2005 to evaluate model performance and future year strategy analyses to assess candidate control strategies. The analyses were conducted in accordance with EPA's modeling guidelines (EPA, 2007a). The PM/haze modeling covers the full calendar year (2002 and 2005) for an eastern U.S. 36 km domain, while the ozone modeling focuses on the summer period (2002 and 2005) for a Midwest 12 km subdomain. The same model (CAMx) was used for ozone, $PM_{2.5}$, and regional haze.

[5] Since 1999, MRPO has received almost $10M in RPO grant funds from USEPA.

Section 2.0 Ambient Data Analyses

An extensive network of air quality monitors in the 5-state region provides data for ozone (and its precursors), $PM_{2.5}$ (both total mass and individual chemical species), and visibility. These data are used to determine attainment/nonattainment designations, support SIP development, and provide air quality information to public (see, for example, www.airnow.gov).

Analyses of the data were conducted to produce a conceptual model, which is a qualitative summary of the physical, chemical, and meteorological processes that control the formation and distribution of pollutants in a given region. This section reviews the relevant data analyses and describes our understanding of ozone, $PM_{2.5,}$ and regional haze with respect to current conditions, data variability (spatial, temporal, and chemical), influence of meteorology (including transport patterns), precursor sensitivity, and source culpability.

2.1 Ozone

In 1979, EPA adopted an ozone standard of 0.12 ppm, averaged over a 1-hour period. This standard is attained when the number of days per calendar year with maximum hourly average concentrations above 0.12 ppm is equal to or less than 1.0, averaged over a 3-year period, which generally reflects a design value (i.e., the 4th highest daily 1-hour value over a 3-year period) less than 0.12 ppm.

In 1997, EPA tightened the ozone standard to 0.08 ppm, averaged over an 8-hour period[6]. The standard is attained if the 3-year average of the 4th-highest daily maximum 8-hour average ozone concentrations (i.e., the design value) measured at each monitor within an area is less than 0.08 ppm (or 85 ppb).

Current Conditions: A map of the 8-hour ozone design values at each monitoring site in the region for the 3-year period 2005-2007 is shown in Figure 1. The “hotter” colors represent higher concentrations, where yellow and orange dots represent sites with design values above the standard. Currently, there are 19 sites in violation of the 8-hour ozone NAAQS in the 5-state region, including sites in the Lake Michigan area, Detroit, Cleveland, Cincinnati, and Columbus.

Table 1 provides the 4th-highest daily 8-hour ozone values and the associated design values since 2001 for several high monitoring sites throughout the region.

[6] On March 12, 2008, USEPA further tightened the 8-hour ozone standard to increase public health protection and prevent environmental damage from ground-level ozone. USEPA set the primary (health) standard and secondary (welfare) standard at the same level: 0.075 ppm (75 ppb), averaged over an 8-hour period.

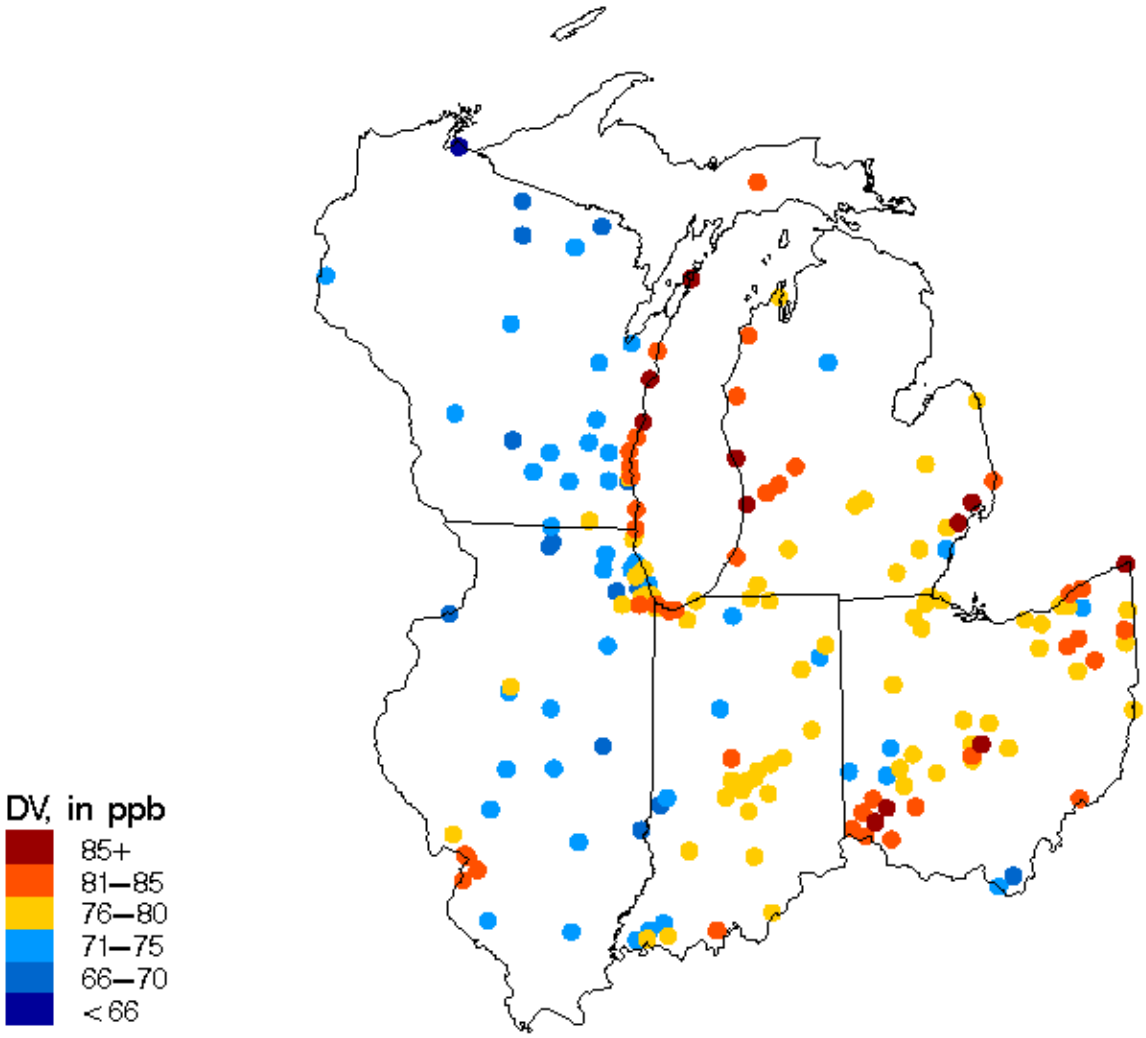


Figure 1. 8-hour ozone design values (2005-2007)

Table 1. Ozone Data for Select Sites in 5-State Region

Key Sites	4th High 8-hour Value								Design Values				
	'01	'02	'03	'04	'05	'06	'07		'01-'03	'02-'04	'03-'05	'04-'06	'05-'07
Lake Michigan Area													
Chiwaukee	99	116	88	78	93	79	85		**101**	**94**	**86**	83	**85**
Racine	92	111	82	69	95	71	77		**95**	**87**	82	78	81
Milwaukee-Bayside	93	99	92	73	93	73	83		**94**	**88**	**86**	79	83
Harrington Beach	102	93	99	72	94	72	84		**98**	**88**	**88**	79	83
Manitowoc	97	83	92	74	95	78	85		**90**	83	**87**	82	**86**
Sheboygan	102	105	93	78	97	83	88		**100**	**92**	**89**	**86**	**89**
Kewaunee	90	92	97	73	88	76	85		**93**	**87**	**86**	*79*	83
Door County	95	95	93	78	101	79	92		**94**	**88**	**90**	**86**	**90**
Hammond	90	101	81	67	87	75	77		**90**	83	78	76	79
Whiting				64	88	81	88					77	**85**
Michigan City	90	107	82	70	84	75	73		**93**	**86**	78	76	77
Ogden Dunes	85	101	77	69	90	70	84		**87**	82	78	76	81
Holland	92	105	96	79	94	91	94		**97**	**93**	**89**	**88**	**93**
Jenison	86	93	91	69	86	83	88		**90**	84	82	79	**85**
Muskegon	95	96	94	70	90	90	86		**95**	**86**	84	83	**88**
Indianapolis Area													
Noblesville	88	101	101	75	87	77	84		**96**	**92**	**87**	79	82
Fortville	89	101	92	72	80	75	81		**94**	**88**	81	75	78
Fort B. Harrison	87	100	91	73	80	76	83		**92**	**88**	81	76	79
Detroit Area													
New Haven	95	95	102	81	88	78	93		**97**	**92**	**90**	82	**86**
Warren	94	92	101	71	89	78	91		**95**	**88**	**87**	79	**86**
Port Huron	84	100	87	74	88	78	89		**90**	**87**	83	80	**85**
Cleveland Area													
Ashtabula (Conneaut)	97	103	99	81	93	86	92		**99**	**94**	**91**	**86**	**90**
Notre Dame (Geauga)	99	115	97	75	88	70	68		**103**	**95**	**86**	77	75
Eastlake (Lake)	89	104	92	79	97	83	74		**95**	**91**	**89**	**86**	84
Akron (Summit)	98	103	89	77	89	77	91		**96**	**89**	**85**	81	**85**
Cincinnati Area													
Wilmington (Clinton)	93	99	96	78	83	81	82		**96**	**91**	**85**	80	82
Sycamore (Hamilton)	88	100	93	76	89	81	90		**93**	**89**	**86**	82	**86**
Hamilton (Butler)	83	100	94	75	86	79	91		**92**	**89**	**85**	80	**85**
Middleton (Butler)	87	98	83	76	88	76	91		**89**	**85**	82	80	**85**
Lebanon (Warren)	85	98	95	81	92	86	88		**92**	**91**	**89**	**86**	**88**
Columbus Area													
London (Madison)	84	97	90	75	81	76	83		**90**	**87**	82	77	80
New Albany (Franklin)	90	103	94	78	92	82	87		**95**	**91**	**88**	84	**87**
Franklin (Franklin)	83	99	84	73	86	79	79		**88**	**85**	81	79	81
Ohio Other Areas													
Marietta (Washington)	85	95	80	77	88	81	86		**86**	84	81	82	**85**
St. Louis Area													
W. Alton (MO)	85	99	91	77	89	91	89		**91**	**89**	**85**	**85**	**89**
Orchard (MO)	88	98	90	76	92	92	83		**92**	**88**	**86**	**86**	**89**
Sunset Hills (MO)	88	98	88	70	89	80	89		**91**	**85**	82	79	**86**
Arnold (MO)	86	93	82	70	92	79	87		**87**	81	81	80	**86**
Margaretta (MO)	80	98	90	72	91	76	91		**89**	**86**	84	79	**86**
Maryland Heights (MO)					88	84	94						**88**

Meteorology and Transport: Most pollutants exhibit some dependence on meteorological factors, especially wind direction, because that governs which sources are upwind and thus most influential on a given sample. Ozone is even more dependent, since its production is driven by high temperatures and sunlight, as well as precursor concentrations (see, for example, Figure 2).

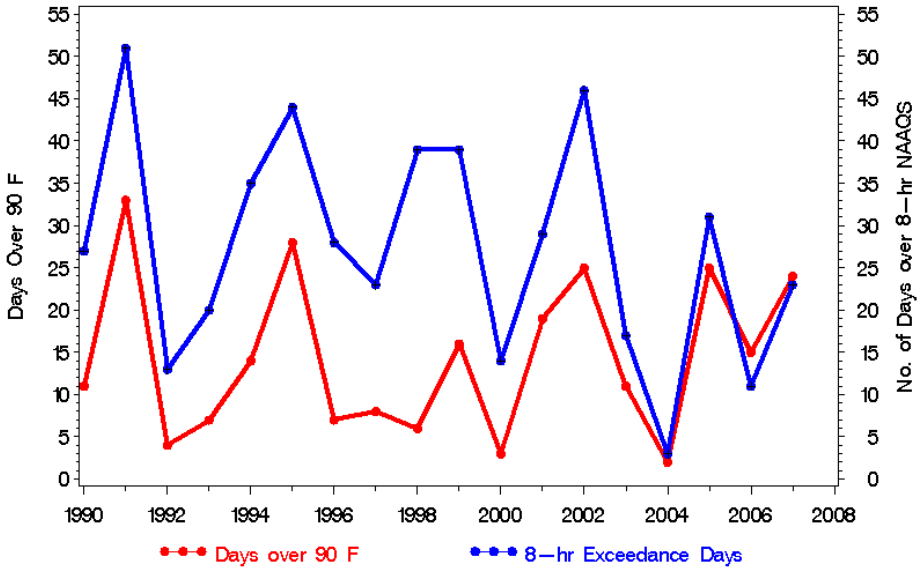


Figure 2. Number of hot days and 8-hour "exceedance" days in 5-state region

Qualitatively, ozone episodes in the region are associated with hot weather, clear skies (sometimes hazy), low wind speeds, high solar radiation, and southerly to southwesterly winds. These conditions are often a result of a slow-moving high pressure system to the east of the region. The relative importance of various meteorological factors is discussed later in this section.

Transport of ozone (and its precursors) is a significant factor and occurs on several spatial scales. Regionally, over a multi-day period, somewhat stagnant summertime conditions can lead to the build-up in ozone and ozone precursor concentrations over a large spatial area. This pollutant air mass can be advected long distances, resulting in elevated ozone levels in locations far downwind. An example of such an episode is shown in Figure 3.

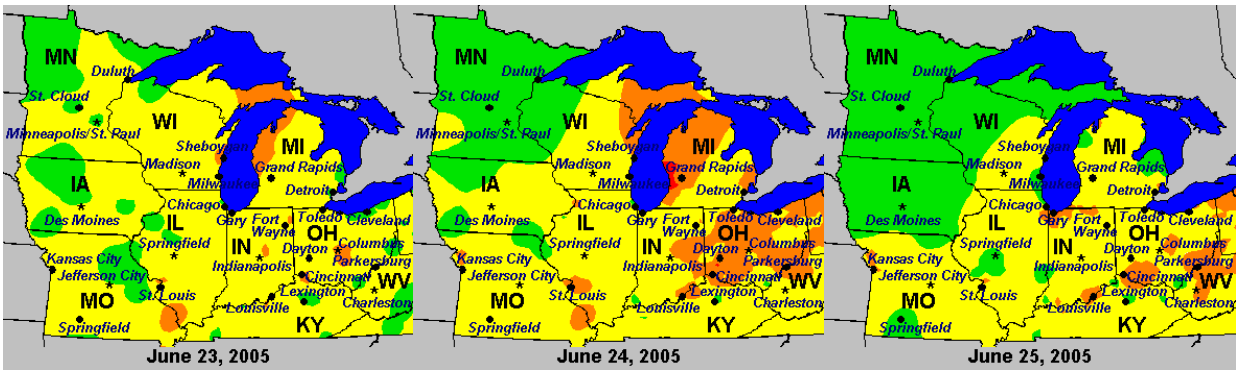


Figure 3. Example of elevated regional ozone concentrations (June 23 – 25, 2005)

Note: hotter colors represent higher concentrations, with orange representing concentrations above the 8-hour standard

Locally, emissions from urban areas add to the regional background leading to ozone concentration hot spots downwind. Depending on the synoptic wind patterns (and local land-lake breezes), different downwind areas are affected (see, for example, Figure 4).

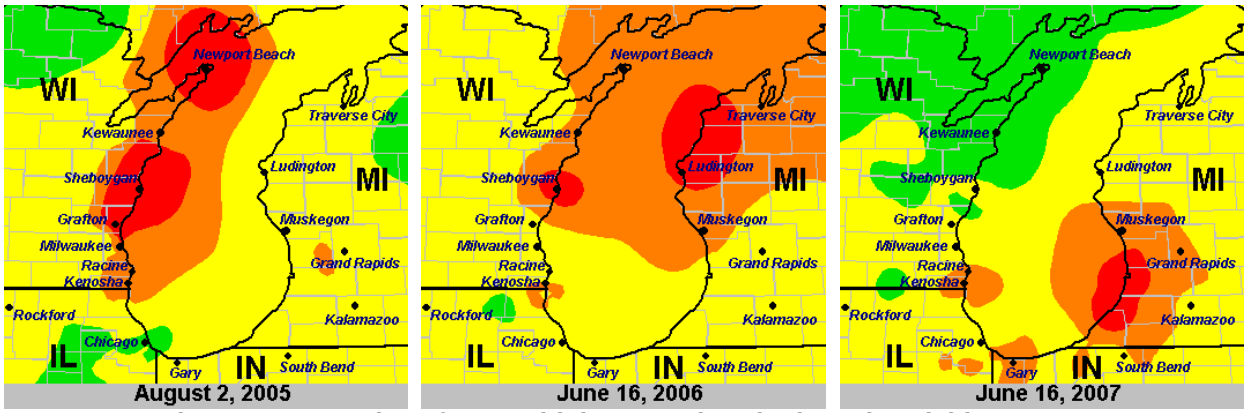


Figure 4. Examples of recent high ozone days in the Lake Michigan area

Note: hotter colors represent higher concentrations, with orange representing concentrations above the 8-hour standard

Aloft (aircraft) measurements in the Lake Michigan area also provide evidence of elevated regional background concentrations and "plumes" from urban areas. For one example summer day (August 20, 2003 – see Figure 5), the incoming background ozone levels were on the order of 80 – 100 ppb and the downwind ozone levels over Lake Michigan were on the order of 100 - 150 ppb (STI, 2004).

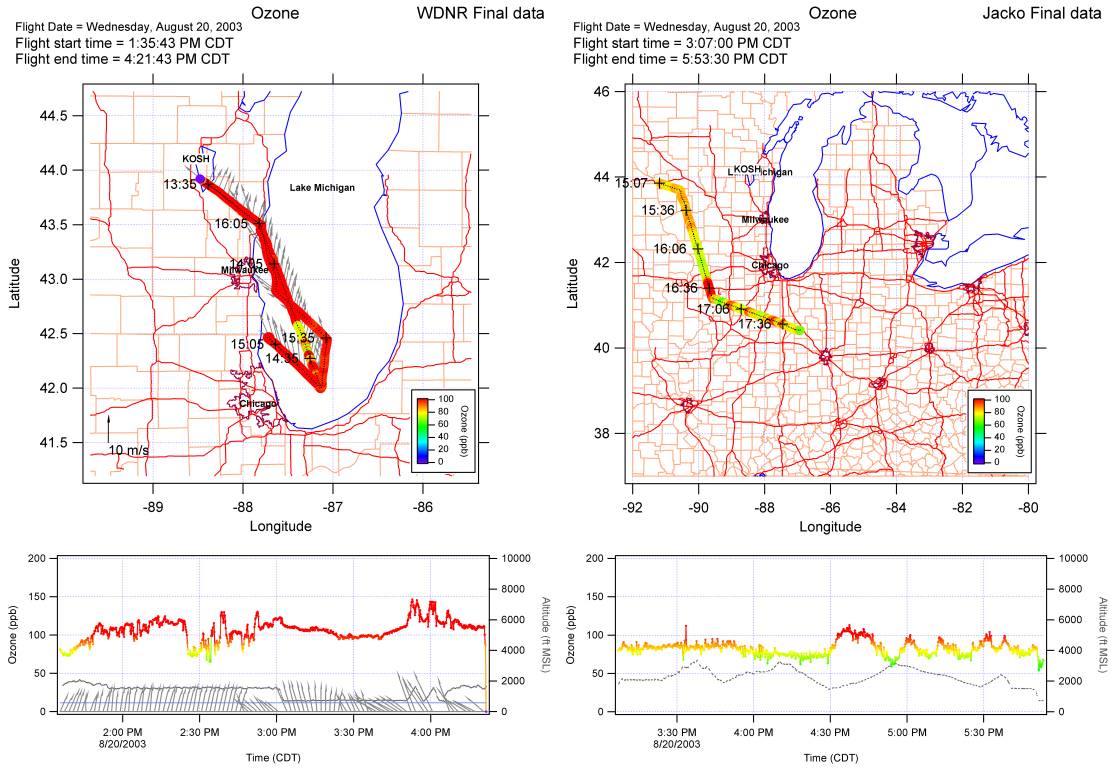


Figure 5. Aircraft ozone measurements over Lake Michigan (left) and along upwind boundary (right) – August 20, 2003 (Note: aircraft measurements reflect instantaneous values)

As discussed in Section 4, residual nonattainment is projected in at least one area in the 5-state region –i.e., western Michigan. To understand the source regions likely impacting high ozone concentrations in western Michigan and estimate the impact of these source regions, two simple transport-related analyses were performed.

First, back trajectories were constructed using the HYSPLIT model for high ozone days (8-hour peak > 80 ppb) during the period 2002-2006 in western Michigan to characterize general transport patterns. Composite trajectory plots for all high ozone days based on data from three sites (Cass County, Holland, and Muskegon) are provided in Figure 6. The plots point back to areas located to the south-southwest (especially, northeastern Illinois and northwestern Indiana) as being upwind on these high ozone days.

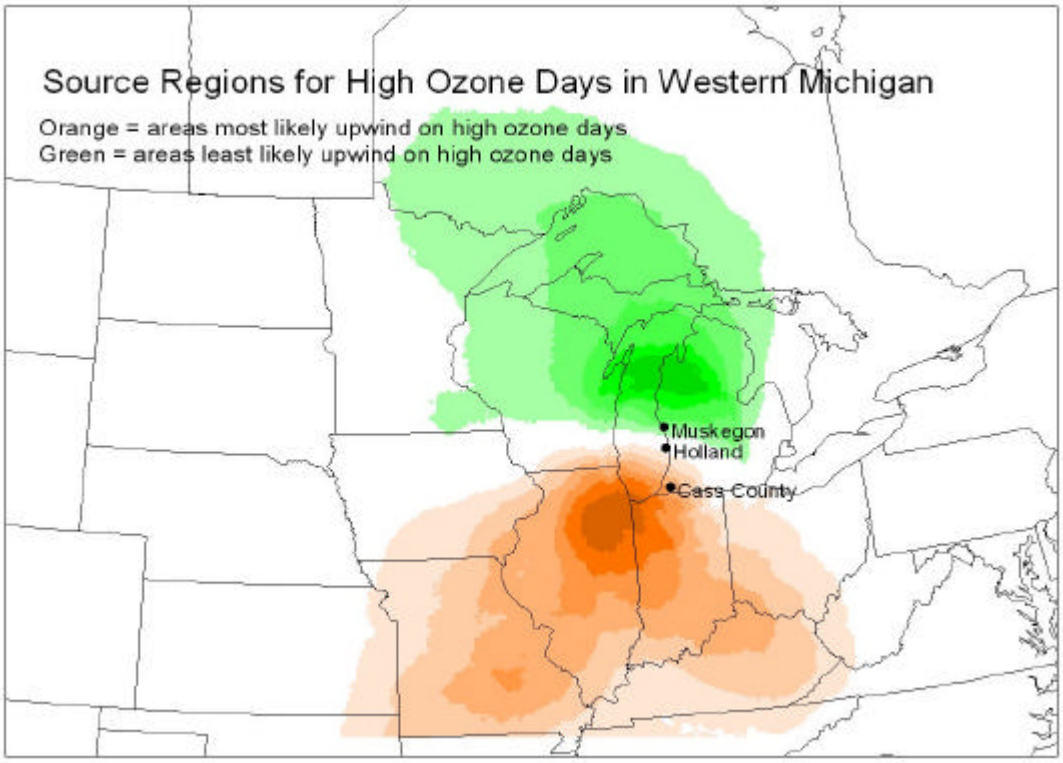


Figure 6 Back trajectory analysis showing upwind areas associated with high ozone concentrations

Second, to assess the impact from Chicago/NW Indiana, Blanchard (2005a) compared ozone concentrations upwind (Braidwood, IL), within Chicago (ten sites in the City), and downwind (Holland and Muskegon) for days in 1999 – 2002 with southwesterly winds - i.e., transport towards western Michigan. Figure 7 shows the distribution of daily peak 8-hour ozone concentrations by day-of-week, with a line connecting the mean values. The difference between day-of-week mean values at downwind and upwind sites indicates that Chicago/NW Indiana contributes about 10-15 ppb to downwind ozone levels.

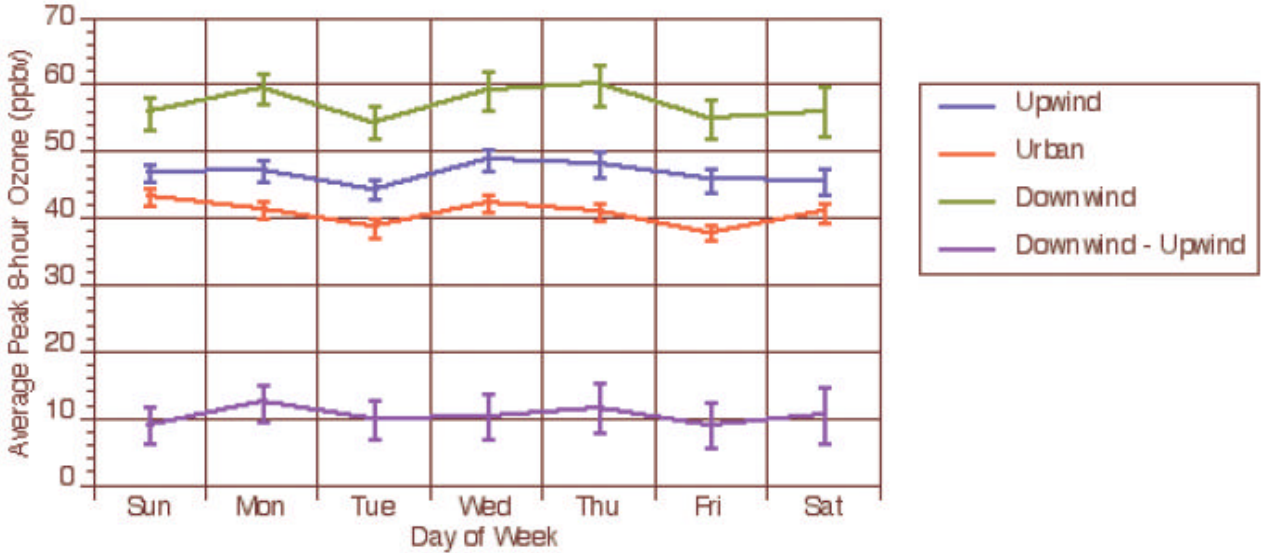


Figure 7. Mean day-of-week peak 8-hour ozone concentrations at sites upwind, within, and downwind of Chicago, 1999 – 2002 (southwesterly wind days)

Based on this information, the following key findings related to transport can be made:

- Ozone transport is a problem affecting many portions of the eastern U.S. The Lake Michigan area (and other areas in the LADCO region) both receive high levels of incoming (transported) ozone and ozone precursors from upwind source areas on many hot summer days, and contribute to the high levels of ozone and ozone precursors affecting downwind receptor areas.

- The presence of a large body of water (i.e., Lake Michigan) influences for the formation and transport of ozone in the Lake Michigan area. Depending on large-scale synoptic winds and local-scale lake breezes, different parts of the area experience high ozone concentrations. For example, under southerly flow, high ozone can occur in eastern Wisconsin, and under southwesterly flow, high ozone can occur in western Michigan.

- Downwind shoreline areas around Lake Michigan are affected by both regional transport of ozone and subregional transport from major cities in the Lake Michigan area. Counties along the western shore of Michigan (from Benton Harbor to Traverse City, and even as far north as the Upper Peninsula) are impacted by high levels of incoming (transported) ozone.

Data Variability: Since 1980, considerable progress has been made to meet the previous 1-hour ozone standard. Figure 8 shows the decline in both the 1-hour and 8-hour design values for the 5-state LADCO region over the last 25 years.

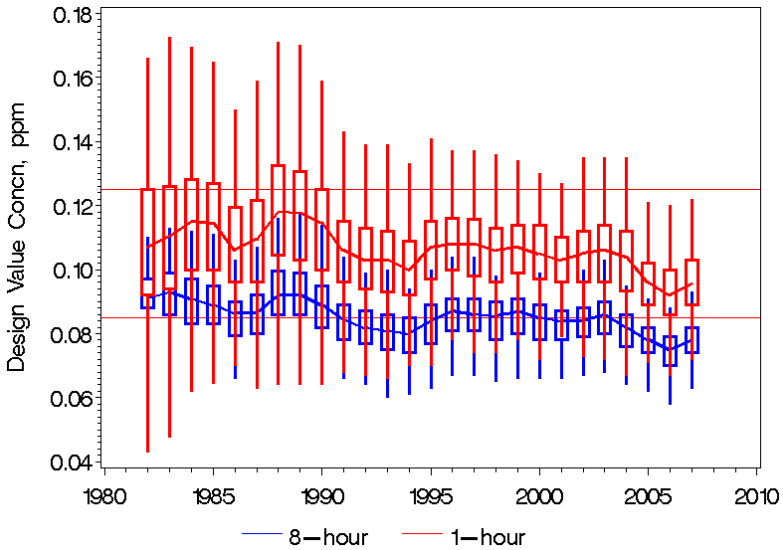


Figure 8 Ozone design value trends in 5-State region

The trend is more dramatic for the higher ozone sites in the 5-state region (see Figure 9). This plot shows a pronounced downward trend in the design value since the 2001-2003 period, due, in part, to the very low 4th high values in 2004.

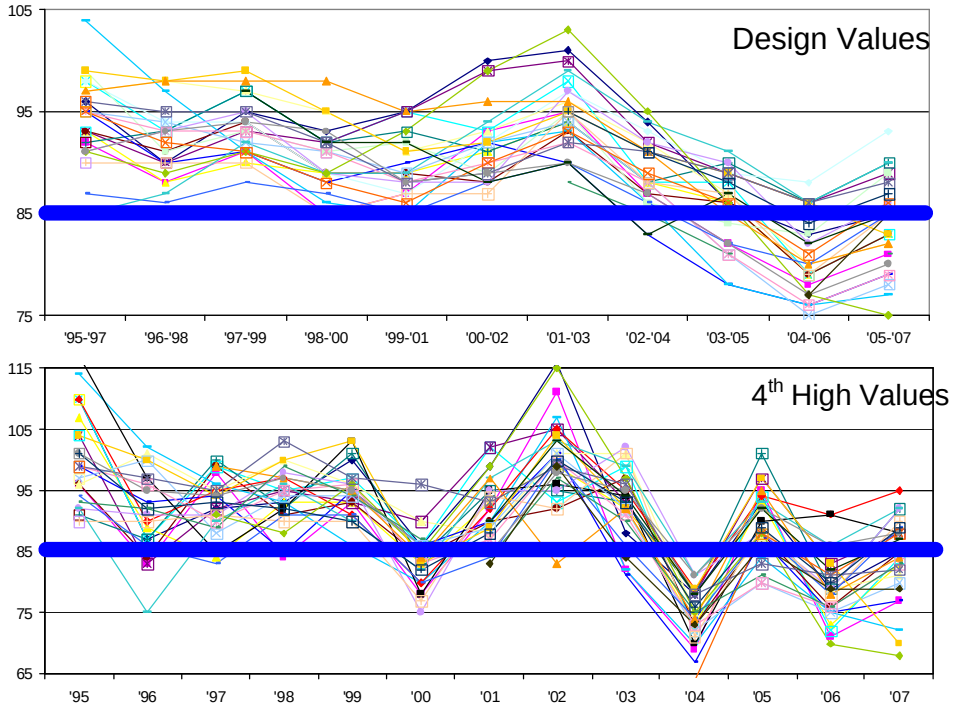


Figure 9. Trend in ozone design values and 4th high values for higher ozone sites in region

The improvement in ozone concentrations is also seen in the decrease in the number of sites measuring nonattainment over the past 15 years in the Lake Michigan area (see Figure 10).

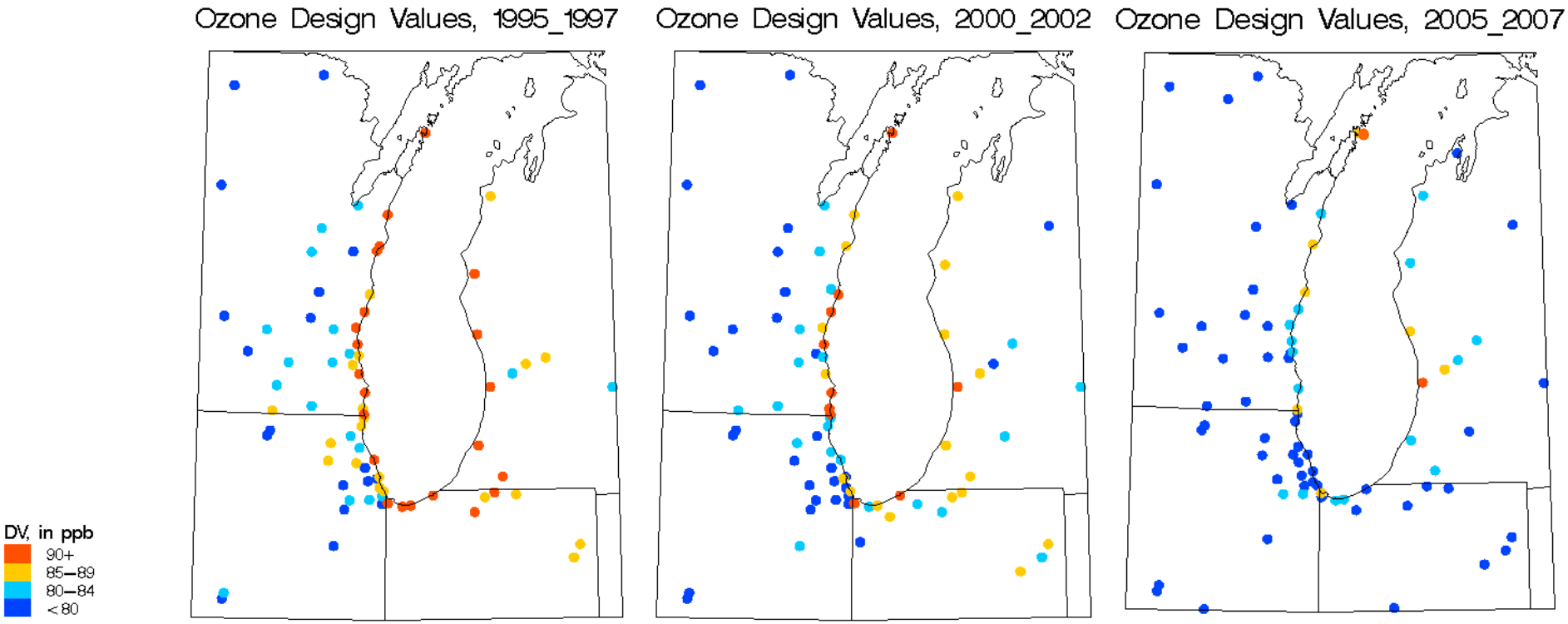


Figure 10. Ozone design value maps for 1995-1997, 2000-2002, and 2005-2007

Given the effect of meteorology on ambient ozone levels, year-to-year variations in meteorology can make it difficult to assess trends in ozone air quality. Two approaches were considered to adjust ozone trends for meteorological influences: an air quality-meteorology statistical model developed by EPA (i.e., Cox method), and statistical grouping of meteorological variables performed by LADCO (i.e., Classification and Regression Trees, or CART).

Cox Method: This method uses a statistical model to 'remove' the annual effect of meteorology on ozone (Cox and Chu, 1993). A regression model was fit to the 1997-2007 data to relate daily peak 8-hour ozone concentrations to six daily meteorological variables plus seasonal and annual factors (Kenski, 2008a). Meteorological variables included were daily maximum temperature, mid-day average relative humidity, morning and afternoon wind speed and wind direction. The model is then used to predict 4th high ozone values. By holding the meteorological effects constant, the long term trend can be examined independently of meteorology. Presumably, any trend reflects changes in emissions of ozone precursors.

Figure 11a shows the meteorologically-adjusted 4th high ozone concentrations for several monitors near major urban areas in the region. The plots indicate a general downward trend since the late 1990s for most cities, indicating that recent emission reductions have had a positive effect in improving ozone air quality.

A similar model was run to examine meteorologically adjusted trends in seasonal average ozone. This model incorporates more meteorological variables, including rain and long-distance transport (direction and distance). Model development was documented in Camalier et al., 2007. The seasonal average trends are shown in Figure 11b. Trends determined by seasonal model for the same set of sites examined above are consistent with those developed by the 4th high model.

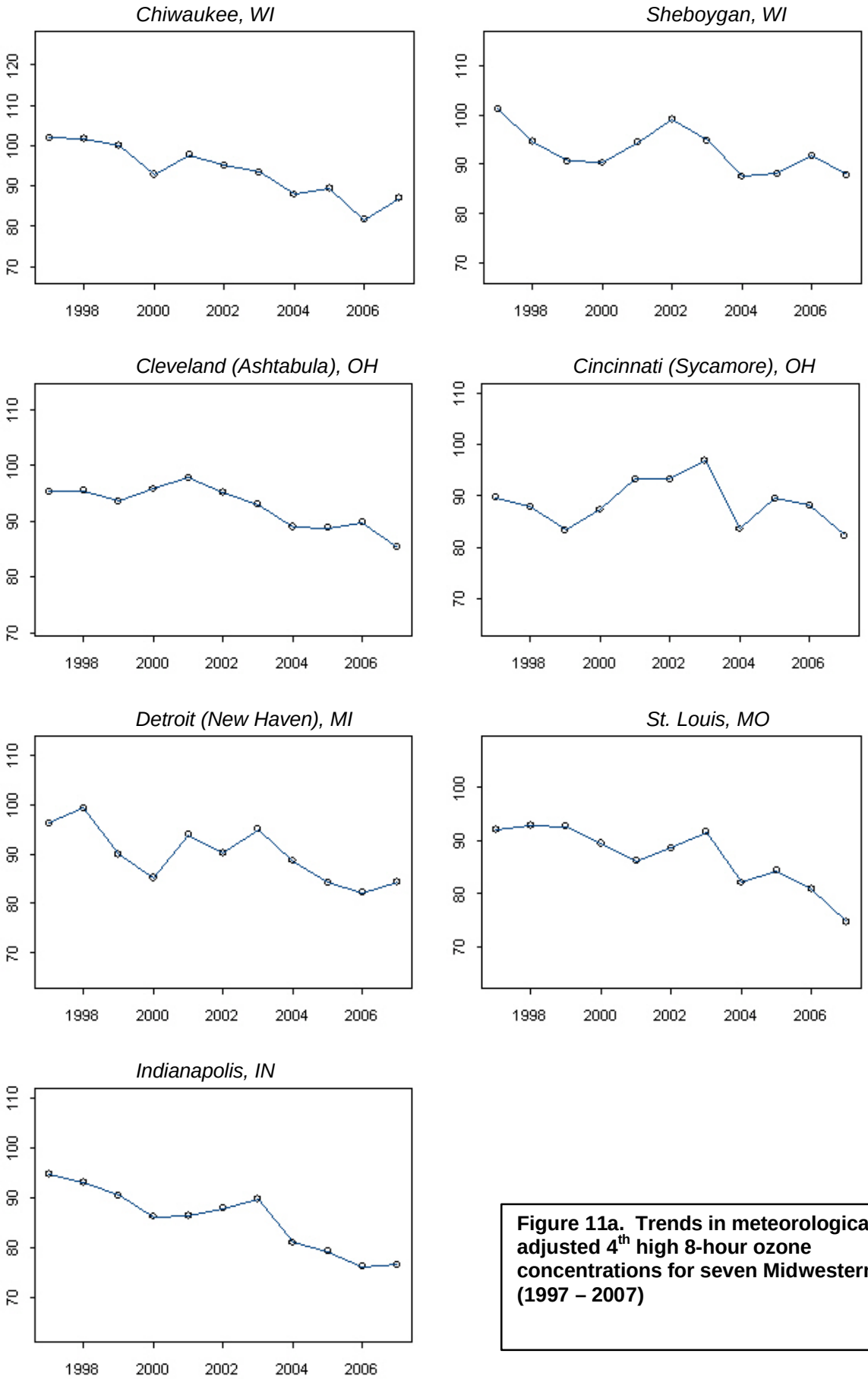


Figure 11a. Trends in meteorologically adjusted 4th high 8-hour ozone concentrations for seven Midwestern sites (1997 – 2007)

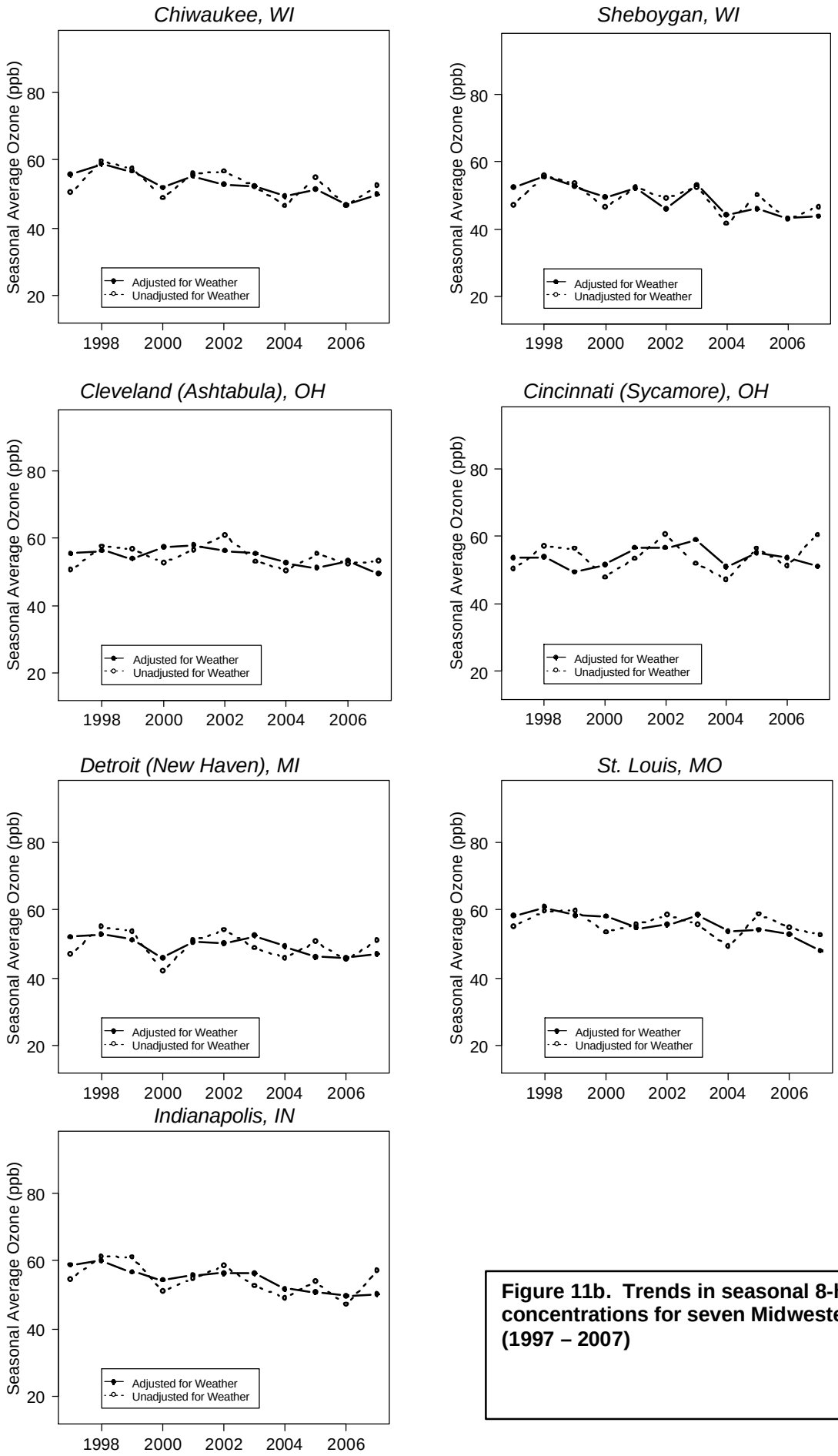


Figure 11b. Trends in seasonal 8-hour ozone concentrations for seven Midwestern sites (1997 – 2007)

CART: Classification and Regression Tree (CART) analysis is another statistical technique which partitions data sets into similar groups (Breiman et al., 1984). CART analysis was performed using data for the period 1995-2007 for 22 selected ozone monitors with current 8-hour design values close to or above the standard (Kenski, 2008b). The CART model searches through 60 meteorological variables to determine which are most efficient in predicting ozone. Although the exact selection of predictive variables changes from site to site, the most common predictors were temperature, wind direction, and relative humidity. Only occasionally were upper air variables, transport time or distance, lake breeze, or other variables significant. (Note, the ozone and meteorological data for the CART analysis are the same as used in the EPA/Cox analysis.)

For each monitor, regression trees were developed that classify each summer day (May-September) by its meteorological conditions. Similar days are assigned to nodes, which are equivalent to branches of the regression tree. Ozone time series for the higher concentration nodes are plotted for select sites in Figure 12. By grouping days with similar meteorology, the influence of meteorological variability on the trend in ozone concentrations is partially removed; the remaining trend is presumed to be due to trends in precursor emissions or other non-meteorological influences. Trends over the 13-year period at most sites were found to be declining, with the exception of Detroit which showed fairly flat trends. Comparison of the average of the high concentration node values for 2001-2003 v. 2005-2007 showed an improvement of about 5 ppb across all sites (even Detroit).

The effect of meteorology was further examined by using an ozone conduciveness index (Kenski, 2008b). This metric reflects the variability from the 13-year average in the number of days in the higher ozone concentration nodes (see Figure 13). Examination of these plots indicates:

- 2002 and 2005 were both above normal, with 2002 tending to be more severe; and

- 2001-2003 and 2005-2007 were both above normal, with no clear pattern in which period was more severe (i.e., ozone conduciveness values were similar at most sites, 2001-2003 values were higher at a few sites, and 2005-2007 values were higher at a few sites).

Given the similarity in ozone conduciveness between 2001-2003 and 2005-2007, the improvement in ozone levels noted above is presumed to be due to non-meteorological factors (i.e., emission reductions).

In conclusion, all three statistical approaches (CART and the two nonlinear regression models) show a similar result; ozone in the urban areas of the LADCO region has declined during the 1997-2007 period, even when meteorological variability is accounted for. The decreases are present whether seasonal average ozone, peak values (annual 4th highs), or a subset of high days with similar meteorology are considered. The consistency in results across models is a good indication that these trends reflect impacts of emission control programs.

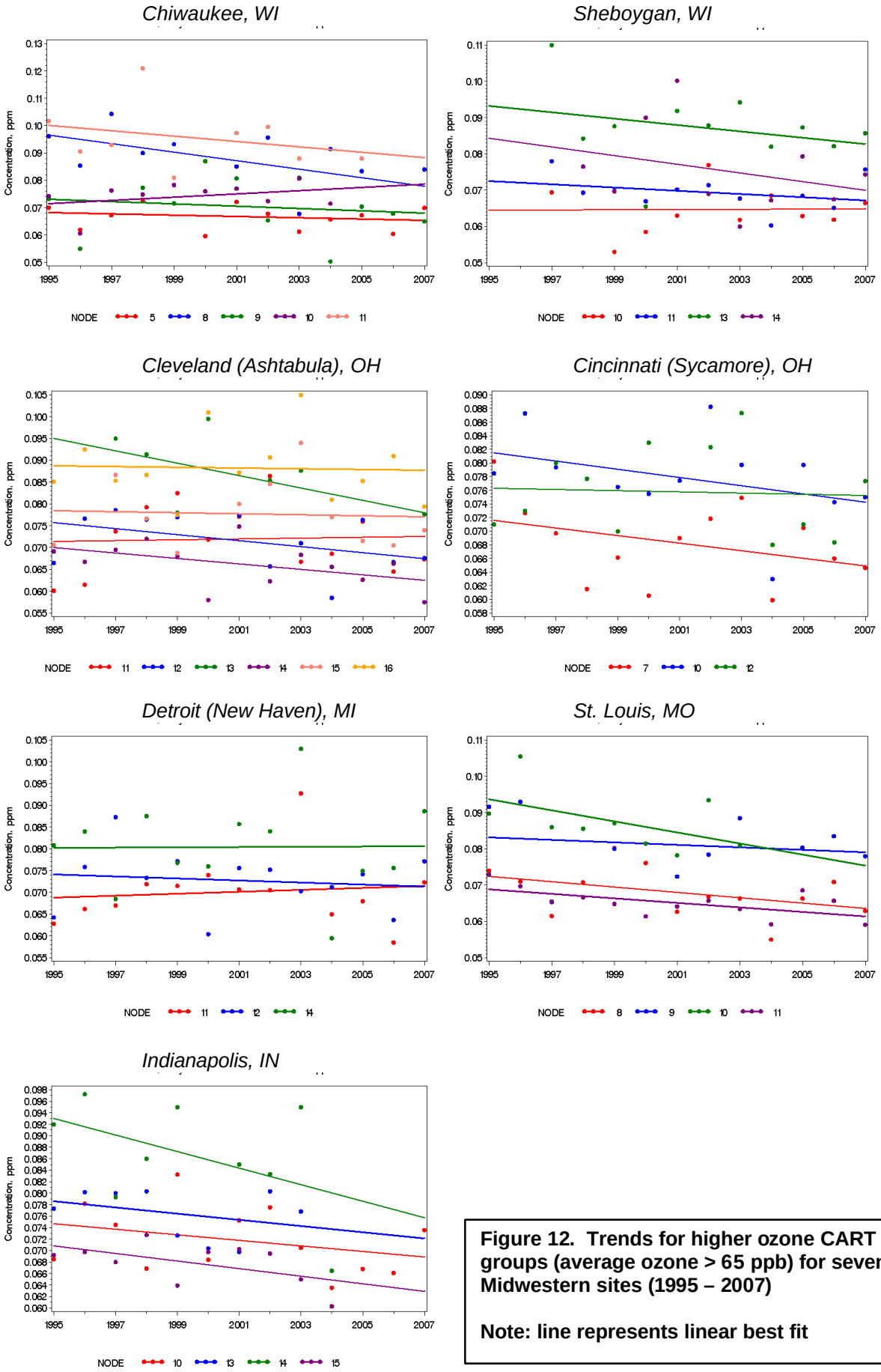
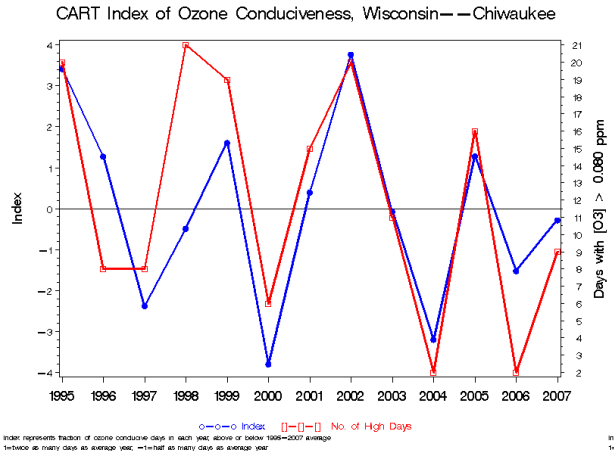
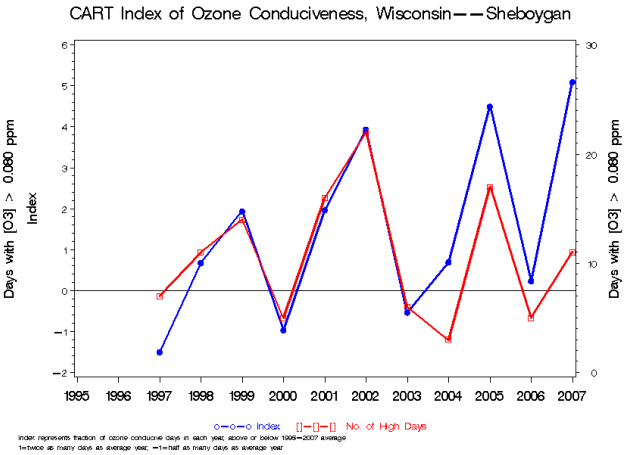
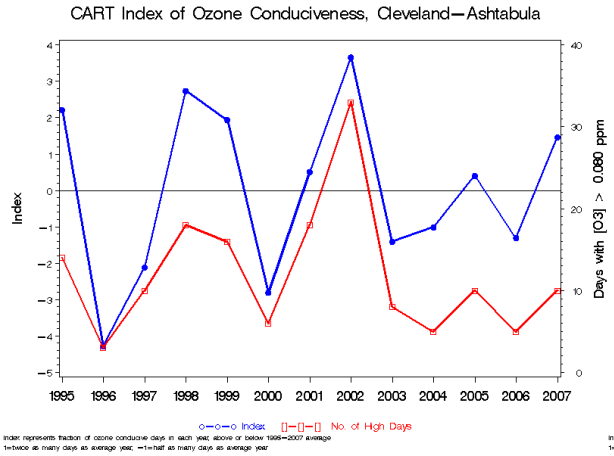


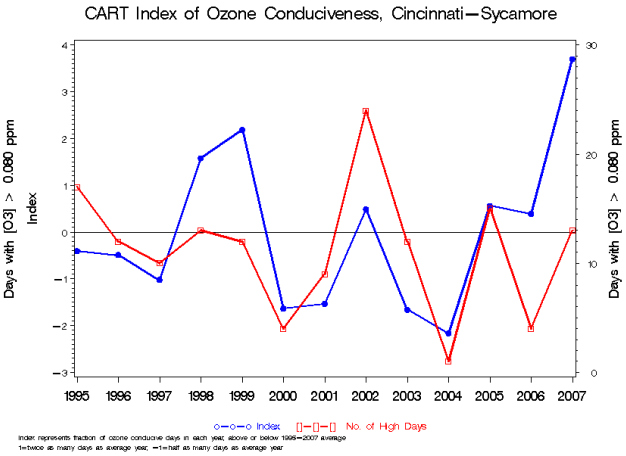
Figure 12. Trends for higher ozone CART groups (average ozone > 65 ppb) for seven Midwestern sites (1995 – 2007)

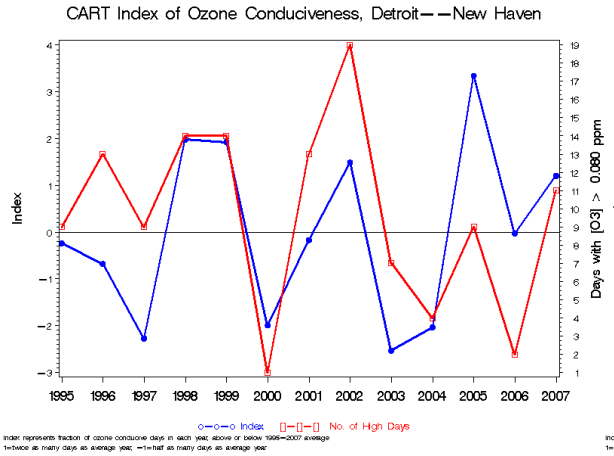
Note: line represents linear best fit

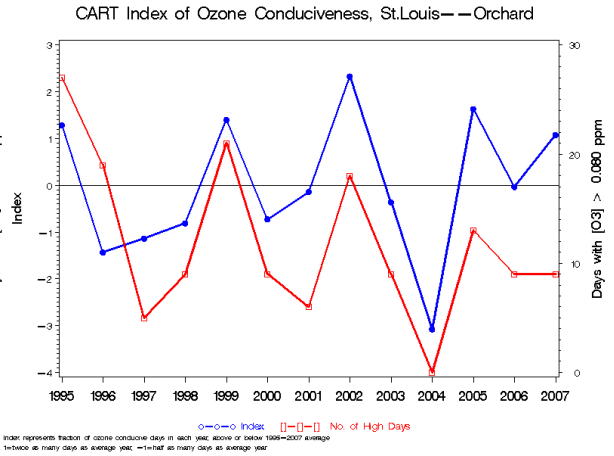












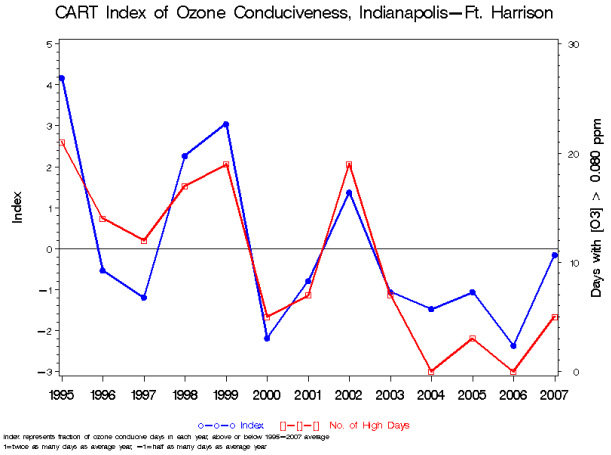


Figure 13. Ozone conduciveness index (and number of high ozone days) for seven Midwestern site (1995 – 2007)

Precursor Sensitivity: Ozone is formed from the reactions of hydrocarbons and nitrogen oxides under meteorological conditions that are conducive to such reactions (i.e., warm temperatures and strong sunlight). In areas with high VOC/NOx ratios, typical of rural environments (with low NOx), ozone tends to be more responsive to reductions in NOx. Conversely, in areas with low VOC/NOx ratios, typical of urban environments (with high NOx), ozone tends to be more responsive to VOC reductions.

An analysis of VOC and NO_x-limitation was conducted with the ozone MAPPER program, which is based on the Smog Production (SP) algorithm (Blanchard, et al., 2003). The "Extent of Reaction" parameter in the SP algorithm provides an indication of VOC and NOx sensitivity:

Extent Range	**Precursor Sensitivity**
< 0.6	VOC-sensitive
0.6 – 0.8	Transitional
> 0.8	NOx-sensitive

A map of the Extent of Reaction values for high ozone days is provided in Figure 14. As can be seen, ozone is usually VOC-limited in cities and NOx-limited in rural areas. (Data from aircraft measurements suggest that ozone is usually NO_x-limited over Lake Michigan and away from urban centers on days when ozone in the urban centers is VOC-limited.) The highest ozone days were found to be NO_x-limited. This analysis suggests that a NOx reduction strategy would be effective in reducing ozone levels. Examination of day-of-week concentrations, however, raises some question about the effectiveness of NOx reductions.

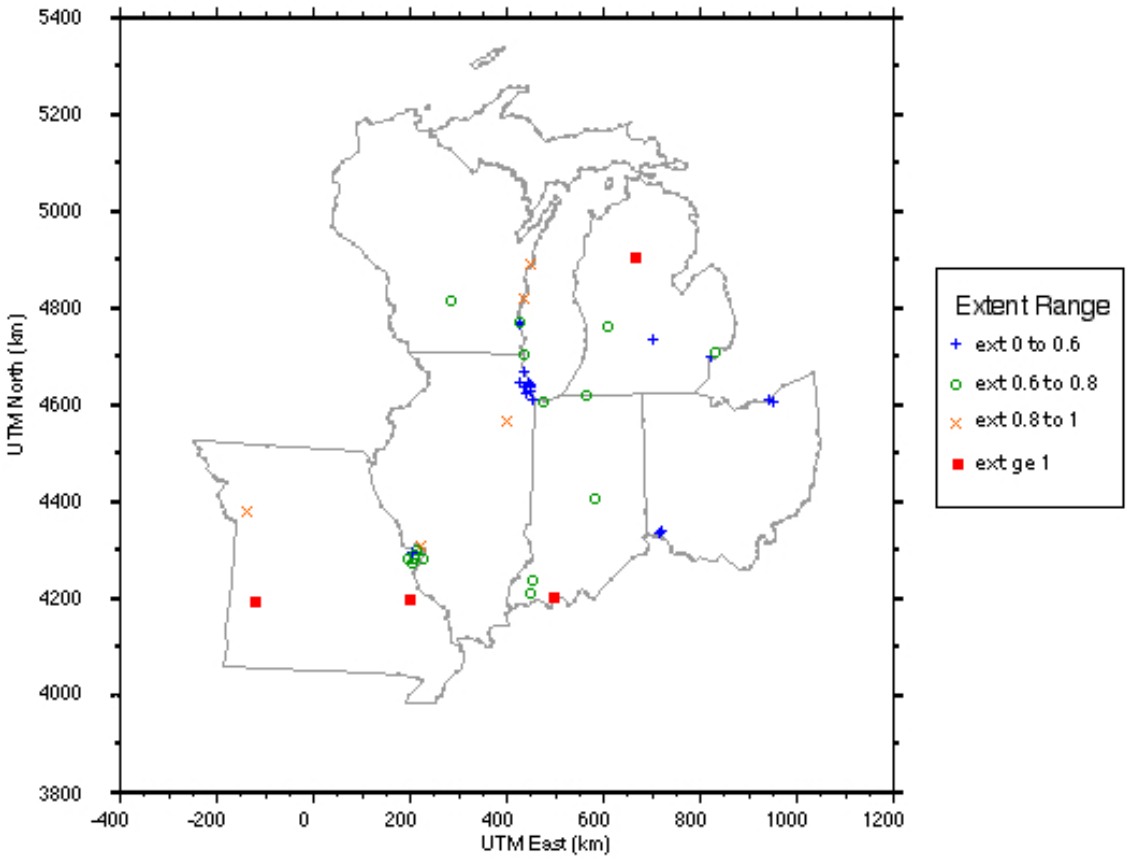


Figure 14. Mean afternoon extent of reaction (1998 – 2002)

Blanchard (2004 and 2005a) examined weekend-weekday differences in ozone and NO_x in the Midwest. All urban areas in these two studies exhibited substantially lower (40-60%) weekend concentrations of NO_x compared to weekday concentrations. Despite lower weekend NO_x concentrations, weekend ozone concentrations were not lower; in fact, most urban sites had higher concentrations of ozone, although the increase was generally not statistically significant (see Figure 15). This small but counterproductive change in **local** ozone concentrations suggests that **local** urban-scale NO_x reductions alone may not be very effective.

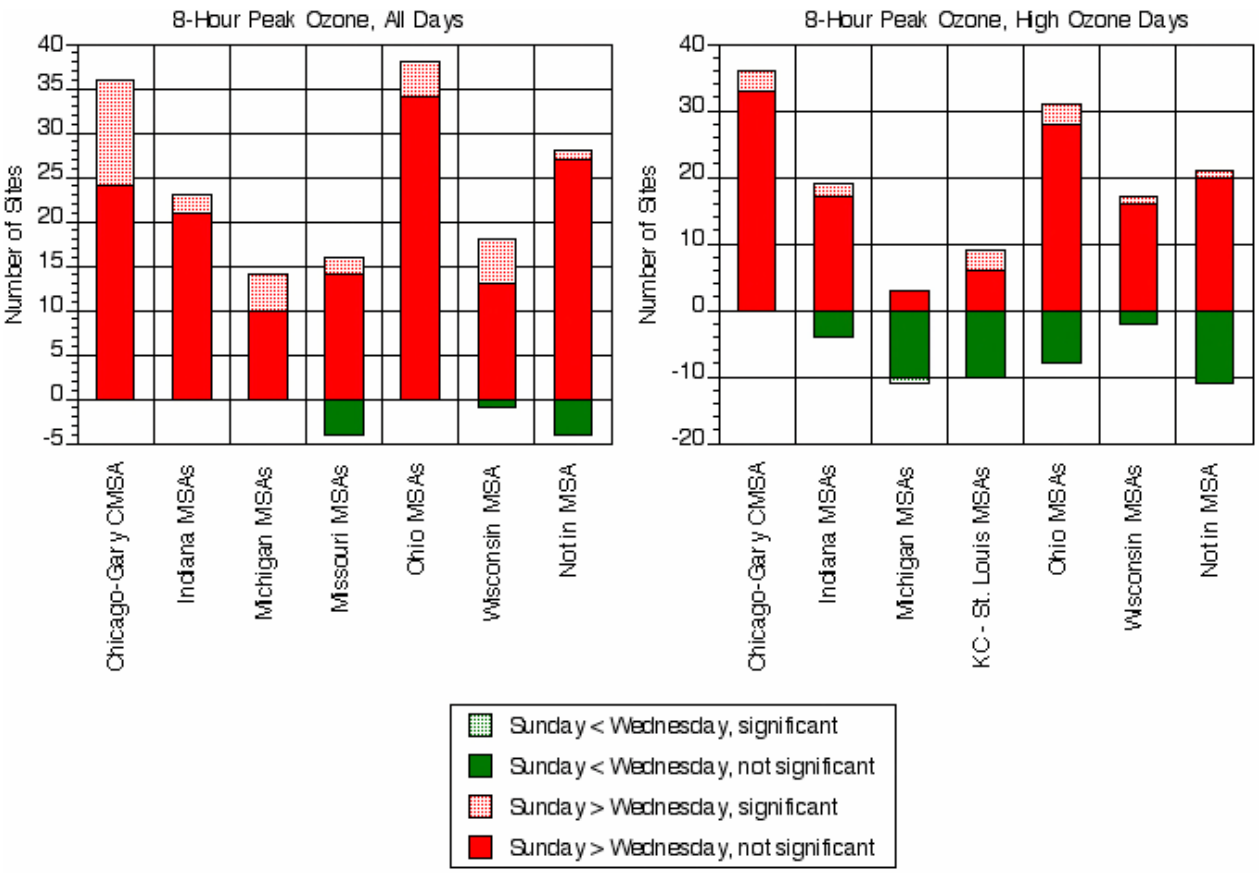


Figure 15. Weekday/weekend differences in 8-hour ozone – number of sites with weekend increase (positive values) v. number of sites with weekend decreases (negative values)

Two additional analyses, however, demonstrate the positive effect of NOx emission reductions on downwind ozone concentrations. First, Blanchard (2005a) looked at the effect of changes in precursor emissions in Chicago on downwind ozone levels in western Michigan. For the transport days of interest (i.e., southwesterly flow during the summers of 1999 – 2002), mean NOx concentrations in Chicago are about 50% lower and mean ozone concentrations at the (downwind) western Michigan sites are about 1.5 – 5.2 ppb (3 – 8 %) lower on Sunday compared to Wednesday. This degree of change in downwind ozone levels suggests a positive, albeit non-linear response to urban area emission reductions.

Second, Environ (2007a) examined the effect of differences in day-of-week emissions in southeastern Michigan on downwind ozone levels. This modeling study found that weekend changes in ozone precursor emissions cause both increases and decreases in Southeast Michigan ozone, depending upon location and time:

- Weekend increases in 8-hour maximum ozone occur in and immediately downwind of the Detroit urban area (i.e., in VOC-sensitive areas).
- Weekend decreases in 8-hour maximum ozone occur outside and downwind of the Detroit urban area (i.e., in NOx-sensitive areas).
- At the location of the peak 8-hour ozone downwind of Detroit, ozone was lower on weekends than weekdays.
- Ozone benefits (reductions) due to weekend emission changes in Southeast Michigan can be transported downwind for hundreds of miles.
- Southeast Michigan benefits from lower ozone transported into the region on Saturday through Monday because of weekend emission changes in upwind areas.

In summary, these analyses suggest that urban VOC reductions and regional (urban and rural) NOx reductions will be effective in lowering ozone concentrations. Local NOx reductions can lead to local ozone increases (i.e., NOx disbenefits), but this effect does not appear to pose a problem with respect to attainment of the standard. It should also be noted that urban VOC and regional NOx reductions are likely to have multi-pollutant benefits (e.g., both lower ozone and $PM_{2.5}$ impacts).

2.2 $PM_{2.5}$

In 1997, EPA adopted the $PM_{2.5}$ standards of 15 ug/m^3 (annual average) and 65 ug/m3 (24-hour average). The annual standard is attained if the 3-year average of the annual average $PM_{2.5}$ concentration is less than or equal to the level of the standard. The daily standard is attained if the 98th percentile of 24-hour $PM_{2.5}$ concentrations in a year, averaged over three years, is less than or equal to the level of the standard.

In 2006, EPA revised the $PM_{2.5}$ standards to 15 ug/m^3 (annual average) and 35 ug/m^3 (24-hour average).

Current Conditions: Maps of annual and 24-hour $PM_{2.5}$ design values for the 3-year period 2005-2007 are shown in Figure 16. The “hotter” colors represent higher concentrations, where red dots represent sites with design values above the annual standard. Currently, there are 30 sites in violation of the annual $PM_{2.5}$ standard.

Table 2 provides the annual $PM_{2.5}$ concentrations and associated design values since 2003 for several high monitoring sites throughout the region.

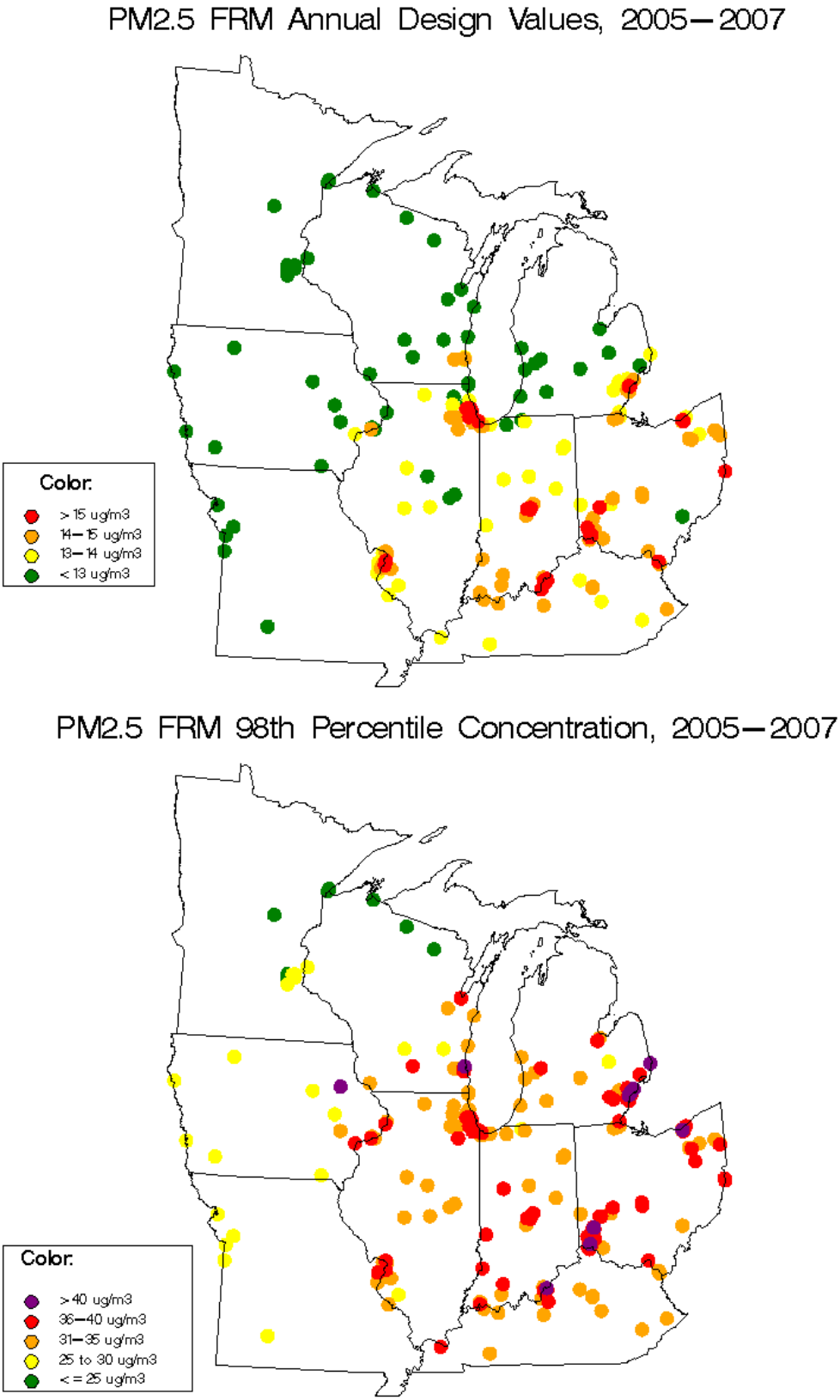


Figure 16. $PM_{2.5}$ design values - annual average (top) and 24-hour average (bottom) (2005-2007)

Table 2. PM2.5 Data for Select Sites in 5-State Region													
			Annual Average Conc.						Design Values				2005 BY	2002 BY
Key Site	**County**	**Site ID**	**'03**	**'04**	**'05**	**'06**	**'07**		**'03 - '05**	**'04 - '06**	**'05 - '07**		**Average w/ 2007**	**Average**
Chicago - Washington HS	Cook	170310022	15.6	14.2	16.9	13.2	15.7		15.6	14.8	15.3		**15.2**	**15.9**
Chicago - Mayfair	Cook	170310052	15.9	15.3	17.0	14.5	15.5		16.1	15.6	15.7		**15.8**	**17.1**
Chicago - Springfield	Cook	170310057	15.6	13.8	16.7	13.5	15.1		15.4	14.7	15.1		**15.0**	**15.6**
Chicago - Lawndale	Cook	170310076	14.8	14.2	16.6	13.5	14.3		15.2	14.8	14.8		14.9	**15.6**
Blue Island	Cook	170312001	14.9	14.1	16.4	13.2	14.3		15.1	14.6	14.6		14.8	**15.6**
Summit	Cook	170313301	15.6	14.2	16.9	13.8	14.8		15.6	15.0	15.2		**15.2**	**16.0**
Cicero	Cook	170316005	16.8	15.2	16.3	14.3	14.8		16.1	15.3	15.1		**15.5**	**16.4**
Granite City	Madison	171191007	17.5	15.4	18.2	16.3	15.1		17.0	16.6	16.5		**16.7**	**17.3**
E. St. Louis	St. Clair	171630010	14.9	14.7	17.1	14.5	15.6		15.6	15.4	15.7		**15.6**	**16.2**
Jeffersonville	Clark	180190005	15.8	15.1	18.5	15.0	16.5		16.5	16.2	16.7		**16.4**	**17.2**
Jasper	Dubois	180372001	15.7	14.4	16.9	13.5	14.4		15.7	14.9	14.9		**15.2**	**15.5**
Gary	Lake	180890031			16.8	13.3	14.5		16.8	15.1	14.9		**15.6**	
Indy - Washington Park	Marion	180970078	15.5	14.3	16.4	14.1	15.8		15.4	14.9	15.4		**15.3**	**16.2**
Indy - W 18th Street	Marion	180970081	16.2	15.0	17.9	14.2	16.1		16.4	15.7	16.1		**16.0**	
Indy - Michigan Street	Marion	180970083	16.3	15.0	17.5	14.1	15.9		16.3	15.5	15.8		**15.9**	**16.6**
Allen Park	Wayne	261630001	15.2	14.2	15.9	13.2	12.8		15.1	14.4	14.0		14.5	**15.8**
Southwest HS	Wayne	261630015	16.6	15.4	17.2	14.7	14.5		16.4	15.8	15.5		**15.9**	**17.3**
Linwood	Wayne	261630016	15.8	13.7	16.0	13.0	13.9		15.2	14.2	14.3		14.6	**15.5**
Dearborn	Wayne	261630033	19.2	16.8	18.6	16.1	16.9		18.2	17.2	17.2		**17.5**	**19.3**
Wyandotte	Wayne	261630036	16.3	13.7	16.4	12.9	13.4		15.5	14.3	14.2		14.7	**16.6**
Middleton	Butler	390170003	17.2	14.1	19.0	14.1	15.4		16.8	15.7	16.2		**16.2**	**16.5**
Fairfield	Butler	390170016	15.8	14.7	17.9	14.0	14.9		16.1	15.5	15.6		**15.8**	**15.9**
Cleveland-28th Street	Cuyahoga	390350027	15.4	15.6	17.3	13.0	14.5		16.1	15.3	14.9		**15.4**	**16.5**
Cleveland-St. Tikhon	Cuyahoga	390350038	17.6	17.5	19.2	14.9	16.2		18.1	17.2	16.8		**17.4**	**18.4**
Cleveland-Broadway	Cuyahoga	390350045	16.4	15.3	19.3	14.0	15.3		17.0	16.2	16.2		**16.5**	**16.7**
Cleveland-E14 & Orange	Cuyahoga	390350060	17.2	16.4	19.4	15.0	15.9		17.7	16.9	16.8		**17.1**	**17.6**
Newburg Hts - Harvard Ave	Cuyahoga	390350065	15.6	15.2	18.6	13.1	15.8		16.5	15.6	15.8		**16.0**	**16.2**
Columbus - Fairgrounds	Franklin	390490024	16.4	15.0	16.4	13.6	14.6		15.9	15.0	14.9		**15.3**	**16.5**
Columbus - Ann Street	Franklin	390490025	15.3	14.6	16.4	13.6	14.7		15.4	14.9	14.9		**15.1**	**16.0**
Columbus - Maple Canyon	Franklin	390490081	14.9	13.6	14.6	12.9	13.1		14.4	13.7	13.5		13.9	**16.0**
Cincinnati - Seymour	Hamilton	390610014	17.0	15.9	19.8	15.5	16.5		17.6	17.1	17.3		**17.3**	**17.7**
Cincinnati - Taft Ave	Hamilton	390610040	15.5	14.6	17.5	13.6	15.1		15.9	15.2	15.4		**15.5**	**15.7**
Cincinnati - 8th Ave	Hamilton	390610042	16.7	16.0	19.1	14.9	15.9		17.3	16.7	16.6		**16.9**	**17.3**
Sharonville	Hamilton	390610043	15.7	14.9	16.9	14.5	14.8		15.8	15.4	15.4		**15.6**	**16.0**
Norwood	Hamilton	390617001	16.0	15.3	18.4	14.4	15.1		16.6	16.0	15.9		**16.2**	**16.3**
St. Bernard	Hamilton	390618001	17.3	16.4	20.0	15.9	16.1		17.9	17.4	17.3		**17.6**	**17.3**
Steubenville	Jefferson	390810016	17.7	15.9	16.4	13.8	16.2		16.7	15.4	15.5		**15.8**	**17.7**
Mingo Junction	Jefferson	390811001	17.3	16.2	18.1	14.6	15.6		17.2	16.3	16.1		**16.5**	**17.5**
Ironton	Lawrence	390870010	14.3	13.7	17.0	14.4	15.0		15.0	15.0	15.4		**15.2**	**15.7**
Dayton	Montgomery	391130032	15.9	14.5	17.4	13.6	15.6		15.9	15.2	15.5		**15.5**	**15.9**
New Boston	Scioto	391450013	14.7	13.0	16.2	14.3	14.0		14.6	14.5	14.8		14.7	**17.1**
Canton - Dueber	Stark	391510017	16.8	15.6	17.8	14.6	15.9		16.7	16.0	16.1		**16.3**	**17.3**
Canton - Market	Stark	391510020	15.0	14.1	16.6	11.9	14.4		15.2	14.2	14.3		14.6	**15.7**
Akron - Brittain	Summit	391530017	15.4	15.0	16.4	13.5	14.4		15.6	15.0	14.8		**15.1**	**16.4**
Akron - W. Exchange	Summit	391530023	14.2	13.9	15.7	12.8	13.7		14.6	14.1	14.1		14.3	**15.6**

When EPA initially set the 24-hour standard at 65 µg/m^3, it also adopted the following concentration ranges for its Air Quality Index (AQI) scale:

Good	< 15 ug/m^3
Moderate	15-40 µg/m^3
Unhealthy for Sensitive Groups (USG)	40-65 µg/m^3
Unhealthy	65-150 µg/m^3

Figure 17 shows the frequency of these AQI categories for major metropolitan areas in the region. Daily average concentrations are often in the moderate range and occasionally in the USG range. Moderate and USG levels can occur any time of the year.

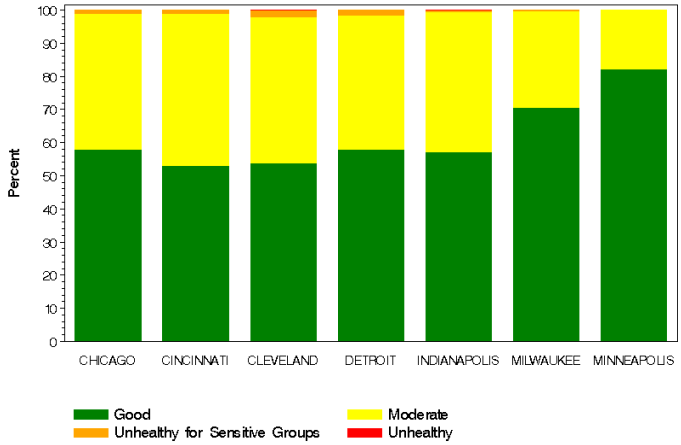


Figure 17. Percent of days in AQI categories for $PM_{2.5}$ (2002-2004)

Data Variability: $PM_{2.5}$ concentrations vary spatially, temporally, and chemically in the region. This variability is discussed further below.

On an annual basis, $PM_{2.5}$ exhibits a distinct and consistent spatial pattern. As seen in Figure 16, across the Midwest, annual concentrations follow a gradient from low values (5-6 µg/m^3) in northern and western areas (Minnesota and northern Wisconsin) to high values (17-18 µg/m^3) in Ohio and along the Ohio River. In addition, concentrations in urban areas are higher than in upwind rural areas, indicating that local urban sources add a significant increment of 2-3 µg/m^3 to the regional background of 12 - 14 µg/m^3 (see Figure 18).

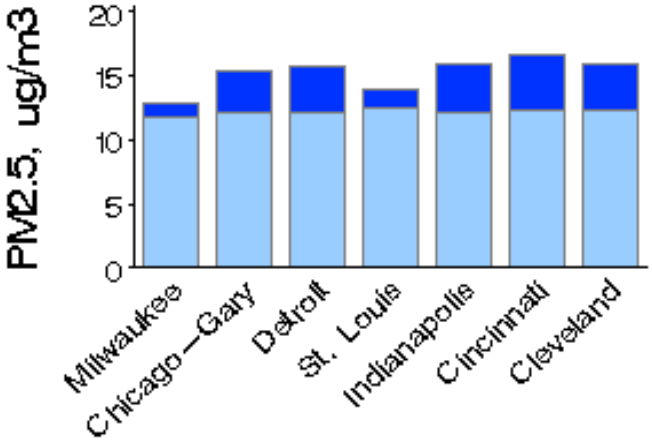


Figure 18. Regional (lighter shading) v. local components (darker shading) of annual average $PM_{2.5}$ concentrations

Because monitoring for $PM_{2.5}$ only began in earnest in 1999, after promulgation of the $PM_{2.5}$ standard, limited data are available to assess trends. Time series based on federal reference method (FRM) $PM_{2.5}$-mass data show a downward trend in each state (see Figure 19)[7].

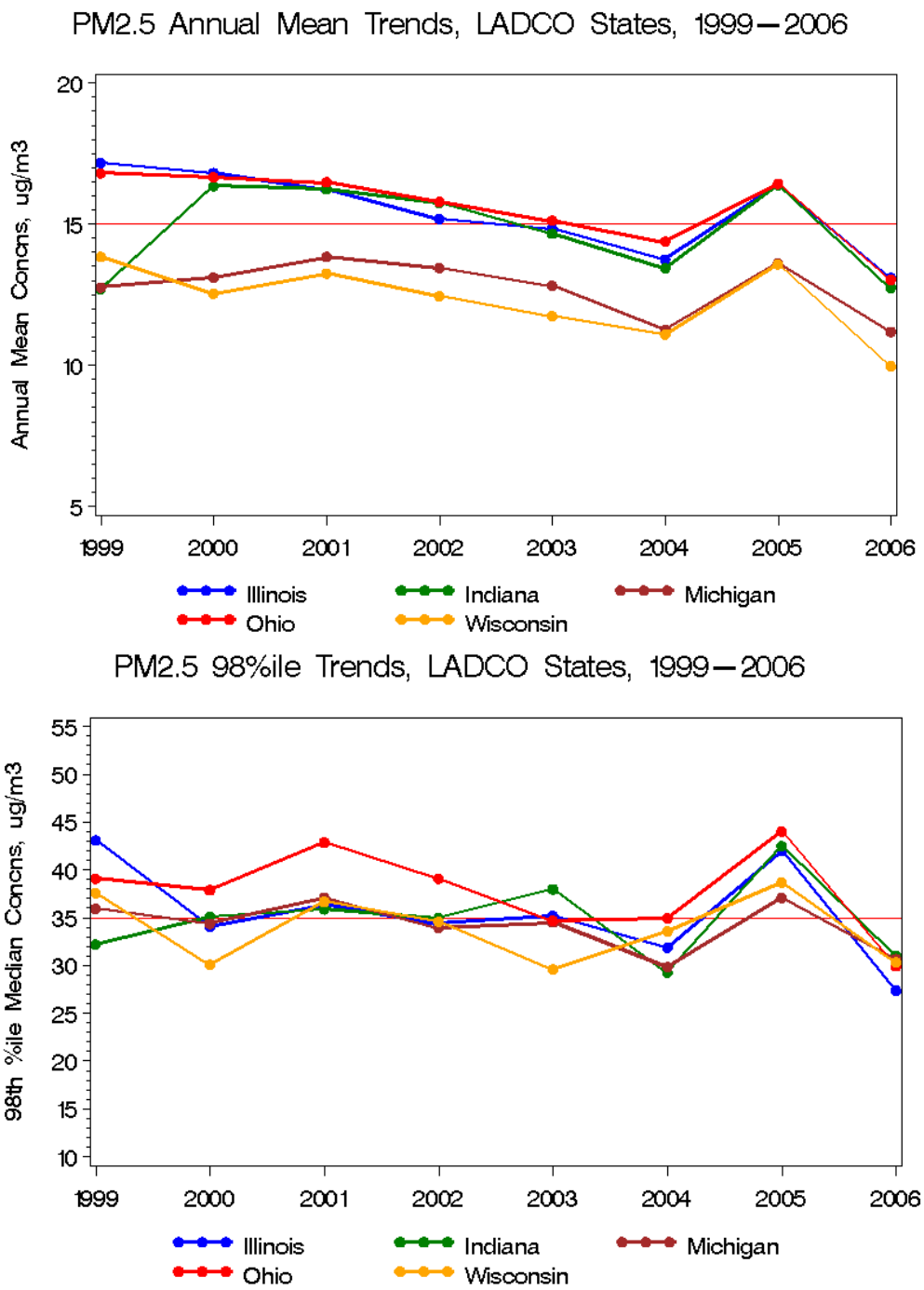


Figure 19. $PM_{2.5}$ trends in annual average (top) and daily concentrations (bottom)

[7] Despite the general downward trend since 1999, all states experienced an increase during 2005. Further analyses are underway to understand this increase (e.g., examination of meteorological and emissions effects).

A statistical analysis of $PM_{2.5}$ trends was performed using the nonparametric Theil test for slope (Hollander and Wolfe, 1973). Trends were generally consistent around the region, for both PM mass and for the individual components of mass. Figure 20 shows trends for $PM_{2.5}$ based on FRM data at sites with six or more years of data since 1999. The size and direction of each arrow shows the size and direction of the trend for each site; solid arrows show statistically significant trends and open arrows show trends that are not significant. Region-wide decreases are widespread and consistent; all sites had decreasing concentration trends (13 of the 38 were statistically significant). The average decrease for this set of sites is -0.24 ug/m^3/year.

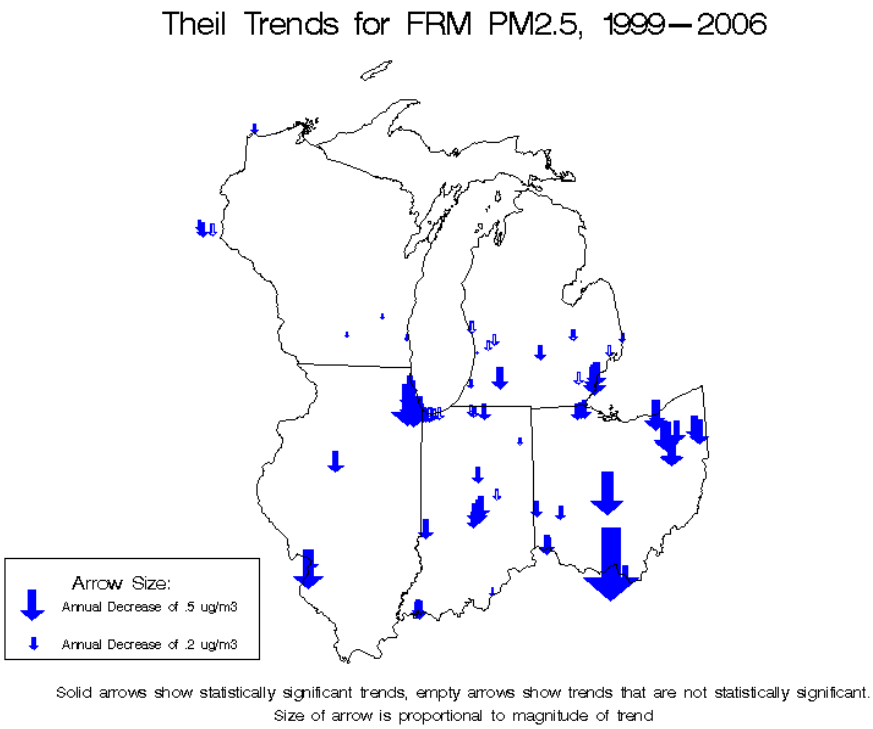


Figure 20. Annual trends in $PM_{2.5}$ mass (1999 – 2006)

Seasonal trends show mostly similar patterns (Figure 21). Trends were downward at most sites and seasons, with overall seasonal averages varying between -0.15 to -0.56 ug/m^3/year. The strongest and most significant decreases took place during the winter quarter (January - March). No statistically significant increasing trends were observed.

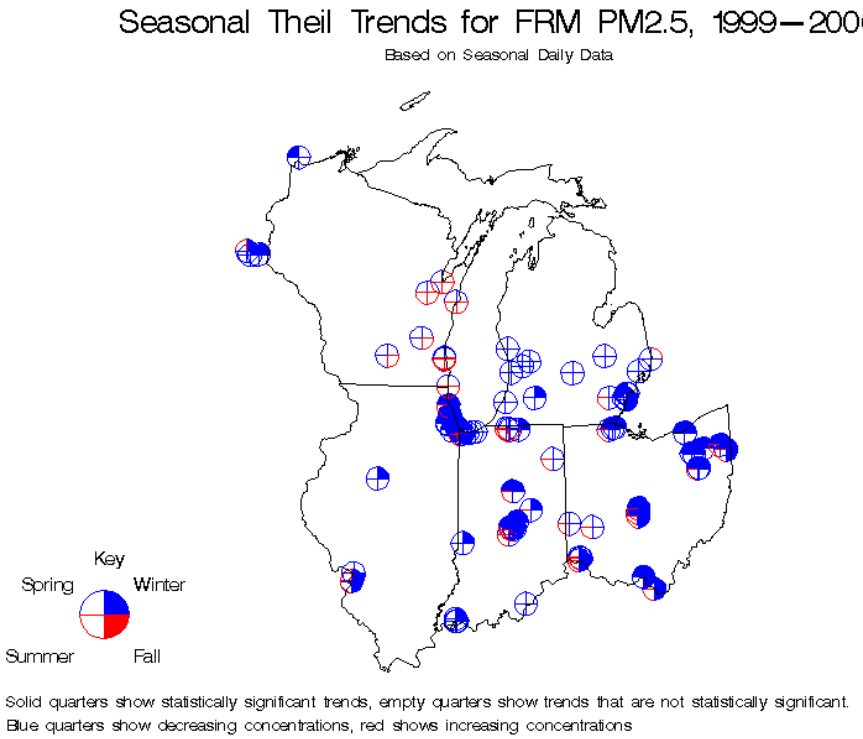


Figure 21. Seasonal trends in $PM_{2.5}$ mass (1999 – 2006)

$PM_{2.5}$ shows a slight variation from weekday to weekend, as seen in Figure 22. Although most cities have slightly lower concentrations on the weekend, the difference is usually less than 1 µg/m^3. There is a more pronounced weekday/weekend difference at monitoring sites that are strongly source-influenced. Rural monitors tend to show less of a weekday/weekend pattern than urban monitors.

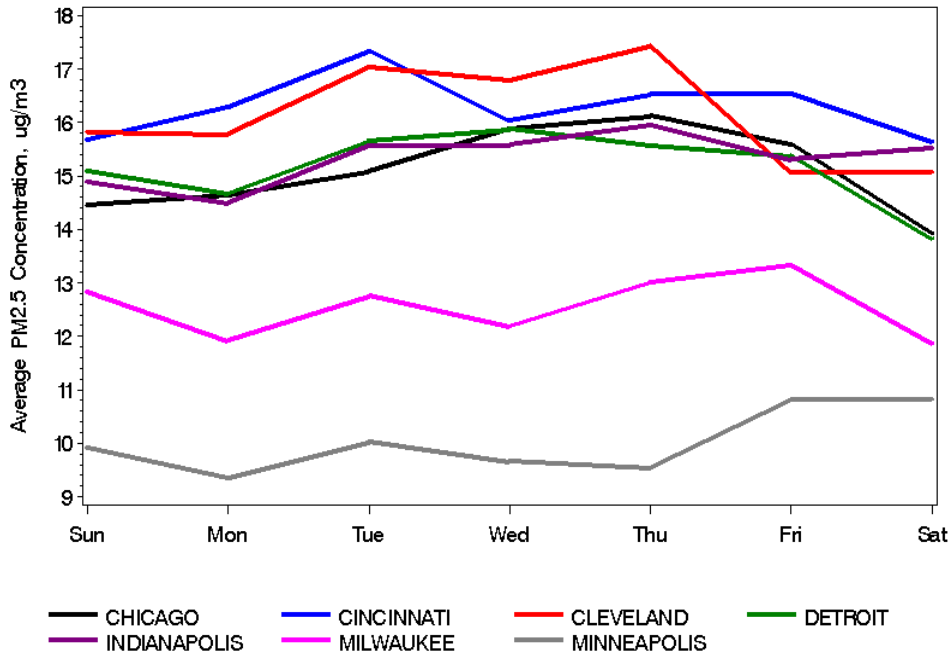


Figure 22 Day-of-week variability in $PM_{2.5}$ (2002-2004)

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

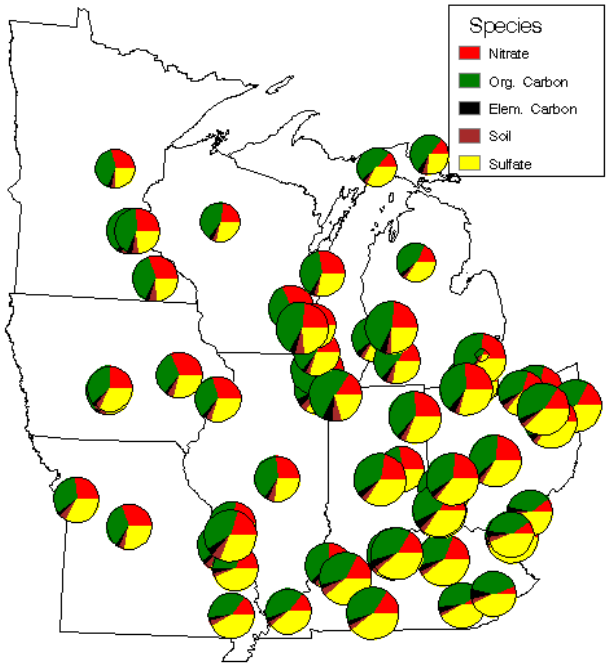


Figure 23. Spatial map of $PM_{2.5}$ chemical composition in the Midwest (2002-2003)

The three major components vary spatially (Figure 23), including notable urban and rural differences (Figure 24). The components also vary seasonally (Figure 25). These patterns account for much of the annual variability in $PM_{2.5}$ mass noted above.

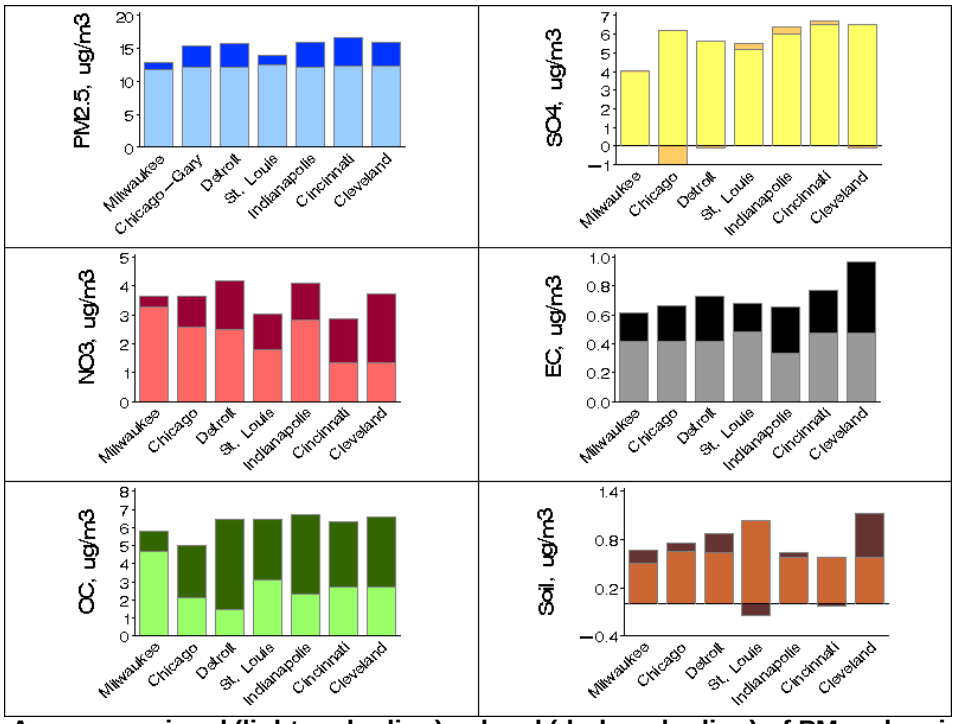


Figure 24. Average regional (lighter shading) v. local (darker shading) of $PM_{2.5}$ chemical species

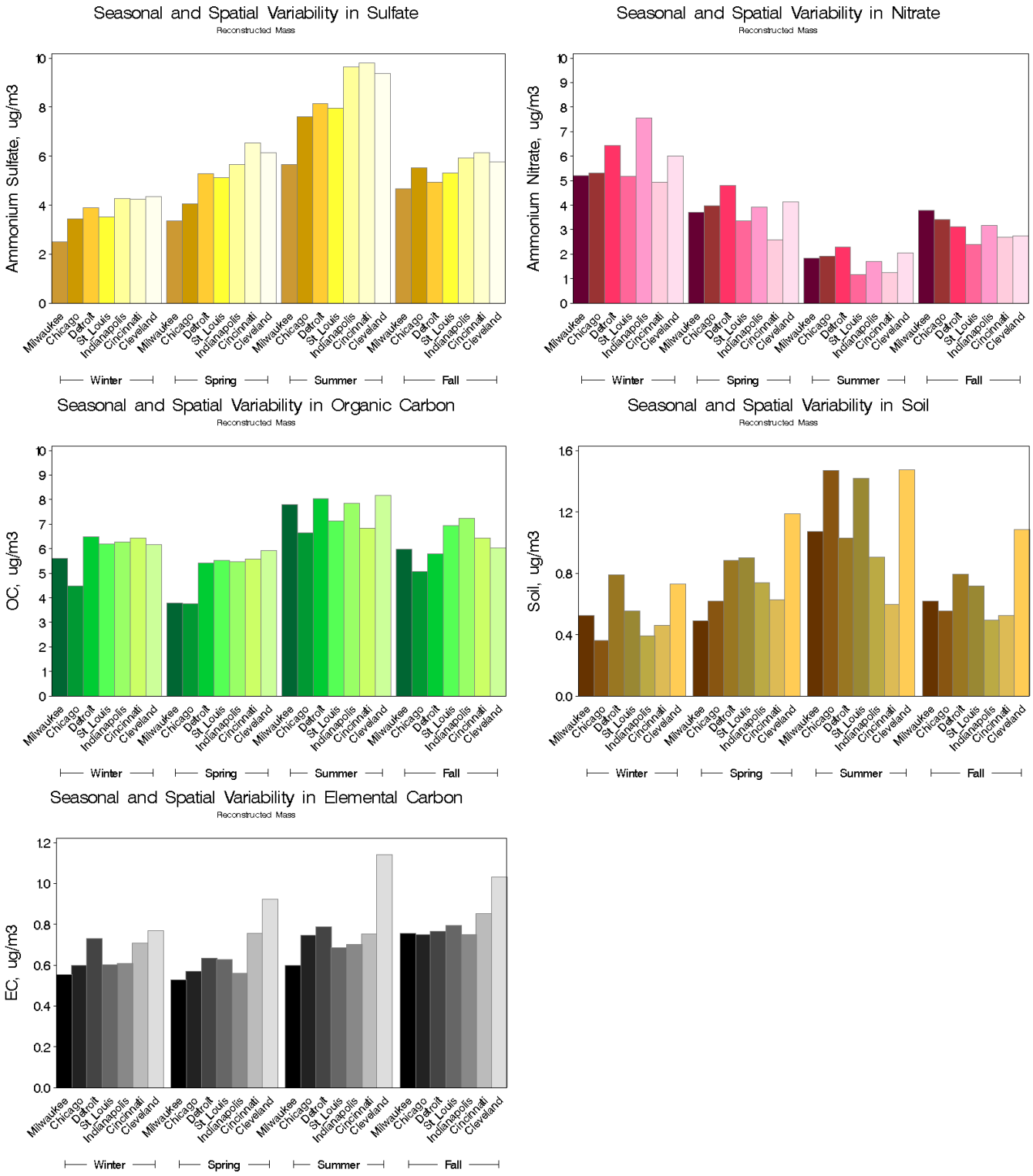


Figure 25 Seasonal and spatial variability in $PM_{2.5}$ components

Ammonium sulfate peaks in the summer and is highest in the southern and eastern parts of the Midwest, closest to the Ohio River Valley. Sulfate is primarily a regional pollutant; concentrations are similar in rural and urban areas and highly correlated over large distances. It is formed when sulfuric acid (an oxidation product of sulfur dioxide) and ammonia react in the atmosphere, especially in cloud droplets. Coal combustion is the primary source of sulfur dioxide; ammonia is emitted primarily from animal husbandry operations and fertilizer use.

Ammonium nitrate has almost the opposite spatial and seasonal pattern, with the highest concentrations occurring in the winter and in the northern parts of the region. Nitrate seems to have both regional and local sources, because urban concentrations are higher than rural upwind concentrations. Ammonium nitrate forms when nitric acid reacts with ammonia, a process that is enhanced when temperatures are low and humidity is high. Nitric acid is a product of the oxidation of nitric oxide, a pollutant that is emitted by combustion processes.

Organic carbon is more consistent from season to season and city to city, although concentrations are generally slightly higher in the summer. Like nitrate, organic carbon has both regional and local components. Particulate organic carbon can be emitted directly from cars and other fuel combustion sources or formed in a secondary process as volatile organic gases react and condense. In rural areas, summer organic carbon has significant contributions from biogenic sources.

Precursor Sensitivity: Data from the Midwest ammonia monitoring network were analyzed with thermodynamic equilibrium models to assess the effect of changes in precursor gas concentrations on $PM_{2.5}$ concentrations (Blanchard, 2005b). These analyses indicate that particle formation responds in varying degrees to reductions in sulfate, nitric acid, and ammonia. Based on Figure 26, which shows $PM_{2.5}$ concentrations as a function of sulfate, nitric acid (HNO3), and ammonia (NH3), several key findings should be noted:

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

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

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

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

Examination of weekend/weekday difference in PM-nitrate and NOx concentrations in the Midwest demonstrate that reductions in local (urban) NOx lead to reductions, albeit non-proportional reductions, in PM-nitrate (Blanchard, 2004). This result is consistent with analyses of continuous PM-nitrate from several US cities, including St. Louis (Millstein, et al, 2007).

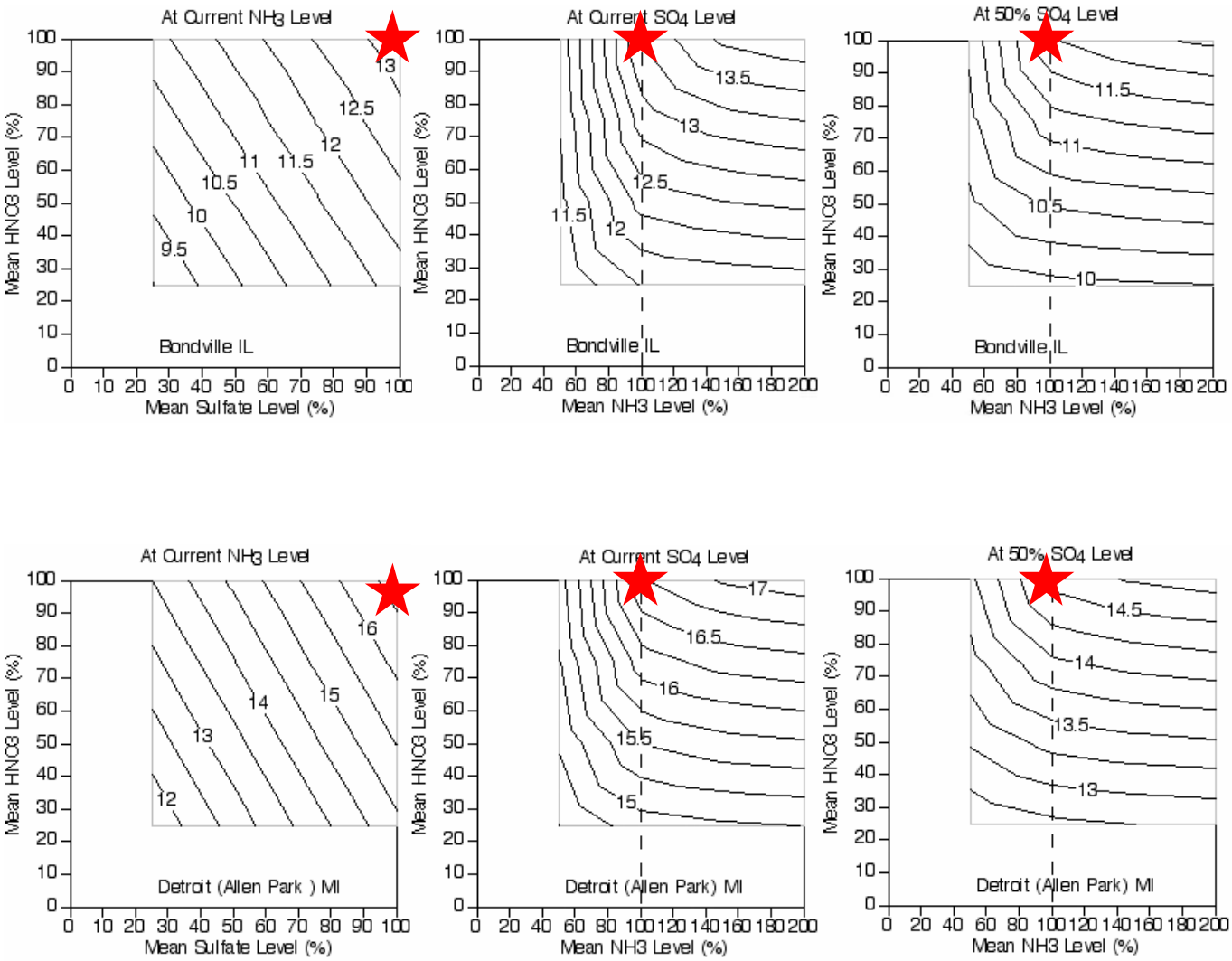


Figure 26. Predicted mean PM fine mass concentrations at Bondville, IL (top) and Detroit (Allen Park), MI (bottom) as functions of changes in sulfate, nitric acid (HNO3), and ammonia (NH3)

Note: starting at the baseline values (represented by the red star), either moving downward (reductions in nitric acid) or moving leftward (reductions in sulfate or ammonia) results in lower $PM_{2.5}$ values

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

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

$PM_{2.5}$ chemical species show noticeable transport influences. Trajectory analyses have demonstrated that high PM-sulfate is associated with air masses that traveled through the sulfate-rich Ohio River Valley (Poirot, et al, 2002 and Kenski, 2004). Likewise, high PM-nitrate is associated with air masses that traveled through the ammonia-rich Midwest. Figure 27 shows results from an ensemble trajectory analysis of 17 rural eastern IMPROVE sites.

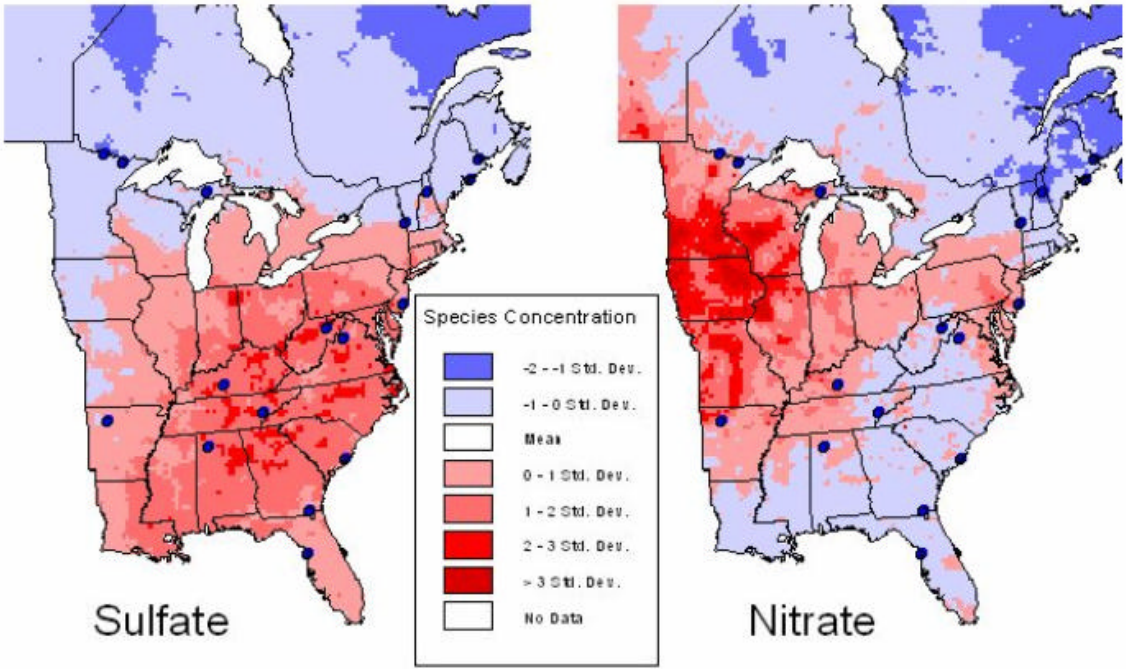


Figure 27. Sulfate and nitrate source regions based on ensemble trajectory analysis

When these results are considered together with analyses of precursor sensitivity (e.g., Figure 26), one possible conclusion is that ammonia control in the Midwest could be effective at reducing nitrate concentrations. The thermodynamic equilibrium modeling shows that ammonia reductions would reduce PM concentrations in the Midwest, but that nitric acid reductions are more effective when the probable reductions in future sulfate levels are considered.

Source Culpability: Three source apportionment studies were performed using speciated $PM_{2.5}$ monitoring data and statistical analysis methods (Hopke, 2005, STI, 2006, and STI, 2008). Figure 28 summarizes the source contributions from these studies. The studies show that a large portion of $PM_{2.5}$ mass consists of secondary, regional impacts, which cannot be attributed to individual facilities or sources (e.g., secondary sulfate, secondary nitrate, and secondary organic aerosols). Nevertheless, wind analyses (e.g., Figure 27) provide information on likely source regions. Regional- or national-scale control programs may be the most effective way to deal with these impacts. EPA's CAIR, for example, will provide for substantial reductions in SO2 emissions over the eastern half of the U.S., which will reduce sulfate (and $PM_{2.5}$) concentrations and improve visibility levels.

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

The carbon sources are not easily identified in complex urban environments. LADCO's Urban Organics Study (STI, 2006) identified four major sources of organic carbon: mobile sources, burning, industrial sources, and secondary organic aerosols. Additional sampling and analysis is underway in Cleveland and Detroit to provide further information on sources of organic carbon.

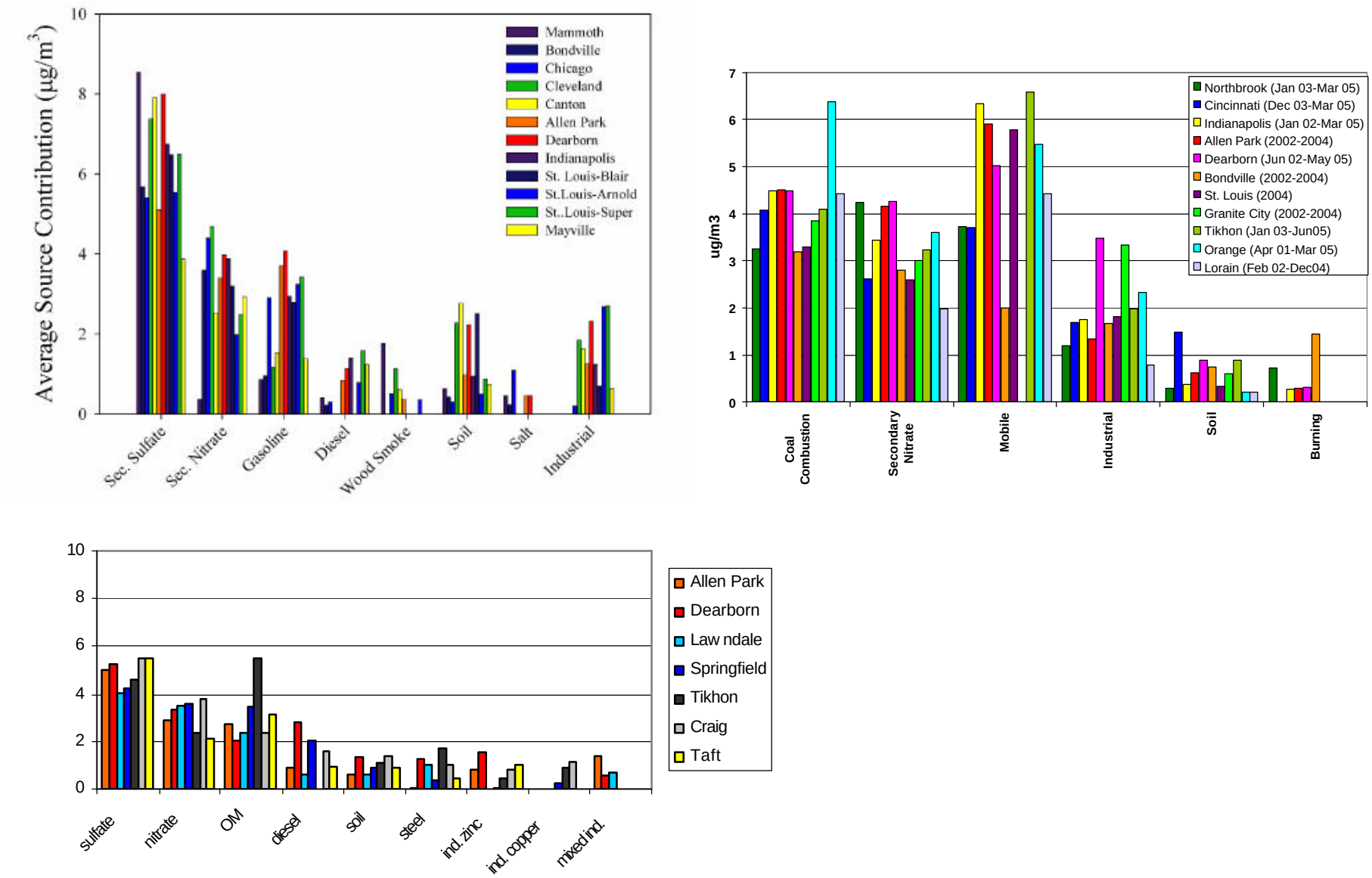


Figure 28. Major Source Contributions in the Midwest based on Hopke, 2005 (upper left), STI, 2006 (upper right), and STI, 2008 (lower left) (Note: the labeling of similar source types varies between studies – e.g., organic carbon/mobile sources are named gasoline and diesel by Hopke, mobile by STI 2006, and OM and diesel by STI 2008)

2.3 Haze

Section 169A of the Clean Air Act sets as a national goal "the prevention of any future, and the remedying of any existing, impairment of visibility in mandatory Class I Federal areas which impairment results from manmade air pollution". To implement this provision, in 1999, EPA adopted regulations to address regional haze visibility impairment (USEPA, 1999). EPA's rule requires states to "make reasonable progress toward meeting the national goal". Specifically, states must establish reasonable progress goals, which provide for improved visibility on the most impaired (20% worst) days sufficient to achieve natural conditions by the year 2064, and for no degradation on the least impaired (20% best) days.

The primary cause of impaired visibility in the Class I areas is pollution by fine particles that scatter light. The degree of impairment, which is expressed in terms of visual range, light extinction (1/Mm), or deciviews (dv), depends not just on the total $PM_{2.5}$ mass concentration, but also on the chemical composition of the particles and meteorological conditions.

Current Conditions: A map of the average light extinction values for the most impaired (20% worst) visibility days for the 5-year baseline period (2000-2004) is shown in Figure 29.

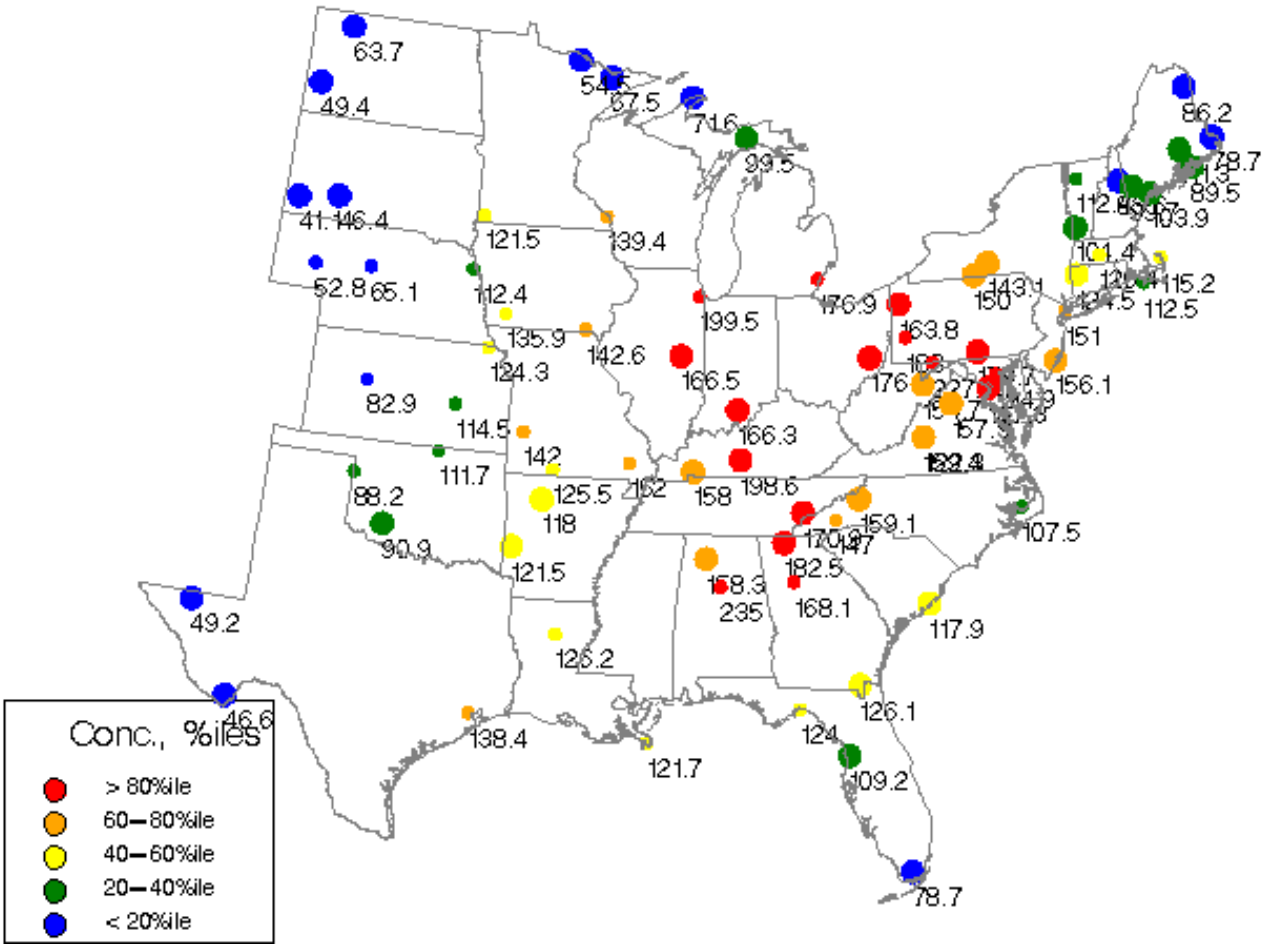


Figure 29. Baseline Visibility Levels for 20% Worst Days (2000 – 2004), units: Mm^{-1}

Initially, the baseline (2000 – 2004) visibility condition values were derived using the average for the 20% worst and 20% best days for each year, as reported on the VIEWS website: http://vista.cira.colostate.edu/views/Web/IMPROVE/SummaryData.aspx . These values were calculated using the original IMPROVE equation for reconstructed light extinction.

Three changes were made to the baseline calculations to produce a new set of values. First, the reconstructed light extinction equation was revised by the IMPROVE Steering Committee in 2005. The new IMPROVE equation was used to calculate updated baseline values.

Second, due to sampler problems, the 2002-2004 data for Boundary Waters were invalid for certain chemical species. (Note, sulfate and nitrate data were valid.) A "substituted" data set was developed by using values from Voyageurs for the invalid species.

Third, LADCO identified a number of days during 2000-2004 where data capture at the Class I monitors was incomplete (Kenski, 2007b). The missing data cause these days to be excluded from the baseline calculations. However, the light extinction due to the remaining measured species is significant (i.e., above the 80th percentile). It makes sense to include these days in the baseline calculations, because they are largely dominated by anthropogenic sources. (Only one of these days is driven by high organic carbon, which might indicate non-anthropogenic aerosol from wildfires.) As seen in Table 3, inclusion of these days in the baseline calculation results in a small, but measurable, effect on the baseline values (i.e., values increase from 0.2 to 0.8 dv).

Table 3. Average of 20% worst days, with and without missing data days

	Average Worst Day DV, per RHR	Average Worst Day DV, with Missing Data Days	Difference
BOWA	19.59	19.86	0.27
ISLE	20.74	21.59	0.85
SENE	24.16	24.38	0.22
VOYA	19.27	19.48	0.21

A summary of the initial and updated baseline values for the Class I areas in northern Michigan and northern Minnesota are presented in Table 4. The updated baseline values reflect the most current, complete understanding of visibility impairing effects and, as such, will be used for SIP planning purposes.

Table 4. Summary of visibility metrics (deciviews) for northern Class I areas

Old IMPROVE Equation (Cite: VIEWS, November 2005)									
		20% Worst Days							
		2000	**2001**	**2002**	**2003**	**2004**	**Baseline Value**	**2018 URI Value**	**Natural Conditions**
Voyageurs		18.50	18.00	19.00	19.20	17.60	18.46	16.74	11.09
BWCA		19.85	19.99	19.68	19.73	17.65	19.38	17.47	11.21
Isle Royale		20.00	22.00	20.80	19.50	19.10	20.28	18.17	11.22
Seney		22.60	24.90	24.00	23.80	22.60	23.58	20.73	11.37
		20% Best Days							
		2000	**2001**	**2002**	**2003**	**2004**	**Baseline Value**		**Natural Conditions**
Voyageurs		6.30	6.20	6.70	7.00	5.40	6.32		3.41
BWCA		5.90	6.52	6.93	6.67	5.61	6.33		3.53
Isle Royale		5.70	6.40	6.40	6.30	5.30	6.02		3.54
Seney		5.80	6.10	7.30	7.50	5.80	6.50		3.69
New IMPROVE Equation (Cite: VIEWS, March 2006)									
		20% Worst Days							
		2000	**2001**	**2002**	**2003**	**2004**	**Baseline Value**	**2018 URI Value**	**Natural Conditions**
Voyageurs		19.55	18.57	20.14	20.25	18.87	19.48	17.74	12.05
BWCA		20.20	20.04	20.76	20.13	18.18	19.86	17.94	11.61
Isle Royale		20.53	23.07	21.97	22.35	20.02	21.59	19.43	12.36
Seney		22.94	25.91	25.38	24.48	23.15	24.37	21.64	12.65
		20% Best Days							
		2000	**2001**	**2002**	**2003**	**2004**	**Baseline Value**		**Natural Conditions**
Voyageurs		7.01	7.12	7.53	7.68	6.37	7.14		4.26
BWCA		6.00	6.92	7.00	6.45	5.77	6.43		3.42
Isle Royale		6.49	7.16	7.07	6.99	6.12	6.77		3.72
Seney		6.50	6.78	7.82	8.01	6.58	7.14		3.73

Notes: (1) BWCA values for 2002 - 2004 reflect "substituted" data.
(2) New IMPROVE equation values include Kenski, 2007 adjustment for missing days

URI = uniform rate of improvement

As noted above, the goal of the visibility program is to achieve natural conditions. Initially, the natural conditions values for each Class I area were taken directly from EPA guidance (EPA, 2003). These values were calculated using the original IMPROVE equation. This equation was revised by the IMPROVE Steering Committee in 2005, and the new IMPROVE equation was used to calculate updated natural conditions values. The updated values are reported on the VIEWS website.

A summary of the initial and updated natural conditions values are presented in Table 4. The updated natural conditions values (based on the new IMPROVE equation) will be used for SIP planning purposes.

Data Variability: For the four northern Class I areas, the most important $PM_{2.5}$ chemical species are ammonium sulfate, ammonium nitrate, and organic carbon. The contribution of these species on the 20% best and 20% worst visibility days (based on 2000 – 2004 data) is provided in Figure 30. For the 20% worst visibility days, the contributions are: sulfate = 35-55%, nitrate = 25-30%, and organic carbon = 12-22%. Although the chemical composition is similar, sulfate increases in importance from west to east and concentrations are highest at Seney (the easternmost site). It should also be noted that sulfate and nitrate contribute more to light extinction than to $PM_{2.5}$ mass because of their hygroscopic properties.

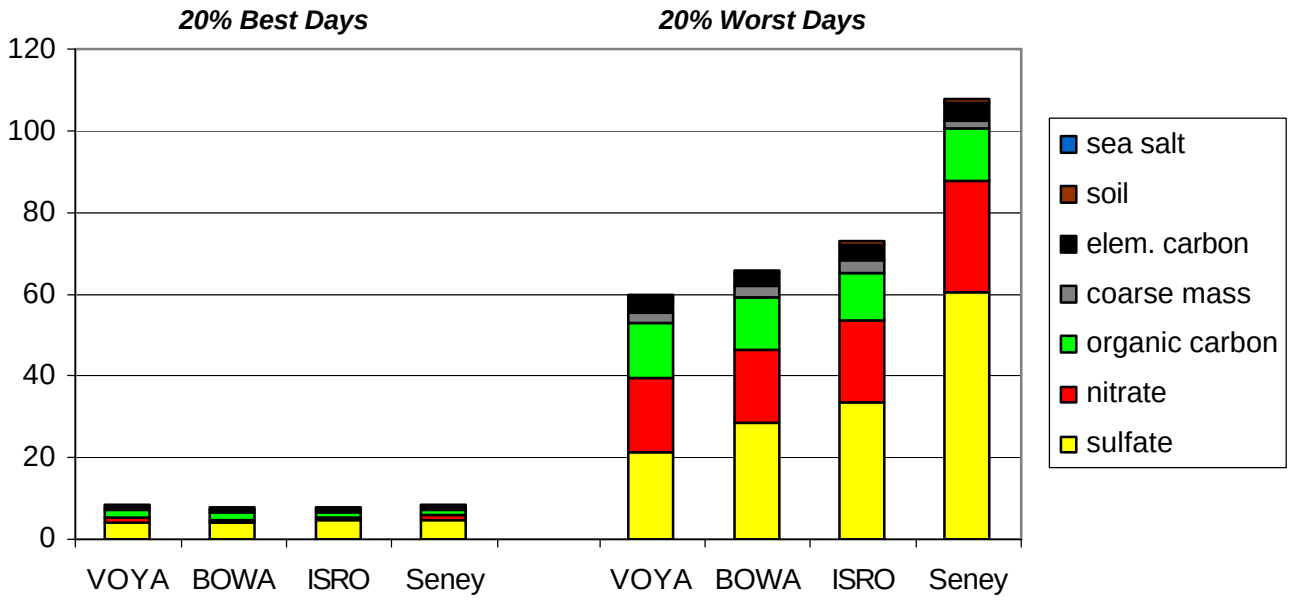


Figure 30. Chemical composition of light extinction for 20% best visibility days (left) and 20% worst visibility days (right) in terms of Mm^{-1}

Analysis of $PM_{2.5}$ mass and chemical species for rural IMPROVE (and IMPROVE-protocol) sites in the eastern U.S. showed a high degree of correlation between $PM_{2.5}$-mass, sulfate, and nitrate levels (see Figure 31). The Class I sites in northern Michigan and northern Minnesota, in particular, are highly correlated for $PM_{2.5}$ mass, sulfates, and organic carbon mass (AER, 2004).

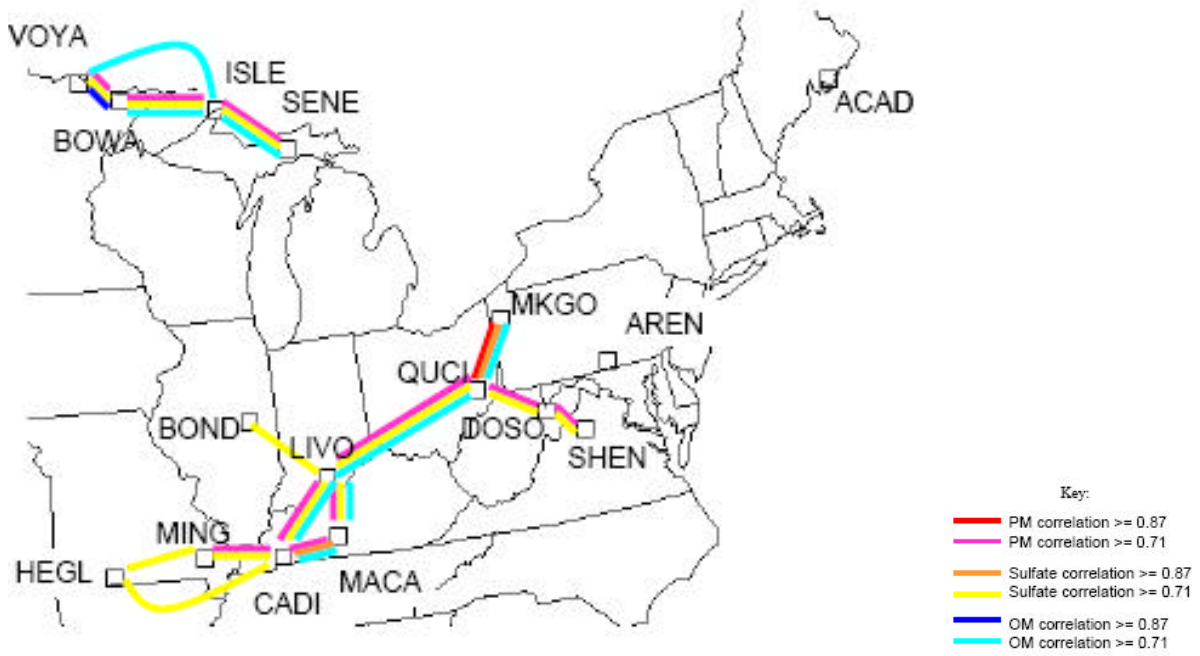


Figure 31. Correlations among IMPROVE (and IMPROVE-protocol) monitoring sites in Eastern U.S.

Long-term trends at Boundary Waters (the only regional site with a sufficient data record) show significant decreases in total $PM_{2.5}$ (-0.005 ug/year) and SO4 (-0.04 ug/year) and an increase in NO3 (+0.01 ug/year). These $PM_{2.5}$ and SO4 trends are generally consistent with long-term trends at other IMPROVE sites in the eastern U.S., which have shown widespread decreases in SO4 and $PM_{2.5}$ (DeBell, et al, 2006). Detecting changes in nitrate has been hampered by uncertainties in the IMPROVE data for particular years and, thus, this estimate should be considered tentative.

Haze in the Midwest Class I areas has no strong seasonal pattern. Poor visibility days occur throughout the year, as indicated in Figure 32. (Note, in contrast, other parts of the country, such as Shenandoah National Park in Virginia, show a strong tendency for the worst air quality days to occur in the summer months.) This figure and Figure 33 (which presents the monthly average light extinction values based on all sampling days) also show that sulfate and organic carbon concentrations are higher in the summer, and nitrate concentrations are higher in the winter, suggesting the importance of different sources and meteorological conditions at different times of the year.

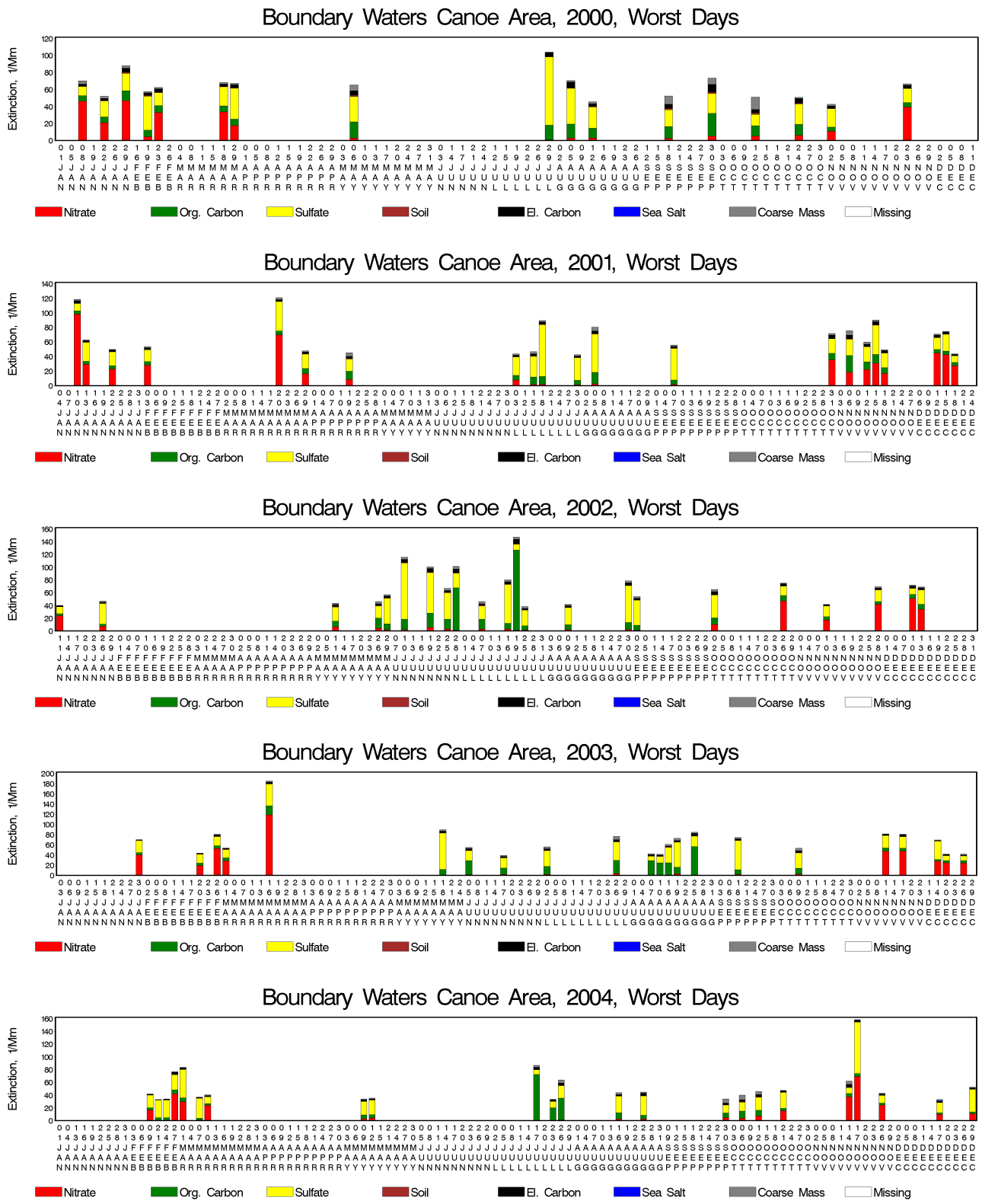


Figure 32. Daily light extinction values for 20% worst days at Boundary Waters (2000 – 2004)

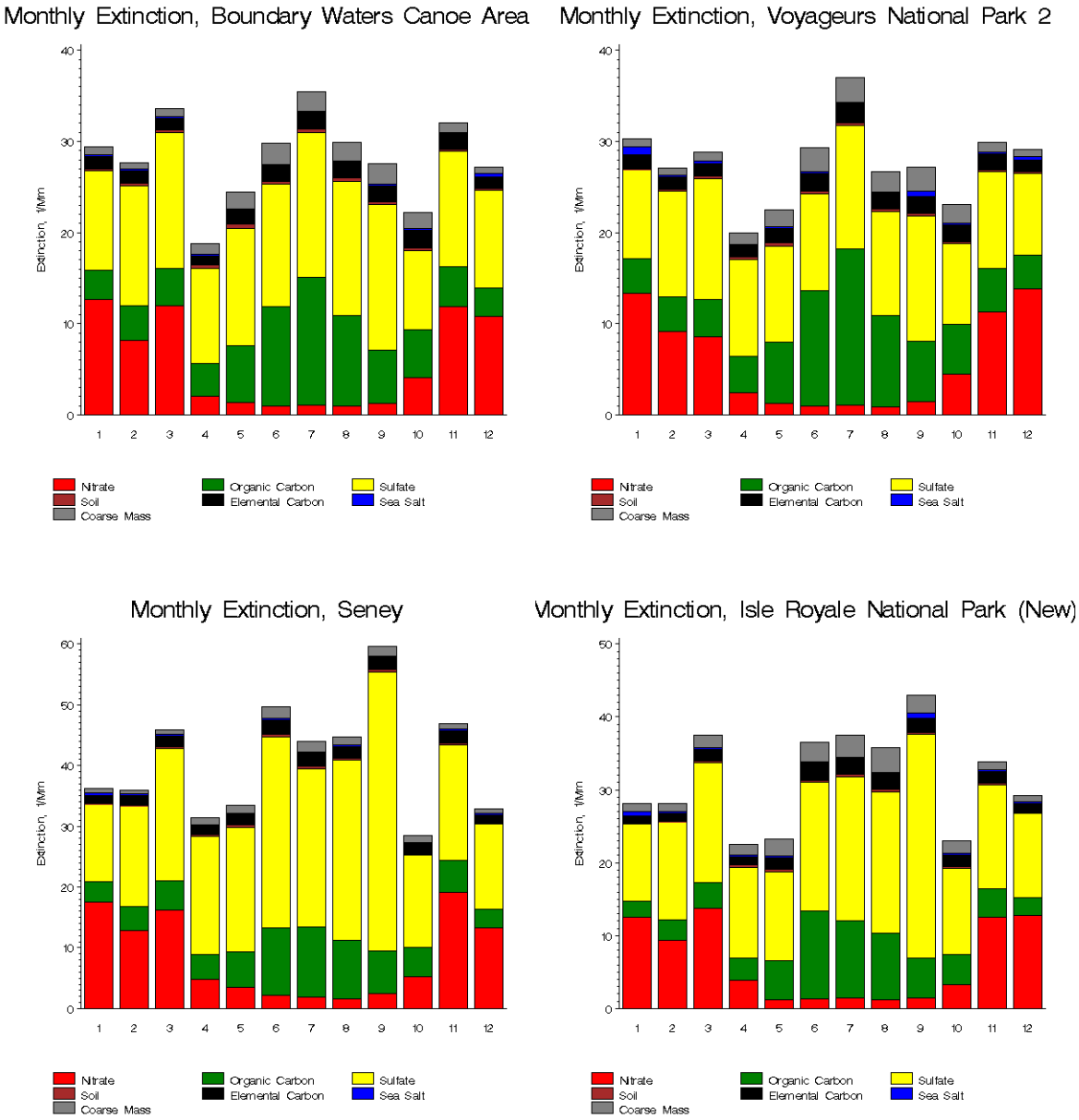


Figure 33. Monthly average light extinction values for northern Class I areas

Precursor Sensitivity: Results from two analyses using thermodynamic equilibrium models provide information on the effect of changes in precursor concentrations on $PM_{2.5}$ concentrations (and, in turn, visibility levels) in the northern Class I areas. First, a preliminary analysis using data collected at Seney indicated that $PM_{2.5}$ there is most sensitive to reductions in sulfate, but is also sensitive to reductions in nitric acid (Blanchard, 2004).

Second, an analysis was performed using data from the Midwest ammonia monitoring network for a site in Minnesota -- Great River Bluffs, which is the closest ammonia monitoring site to the northern Class I areas (Blanchard, 2005b). Figure 34 shows $PM_{2.5}$ concentrations as a function of sulfate, nitric acid (HNO3), and ammonia (NH3). Reductions in sulfate (i.e., movement to the left of baseline value [represented by the red star]), as well as reductions in nitric acid (i.e., movement downward) and NH3 (i.e., movement to the left), result in lower $PM_{2.5}$ concentrations. Thus, reductions in sulfate, nitric acid, and ammonia will lower $PM_{2.5}$ concentrations and improve visibility in the northern Class I areas.

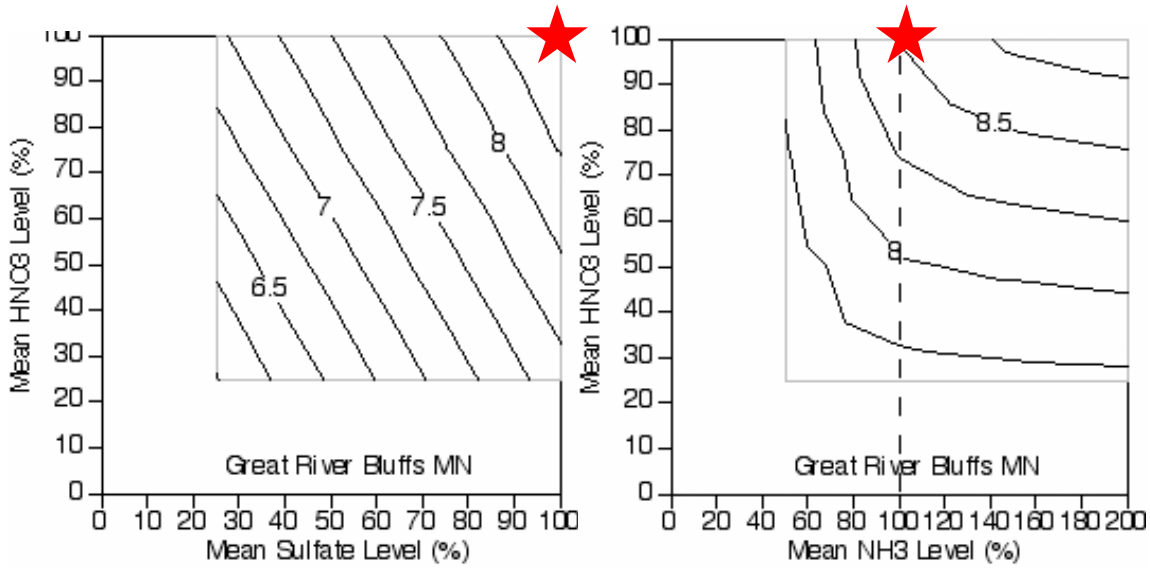


Figure 34. Predicted $PM_{2.5}$ mass concentrations at Great River Bluffs, MN as functions of changes in sulfate, nitric acid, and ammonia

Meteorology and Transport: The role of meteorology in haze is complex. Wind speed and wind direction govern the movement of air masses from polluted areas to the cleaner wilderness areas. As noted above, increasing humidity increases the efficiency with which sulfate and nitrate aerosols scatter light. Temperature and humidity together govern whether ammonium nitrate can form from its precursor gases, nitric acid and ammonia. Temperature and sunlight also play an indirect role in emissions of biogenic organic species that condense to form particulate organic matter; emissions increase in the summer daylight hours.

Trajectory analyses were performed to understand transport patterns for the 20% worst and 20% best visibility days. The composite results for the four northern Class I areas are provided in Figure 35. The orange areas are where the air is most likely to come from, and the green areas are where the air is least likely to come from. As can be seen, bad air days are generally associated with transport from regions located to the south, and good air days with transport from Canada.

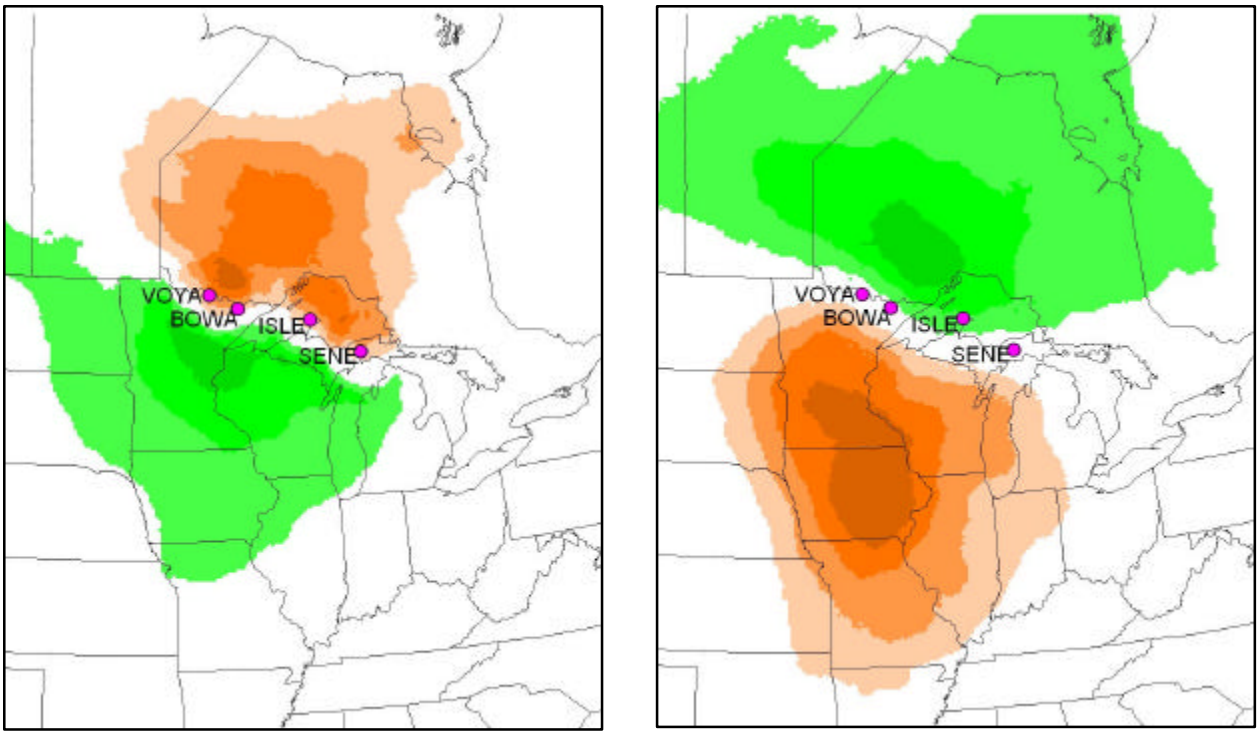


Figure 35. Composite back trajectories for light extinction- 20% best visibility days (left) and 20% worst visibility days (right) (2000 – 2005)

Source Culpability: Air quality data analyses (including the trajectory analyses above) and dispersion modeling were used to provide information on source region and source sector contributions to regional haze in the northern Class I areas (see MRPO, 2008). Based on this information, the most important contributing states are Michigan, Minnesota, and Wisconsin, as well as Missouri, North Dakota, Iowa, Indiana and Illinois (see, for example, Figure 35 above). The most important contributing pollutants and source sectors are SO2 emissions from electrical generating units (EGUs) and certain non-EGUs, which lead to sulfate formation, and NOx emissions from a variety of source types (e.g., motor vehicles), which lead to nitrate formation. Ammonia emissions from livestock waste and fertilizer applications are also important, especially for nitrate formation.

A source apportionment study was performed using monitoring data from Boundary Waters and statistical analysis methods (DRI, 2005). The study shows that a large portion of $PM_{2.5}$ mass consists of secondary, regional impacts, which cannot be attributed to individual facilities or sources (e.g., secondary sulfate, secondary nitrate, and secondary organic aerosols). Industrial sources contribute about 3-4% and mobile sources about 4-7% to $PM_{2.5}$ mass.

A special study was performed in Seney to identify sources of organic carbon (Sheesley, et al, 2004). As seen in Figure 36, the highest $PM_{2.5}$ concentrations occurred during the summer, with organic carbon being the dominant species. The higher summer organic carbon concentrations were attributed mostly to secondary organic aerosols of biogenic origin because of the lack of primary emission markers, and concentrations of know biogenic-related species (e.g., pinonic acid – see Figure 36) were also high during the summer.

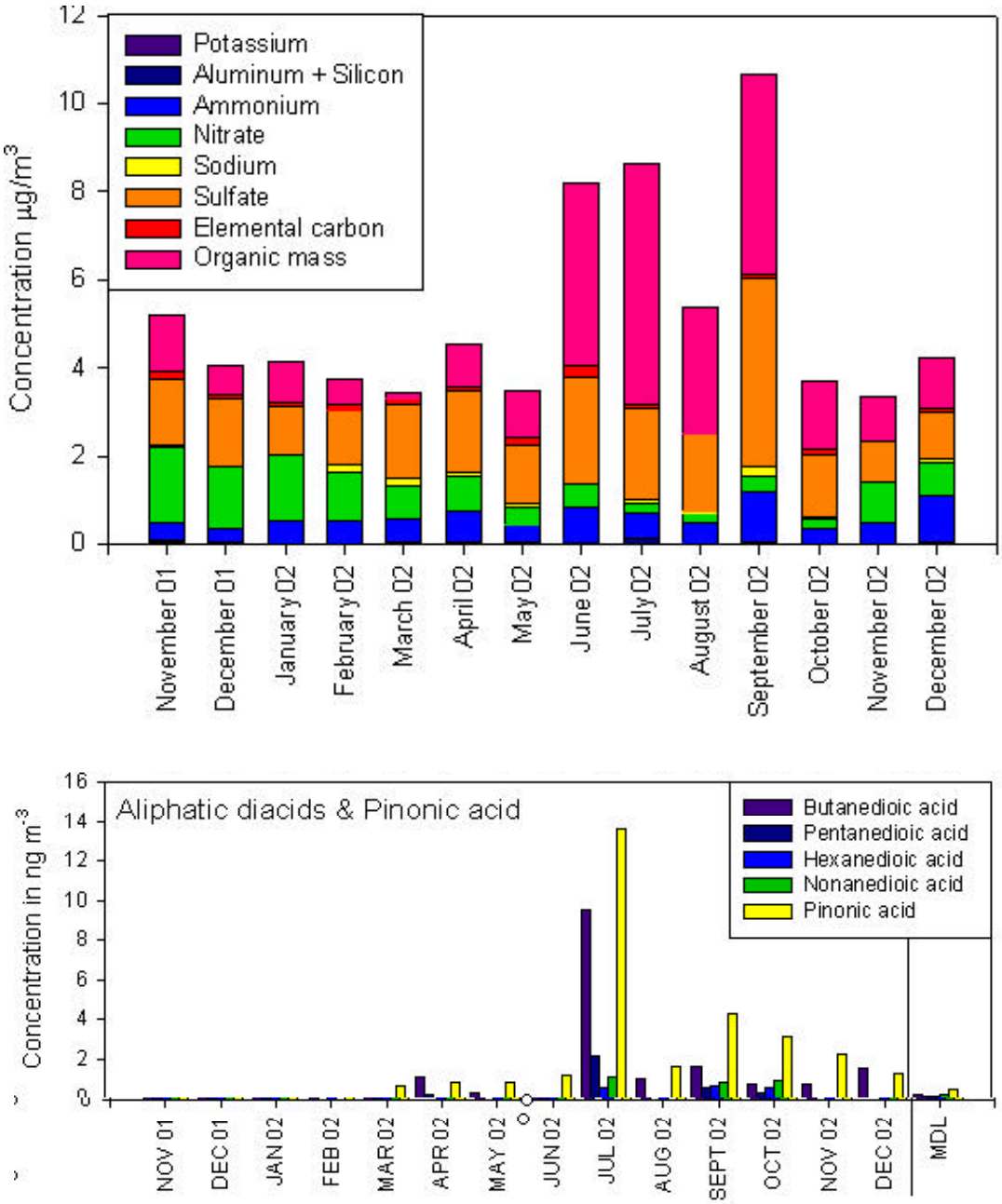


Figure 36. Monthly concentrations of $PM_{2.5}$ species (top), and secondary and biogenic-related organic carbon species in Seney (bottom)

Although the Seney study showed that biomass burning was a relatively small contributor to organic carbon on an annual average basis, episodic impacts are apparent (see, for example, high organic carbon days in Figure 32). To assess further whether burning is a significant contributor to visibility impairment in the northern Class I areas, the $PM_{2.5}$ chemical speciation data were examined for days with high organic carbon and elemental carbon concentrations, which are indicative of biomass burning impacts. Only a handful of such days were identified:

Table 5. Days with high OC and EC concentrations in northern Class I areas

Site	2000	2001	2002	2003	2004
Voyageurs	---	---	Jun 1	Aug 25	Jul 17
			Jun 28		
			Jul 19		
Boundary Waters	---	---	Jun 28	Aug 25	Jul 17
			Jul 19		
Isle Royale	---	---	Jun 1	Aug 25	---
			Jun 28		
Seney	---	---	Jun 28	---	---

Back trajectories on these days point mostly to wildfires in Canada. Elimination of these high organic carbon concentration days has a small effect in lowering the baseline visibility levels in the northern Class I areas (i.e., Minnesota Class I areas change by about 0.3 deciviews and Michigan Class I areas change by less than 0.2 deciviews). This suggests that fire activity, although significant on a few days, is on average a relatively small contributor to visibility impairment in the northern Class I areas.

In summary, these analyses show that organic carbon in the northern Class I is largely uncontrollable.

Section 3.0 Air Quality Modeling

Air quality models are relied on by federal and state regulatory agencies to support their planning efforts. Used properly, models can assist policy makers in deciding which control programs are most effective in improving air quality, and meeting specific goals and objectives. For example, models can be used to conduct "what if" analyses, which provide information for policy makers on the effectiveness of candidate control programs.

The modeling analyses were conducted in accordance with EPA's modeling guidelines (EPA, 2007a). Further details of the modeling are provided in two protocol documents: LADCO, 2007a and LADCO, 2007b.

This section reviews the development and evaluation of the modeling system used for the multi-pollutant analyses. Application of the modeling system (i.e., attainment demonstration for ozone and $PM_{2.5}$, and reasonable progress assessment for haze) is covered in the following sections.

3.1 Selection of Base Year

Two base years were used in the modeling analyses: 2002 and 2005. EPA's modeling guidance recommends using 2002 as the baseline inventory year, but also allows for use of an alternative baseline inventory year, especially a more recent year. Initially, LADCO conducted modeling with a 2002 base year (i.e., Base K/Round 4 modeling, which was completed in 2006). A decision was subsequently made to conduct modeling with a 2005 base year (i.e., Base M/Round 5, which was completed in 2007). As discussed in the previous section, 2002 and 2005 both had above normal ozone conducive conditions, although 2002 was more severe compared to 2005. Examination of multiple base years provides for a more complete technical assessment. Both sets of model runs are discussed in this document.

3.2 Future Years of Interest

To address the multiple attainment requirements for ozone and $PM_{2.5}$, and reasonable progress goals for regional haze, several future years are of interest:

- 2008 Planning year for ozone basic nonattainment areas (attainment date 2009)[8]
- 2009 Planning year for ozone moderate nonattainment areas and $PM_{2.5}$ nonattainment areas (attainment date 2010)
- 2012 Planning year for ozone moderate nonattainment areas and $PM_{2.5}$ nonattainment areas, with 3-year extension (attainment date 2013)
- 2018 First milestone year for regional haze planning

[8] According to USEPA's ozone implementation rule (USEPA, 2005), emission reductions needed for attainment must be implemented by the beginning of the ozone season immediately preceding the area's attainment date. The PM2.5 implementation rule contains similar provisions – i.e., emission reductions should be in place by the beginning of the year preceding the attainment date (USEPA, 2007c). The logic for requiring emissions reductions by the year (or season) immediately preceding the attainment year follows from language in the Clean Air Act, and the ability for an area to receive up to two 1-year extensions. Therefore, emissions in the year preceding the attainment year should be at a level that is consistent with attainment. It also follows that the year preceding the attainment year should be modeled for attainment planning purposes.

Detailed emissions inventories were developed for 2009 and 2018. To support modeling for other future years, less rigorous emissions processing was conducted (e.g., 2012 emissions were estimated for several source sectors by interpolating between 2009 and 2018 emissions).

3.3 Modeling System

The air quality analyses were conducted with the CAMx model, with emissions and meteorology generated using EMS (and CONCEPT) and MM5, respectively. The selection of CAMx as the primary model is based on several factors: performance, operator considerations (e.g., ease of application and resource requirements), technical support and documentation, model extensions (e.g., 2-way nested grids, process analysis, source apportionment, and plume-in-grid), and model science. CAMx model set-up for Base M and Base K is summarized below:

Base M (2005)	Base K (2002)
• CAMx v4.50	* CAMx 4.30
• CB05 gas phase chemistry	* CB-IV with updated gas-phase chemistry
• SOA chemistry updates	* No SOA chemistry updates
• AERMOD dry deposition scheme	* Wesley-based dry deposition
• ISORROPIA inorganic chemistry	• ISORROPIA inorganic chemistry
• SOAP organic chemistry	• SOAP organic chemistry
• RADM aqueous phase chemistry	• RADM aqueous phase chemistry
• PPM horizontal transport	• PPM horizontal transport

3.4 Domain/Grid Resolution

The National RPO grid projection was used for this modeling. A subset of the RPO domain was used for the LADCO modeling. For $PM_{2.5}$ and haze, the large eastern U.S. grid at 36 km (see box on right side of Figure 36) was used. A $PM_{2.5}$ sensitivity run was also performed for this domain at 12 km. For ozone, the smaller grid at 12 km (see shaded portion of the box on the right side of Figure 37) was used for most model runs. An ozone sensitivity run was also performed with a 4km sub-grid over the Lake Michigan area and Detroit/Cleveland.

The vertical resolution in the air quality model consists of 16 layers extending up to 15 km, with higher resolution in the boundary layer.

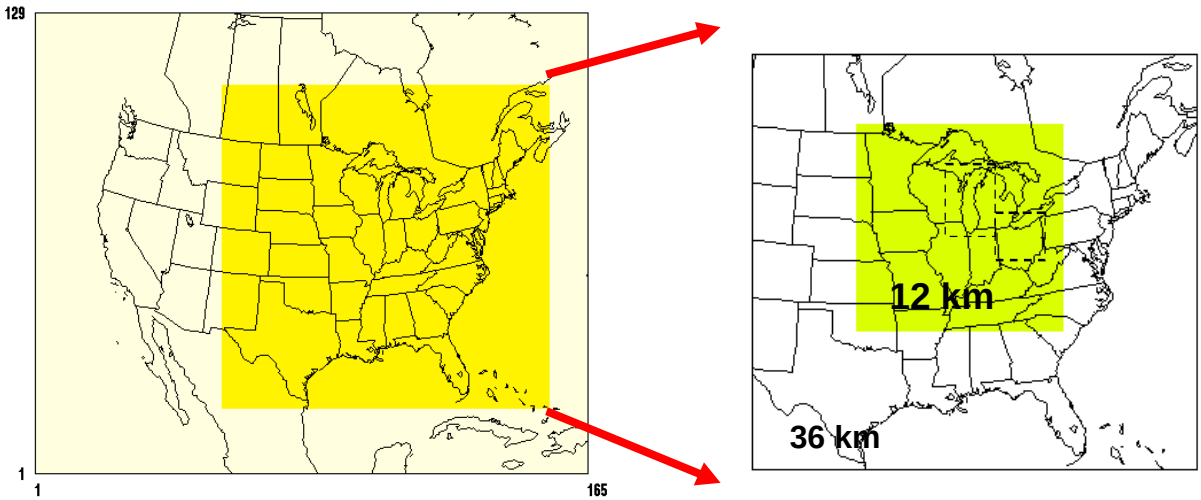


Figure 37. Modeling grids – RPO domain (left) and LADCO modeling domain (right)

3.5 Model Inputs: Meteorology

Meteorological inputs were derived using the Fifth-Generation NCAR/Penn State Meteorological Model (MM5) – version 3.6.3 for the years 2001–2003, and version 3.7 for the year 2005. The MM5 modeling domains are consistent with the National RPO grid projections (see Figure 38).

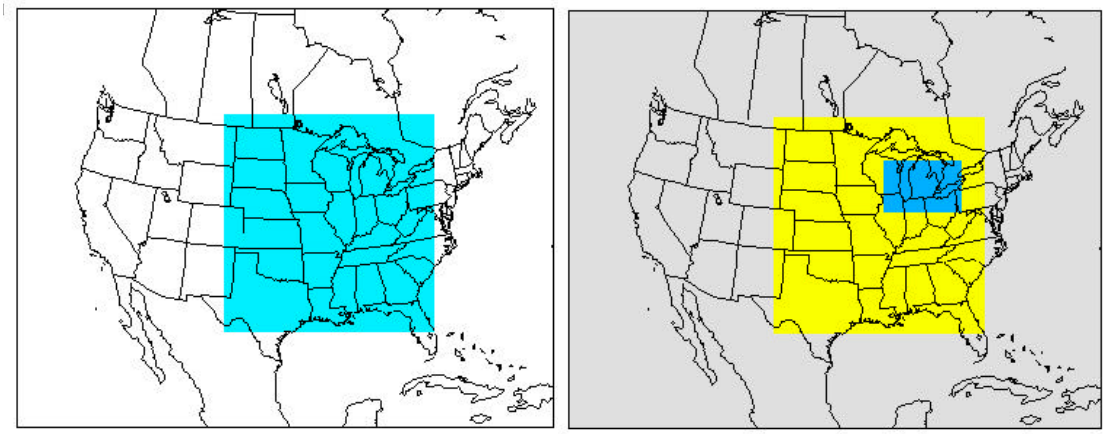


Figure 38. MM5 modeling domain for 2001-2003 (left) and 2005 (right)

The annual 2002 36 km MM5 simulation was completed by Iowa DNR. The 36/12 km 2-way nested simulation for the summers of 2001, 2002, and 2003 were conducted jointly by Illinois EPA and LADCO. The 36 km non-summer portion of the annual 2003 simulation was conducted by Wisconsin DNR. The annual 2005 36/12 km (and summer season 4 km) MM5 modeling was completed by Alpine Geophysics. Wisconsin DNR also completed 36/12 km MM5 runs for the summer season of 2005.

Model performance was assessed quantitatively with the METSTAT tool from Environ. The metrics used to quantify model performance include mean observation, mean prediction, bias, gross error, root mean square error, and index of agreement. Model performance metrics were calculated for several sub-regions of the modeling domain (Figure 39) and represent hourly spatial averages of multiple monitor locations. Additional analysis of rainfall is done on a monthly basis.

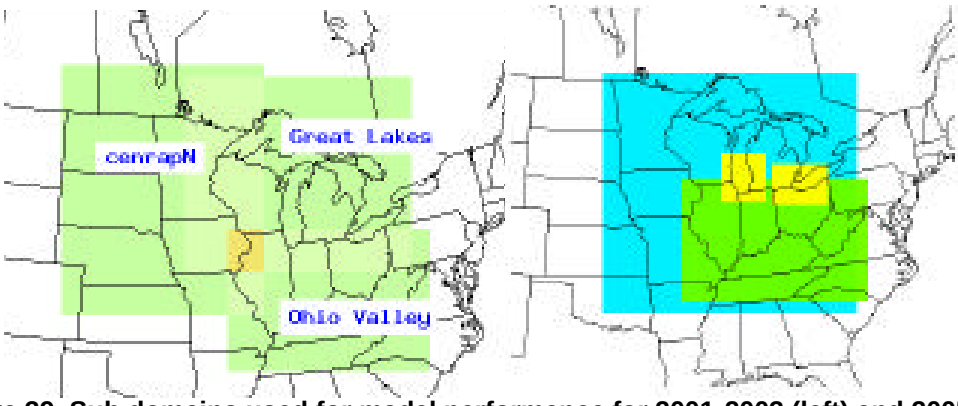


Figure 39. Sub-domains used for model performance for 2001-2003 (left) and 2005 (right)

A summary of the performance evaluation results for the meteorological modeling is provided below. Further details are provided in two summary reports (LADCO, 2005 and LADCO, 2007c).

Temperature: The biggest issue with the performance in the upper Midwest is the existence of a cool diurnal temperature bias in the winter and warm temperature bias over night during the summer (see Figure 40). These features are common to other annual MM5 simulations for the central United States and do not appear to adversely affect model performance.

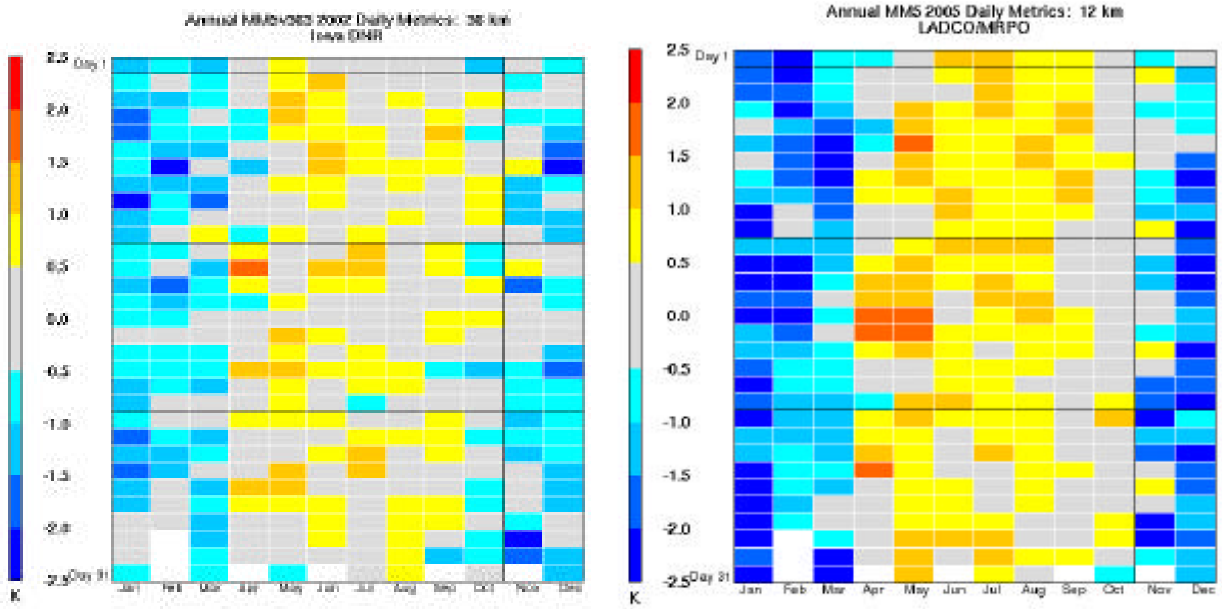


Figure 40. Daily temperature bias for 2002 (left) and 2005 (right) with hotter colors (yellow/orange/red) representing overestimates and cooler colors (blues) representing underestimates

Note: months are represented from left to right (January to December) and days are represented from top to bottom (1 to 30(31) – i.e., upper left hand corner is January 1 and lower right hand corner is December 31

Wind Fields: The wind fields are generally good. Wind speed bias is less than 0.5 m/sec and wind speed error is consistently between 1.0 and 1.5 m/sec. Wind direction error is generally within 15-30 degrees.

Mixing Ratio: The mixing ratio (a measure of humidity) is over-predicted in the late spring and summer months, and mixing ratio error is highest during this period. There is little bias and error during the cooler months when there is less moisture in the air.

Rainfall: The modeled and observed rainfall totals show good agreement spatially and in terms of magnitude in the winter, fall, and early spring months. There are, however, large over-predictions of rainfall in the late spring and summer months (see Figure 41). These over-predictions are seen spatially and in magnitude over the entire domain, particularly in the Southeast United States, and are likely due to excessive convective rainfall being predicted in MM5. This over-prediction of rainfall in MM5 does not necessarily translate into over-prediction of wet deposition in the photochemical model. CAMx does not explicitly use the convective and non-convective rainfall output by MM5, but estimates wet scavenging by hydrometeors using cloud, ice, snow, and rain water mixing ratios output by MM5. Nevertheless, this could have an effect on model performance for $PM_{2.5}$, as discussed in Section 3.7, and may warrant further attention.

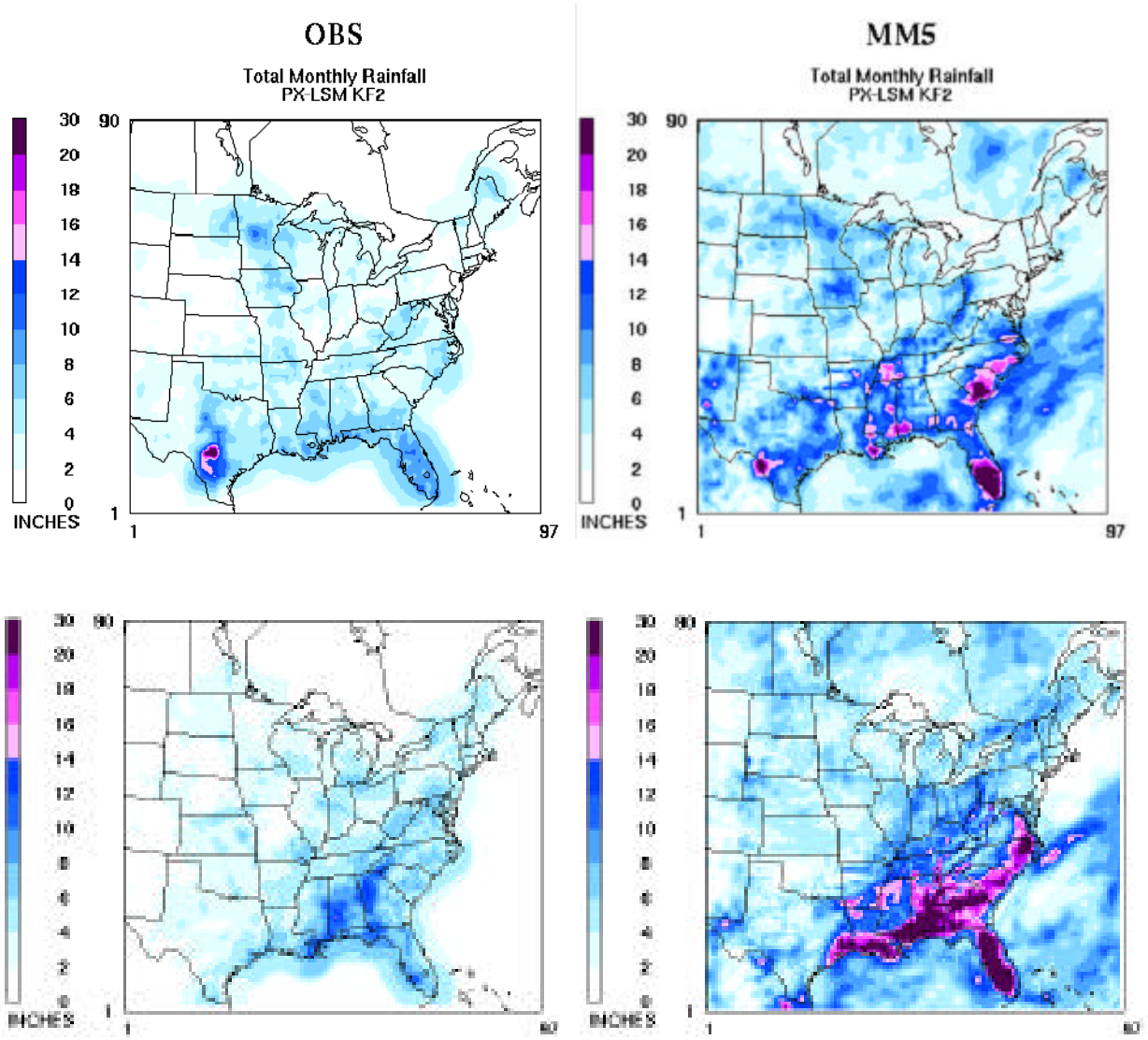


Figure 41. Comparison of observed (left column) and modeled (right column) monthly rainfall for July 2002 (top) and July 2005 (bottom)

3.6 Model Inputs: Emissions

Emission inventories were prepared for two base years: 2002 (Base K) and 2005 (Base M), and several future years: 2008, 2009, 2012, and 2018. Further details of the emission inventories are provided in two summary reports (LADCO, 2006a and LADCO, 2008a) and the following pages of the LADCO web site:

http://www.ladco.org/tech/emis/basek/BaseK_Reports.htm
http://www.ladco.org/tech/emis/r5/round5_reports.htm

For on-road, nonroad, ammonia, and biogenic sources, emissions were estimated by models. For the other sectors (point sources, area sources, and MAR [commercial marine, aircraft, and railroads]), emissions were prepared using data supplied by the LADCO States and other RPOs.

Base Year Emissions: State and source sector emission summaries for 2002 (Base K) and 2005 (Base M) are compared in Figure 42. Additional detail is provided in Tables 6a (all sectors – tons per day) and 6b (EGUs – tons per year).

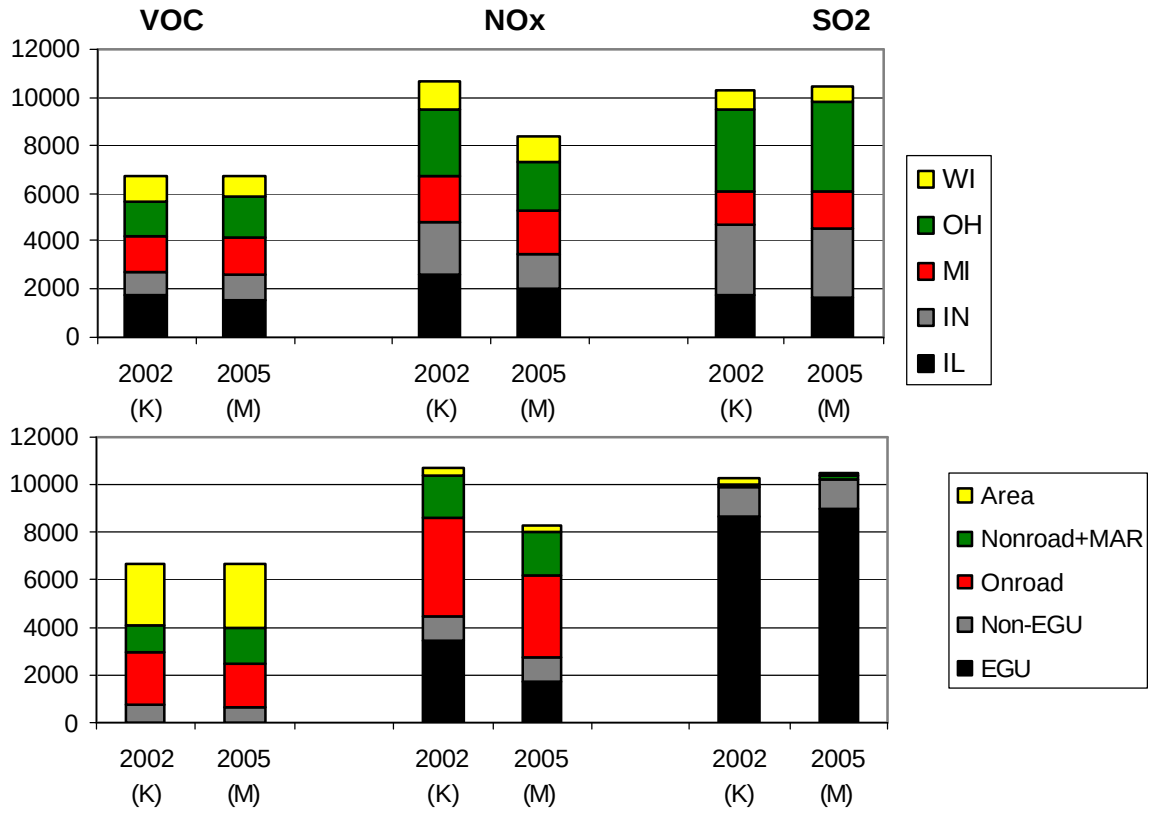


Figure 42. Base K and Base M emissions for 5-state LADCO region by state (top) and source sector (bottom), units: tons per summer weekday

A summary of the base year emissions by sector for the LADCO States is provided below.

	VOC	Base M	BaseK	Base M	BaseK	BaseK	Base M	NOx	Base M	BaseK	Base M	BaseK	BaseK	Base M	SOX	Base M	BaseK	Base M	BaseK	BaseK	Base M	PM2.5	Base M	BaseK	Base M	BaseK	BaseK	Base M
July	2002	2005	2009	2009	2012	2018	2018	2002	2005	2009	2009	2012	2018	2018	2002	2005	2009	2009	2012	2018	2018	2002	2005	2009	2009	2012	2018	2018
Nonroad																												
IL	224	321	164	257	149	130	213	324	333	263	275	224	154	155	31	33	5	5	0.6	0.4	0.4		30		24			14
IN	125	195	94	160	95	95	128	178	191	142	158	141	141	89	17	19	3	3	3	0.3	0.2		17		13			7
MI	348	414	307	350	276	222	271	205	239	159	197	133	93	112	19	22	3	3	0.5	0.3	0.3		22		18			11
OH	222	356	161	294	145	126	238	253	304	195	246	162	109	135	23	29	4	5	0.5	0.3	0.4		27		22			13
WI	214	238	194	203	175	140	157	145	157	114	129	97	69	77	13	15	2	2	0.3	0.2	0.2		14		12			7
5-State Total	1133	1524	920	1264	840	713	1007	1105	1224	873	1005	757	566	568	103	118	17	18	4.9	1.5	1.5		110		89			52
U.S. Total	8463	9815	5442	8448		5244	6581	6041	9060	6057	8120		5832	5100	505	654	117	153		104	13		573		750			475
MAR																												
IL	10	11	10	10	10	10	6	277	246	201	228	195	186	165	0	22	0	19	0	0	17		7		6			4
IN	5	5	5	5	5	5	3	123	93	89	87	87	84	65	0.2	8	0.2	7	0.2	0.2	6		2		2			2
MI	7	7	7	7	7	8	7	114	87	112	82	111	110	65	0.6	21	0.7	14	0.7	0.8	8		3		3			2
OH	8	7	8	7	8	8	5	177	134	128	126	126	122	94	0.4	14	0.3	12	0.3	0.3	10		4		4			2
WI	4	4	4	4	4	4	3	79	58	59	54	59	57	41	12.7	8	9.5	6	9.5	8.7	5		2		2			1
5-State Total	34	34	34	33	34	35	24	770	618	589	577	578	559	430	13.9	73	10.7	58	10.7	10	46		18		17			11
U.S. Total	307	317	321	157	329	346	334	4968	4515	4002	1813	3964	3919	3812	620	512	509	122	509	503	290		147		57			165
OtherArea																												
IL	679	675	688	594	700	738	582	62	48	68	48	70	73	49	11	11	12	16	12	13	16		40		64			69
IN	354	391	365	358	373	398	384	62	56	65	58	67	69	59	158	32	150	32	151	153	32		2		2			2
MI	518	652	516	562	520	541	549	49	49	52	50	53	54	51	71	29	68	29	68	68	28		111		114			120
OH	546	604	550	506	558	593	487	50	93	59	108	60	62	108	22	6	34	15	35	35	14		19		35			34
WI	458	315	467	290	474	506	293	32	37	34	37	34	35	37	9	17	9	13	10	10	13		11		12			12
5-State Total	2555	2637	2586	2310	2625	2776	2295	255	283	278	301	284	293	304	271	95	273	105	276	279	103		183		227			237
U.S. Total	17876	21093	18638	18683		20512	24300	3856	4899	4100	4220		4418	5357	2075	2947	2062	2559		2189	2709		2735		2621			2570
On-Road																												
IL	446	341	314	268	260	197	151	890	748	578	528	474	300	201		9		4			3		13		10			6
IN	405	282	237	235	193	150	138	703	541	425	402	313	187	173		11		3			2		9		7			2
MI	522	351	335	269	303	217	163	926	722	680	501	619	385	204		14		4			3		12		9			3
OH	574	680	365	424	340	238	242	1035	934	609	693	512	270	274		18		4			4		16		12			4
WI	238	175	144	119	117	88	68	481	457	303	322	226	118	138		9		2			2		8		6			2
5-State Total	2185	1829	1395	1315	1213	890	762	4035	3402	2595	2446	2144	1260	990		61		17			14		58		44			17
U.S. Total	14263				7825			23499				13170																
EGU																												
IL	9	7	8	6	8	9	7	712	305	227	275	244	231	224	1310	1158	944	958	789	810	869		13		34			77
IN	6	6	6	6	7	6	6	830	393	406	370	424	283	255	2499	2614	1267	1033	1263	1048	1036		16		73			74
MI	12	6	11	4	11	12	4	448	393	218	242	219	247	243	1103	1251	1022	667	1031	1058	725		15		25			29
OH	5	4	6	5	7	7	6	1139	408	330	280	322	271	285	3131	3405	1463	1326	994	701	983		28		94			80
WI	3	5	3	2	4	4	3	293	213	146	165	139	147	177	602	545	512	460	492	500	435		0		22			25
5-State Total	35	28	34	23	37	38	26	3422	1712	1327	1332	1348	1179	1184	8645	8973	5208	4444	4569	4117	4048		72		248			285
U.S. Total	214	140	195	124	197	215	138	14371	10316	7746	7274	7721	7007	6095	31839	34545	20163	16903	17629	14727	14133		685		1131			1571
Non-EGU																												
IL	313	221	286	218	305	350	258	356	330	334	218	338	343	235	373	423	251	335	257	249	346		16		17			19
IN	150	130	160	137	170	199	167	238	179	212	175	216	225	178	292	218	270	216	274	290	180		35		36			44
MI	123	116	115	119	122	139	140	216	240	208	242	214	229	271	162	158	166	148	171	185	163		20		21			25
OH	77	84	75	87	79	90	104	177	175	157	166	160	167	178	240	289	231	288	210	216	293		27		28			33
WI	88	84	97	87	104	120	106	98	97	91	93	92	94	81	163	156	154	152	155	156	85		0		0.1			0.1
5-State Total	751	635	733	648	780	898	775	1085	1021	1002	894	1020	1058	943	1230	1244	1072	1139	1067	1096	1067		98		102			121
U.S. Total	4087	3877	4409		4700	5378		6446	6730	6129		6435	6952		5759	5630	6093		6340	6970					1444			1777
IL	1681	1576	1470	1353	1432	1434	1217	2621	2010	1671	1572	1545	1287	1029	1725	1656	1212	1337	1059	1072	1251		119		155			189
IN	1045	1009	867	901	843	853	826	2134	1453	1339	1250	1248	989	819	2966	2902	1690	1294	1691	1492	1256		81		133			131
MI	1530	1546	1291	1311	1239	1139	1134	1958	1730	1429	1314	1349	1118	946	1356	1495	1260	865	1271	1312	927		183		190			190
OH	1432	1735	1165	1323	1137	1062	1082	2831	2048	1478	1619	1342	1001	1074	3416	3761	1732	1650	1240	953	1304		121		195			166
WI	1005	821	909	705	878	862	630	1128	1019	747	800	647	520	551	800	750	687	635	667	675	540		35		54			47
5-State Total	6693	6687	5702	5593	5529	5350	4889	10672	8260	6664	6555	6131	4915	4419	10263	10564	6581	5781	5928	5504	5280		539		727			723

Table 6b. EGU Emissions for Midwest States (2018)						
	Heat Input (MMBTU/year)	Scenario	SO2 (tons/year)	SO2 (lb/MMBTU)	NOx (tons/year)	NOx (lb/MMBTU)
IL	**980,197,198**	**2001 - 2003 (average)**	**362,417**	**0.74**	**173,296**	**0.35**
		IPM 2.1.9	241,000		73,000	
	1,310,188,544	IPM3.0 (base)	277,337	0.423	70,378	0.107
		IPM3.0 - will do	140,296	0.214	62,990	0.096
		IPM3.0 - may do	140,296	0.214	62,990	0.096
IN	**1,266,957,401**	**2001 - 2003 (average)**	**793,067**	**1.25**	**285,848**	**0.45**
		IPM 2.1.9	377,000		95,000	
	1,509,616,931	IPM3.0 (base)	361,835	0.479	90,913	0.120
		IPM3.0 - will do	417,000	0.552	94,000	0.125
		IPM3.0 - may do	417,000	0.552	94,000	0.125
MI	**756,148,700**	**2001 - 2003 (average)**	**346,959**	**0.92**	**132,995**	**0.35**
		IPM 2.1.9	399,000		100,000	
	1,009,140,047	IPM3.0 (base)	244,151	0.484	79,962	0.158
		IPM3.0 - will do	244,151	0.484	79,962	0.158
		IPM3.0 - may do	244,151	0.484	79,962	0.158
OH	**1,306,296,589**	**2001 - 2003 (average)**	**1,144,484**	**1.75**	**353,255**	**0.54**
		IPM 2.1.9	216,000		84,000	
	1,628,081,545	IPM3.0 (base)	316,883	0.389	96,103	0.118
		IPM3.0 - will do	348,000		101,000	
		IPM3.0 - may do	348,000		101,000	
WI	**495,475,007**	**2001 - 2003 (average)**	**191,137**	**0.77**	**90,703**	**0.36**
		IPM 2.1.9	155,000		46,000	
	675,863,447	IPM3.0 (base)	127,930	0.379	56,526	0.167
		IPM3.0 - will do	150,340	0.445	55,019	0.163
		IPM3.0 - may do	62,439	0.185	46,154	0.137
IA	**390,791,671**	**2001 - 2003 (average)**	**131,080**	**0.67**	**77,935**	**0.40**
		IPM 2.1.9	147,000		51,000	
	534,824,314	IPM3.0 (base)	115,938	0.434	59,994	0.224
		IPM3.0 - will do	115,938	0.434	59,994	0.224
		IPM3.0 - may do	100,762	0.377	58,748	0.220
MN	**401,344,495**	**2001 - 2003 (average)**	**101,605**	**0.50**	**85,955**	**0.42**
		IPM 2.1.9	86,000		42,000	
	447,645,758	IPM3.0 (base)	61,739	0.276	41,550	0.186
		IPM3.0 - will do	54,315	0.243	49,488	0.221
		IPM3.0 - may do	51,290	0.229	39,085	0.175
MO	**759,902,542**	**2001 - 2003 (average)**	**241,375**	**0.63**	**143,116**	**0.37**
		IPM 2.1.9	281,000		78,000	
	893,454,905	IPM3.0 (base)	243,684	0.545	72,950	0.163
		IPM3.0 - will do	237,600	0.532	72,950	0.163
		IPM3.0 - may do	237,600	0.532	72,950	0.163
ND	**339,952,821**	**2001 - 2003 (average)**	**145,096**	**0.85**	**76,788**	**0.45**
		IPM 2.1.9	109,000		72,000	
	342,685,501	IPM3.0 (base)	41,149	0.240	44,164	0.258
		IPM3.0 - will do	56,175	0.328	58,850	0.343
		IPM3.0 - may do	56,175	0.328	58,850	0.343
SD	**39,768,357**	**2001 - 2003 (average)**	**12,545**	**0.63**	**15,852**	**0.80**
		IPM 2.1.9	12,000		15,000	
	44,856,223	IPM3.0 (base)	4,464	0.199	2,548	0.114
		IPM3.0 - will do	4,464	0.199	2,548	0.114
		IPM3.0 - may do	4,464	0.199	2,548	0.114

On-road Sources: For 2002, EMS was run by LADCO using VMT and MOBILE6 inputs supplied by the LADCO States. EMS was run to generate 36 days (weekday, Saturday, Sunday for each month) at 36 km, and 9 days (weekday, Saturday, Sunday for June – August) at 12 km. For 2005, CONCEPT was run by a contractor (Environ) using transportation data (e.g., VMT and vehicle speeds) supplied by the state and local planning agencies in the LADCO States and Minnesota for 24 networks. These data were first processed with T3 (Travel Demand Modeling [TDM] Transformation Tool) to provide input files for CONCEPT to calculate link-specific, hourly emission estimates (Environ, 2008). CONCEPT was run with meteorological data for a July and January weekday, Saturday, and Sunday (July 15 – 17 and January 16 – 18). A spatial plot of emissions is provided in Figure 43.

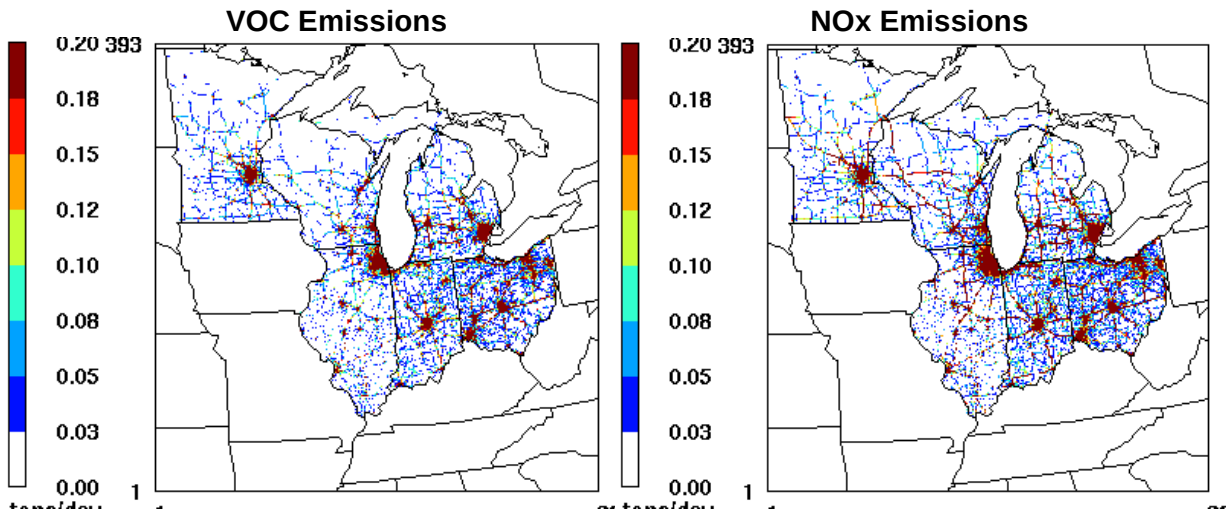


Figure 43. Motor vehicle emissions for VOC (left) and NOx (right) for a July weekday (2005)

Off-road Sources: For 2002 and 2005, NMIM and NMIM2005, respectively, were run by Wisconsin DNR. Additional off-road sectors (i.e., commercial marine, aircraft, and railroads [MAR]) were handled separately. Local data for agricultural equipment, construction equipment, commercial marine, recreational marine, and railroads were prepared by contractors (Environ, 2004, and E.H. Pechan, 2004). For Base M, updated local data for railroads and commercial marine were prepared by a contractor (Environ, 2007b, 2007c). Table 7 compares the Base M 2005 and Base K 2002 emissions. Compared to 2002, the new 2005 emissions reflect substantially lower commercial marine emissions and lower locomotive NOx emissions.

Table 7. Locomotive and commercial marine emissions for the five LADCO States (2002 v. 2005)

	Railroads (TPY)			Commercial Marine (TPY)	
	2002	2005		2002	2005
VOC	7,890	7,625		1,562	828
CO	20,121	20,017		8,823	6,727
NOx	182,226	145,132		64,441	42,336
PM	5,049	4,845		3,113	1,413
SO2	12,274	12,173		25,929	8,637
NH3	86	85		----	----

Area Sources: For 2002 and 2005, EMS was run by LADCO using data supplied by the LADCO States to produce weekday, Saturday, and Sunday emissions for each month. For 2005, special attention was given to two source categories: industrial adhesive and sealant solvents (which were dropped from the inventory to avoid double-counting) and outdoor wood boilers (which were added to the inventory).

Point Sources: For 2002 and 2005, EMS was run by LADCO using data supplied by the LADCO States to produce weekday, Saturday, and Sunday emissions for each month. For EGUs, the annual and summer season emissions were temporalized for modeling purposes using profiles prepared by Scott Edick (Michigan DEQ) based on CEM data.

Biogenics: For Base M, a contractor (Alpine) provided an updated version of the CONCEPT/MEGAN biogenics model. Compared to the previous (EMS/BIOME) emissions, there is more regional isoprene using MEGAN compared to the BIOME estimates used for Base K (see Figure 44). Also, with the secondary organic aerosol updates to the CAMx air quality model, Base M includes emissions for monoterpenes and sesquiterpenes, which are pre-cursors of secondary $PM_{2.5}$ organic carbon mass.

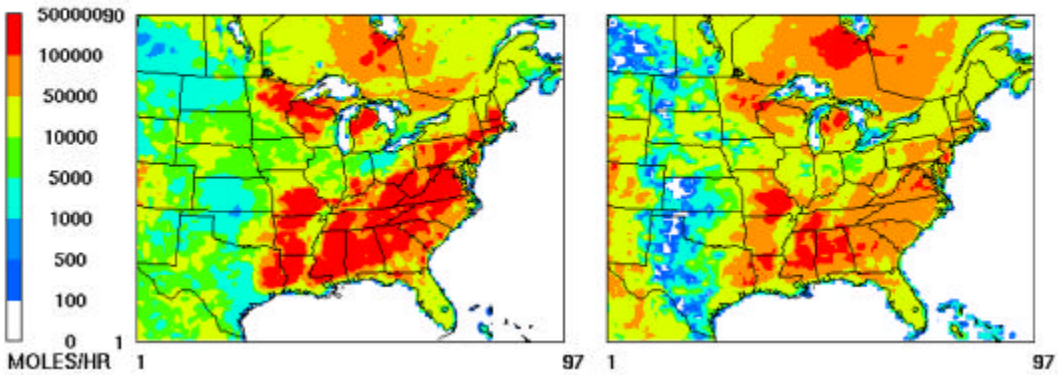


Figure 44. Isoprene emissions for Base M (left) v. Base K (right)

Ammonia: For Base M, the CMU-based 2002 (Base K) ammonia emissions were projected to 2005 using growth factors from the Round 4 emissions modeling. These emissions were then adjusted by applying temporal factors by month based on the process-based ammonia emissions model (Zhang, et al, 2005, and Mansell, et al, 2005). A plot of average daily emissions by state and month is provided in Figure 45. A spatial plot of emissions is provided in Figure 46, which shows high emissions densities in the central U.S.

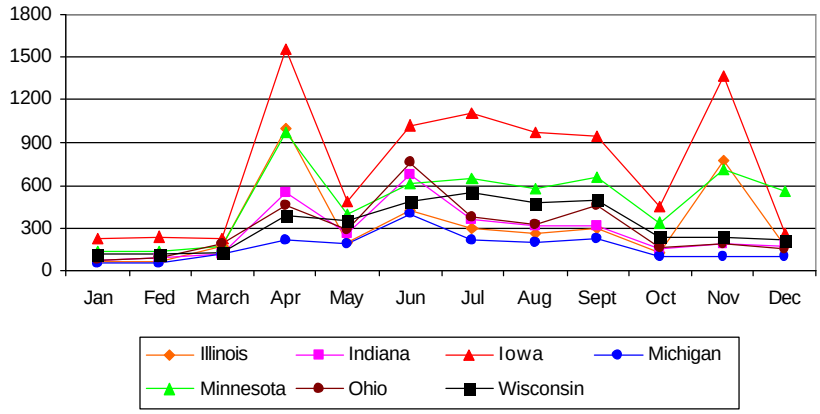


Figure 45. Average daily ammonia emissions for Midwest States by month (2005) - (units: average daily emissions – tons per day)

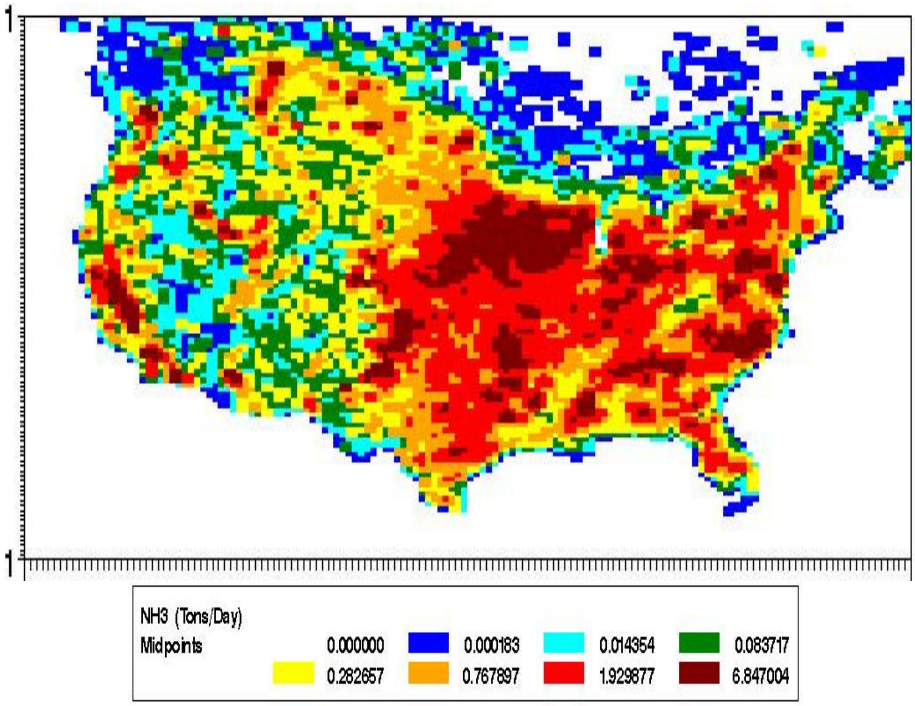


Figure 46. Ammonia emissions for a July weekday (2005) – 12 km modeling domain

Canadian Emissions: For Base M, Scott Edick (Michigan DEQ) processed the 2005 Canadian National Pollutant Release Inventory, Version 1.0 (NPRI). Specifically, a subset of the NPRI data (emissions and stack parameters) relevant to the air quality modeling were reformatted. The resulting emissions represent a significant improvement in the base year emissions.

A spatial plot of point source SO2 and NOx emissions is provided in Figure 47. Additional plots and emission reports are available on the LADCO website (http://www.ladco.org/tech/emis/basem/canada/index.htm).

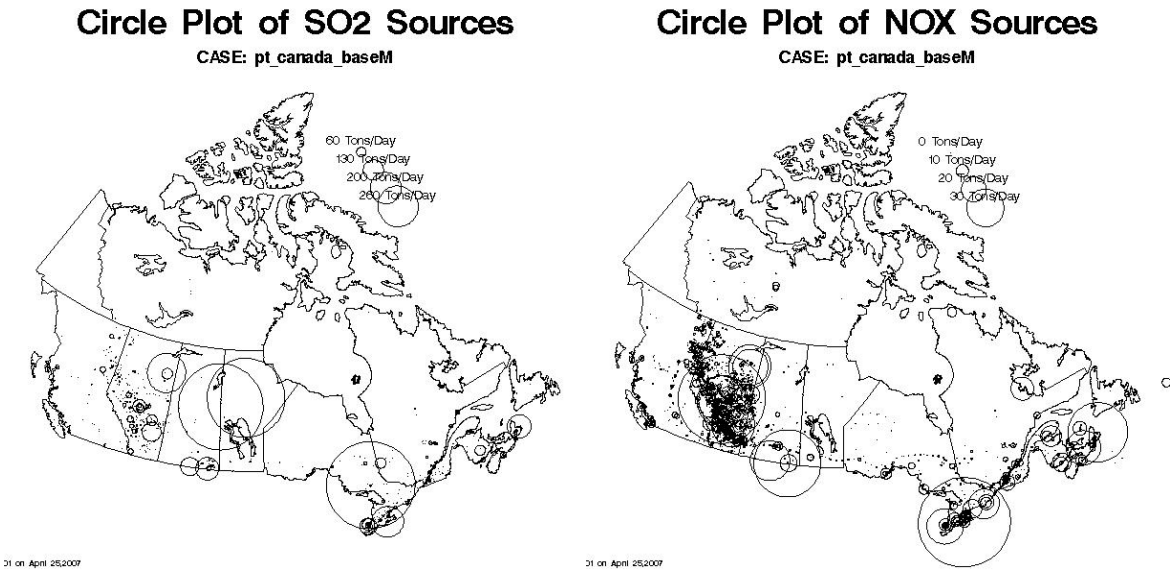


Figure 47. Canadian point source emissions for SO2 (left) and NOx (right)

Fires: For Base K, a contractor (EC/R, 2004) developed a 2001, 2002, and 2003 fire emissions inventory for eight Midwest States (five LADCO states plus Iowa, Minnesota, and Missouri), including emissions from wild fires, prescribed fires, and agricultural burns. Projected emissions were also developed for 2010 and 2018 assuming "no smoke management" and "optimal smoke management" scenarios. An early model sensitivity run showed very little difference in modeled $PM_{2.5}$ concentrations. Consequently, the fire emissions were not included in subsequent modeling runs (i.e., they were not in the Base K or Base M modeling inventories).

Future Year Emissions: Complete emission inventories were developed for several future years: Base K – 2009, 2012, and 2018, and Base M – 2009 and 2018. In addition, 2008 (Base K and Base M) and 2012 (Base M) proxy inventories were estimated based on the 2009 and 2018 data. (Note, the EGU emissions for the Base M 2012 inventory were based on EPA's IPM3.0 modeling.)

Source sector emission summaries for the base years and future years are shown in Figure 48. Additional detail is provided in Tables 6a and 6b.

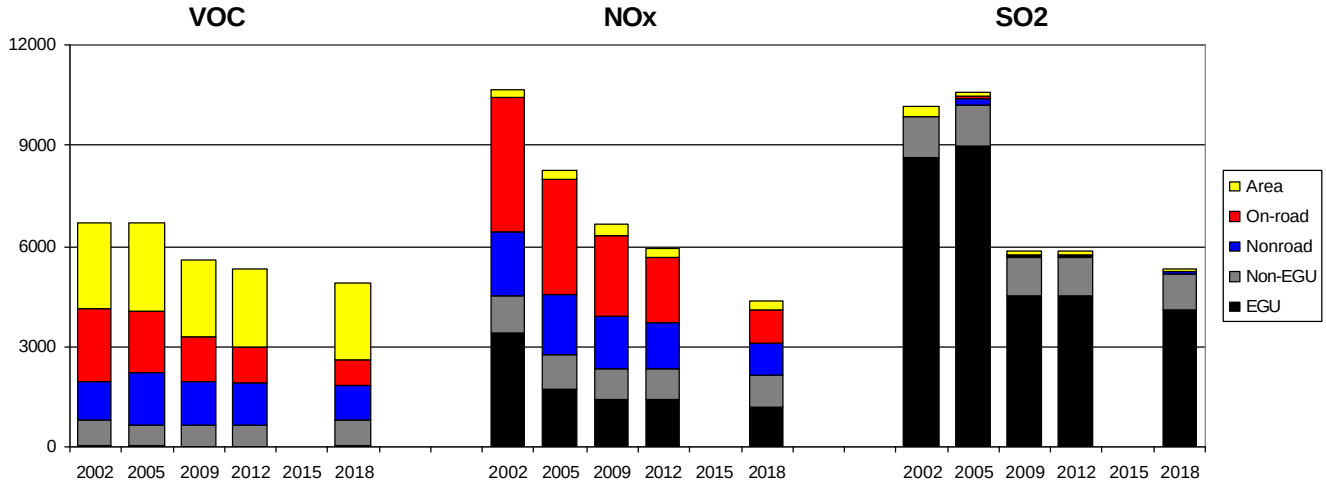


Figure 48. Base year and future year emissions for 5-State LADCO Region (TPD, July weekday)

For on-road, and nonroad, the future year emissions were estimated by models (i.e., EMS/CONCEPT and NMIM, respectively). One adjustment was made to the 2009 and 2018 motor vehicle emission files prepared by Environ with CONCEPT. To reflect newer transportation modeling conducted by CATS for the Chicago area, emissions were increased by 9% in 2009 and 2018. The 2005 base year and adjusted 2009 and 2018 motor vehicle emissions are provided in Table 8.

Table 8. Motor Vehicle Emissions Produced by CONCEPT Modeling (July weekday – tons per day)

Year	State	Sum of CO	Sum of TOG	Sum of NOx	Sum of PM2.5	Sum of SO2	Sum of NH3	Sum of VMT
2005	IL	3,684.3	341.5	748.2	12.9	9.6	35.9	344,087,819.6
	IN	3,384.9	282.0	541.1	8.9	11.1	25.7	245,537,231.9
	MI	4,210.3	351.9	722.0	12.4	13.9	35.3	340,834,025.9
	MN	2,569.1	218.7	380.5	6.3	7.6	17.7	170,024,599.7
	OH	6,113.4	679.8	933.6	16.2	18.8	36.5	360,521,068.6
	WI	2,206.0	175.1	457.5	7.8	9.2	19.7	189,123,964.3
Total		22,168.0	2,049.0	3,782.9	64.5	70.2	170.8	1,650,128,709.9
2009	IL	2,824.4	268.0	527.8	10.1	4.2	38.9	372,132,591.1
	IN	2,839.5	234.9	401.9	6.7	2.8	26.1	249,817,026.3
	MI	3,172.0	269.2	500.9	9.2	4.0	37.1	356,347,010.5
	MN	2,256.8	206.3	307.5	5.1	2.3	21.5	204,443,017.8
	OH	4,619.2	423.7	693.5	11.8	4.7	39.5	387,428,127.2
	WI	1,673.4	119.4	322.1	5.7	2.3	20.6	197,729,964.9
Total		17,385.3	1,521.5	2,753.6	48.7	20.3	183.6	1,767,897,737.8
2018	IL	2,084.7	151.5	200.7	6.3	3.7	43.1	413,887,887.3
	IN	2,217.3	138.4	173.0	4.4	2.6	30.2	288,042,232.1
	MI	2,434.3	163.5	204.1	5.9	3.6	40.5	388,128,431.8
	MN	1,799.6	123.1	137.1	3.6	2.2	24.9	237,022,213.7
	OH	3,361.5	242.5	274.1	6.8	4.0	43.1	421,694,093.4
	WI	1,255.5	68.4	138.5	3.9	2.0	22.2	218,277,167.5
Total		13,152.9	887.5	1,127.5	30.8	18.1	203.9	1,967,052,025.8

For EGUs, future year emissions were based on IPM2.1.9 modeling completed by the RPOs in July 2005 Base K and IPM3.0 completed by EPA in February 2007 for Base M. Several CAIR scenarios were assumed:

Base K
1a: IPM2.1.9, with full trading and banking
1b: IPM2.1.9, with restricted trading (compliance with state-specific emission budgets) and full trading
1d: IPM2.1.9, with restricted trading (compliance with state-specific emission budgets)

Base M
5a: EPA's IPM3.0 was assumed as the future year base for EGUs.
5b: EPA's IPM3.0, with several "will do" adjustments identified by the States. These adjustments should reflect a legally binding commitment (e.g., signed contract, consent decree, or operating permit).
5c: EPA's IPM3.0, with several "may do" adjustments identified by the States. These adjustments reflect less rigorous criteria, but should still be some type of public reality (e.g., BART determination or press announcement).

For other sectors (area, MAR, and non-EGU point sources), the future year emissions for the LADCO States were derived by applying growth and control factors to the base year inventory. These factors were developed by a contractor (E.H. Pechan, 2005 and E.H. Pechan, 2007). For the non-LADCO States, future year emission files were based on data from other RPOs.

Growth factors were based initially on EGAS (version 5.0), and were subsequently modified (for select, priority categories) by examining emissions activity data. Due to a lack of information on future year conditions, the biogenic VOC and NOx emissions, and all Canadian emissions were assumed to remain the constant between the base year and future years.

A "base" control scenario was prepared for each future year based on the following "on the books" controls:

On-Highway Mobile Sources
- Federal Motor Vehicle Emission Control Program, low-sulfur gasoline and ultra-low sulfur diesel fuel
- Inspection - maintenance programs, including IL's vehicle emissions tests (NE IL), IN's vehicle emissions testing program (NW IN), OH's E-check program (NE OH), and WI's vehicle inspection program (SE WI) – note: a special emissions modeling run was done for the Cincinnati/Dayton area to reflect the removal of the state's E-check program and inclusion of low RVP gasoline
- Reformulated gasoline, including in Chicago-Gary,-Lake County, IL,IN; and Milwaukee, Racine, WI

Off-Highway Mobile Sources
- Federal control programs incorporated into NONROAD model (e.g., nonroad diesel rule), plus the evaporative Large Spark Ignition and Recreational Vehicle standards
- Heavy-duty diesel (2007) engine standard/Low sulfur fuel
- Federal railroad/locomotive standards
- Federal commercial marine vessel engine standards

Area Sources (Base M only)
- Consumer solvents
- AIM coatings
- Aerosol coatings
- Portable fuel containers

Power Plants
- Title IV (Phases I and II)
- NOx SIP Call
- Clean Air Interstate Rule

Other Point Sources

- VOC 2-, 4-, 7-, and 10-year MACT standards
- Combustion turbine MACT

Other controls included in the modeling include: consent decrees (refineries, ethanol plants, and ALCOA)[9], NOx RACT in Illinois and Ohio[10], and BART for a few non-EGU sources in Indiana and Wisconsin.

For Base K, several additional control scenarios were considered:

Scenario 2 – "base" controls plus additional controls recommended in LADCO White Papers for stationary and mobile sources

Scenario 3 – Scenario 2 plus additional White Papers for stationary and mobile sources

Scenario 4 – "base" controls plus additional candidate control measures under discussion by State Commissioners

Scenario 5 – "base" controls plus additional candidate control measures identified by the LADCO Project Team

3.7 Basecase Modeling Results

The purpose of the basecase modeling is to evaluate model performance (i.e., assess the model's ability to reproduce the observed concentrations). The model performance evaluation focused on the magnitude, spatial pattern, and temporal of modeled and measured concentrations. This exercise was intended to assess whether, and to what degree, confidence in the model is warranted (and to assess whether model improvements are necessary).

Model performance was assessed by comparing modeled and monitored concentrations. Graphical (e.g., side-by-side spatial plots, time series plots, and scatter plots) and statistical analyses were conducted. No rigid acceptance/rejection criteria were used for this study. Instead, the statistical guidelines recommended by EPA and other modeling studies (e.g., modeling by the other RPOs) were used to assess the reasonableness of the results. The model performance results presented here describe how well the model replicates observed ozone and $PM_{2.5}$ concentrations after a series of iterative improvements to model inputs.

Ozone: Spatial plots are provided for high ozone periods in June 2002 and June 2005 (see Figures 49a and 49b). The plots show that the model is doing a reasonable job of reproducing the magnitude, day-to-day variation, and spatial pattern of ozone concentrations. There is a tendency, however, to underestimate the magnitude of regional ozone levels. This is more apparent with the 2002 modeling; the regional concentrations in the 2005 modeling agree better with observations due to model and inventory improvements.

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[9] E.H. Pechan's original control file included control factors for three sources in Wayne County, MI. These control factors were not applied in the regional-scale modeling to avoid double-counting with the State's local-scale analysis for PM2.5

[10] NOx RACT in Wisconsin is included in the 2005 basecase (and EGU "will do" scenario). NOx RACT in Indiana was not included in the modeling inventory.

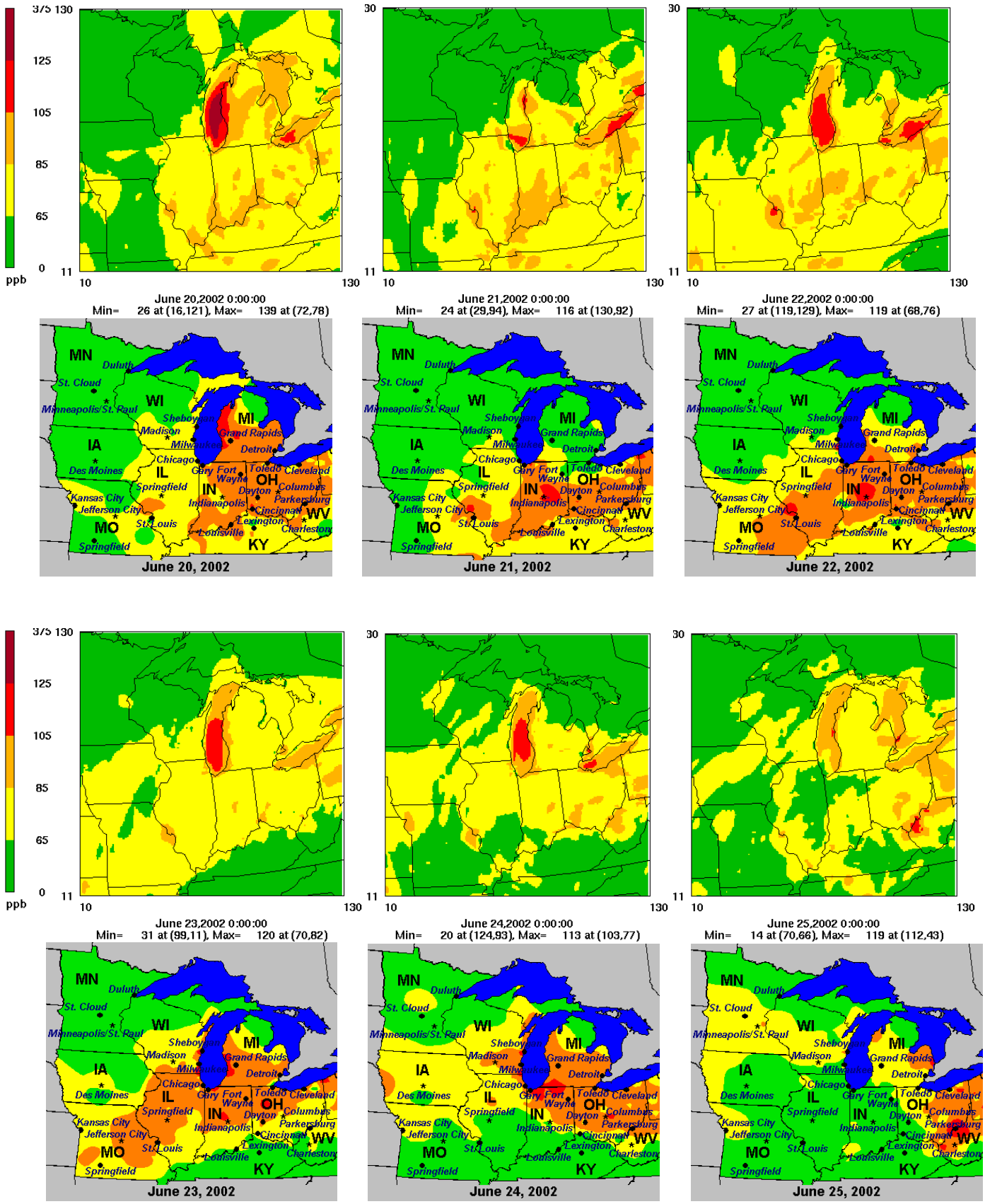


Figure 49a. Modeled (top) v. monitored (bottom) 8-hour ozone concentrations: June 20 – 25, 2002

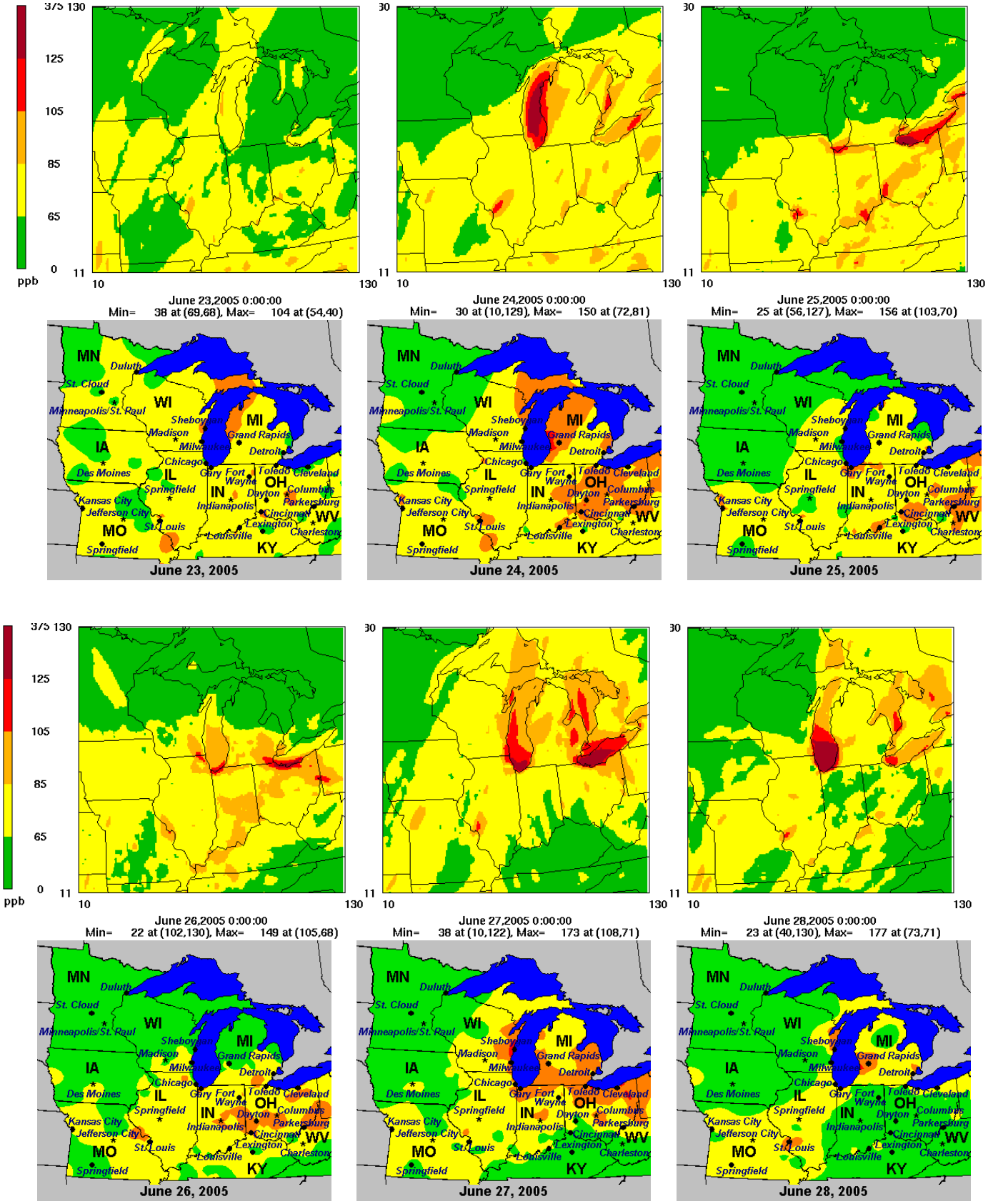


Figure 49b Modeled (top) v. monitored (bottom) 8-hour ozone concentrations: June 23– 28 2005

Standard model performance statistics were generated for the entire 12 km domain, and by day and by monitoring site. The domain-wide mean normalized bias for the 2005 base year is similar to that for the 2002 base year and is generally within 30% (see Figure 50).

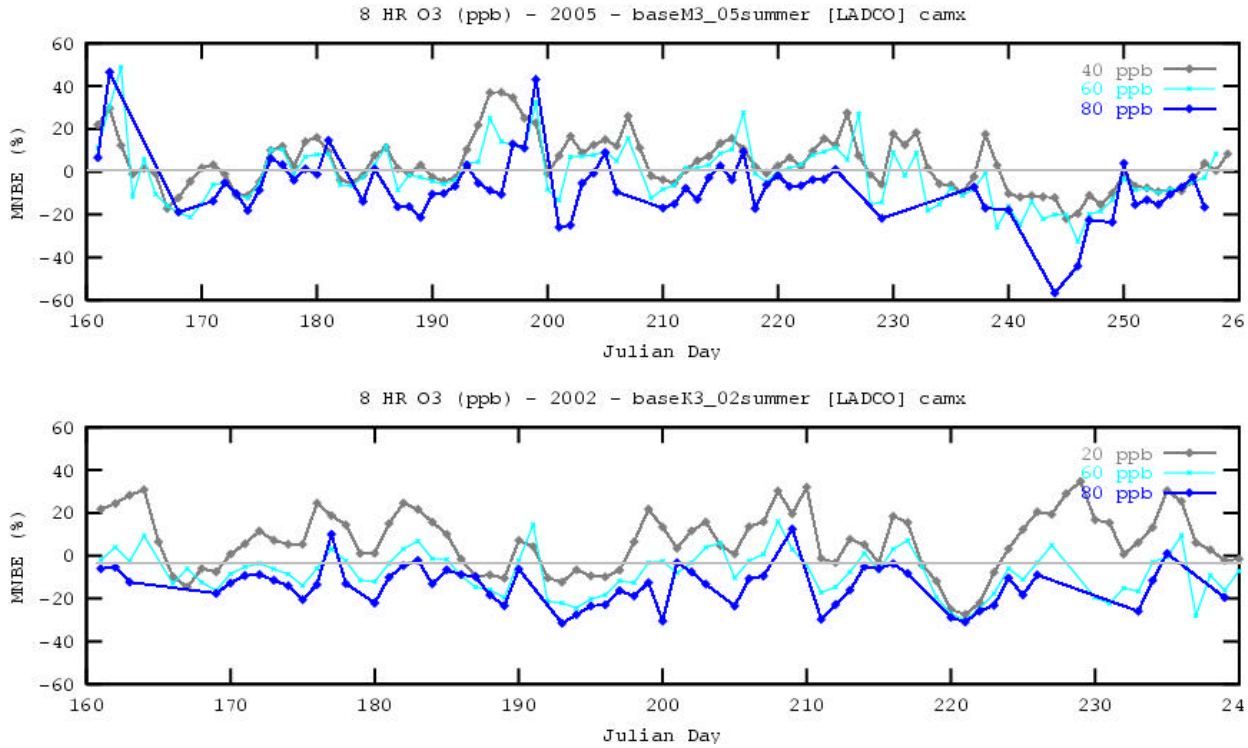


Figure 50. Mean bias for summer 2005 (Base M) and summer 2002 (Base K)

Station-average metrics (over the entire summer) are shown in Figure 51. The bias results further demonstrate the model's tendency to underestimate absolute ozone concentrations.

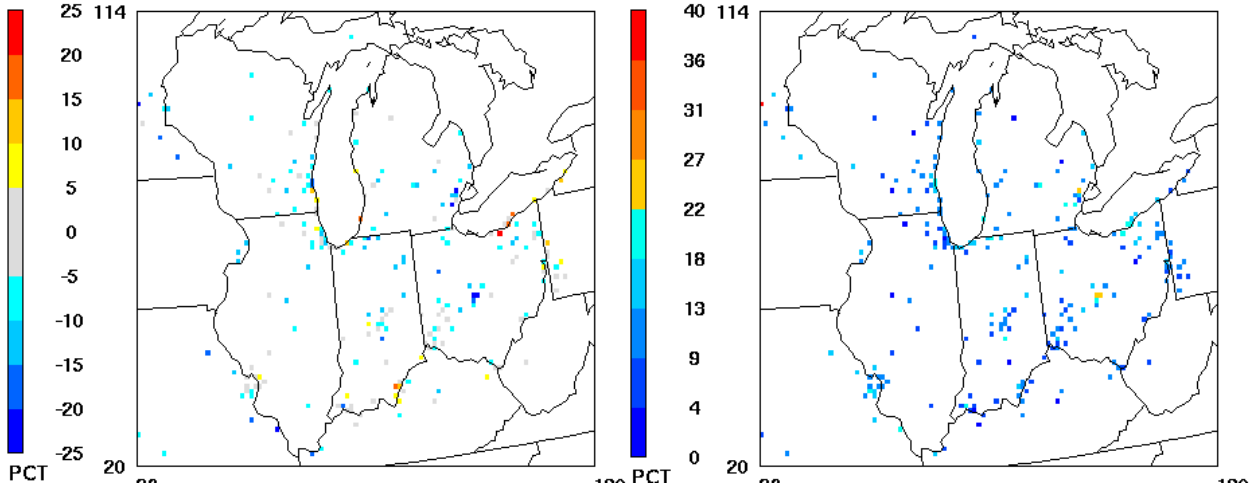


Figure 51. Mean bias (left) and gross error (right) for summer 2005

A limited 4 km ozone analysis was performed by LADCO to address the effect of grid spacing. For this modeling, 4 km grids were placed over Lake Michigan and the Detroit-Cleveland area (see Figure 52). Model inputs included 4 km emissions developed by LADCO (consistent with Base K/Round 4) and the 4 km meteorology developed by Alpine Geophysics.

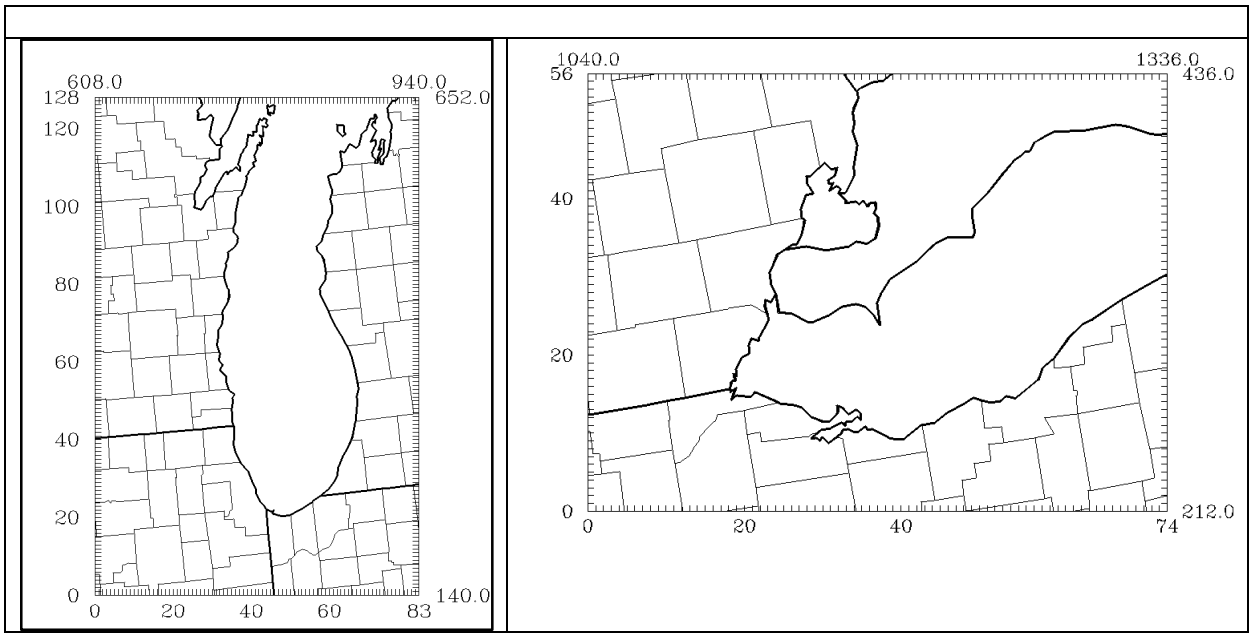


Figure 52. 4 km grids for Lake Michigan region and Detroit-Cleveland region

Hourly time series plots were prepared for several monitors (see Figure 53). The results are similar at 12 km and 4 km, with some site-by-site and day-by-day differences.

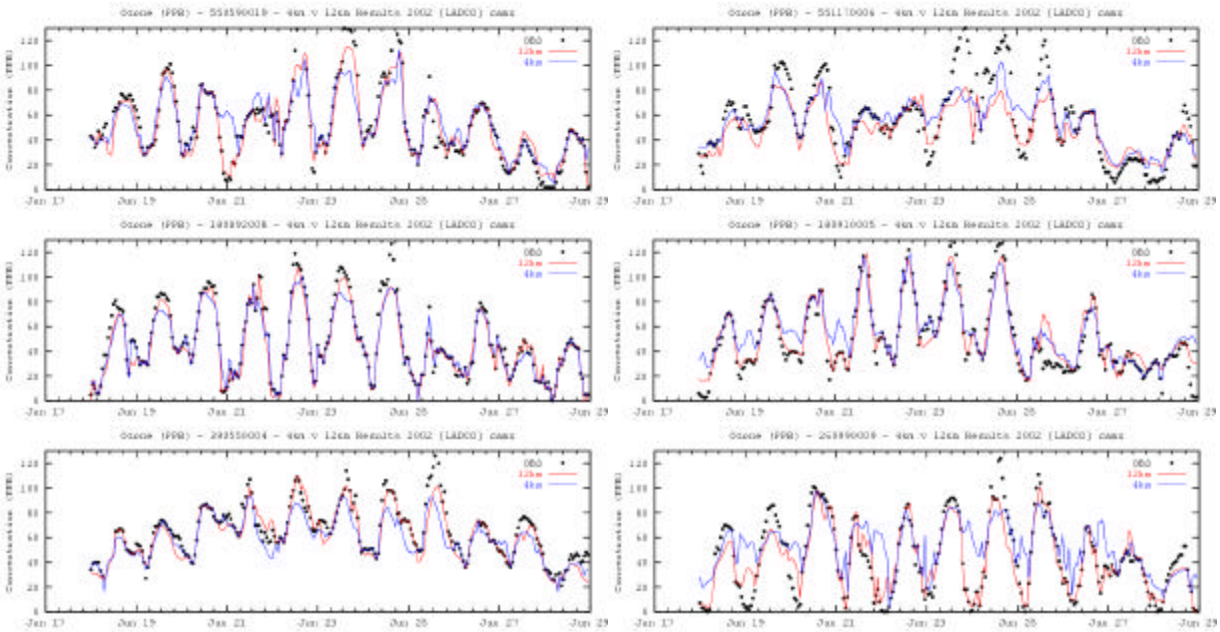
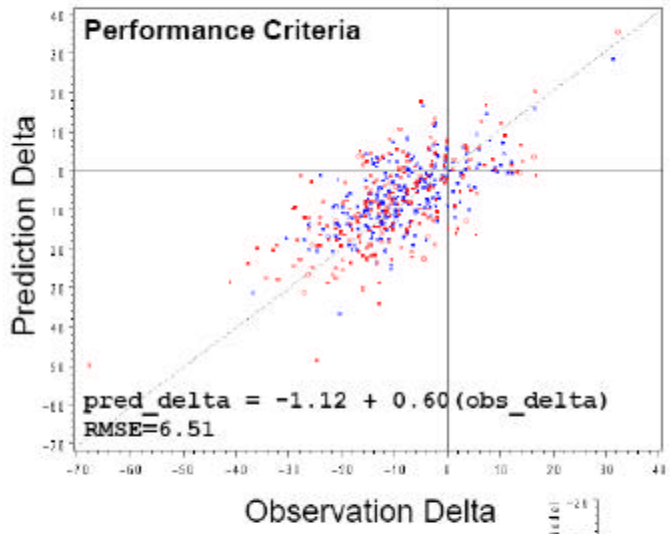


Figure 53. Ozone time series plots for 12 km and 4 km modeling (June 17-29, 2002)

An additional diagnostic analysis was performed to assess the response of the modeling system to changes in emissions (Baker and Kenski, 2007). Specifically, the 2002-to-2005 change in observed ozone concentrations was compared to the change in modeled ozone concentrations based on the 95th percentile(and above) concentration values for each monitor. This analysis was also done with the inclusion of model performance criteria which eliminated poorly performing days (i.e., error > 35%). The results show good agreement in the modeled and monitored ozone concentration changes (e.g., ozone improves by about 9-10 ppb between 2002 and 2005 according to the model and the measurements) – see Figure 54. This provides further support for using the model to develop ozone control strategies.



	MP Criteria	No MP Cr.
Obs_abs_delta	-8.4	-8.8
Pred_abs_delta	-6.2	-4.6
Obs_pct_delta	-10.5	-10.9
Pred_pct_delta	-8.7	-6.7
r	0.64	0.51
r^2	0.41	0.26

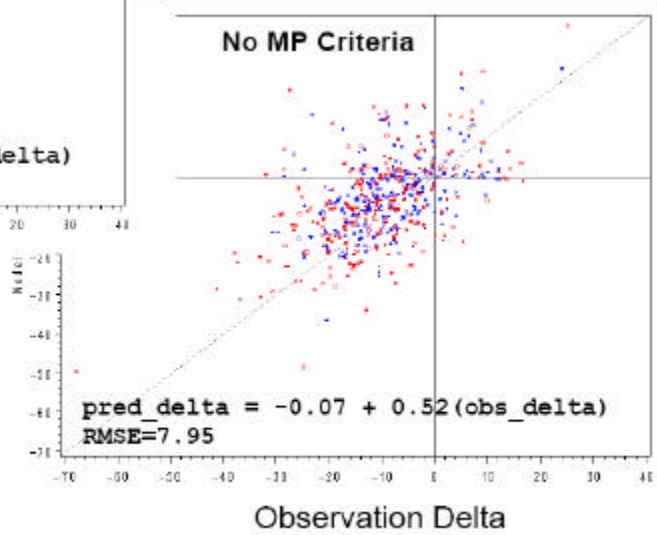


Figure 54. Comparison of change in predicted and observed ozone concentrations (2002 v. 2005)

$PM_{2.5}$: Time series plots of the monthly average mean bias and annual fractional bias for Base M and Base K are shown in Figure 55. As can be seen, Base M model performance for most species is fair (i.e., close to "no bias" throughout most of the year), with two main exceptions. First, the Base M and Base K results for organic carbon are poor, suggesting the need for more work on primary organic carbon emissions. Second, the Base M results for sulfate, while acceptable (i.e., bias values are within 35%), are not as good as the Base K results (e.g., noticeable underprediction during the summer months).

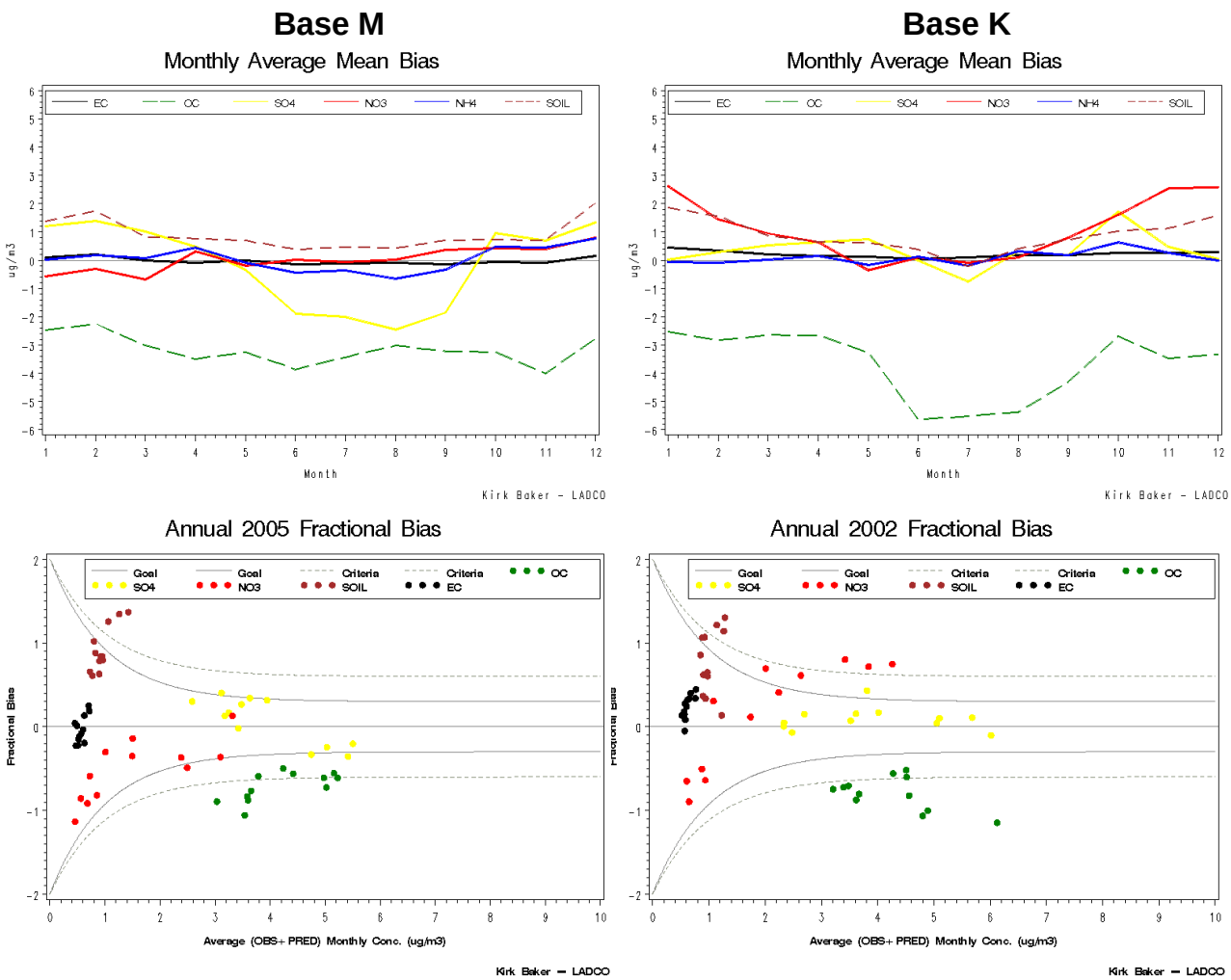


Figure 55. $PM_{2.5}$ Model performance - monthly average mean bias and annual fractional bias for Base M (left column) and Base K (right column)

Two analyses were undertaken to understand sulfate model performance for 2005:

- Assess Meteorological Influences: The MM5 model performance evaluation showed that rainfall is over-predicted by MM5 over most of the domain during the summer months (LADCO, 2007c). Because CAMx does not explicitly use the rainfall output by MM5, this may or may not result in over-prediction sulfate wet deposition (and under-prediction of sulfate concentrations). A sensitivity run was performed with no wet deposition for July, August, and September. The resulting model performance (see green line in Figure 56) showed a noticeable difference from the basecase (i.e., higher sulfate concentrations), and suggests that further evaluation of MM5 precipitation fields may be warranted.

- Assess Emissions Influences: The major contributor to sulfate concentrations in the region is SO2 emitted from EGUs. The basecase modeling inventory for EGUs is based on annual emissions, which were allocated to a typical weekday, Saturday, and Sunday by month using CEM-based temporal profiles. A sensitivity run was performed using day-specific emissions. The resulting model performance (see purple line in Figure 56) showed little difference from the basecase.

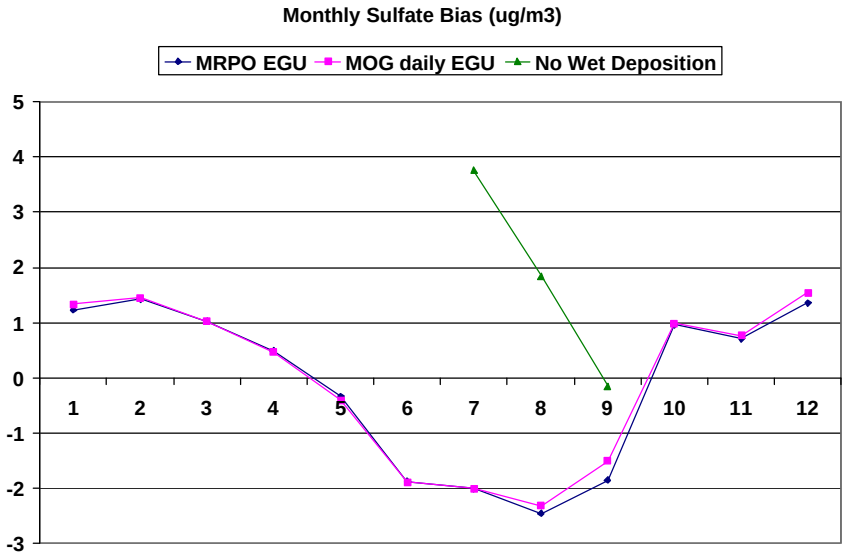


Figure 56. Monthly sulfate bias for Base M (MRPO EGU) v. two sensitivity analyses (Note: positive values indicate over-prediction, negative values indicate under-prediction)

To assess the effect of the wet deposition issue on future year modeled values, another sensitivity run was conducted with no wet deposition in Quarters 2-3 for the base year (2005) and 2018. The resulting future year values were only slightly different from the current base strategy run. In general, the future year values (without wet deposition) were a little higher (+0.15 ug/m^3 or less) in the Ohio Valley and a little lower (-.10 ug/m^3 of less) in the Great Lakes region. This sensitivity run provides a bound for sulfate wet deposition issue in terms of the attainment test, given that having no wet deposition is unrealistic. The results suggest that even with an improved wet deposition treatment, the Base M strategy results are not expected to change very much.

Time series plots of daily sulfate, nitrate, elemental carbon, and organic carbon concentrations for three Midwestern locations are presented in Figures 57 (2002) and 58 (2005). These results are consistent with the model performance statistics (i.e., good agreement for sulfates and nitrates and poor agreement [large underprediction] for organic carbon).

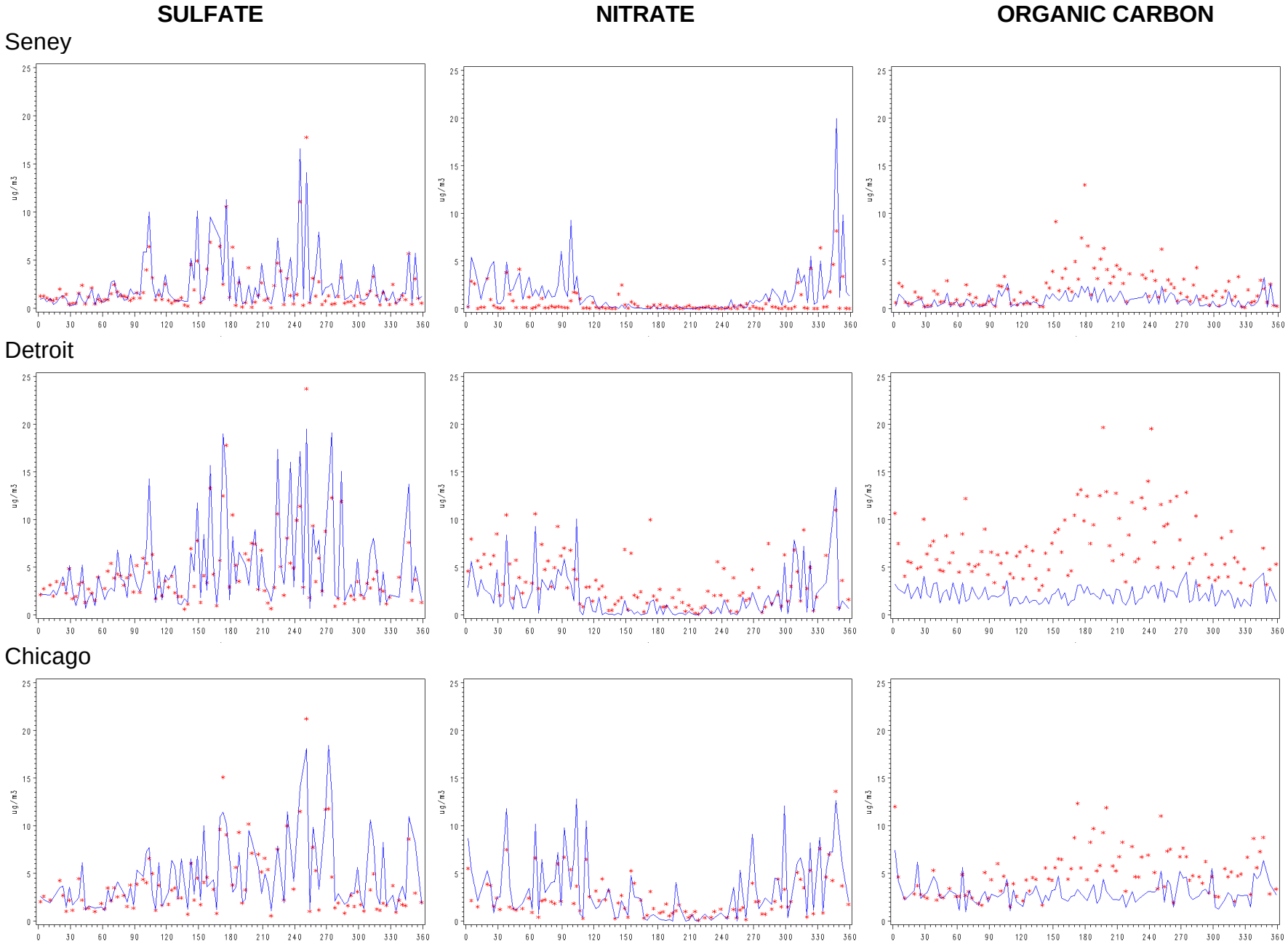
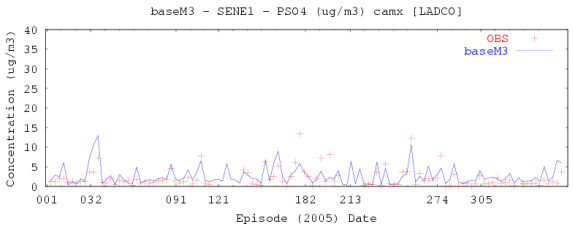
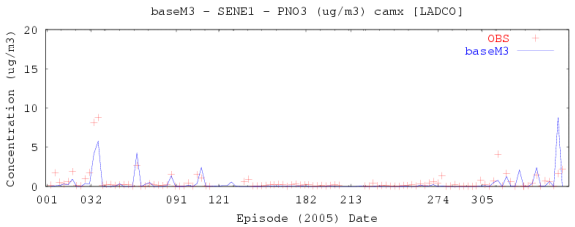


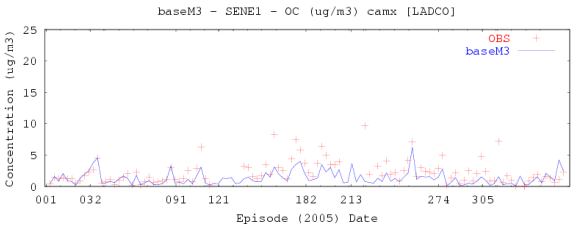
Figure 57. Time series of sulfate, nitrate, and organic carbon at three Midwest sites for 2005

SULFATE **NITRATE** **ORGANIC CARBON**

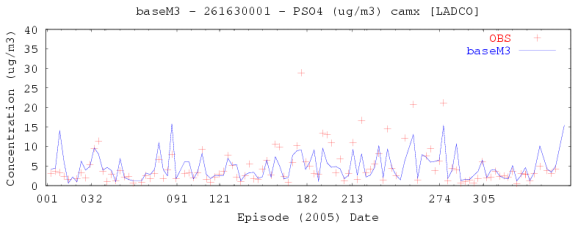
Seney

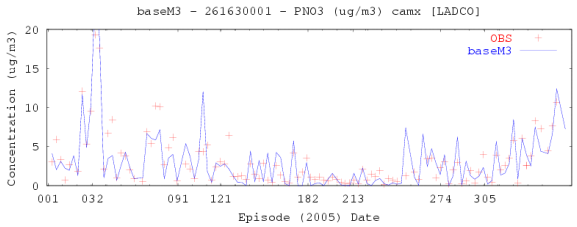


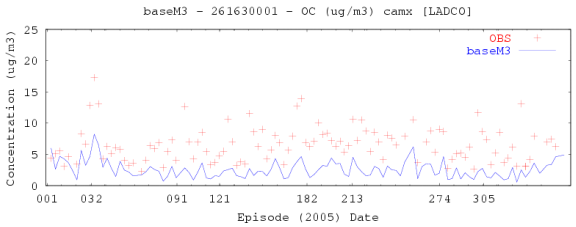




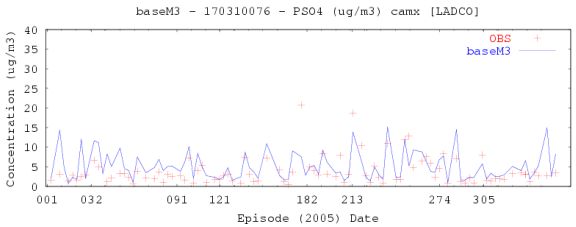
Detroit

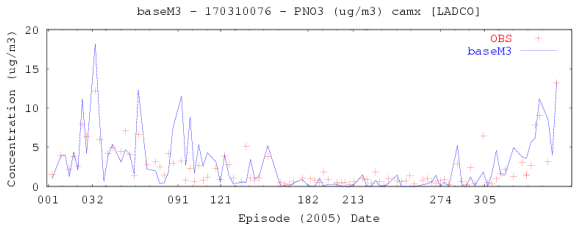






Chicago





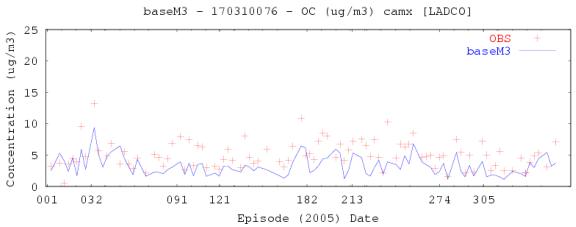


Figure 58. Time series of sulfate, nitrate, and organic carbon at three Midwest sites for 2005

In summary, model performance for ozone and $PM_{2.5}$ is generally acceptable and can be characterized as follows:

Ozone

- Good agreement between modeled and monitored concentration for higher concentration levels (> 60 ppb) – i.e., bias within 30%

- Regional modeled concentrations appear to be underestimated in the 2002 base year, but show better agreement (with monitored data) in the 2005 base year due to model and inventory improvements.

- Day-to-day and hour-to-hour variation in and spatial patterns of modeled concentrations are consistent with monitored data

- Model accurately simulates the change in monitored ozone concentrations due to reductions in precursor emissions.

$PM_{2.5}$

- Good agreement in the magnitude of fine particle mass, but some species are overestimated and some are underestimated (during periods of the year when it is important)
    - Sulfates: good agreement in the 2002 base year, but underestimated in the summer in the 2005 base year due probably to meteorological factors
    - Nitrates: slightly overestimated in the winter in the 2002 base year, but good agreement in the 2005 base year as a result of model and inventory improvements
    - Organic Carbon: grossly underestimated in the 2002 and 2005 base years due likely to missing primary organic carbon emissions and, possibly, other factors (e.g., grid resolution and model chemistry).

- Temporal variation and spatial patterns of modeled concentrations are consistent with monitored data

Several observations should be noted on the implications of these model performance findings on the attainment modeling presented in the following section. First, it has been demonstrated that model performance overall is acceptable and, thus, the model can be used for air quality planning purposes. Second, consistent with EPA guidance, the model is used in a relative sense to project future year values. EPA suggests that this approach “should reduce some of the uncertainty attendant with using absolute model predictions alone” (EPA, 2007a). Furthermore, the attainment modeling is supplemented by additional information to provide a weight of evidence determination.

Section 4.0 Attainment Demonstration for Ozone and $PM_{2./5}$

Air quality modeling and other information were used to determine whether existing ("on the books") controls would be sufficient to provide for attainment of the NAAQS for ozone and $PM_{2.5}$ and if not, then what additional emission reductions would be necessary for attainment. Traditionally, attainment demonstrations involved a "bright line" test in which a single modeled value was compared to the ambient standard. To provide a more robust assessment of expected future year air quality, EPA's modeling guidelines call for consideration of supplemental information. This section summarizes the results of the primary (guideline) modeling analysis and a weight of evidence determination based on the modeling results and other supplemental analyses.

4.1 Future Year Modeling Results

The purpose of the future year modeling is to assess the effectiveness of existing and possible additional control programs. The model was used in a relative sense to project future year values, which are then compared to the standard to determine attainment/nonattainment. Specifically, the modeling test consists of the following steps:

(1) Calculate base year design values: For ozone and $PM_{2.5}$, the base year design values were derived by averaging the three 3-year periods centered on the emissions base year:

2002 base year: 2000-2002, 2001-2003, and 2002-2004
2005 base year: 2003-2005, 2004-2006, and 2005-2007[11]

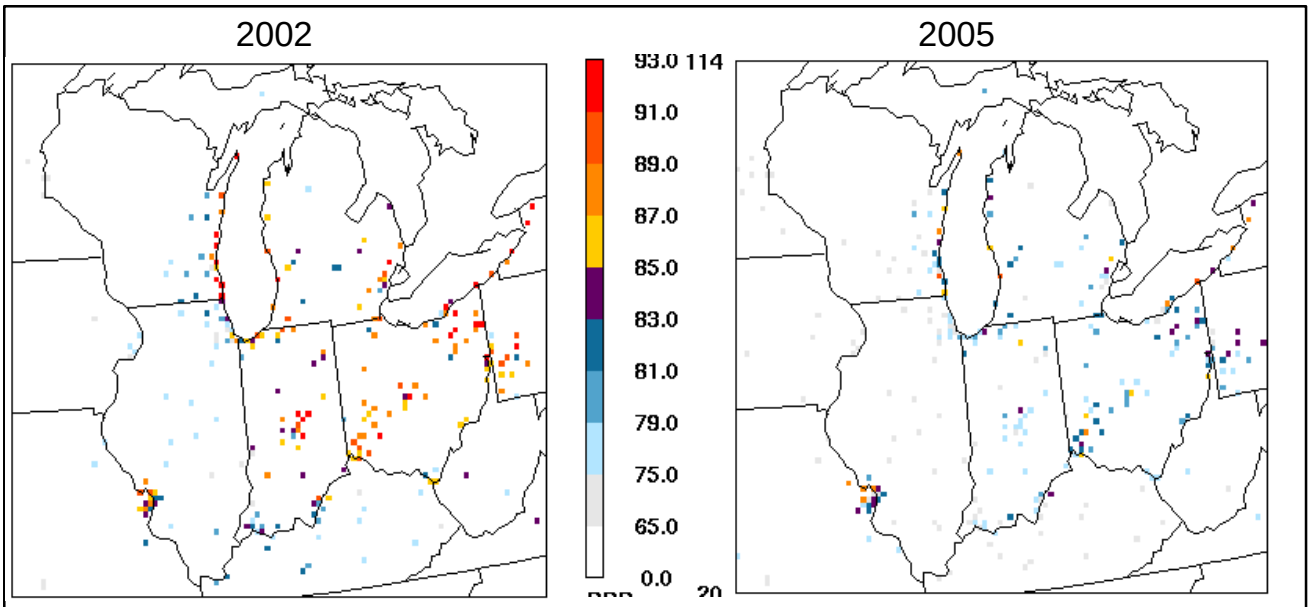
(2) Estimate the expected change in air quality: For each grid cell, a relative reduction factor (RRF) is calculated by taking the ratio of the future year and baseline modeling results.

(3) Calculate future year values: For each grid cell (with a monitor), the RRFs are multiplied by the base year design values to project the future year values

(4) Assess attainment: Future year values are compared to the NAAQS to assess attainment or nonattainment.

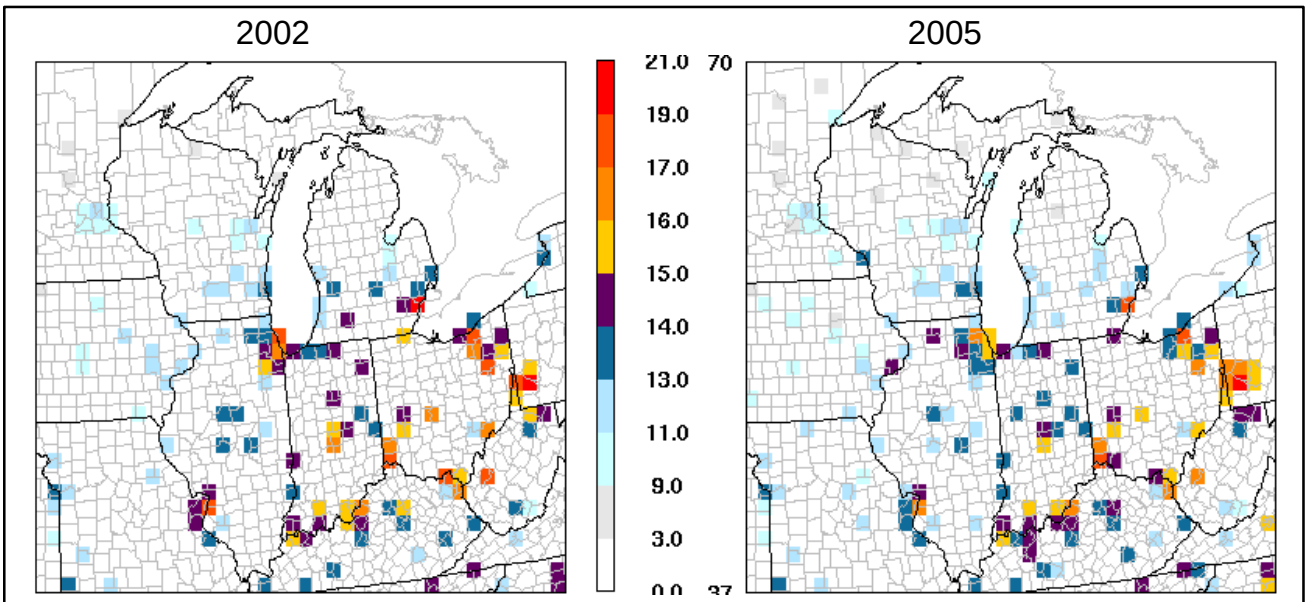
A comparison of the 2002 and 2005 base year design values for ozone and $PM_{2.5}$ is provided in Figure 59. In general, the figure shows that the 2005 base year design values are much lower than the 2002 base year design values, especially for ozone.

[11] A handful of source-oriented PM2.5 monitors in Illinois and Indiana were excluded from the annual attainment test, because these monitors are not to be used to judging attainment of the annual standard.



Statistical Summary

	2002	2005
# Sites > NAAQS	93	9
Peak Value	99.0 ppb	90.0 ppb
Ave Exceedance Amount	7 ppb	2 ppb



Statistical Summary

	2002	2005
# Sites > NAAQS	58	41
Peak Value	19.3 ug/m^3	17.7 ug/m^3
Ave Exceedance Amount	1.2 ug/m^3	0.9 ug/m^3

Figure 59. 2002 v. 2005 base year design values for ozone (top) and $PM_{2.5}$ (bottom)

Ozone results are provided for those grid cells with ozone monitors. The RRF calculation considers all nearby grid cells (i.e., 3x3 for 12 km modeling) and a threshold of 85 ppb. (If there were less than 10 days above this value, then the threshold was lowered until either there were 10 days or the threshold reached 70 ppb.) $PM_{2.5}$ results are provided for those grid cells with FRM ($PM_{2.5}$-mass) monitors. Spatial mapping was performed to extrapolate $PM_{2.5}$-speciation data from STN and IMPROVE sites to FRM sites. RRF values for $PM_{2.5}$ were derived as a function of quarter and chemical species.

Additional, hot-spot modeling will be performed by the states for certain $PM_{2.5}$ nonattainment areas (e.g., Detroit, Cleveland, and Granite City) to address primary emissions from local point sources which may not be adequately accounted for by the regional grid modeling. This modeling will consist of Gaussian dispersion modeling (e.g., AERMOD) performed in accordance with EPA's modeling guidance (see Section 5.3 of the April 2007 guidance document). Further analyses will need to be undertaken to determine how to best combine the regional modeling and the hot-spot modeling. This could mean some adjustment to the model results presented in this document to reflect better the regional component.

The ozone and $PM_{2.5}$ modeling results are provided in Appendix I for select monitors (high concentration sites) in the 5-state region for the following future years of interest: 2008 (ozone only), 2009, 2012, and 2018. (Note, RRF values for ozone, and for $PM_{2.5}$ by season and chemical species are also included in Appendix I for key monitoring sites.) A summary of the modeling results is provided in Table 9 (ozone) and Table 10 ($PM_{2.5}$), and spatial maps of the Base M future year concentrations are provided in Figures 60-62.

Table 9. Summary of Ozone Modeling Results											
Key Sites		**2008**			**2009**			**2012**			**2018**
		Round 5	Round 4		Round 5	Round 4		Round 5	Round 4		Round 5
Lake Michigan Area											
Chiwaukee	550590019	82.0	**93.0**		82.3	**92.0**		80.9	**90.3**		76.2
Racine	551010017	77.6	**85.9**		77.5	84.9		76.1	82.9		71.2
Milwaukee-Bayside	550190085	79.6	**85.4**		79.8	84.9		78.0	82.3		72.7
Harrington Beach	550890009	80.0	**86.7**		80.1	**85.4**		78.3	82.9		72.5
Manitowoc	550710007	81.3	80.3		80.8	78.9		78.6	76.3		72.5
Sheboygan	551170006	84.4	**90.0**		84.0	**88.9**		81.8	**86.4**		75.4
Kewaunee	550610002	78.9	82.5		78.1	81.0		75.9	79.1		69.9
Door County	550290004	84.8	83.6		83.9	81.8		81.5	79.3		74.7
Hammond	180892008	75.4	**86.9**		75.4	**86.6**		74.6	**86.3**		71.6
Whiting	180890030	77.0			77.0			76.2			73.1
Michigan City	180910005	74.2	**87.4**		73.9	**86.5**		72.5	**85.4**		68.1
Ogden Dunes	181270020	75.7	82.3		75.6	82.8		74.5	82.0		70.8
Holland	260050003	**85.6**	84.9		**85.3**	83.4		82.8	81.0		76.1
Jenison	261390005	77.9	78.7		77.1	77.6		74.5	75.5		68.7
Muskegon	261210039	80.8	82.7		80.5	81.5		78.0	79.4		71.9
Indianapolis Area											
Noblesville	189571001	78.0	**85.2**		78.1	83.7		75.6	82.0		68.7
Fortville	180590003	73.9	**85.1**		73.9	83.8		71.4	82.1		65.1
Fort B. Harrison	180970050	74.8	84.8		75.1	83.7		73.2	82.4		69.1
Detroit Area											
New Haven	260990009	82.7	**86.3**		81.4	**85.3**		80.2	83.5		76.1
Warren	260991003	82.5	84.3		81.3	83.3		80.7	81.9		77.6
Port Huron	261470005	79.0	80.5		77.5	79.1		75.5	77.0		70.9
Cleveland Area											
Ashtabula	390071001	84.9	84.7		83.4	82.7		81.0	80.2		75.1
Geauga	390550004	75.7	**90.3**		74.7	**88.8**		72.7	**86.2**		67.3
Eastlake	390850003	82.8	84.2		81.9	82.8		80.5	80.6		76.2
Akron	391530020	79.3	83.0		78.1	81.4		75.6	78.5		68.7
Cincinnati Area											
Wilmington	390271002	77.8	84.8		77.5	83.5		74.9	81.1		68.3
Sycamore	390610006	81.7	**85.4**		81.9	84.7		80.3	82.9		74.6
Lebanon	391650007	83.6	80.1		83.0	79.0		80.7	77.0		74.2
Columbus Area											
London	390970007	75.4	79.9		75.0	78.4		72.6	76.5		66.3
New Albany	390490029	82.4	84.1		81.8	82.6		79.6	80.2		73.0
Franklin	290490028	77.0	77.7		75.9	76.5		74.1	74.7		69.0
St. Louis Area											
W. Alton (MO)	291831002	82.4	**86.1**		81.0	**85.2**		78.6	84.0		74.9
Orchard (MO)	291831004	83.3	83.3		82.0	82.2		80.0	80.4		76.2
Sunset Hills (MO)	291890004	79.5	82.8		78.7	81.9		77.1	80.6		73.9
Arnold (MO)	290990012	78.7	78.4		77.2	77.4		75.6	75.8		72.0
Margaretta (MO)	295100086	79.8	84.0		79.3	83.4		77.9	82.5		74.4
Maryland Heights (MO)	291890014	84.5			83.4			81.7			78.1

Table 10. Summary of PM2.5 Modeling Results									
			2009			2012		2018	
County	**Site ID**	**Site**	**Round 5**	**Round4**		**Round 5**	**Round4**	**Round 5**	**Round4**
Cook	170310022	Chicago - Washington HS	14.1	14.8		14.0	14.6	13.9	14.4
Cook	170310052	Chicago - Mayfair	14.4	**15.8**		14.2	**15.5**	13.9	**15.0**
Cook	170310057	Chicago - Springfield	13.9	14.5		13.8	14.3	13.7	14.1
Cook	170310076	Chicago - Lawndale	13.8	14.5		13.7	14.3	13.6	14.1
Cook	170312001	Blue Island	13.7	14.5		13.6	14.3	13.4	14.1
Cook	170313301	Summit	14.2	14.8		14.0	14.6	13.9	14.4
Cook	170316005	Cicero	14.4	**15.3**		14.3	**15.1**	14.2	14.9
Madison	171191007	Granite City	**15.1**	**16.0**		14.9	**15.8**	14.3	**15.5**
St. Clair	171630010	E. St. Louis	14.1	14.9		13.9	14.7	13.4	14.5
Clark	180190005	Jeffersonville	13.8	**15.5**		13.7	**15.0**	13.4	14.4
Dubois	180372001	Jasper	12.4	13.8		12.2	13.5	11.8	13.0
Lake	180890031	Gary	13.0			12.8		12.4	
Marion	180970078	Indy-Washington Park	12.8	14.5		12.6	14.2	12.0	13.7
Marion	180970083	Indy- Michigan Street	13.4	14.8		13.1	14.9	12.6	14.0
Wayne	261630001	Allen Park	13.0	14.5		12.8	14.1	12.4	13.3
Wayne	261630015	Southwest HS	14.2	**15.8**		13.9	**15.3**	13.5	14.4
Wayne	261630016	Linwood	13.1	14.1		12.8	13.7	12.5	13.0
Wayne	261630033	Dearborn	**15.8**	**17.7**		**15.5**	**17.1**	**15.1**	**16.1**
Wayne	261630036	Wyandotte	13.1	**15.1**		12.8	14.7	12.5	13.9
Butler	390170003	Middleton	13.5	14.2		13.2	13.7	12.8	13.1
Butler	390170016	Fairfield	13.1	13.5		12.9	12.9	12.5	12.2
Cuyahoga	390350027	Cleveland-28th Street	13.5	14.4		13.2	13.8	12.7	12.9
Cuyahoga	390350038	Cleveland-St. Tikhon	**15.2**	**16.1**		14.8	**15.4**	14.3	14.4
Cuyahoga	390350045	Cleveland-Broadway	14.4	14.6		14.0	14.0	13.5	13.1
Cuyahoga	390350060	Cleveland-GT Craig	15.0	**15.3**		14.6	14.7	14.1	13.7
Cuyahoga	390350065	Newburg Hts - Harvard Ave	14.0	14.1		13.6	13.5	13.1	12.6
Franklin	390490024	Columbus - Fairgrounds	12.9	14.6		12.6	14.0	12.0	13.0
Franklin	390490025	Columbus - Ann Street	12.7	14.1		12.4	13.5	11.9	12.5
Franklin	390490081	Columbus - Maple Canyon	11.7	14.0		11.4	13.4	10.9	12.5
Hamilton	390610014	Cincinnati - Seymour	14.5	**15.5**		14.3	14.8	13.8	14.0
Hamilton	390610040	Cincinnati - Taft Ave	12.8	13.6		12.6	13.0	12.2	12.3
Hamilton	390610042	Cincinnati - 8th Ave	14.0	14.6		13.8	14.0	13.4	13.2
Hamilton	390610043	Sharonville	12.9	13.6		12.7	13.0	12.3	12.2
Hamilton	390617001	Norwood	13.4	14.2		13.2	13.6	12.8	12.8
Hamilton	390618001	St. Bernard	14.7	**15.2**		14.4	14.6	14.0	13.8
Jefferson	390810016	Steubenville	12.8	**16.3**		12.5	**15.9**	12.7	**16.2**
Jefferson	390811001	Mingo Junction	13.5	**15.5**		13.2	**15.0**	13.4	**15.3**
Lawrence	390870010	Ironton	12.8	14.2		12.5	13.7	12.3	13.2
Montgomery	391130032	Dayton	13.2	13.7		12.9	13.2	12.4	12.3
Scioto	391450013	New Boston	12.1	**15.4**		11.9	14.8	11.6	14.2
Stark	391510017	Canton - Dueber	14.0	**15.0**		13.6	14.3	13.3	13.6
Stark	391510020	Canton - Market	12.6	13.6		12.3	13.0	11.9	12.2
Summit	391530017	Akron - Brittain	13.0	14.4		12.7	13.6	12.3	12.9
Summit	391530023	Akron - W. Exchange	12.3	13.6		12.0	13.0	11.5	12.2

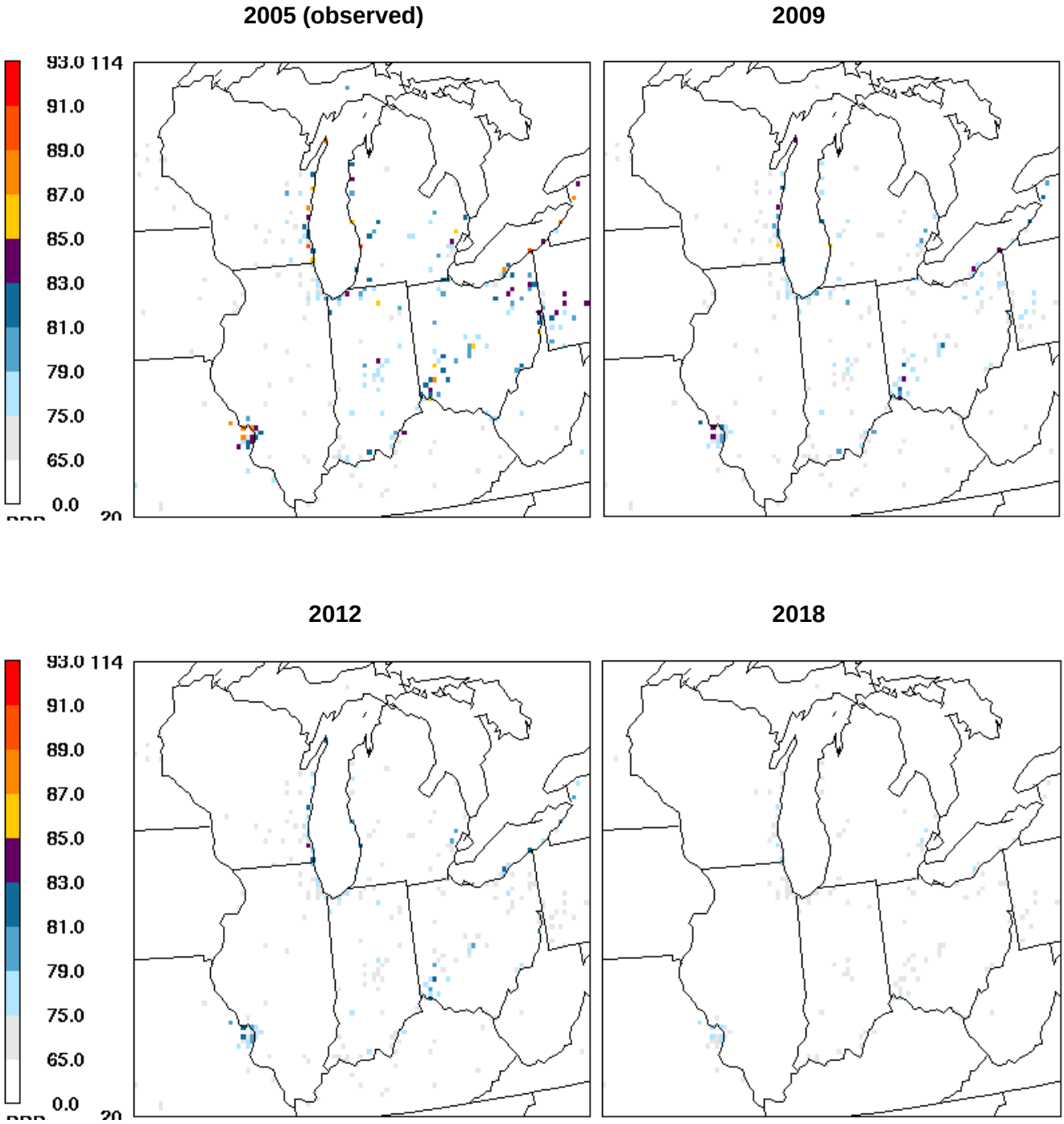


Figure 60. Observed base year and projected future year design values for ozone – Base M

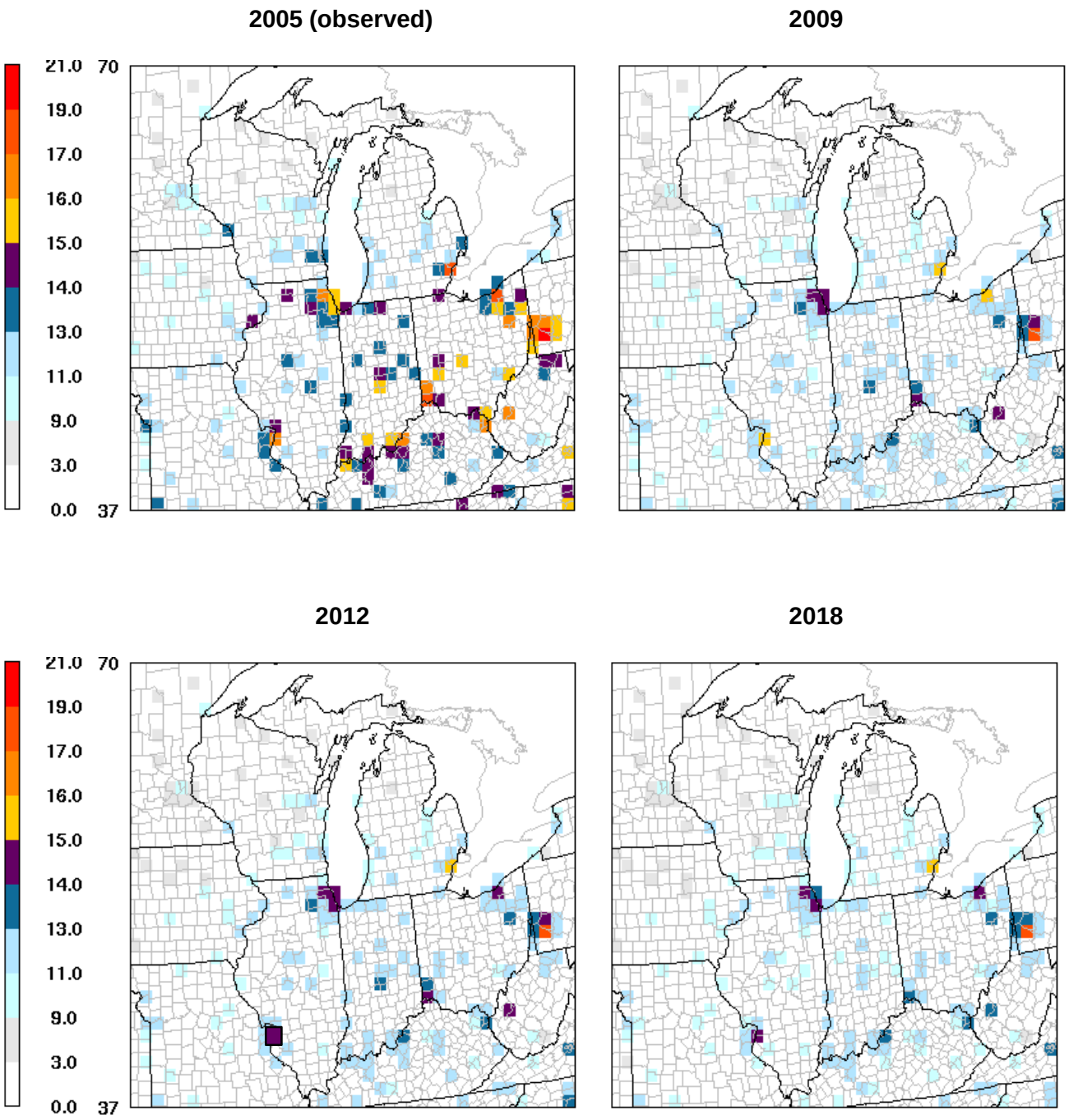


Figure 61. Observed base year and projected future year design values for $PM_{2.5}$ (annual average)–Base M

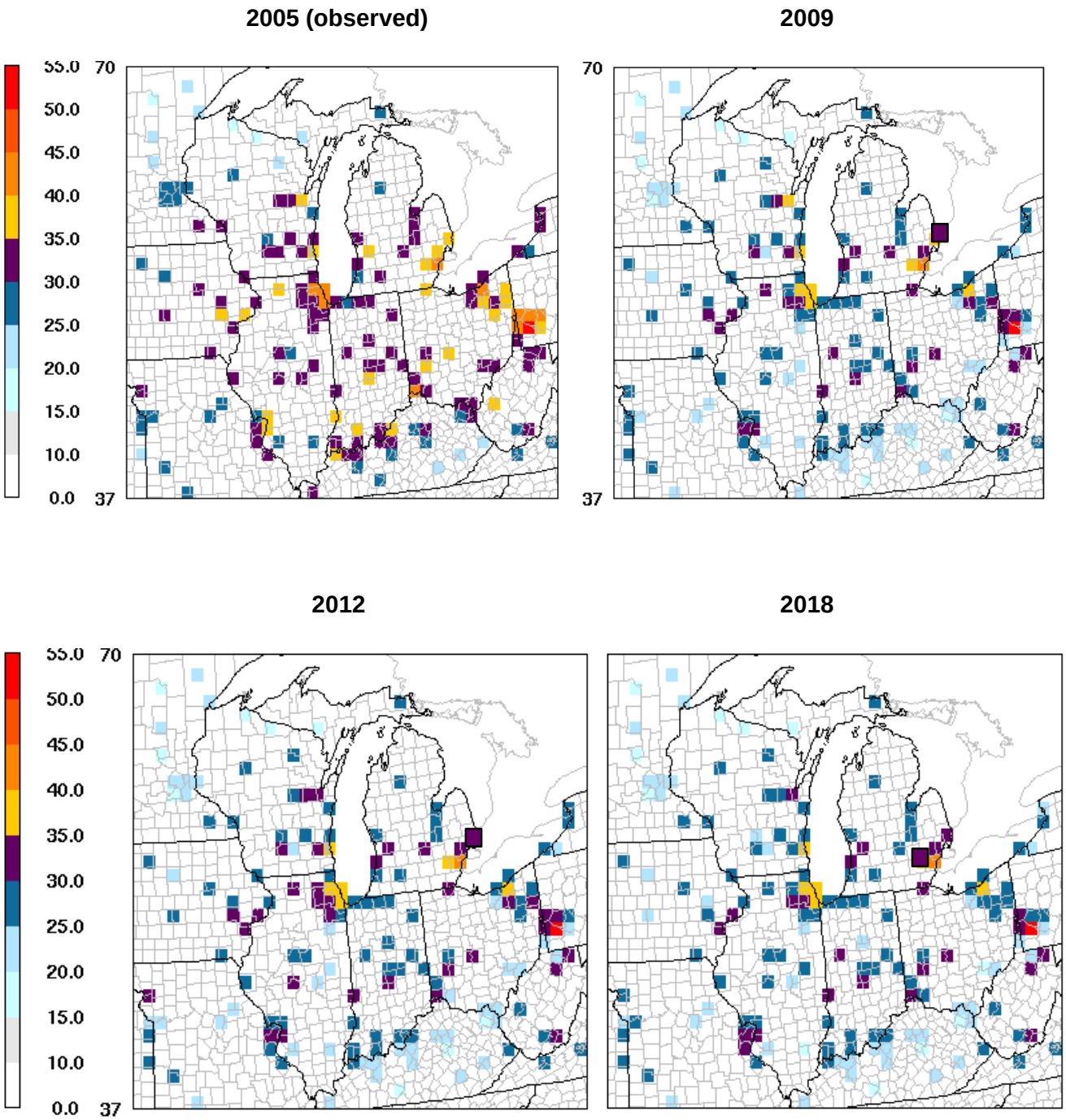


Figure 62. Observed base year and projected future year design values for $PM_{2.5}$ (24-hr average)-Base M

The number of monitors with design values above the standard are as follows:

Table 11. Number of sites above standard

Ozone (8 hour: 85 ppb)											
State	2002	2005		2009			2012			2018	
	BaseK	Base M		BaseK	Base M		BaseK	Base M		BaseK	Base M
IL	3	0		0	0		0	0		0	0
IN	22	0		0	0		0	0		0	0
MI	15	3		1	1		0	0		0	0
OH	40	4		1	0		1	0		0	0
WI	13	2		4	0		3	0		1	0
Total	93	9		6	1		4	0		1	0
PM2.5 (Annual: 15 ug/m^3)											
State	2002	2005		2009			2012			2018	
	BaseK	Base M		BaseK	Base M		BaseK	Base M		BaseK	Base M
IL	11	7		3	1		3	0		2	0
IN	10	6		1	0		1	0		0	0
MI	6	2		3	1		2	1		0	0
OH	31	26		7	1		4	0		1	1
WI	0	0		0	0		0	0		2	0
Total	58	41		14	3		10	1		5	1

The modeling results above reflect the "base" controls identified in Section 3.6, with EGU emissions based on IPM modeling (i.e., Round 4 – IPM2.1.9, and Round 5 – IPM3.0). In addition, two sets of alternative future year EGU emissions were examined in Round 5. First, alternative control assumptions were provided for several facilities by the states (i.e., "will do" and "may do" scenarios). In general, these scenarios produced a small change in future year ozone and $PM_{2.5}$ concentrations (i.e., about 0.1 ug/m^3 for $PM_{2.5}$ and 0.1-0.2 ppb for ozone). Second, EPA suggested adjustments to the 2010 IPM emissions to reflect 2009 conditions. The revised (2009) SO2 emissions represent a 5-6% increase in domainwide SO2 emissions. The increased SO2 emissions result in slightly greater annual average $PM_{2.5}$ concentrations (on the order of 0.1 – 0.2 ug/m^3), but do not produce any new residual nonattainment areas.

The limited 4 km ozone modeling (based on Base K) performed by LADCO included a future year analysis for 2009. The figure below shows the 2009 values with 12 km and 4 km grid spacing for the LADCO modeling and similar modeling conducted by a stakeholder group (Midwest Ozone Group).

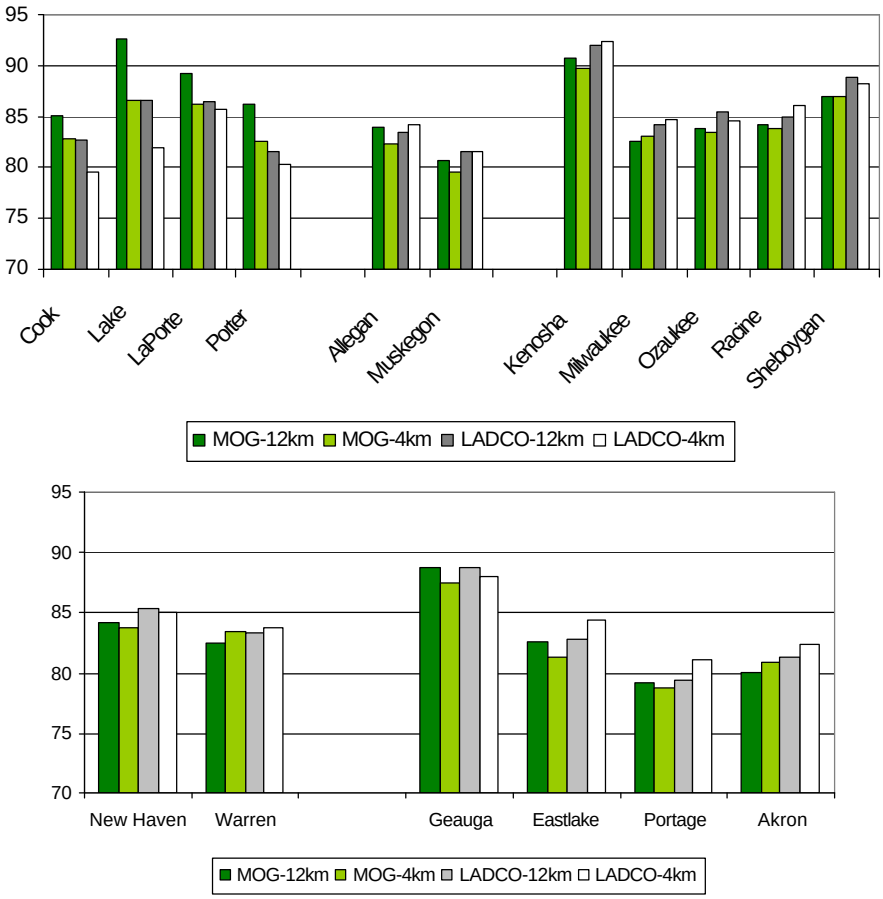


Figure 63. Future year (2009) values for Lake Michigan area (top) and Detroit-Cleveland region (bottom)

These results show that the 12 km and 4 km values are similar, with the most notable changes in northwestern Indiana and northeastern Illinois (e.g., 4 km values are as much as 4 ppb lower than 12 km values). The differences in the southern part of the Lake Michigan area are plausible, given the tight emissions gradient there (i.e., finer grid resolution appears to provide more appropriate representation).

In light of these findings, 12 km grid spacing can continue to be used for ozone modeling, but the Base K/Round 4 results for northwestern Indiana/northeastern Illinois should be viewed with caution (i.e., probably 1 – 4 ppb too high).

In summary, the ozone modeling provides the following information for the nonattainment areas in the region (see Table 12):

Table 12. Ozone Nonattainment Areas in the LADCO Region (as of December 31, 2007)

Area Name	Category	Number of Counties	Attainment Deadline
Detroit-Ann Arbor, MI	Marginal	8	2007
Chicago-Gary-Lake County, IL-IN	Moderate	10	2010
Cleveland-Akron-Lorain, OH	Moderate	8	2010
Milwaukee-Racine, WI	Moderate	6	2010
Sheboygan, WI	Moderate	1	2010
St Louis, MO-IL	Moderate	4	2010
Allegan Co, MI	Subpart 1	1	2009
Cincinnati-Hamilton, OH-KY-IN	Subpart 1	6	2009
Columbus, OH	Subpart 1	6	2009
Door Co, WI	Subpart 1	1	2009
Kewaunee Co, WI	Subpart 1	1	2009
Manitowoc Co, WI	Subpart 1	1	2009
		53	

Marginal Areas (2007 attainment date): No modeling was conducted for the 2006 SIP planning year. Rather, 2005 – 2007 air quality data are available to determine attainment.

Basic (Subpart 1) Areas (2009 attainment date): The modeling results for the 2008 SIP planning year show:

- Base K: all areas in attainment, except Cincinnati and Indianapolis
- Base M: all areas in attainment, except Holland (Allegan County)

Moderate Areas (2010 attainment date): The modeling results for the 2009 SIP planning year show:

- Base K: all areas still in nonattainment
- Base M: all areas in attainment

The $PM_{2.5}$ modeling results show:

- Base K: all areas in attainment, except for Chicago, Cincinnati, Cleveland, Detroit, Granite City (IL), Louisville, Portsmouth (OH), and Steubenville
- Base M: all areas in attainment, except for Cleveland, Detroit, and Granite City (IL)

With respect to the new lower 8-hour ozone standard, the modeling about 30 sites in 2012 and 5 sites in 2018 with design values greater than 75 ppb. With respect to the new lower 24-hour $PM_{2.5}$ standard, the modeling shows 13 sites in 2012 and 10 in 2018 with design values greater than 35 ug/m^3.

4.2 Supplemental Analyses

EPA's modeling guidelines recommend that attainment demonstrations consist of a primary (guideline) modeling analysis and supplemental analyses. Three basic types of supplemental analyses are recommended:

- additional modeling
- analyses of trends in ambient air quality and emissions, and
- observational models and diagnostic analyses

Furthermore, according to EPA's guidelines, if the future year modeled values are "close" to the standard (i.e., 82 – 87 ppb for ozone and 14.5 – 15.5 ug/m^3 for $PM_{2.5}$), then the results of the primary modeling should be reviewed along with the supplemental information in a "weight of evidence" assessment of whether each area is likely to achieve timely attainment.

A WOE determination for ozone and $PM_{2.5}$ is provided in the following sections. Special attention is given to the following areas with future year modeled values that exceed or are "close" to the ambient standard (see Appendix I):

Ozone	**PM2.5**
Lake Michigan area	Chicago, IL
Cleveland, OH	Cleveland, OH
Cincinnati, OH	Cincinnati, OH
	Granite City, IL
	Detroit, MI

4.3 Weight-of-Evidence Determination for Ozone

The WOE determination for ozone consists of the primary modeling and other supplemental analyses (some of which were discussed in Section 2). A summary of this information is provided below.

Primary (Guideline) Modeling: The guideline modeling is presented in Section 4.1. Key findings from this modeling include:

- Base M regional modeling shows attainment by 2008 and 2009 at all sites, except Holland (MI), and attainment at all sites by 2012.

- Base K modeling results reflect generally higher future year values, and show more sites in nonattainment compared to the Base M modeling. The difference in the two modeling analyses is due mostly to lower base year design values in Base M.

- Base K and Base M modeling analyses are considered "SIP quality", so the attainment demonstration for ozone should reflect a weight-of-evidence approach, with consideration of monitoring based information.

- Base M modeling also shows that the proposed lower 8-hour standard will not be met at many sites, even by 2018, with existing controls.

Additional Modeling: Four additional modeling analyses were considered: (1) re-examination of the primary modeling to estimate attainment probabilities, (2) remodeling with different assumptions, (3) an unmonitored area analysis, and (4) EPA's latest regional ozone modeling. Each of these analyses is described below.

First, the primary modeling results (which were initially processed using EPA's attainment test) were re-examined to estimate the probability of attaining the ozone standard (Lopez, 2007, and LADCO, 2008b). Seven estimates of future year ozone concentrations were calculated based on model-based RRFs and appropriate monitor-based concentrations for each year between 2001 and 2007. RRF values for 2001, 2003, 2004, 2006, and 2007 were derived based on the 2002 and 2005 modeling results. Monitor-based concentrations reflect 4th high values, design values, or average of three design values centered on the year in question. The probability of attainment was determined as the percentage of these seven estimates below the standard. The results indicate that sites in the Lake Michigan area (Chiwaukee, Sheboygan, Holland, Muskegon), Cleveland (Ashtabula), and St. Louis (W Alton) have a fairly low probability of attainment by 2009 (i.e., about 50% or less).

Second, the primary modeling analysis was redone with different types of assumptions for calculating base year design values (i.e., using the 3-year period centered on base year, and using the highest 3-year period that includes the base year), and for calculating RRFs (i.e., using all days with base year modeled value > 70 ppb, and using all days with base year modeled value > 85 ppb, with at least 10 days and "acceptable" model performance). The results for several high concentration sites are presented in Tables 13a and 13b for 2009. The different modeling assumptions produce eight estimates of future year ozone concentrations. The highest estimates are associated with base year design values representing the 3-year average for 2001-2003, and the lowest estimates are associated with base year design values representing the 3-year average 2004-2006. The different RRF approaches produce little change in future year ozone concentrations. This suggests that future year concentration estimates are most sensitive to the choice of the base year and the methodology used to derive the base year design values.

Third, EPA's modeling guidelines recommend that an "unmonitored area analysis" be included as a supplemental analysis, particularly in nonattainment areas where the monitoring network just meets or minimally exceeds the size of the network required to report data to EPA's Air Quality System. The purpose of this analysis is to identify areas where future year values are predicted to be greater than the NAAQS.

Based on examination of the spatial plots in Figures 49a and 49b, the most notable areas of high modeled ozone concentrations are over the Great Lakes. Over-water monitoring, however, is not required by EPA[12]. A cursory analysis of unmonitored areas for ozone was performed by LADCO using an earlier version of the 2002 base year modeling (i.e, Base I) (Baker, 2005). Base year and future year "observed" values were derived for unmonitored grid cells using the absolute modeled concentrations (in all grid cells) and the observed values (in monitored grid cells). A spatial map of the estimated 2009 values is provided in Figure 64. As can be seen, there are very few (over land) grid cells where additional monitors may be desirable. This indicates that the current modeling analysis, which focuses on monitored locations, is addressing areas of high ozone throughout the region.

[12] Air quality measurements over Lake Michigan were collected by LADCO previously to understand ozone transport in the area (see, for example, Figure 5). Due to cut-backs in USEPA funding, however, these measurements were discontinued in 2003.

Table 13a. Primary and Additional Ozone Modeling Results – Lake Michigan and Cleveland Areas (2009)

2009 Modeling Results		Lake Michigan Area								Cleveland Area		
		Chiwaukee	Harr.Beach	Sheboygan	DoorCounty	Holland	Hammond	MichiganCity		Ashtabula	Geauga	Eastlake
		550590019	550890009	551170006	550290004	260050003	180892008	180910005		390071001	390550004	390850003
Attainment Test (based on EPA guidance-2002 baseyear)												
Base Year Design Value (average of three 3-year periods)		*98.3*	*93.0*	*97.0*	*91.0*	*94.0*	*88.3*	*90.3*		*95.7*	*99.0*	*92.7*
RRF (all days > 85 ppb, or at least 10 days)		0.935	0.918	0.916	0.899	0.888	0.980	0.958		0.865	0.897	0.894
Future Year Design Value		**91.9**	**85.4**	**88.9**	**81.8**	83.5	**86.5**	**86.5**		82.8	**88.8**	82.9
Attainment Test (based on EPA guidance-2005 baseyear)												
Base Year Design Value (average of three 3-year periods)		*84.7*	*83.3*	*88.0*	*88.7*	*90.0*	*77.7*	*77.0*		*89.0*	*79.3*	*86.3*
RRF (all days > 85 ppb, or at least 10 days)		0.972	0.961	0.955	0.946	0.948	0.971	0.960		0.937	0.942	0.949
Future Year Design Value		82.3	80.1	84.0	83.9	**85.3**	75.4	73.9		83.4	74.7	81.9
Weight of Evidence (alternative approaches-2002baseyear)												
Alt 1 - Base Year Des. Value (3-year period centered on 2002)		*101.0*	*98.0*	*100.0*	*94.0*	*97.0*	*90.0*	*93.0*		*99.0*	*103.0*	*95.0*
Alt 2 - Base Year Des. Value (Highest 3-year period including 2002)		*101.0*	*98.0*	*100.0*	*94.0*	*97.0*	*92.0*	*93.0*		*99.0*	*103*	*95.0*
RRF (all days > 85 ppb, or at least 10 days)		0.935	0.918	0.916	0.899	0.888	0.980	0.958		0.865	0.897	0.894
Alt 1 - Future Year Projected Value		**94.4**	**90.0**	**91.6**	84.5	**86.1**	**88.2**	**89.1**		**85.6**	**92.4**	84.9
Alt 2 - Future Year Projected Value		**94.4**	**90.0**	**91.6**	84.5	**86.1**	**90.2**	**89.1**		**85.6**	**92.4**	84.9
Alt 1 - RRF (all days > 70 ppb)		0.933	0.918	0.912	0.907	0.893	0.969	0.947		0.876	0.907	0.900
Alt 1 - Future Year Projected Value		**94.2**	**90.0**	**91.2**	**85.3**	**86.6**	**87.2**	**88.1**		**86.7**	**93.4**	**85.5**
Alt 2 - Future Year Projected Value		**94.2**	**90.0**	**91.2**	**85.3**	**86.6**	**89.1**	**88.1**		**86.7**	**93.4**	**85.5**
Alt 2 - RRF (all days > 85 ppb, or at least 10 days; with acceptable model performance)		0.945	0.904	0.910	0.904	0.887	0.976	0.964		0.866	0.896	0.894
Alt 1 - Future Year Projected Value		**95.4**	**88.6**	**91.0**	**85.0**	**86.0**	**87.8**	**89.7**		**85.7**	**92.3**	84.9
Alt 2 - Future Year Projected Value		**95.4**	**88.6**	**91.0**	**85.0**	**86.0**	**89.8**	**89.7**		**85.7**	**92.3**	84.9
Weight of Evidence (alternative approaches-2005baseyear)												
Alt 1 - Base Year Des. Value (3-year period centered on 2005)		*83.0*	*79.0*	*86.0*	*86.0*	*88.0*	*76.0*	*76.0*		*86.0*	*77.0*	*86.0*
Alt 2 - Base Year Des. Value (Highest 3-year period including 2005)		*86.0*	*88.0*	*89.0*	*90.0*	*93.0*	*79.0*	*78.0*		*91.0*	*86.0*	*89.0*
Alt 1 - Future Year Projected Value		80.7	75.9	82.1	81.4	83.4	73.8	73.0		80.6	72.5	81.6
Alt 2 - Future Year Projected Value		83.6	84.6	**85.0**	**85.1**	**88.2**	76.7	74.9		**85.3**	81.0	84.5

Table 13b. Primary and Additional Ozone Modeling Results – Cincinnati, Columbus, St. Louis, Indianapolis, and Detroit (2009)

2009 Modeling Results	Cincinnati Area			Columbus	St. Louis Area		Indianapolis Area		Detroit Area
	Wilmington	Lebanon	Sycamore	NewAlbany	W. Alton	OrchardFarm	Noblesville	Fortville	New Haven
	390271002	39165007	390610006	390490029	291831002	291831004	180571001	18059003	260990009
Attainment Test (based on EPA guidance-2002 baseyear)									
Base Year Design Value (average of three 3-year periods)	*94.3*	*90.7*	*90.7*	*94.0*	*90.0*	*90.0*	*93.7*	*91.3*	*92.3*
RRF (all days > 85 ppb, or at least 10 days)	0.885	0.908	0.938	0.888	0.947	0.914	0.894	0.918	0.924
Future Year Design Value	83.5	82.4	**85.1**	83.5	**85.2**	82.3	83.8	83.8	**85.3**
Attainment Test (based on EPA guidance-2005 baseyear)									
Base Year Design Value (average of three 3-year periods)	*82.3*	*87.7*	*84.3*	*86.3*	*86.3*	*87.0*	*83.3*	*78.7*	*86.0*
RRF (all days > 85 ppb, or at least 10 days)	0.941	0.947	0.967	0.947	0.938	0.942	0.945	0.947	0.947
Future Year Design Value	77.4	83.1	81.5	81.7	80.9	82.0	78.7	74.5	81.4
Weight of Evidence (alternative approaches-2002baseyear)									
Alt 1 - Base Year Des. Value (3-year period centered on 2002)	*96.0*	*92.0*	*93.0*	*95.0*	*91.0*	*92.0*	*96.0*	*94.0*	*97.0*
Alt 2 - Base Year Des. Value (Highest 3-year period including 2002)	*96.0*	*92.0*	*93.0*	*96.0*	*91.0*	*92.0*	*96.0*	*94.0*	*97.0*
RRF (all days > 85 ppb, or at least 10 days)	0.885	0.908	0.938	0.888	0.947	0.914	0.894	0.918	0.924
Alt 1 - Future Year Projected Value	**85.0**	83.5	**87.2**	84.4	**86.2**	84.1	**85.8**	**86.3**	**89.6**
Alt 2 - Future Year Projected Value	**85.0**	83.5	**87.2**	**85.2**	**86.2**	84.1	**85.8**	**86.3**	**89.6**
Alt 1 - RRF (all days > 70 ppb)	0.885	0.914	0.940	0.901	0.945	0.911	0.912	0.907	0.918
Alt 1 - Future Year Projected Value	**85.0**	84.1	**87.4**	**85.6**	**86.0**	83.8	**87.6**	**85.3**	**89.0**
Alt 2 - Future Year Projected Value	**85.0**	84.1	**87.4**	**86.5**	**86.0**	83.8	**87.6**	**85.3**	**89.0**
Alt 2 - RRF (all days > 85 ppb, or at least 10 days; with acceptable model performance)	0.880	0.911	0.940	0.886	0.951	0.913	0.894	0.916	0.935
Alt 1 - Future Year Projected Value	84.5	83.8	**87.4**	84.2	**86.5**	84.0	**85.8**	**86.1**	**90.7**
Alt 2 - Future Year Projected Value	84.5	83.8	**87.4**	**85.1**	**86.5**	84.0	**85.8**	**86.1**	**90.7**
Weight of Evidence (alternative approaches-2005baseyear)									
Alt 1 - Base Year Des. Value (3-year period centered on 2005)	*80.0*	*86.0*	*81.0*	*84.0*	*85.0*	*86.0*	*80.0*	*76.0*	*82.0*
Alt 2 - Base Year Des. Value (Highest 3-year period including 2005)	*85.0*	*89.0*	*86.0*	*88.0*	*89.0*	*89.0*	*87.0*	*81.0*	*90.0*
Alt 1 - Future Year Projected Value	75.3	81.4	78.3	79.5	79.7	81.0	75.6	72.0	77.7
Alt 2 - Future Year Projected Value	80.0	84.3	83.2	83.3	83.5	83.8	82.2	76.7	**85.2**

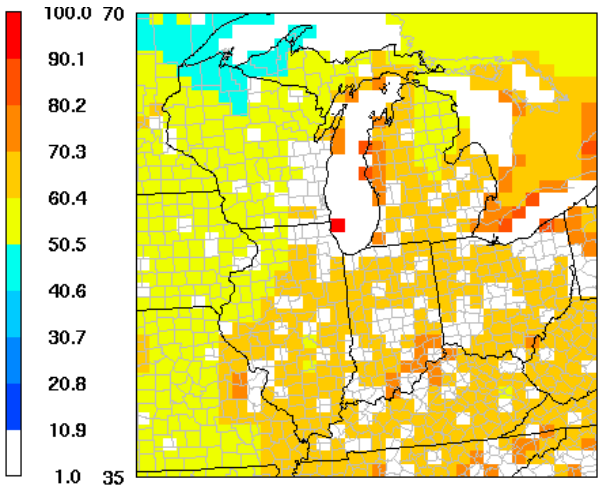


Figure 64. Estimated Future Year Values (unmonitored grid cells)

Finally, EPA's latest regional ozone modeling was considered as corroborative information. This modeling was performed as part of the June 2007 proposal to revise the ozone standard (EPA, 2007b). EPA applied the CMAQ model with 2001 meteorology to first estimate ozone levels in 2020 based on the current standard and national rules in effect or proposed (i.e., the baseline), and then to evaluate strategies for attaining a more stringent (70 ppb) primary standard. Baseline (2020) ozone levels were predicted to be below the current standard in 481 of the 491 counties with ozone monitors. Of the 10 counties predicted to be above the standard, there is one county in the LADCO region (i.e., Kenosha County, WI at 86 ppb). This result is consistent with LADCO's Base K modeling for 2018 (i.e., Kenosha County, WI at 86.7 ppb), which is not surprising given that EPA's modeling and LADCO's Base K modeling have a similar base year (2001 v. 2002).

Analysis of Trends: EPA's modeling guidelines note that while air quality models are generally the most appropriate tools for assessing the expected impacts of a change in emissions, it may also be possible to extrapolate future trends based on measured historical trends of air quality and emissions. To do so, USEPA's guidance suggests that ambient trends should first be normalized to account for year-to-year variations in meteorological conditions (EPA, 2002). Meterologically-adjusted 4th high 8-hour ozone concentrations were derived using the air quality – meteorological regression model developed by EPA (i.e., Cox method – see Section 2.1).

The historical trend in these met-adjusted ozone concentrations were extrapolated to estimate future year ozone concentrations based on historical and projected trends in precursor emissions. Both VOC and NOx emissions affect ozone concentrations. Given that observation-based methods show that urban areas in the region are generally VOC-limited and rural areas in the region are NOx-limited (see Section 2.1), urban VOC emissions and regional NOx emissions are considered important. The trends in urban VOC and regional NOx emissions were calculated to produce appropriate weighting factors.

The resulting 2009 and 2012 ozone values are provided in Figure 65, along with the primary and alternative modeling ozone values for key sites in the Lake Michigan, Cleveland, and Cincinnati areas. The results reflect a fairly wide scatter, but, on balance, the supplemental information is supportive of the primary modeling results (i.e., sites in the Lake Michigan area and Cleveland are expected to be close to the standard).

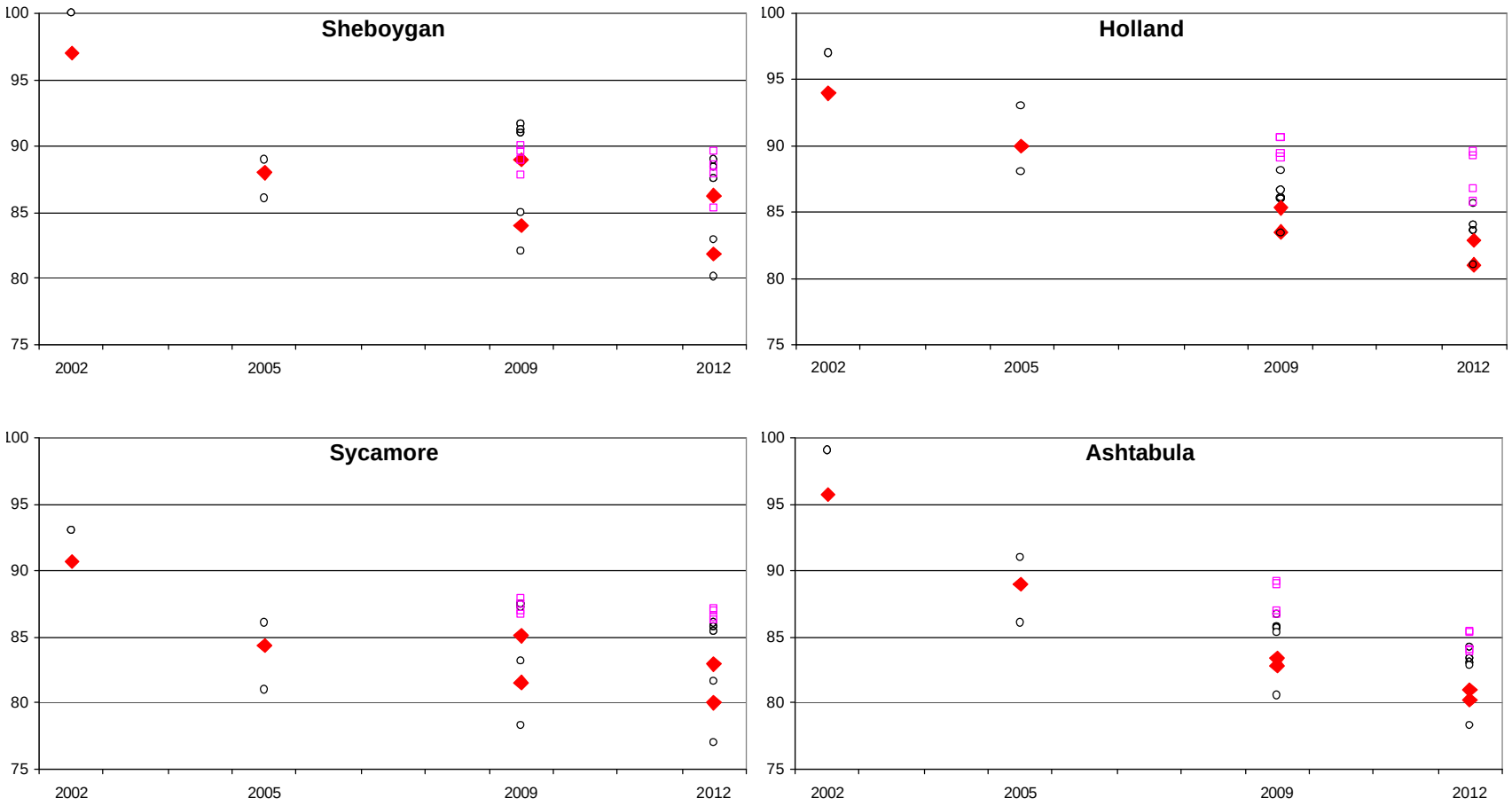


Figure 65. Estimates of Future Year Ozone Concentrations – Lake Michigan Area (Sheboygan and Holland), Cincinnati (Sycamore), and Cleveland (Ashtabula)

Note: Primary (guideline) modeling values (Base K and Base M results) are represented by large red diamonds, additional modeling values by small black circles, and trends-based values by small pink squares

Observational Models and Diagnostic Analyses: The observation-based modeling (i.e., MAPPER) is presented in Section 3. The key findings from this modeling are that most urban areas are VOC-limited and rural areas are NOx-limited.

The primary diagnostic analysis is source apportionment modeling with CAMx to provide more quantitative information on source region (and source sector) impacts (Baker, 2007a). Specifically, the model estimated the impact of 18 geographic source regions (which are identified in Figure 66) and 6 source sectors (EGU point, non-EGU point, on-road, off-road, area, and biogenic sources) at ozone monitoring sites in the region.

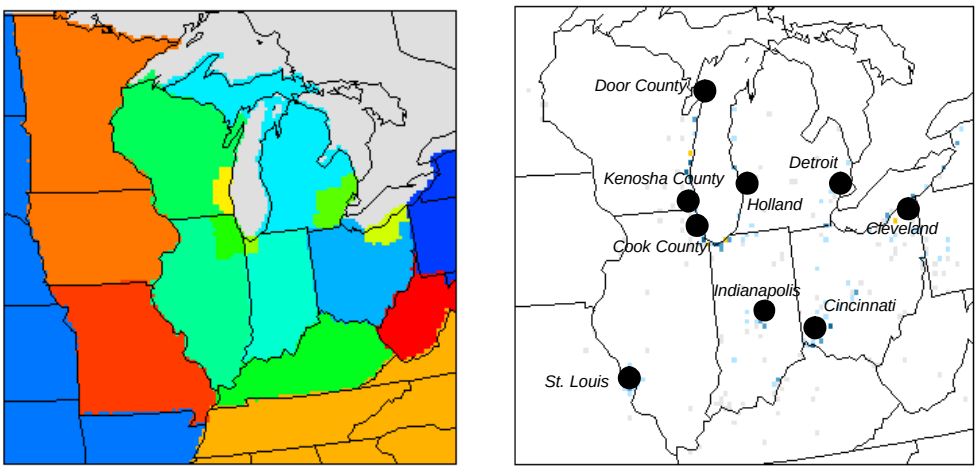


Figure 66. Source regions (left) and key monitoring sites (right) for ozone modeling analysis

Modeling results for 2009 (Base M) and 2012 (Base K) are provided in Appendix II for several key monitoring sites. For each monitoring site, there are two graphs: one showing sector-level contributions, and one showing source region and sector-level contributions in terms of percentages. (Note, in the sector-level graph, the contributions from NOx emissions are shown in blue, and from VOC emissions in green.)

The sector-level results (see, for example, Figure 67) show that on-road and nonroad NOx emissions generally have the largest contributions at the key monitor locations (> 15% each). EGU and non-EGU NOx emissions are also important contributors (> 10% each). The source group contributions vary by receptor location due to emissions inventory differences.

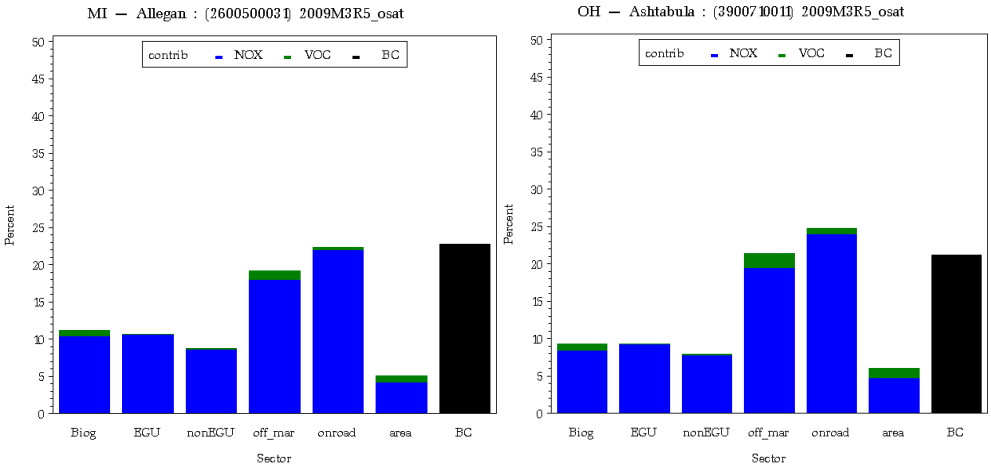


Figure 67. Source-sector results for Holland (left) and Ashtabula (right) monitors – 2009 (Base M)

The source region results (see, for example, Figure 68) show that while nearby areas generally have the highest impacts (e.g., the northeastern IL/northwestern IN/southeastern WI nonattainment area contributes 25-35% to high sites in the Lake Michigan area, and Cleveland nonattainment counties contribute 20-25% to high sites in northeastern Ohio), there is an even larger regional impact (i.e., contribution from other states).

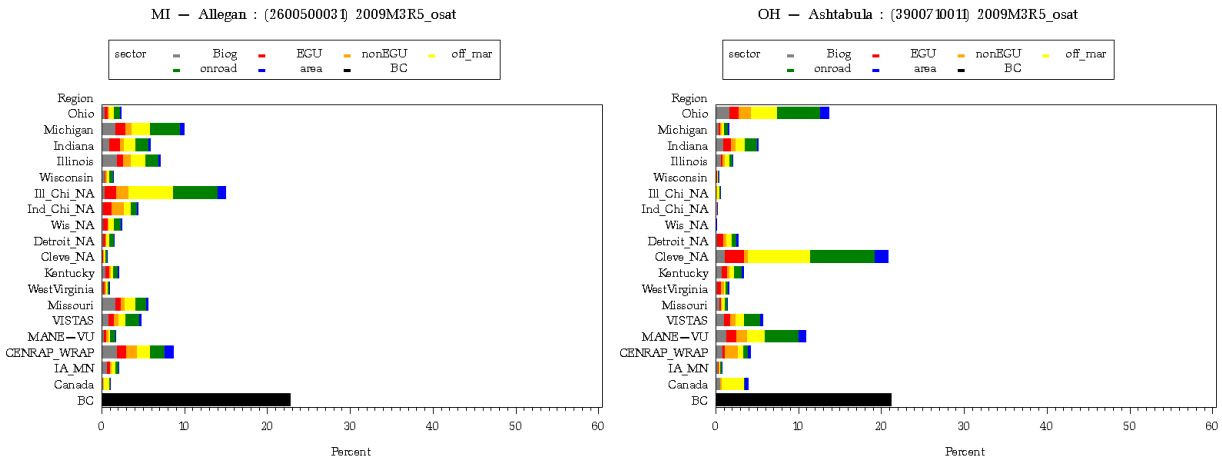


Figure 68. Source-region results for Holland (left) and Ashtabula (right) monitors – 2009 (Base M)

Summary: Air quality modeling and other supplemental analyses were performed to estimate future year ozone concentrations. Based on this information, the following general conclusions can be made:

- Existing ("on the books") controls are expected to produce significant improvement in ozone air quality.

- The choice of the base year affects the future year model projections. A key difference between the base years of 2002 and 2005 is meteorology. As noted above, 2002 was more ozone conducive than 2005. The choice of which base year to use as the basis for the SIP is a policy decision (i.e., how much safeguard to incorporate).

- Most sites are expected to meet the current 8-hour standard by the applicable attainment date, except, for sites in western Michigan and, possibly, in eastern Wisconsin and northeastern Ohio.

- Current monitoring data show significant nonattainment in these areas (e.g., peak design values on the order of 90 – 93 ppb). It is not clear whether sufficient emission reductions will occur in the next couple of years to provide for attainment.

- Attainment by the applicable attainment date is dependent on actual future year meteorology (e.g., if the weather conditions are consistent with [or less severe than] 2005, then attainment is likely) and actual future year emissions (e.g., if the emission reductions associated with the existing controls are achieved, then attainment is likely). On the other hand, if either of these conditions is not met, then attainment may be less likely.

4.3 Weight-of-Evidence Determination for $PM_{2.5}$

The WOE determination for $PM_{2.5}$ consists of the primary modeling and other supplemental analyses. A summary of this information is provided below.

Primary (Guideline) Modeling: The results of the guideline modeling are presented in Section 4.1. Key findings from this modeling include:

- Base M regional modeling shows attainment by 2009 at all sites, except Detroit, Cleveland, and Granite City, and attainment at all sites by 2012, except for Detroit and Granite City.

  The regional modeling for $PM_{2.5}$ does not reflect any air quality benefit expected from local controls. States are conducting local-scale analyses and will use these results, in conjunction with the regional-scale modeling, to support their attainment demonstrations for $PM_{2.5}$

- Base K modeling results reflect generally higher future year values, and show more sites in nonattainment in 2009 and 2012 compared to the Base M modeling. The difference in the two modeling analyses is due mostly to lower base year design values in Base M.

- Base K and Base M modeling analyses are considered "SIP quality", so the attainment demonstration for $PM_{2.5}$ should reflect a weight-of-evidence approach, with consideration of monitoring based information.

- Base M modeling also shows that the new $PM_{2.5}$ 24-hour standard will not be met at many sites, even by 2018, with existing controls.

Additional Modeling: EPA's latest regional $PM_{2.5}$ modeling was considered as corroborative information. This modeling was performed as part of the September 2006 revision to the $PM_{2.5}$ standard (USEPA, 2006). EPA applied the CMAQ model with 2001 meteorology to estimate $PM_{2.5}$ levels in 2015 and 2020 first with national rules in effect or proposed, and then with additional controls to attain the current standard (15 ug/m^3 annual/65 ug/m^3 daily). Additional analyses were performed to evaluate strategies for attaining more stringent standards in 2020 (15/35, and 14/35). Baseline (2015) $PM_{2.5}$ levels were predicted to be above the current standard in four counties in the LADCO region: Madison County, IL at 15.2 ug/m^3, Wayne County, MI at 17.4, Cuyahoga County, OH at 15.4, and Scioto County, OH at 15.6. These results are consistent with LADCO's Base K modeling for 2012/2018, which is not surprising given that EPA's modeling and LADCO's Base K modeling have a similar base year (2001 v. 2002).

Observational Models and Diagnostic Analyses: The observation-based modeling (i.e., application of thermodynamic equilibrium models) is presented in Section 3. The key findings from this modeling are that $PM_{2.5}$ mass is sensitive to reductions in sulfate, nitric acid, and ammonia concentrations. Even though sulfate reductions cause more ammonia to be available to form ammonium nitrate (PM-nitrate increases slightly when sulfate is reduced), this increase is generally offset by the sulfate reductions, such that $PM_{2.5}$ mass decreases. Under conditions with lower sulfate levels (i.e., proxy of future year conditions), $PM_{2.5}$ is more sensitive to reductions in nitric acid compared to reductions in ammonia.

The primary diagnostic analysis is source apportionment modeling with CAMx to provide more quantitative information on source region (and source sector) impacts (Baker, 2007b). Specifically, the model estimated the impact of 18 geographic source regions (which are identified in Figure 69) and 6 source sectors (EGU point, non-EGU point, on-road, off-road, area, and biogenic sources) at $PM_{2.5}$ monitoring sites in the region.

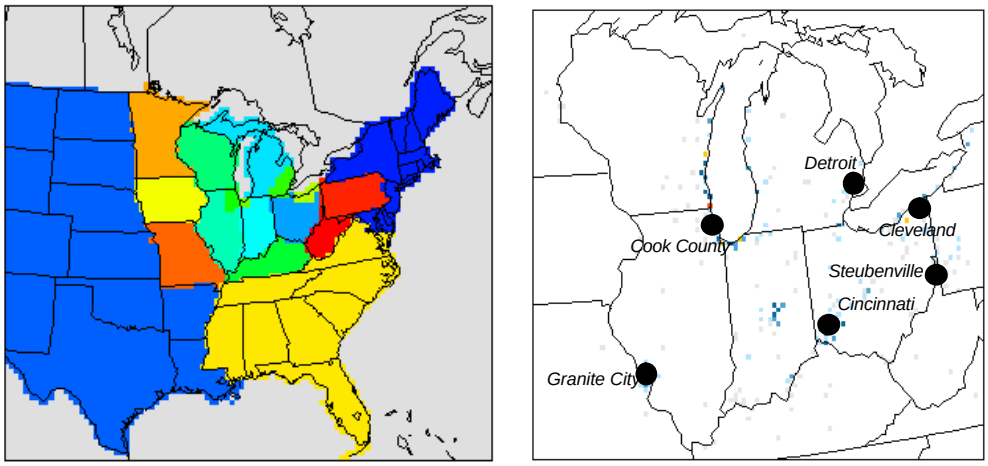


Figure 69. Source regions (left) and key monitoring sites (right) for $PM_{2.5}$ modeling analysis

Modeling results for 2012 (Base K) and 2018 (Base M) are provided in Appendix III for several key monitoring sites. For each monitoring site, there are two graphs: one showing sector-level contributions, and one showing source region and sector-level contributions in terms of absolute modeled values.

The sector-level results (see, for example, Figure 70) show that EGU sulfate, non-EGU-sulfate, and area organic carbon emissions generally have the largest contributions at the key monitor locations (> 15% each). Ammonia emissions are also important contributors (> 10%). The source group contributions vary by receptor location due to emissions inventory differences.

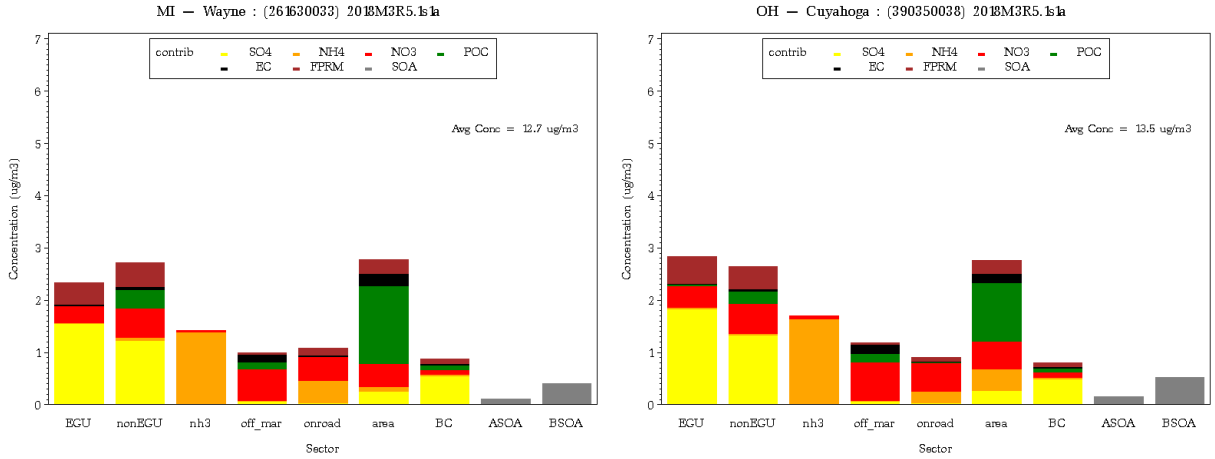


Figure 70. Source-sector results for Detroit (left) and Cleveland (right) monitors – 2018 (Base M)

The source region results (see, for example, Figure 71) show that while nearby areas generally have the highest impacts (e.g., Detroit nonattainment counties contribute 40% to high sites in southeastern Michigan, and Cleveland nonattainment counties contribute 35% to high sites in northeastern Ohio), there is an even larger regional impact (i.e., contribution from other states).

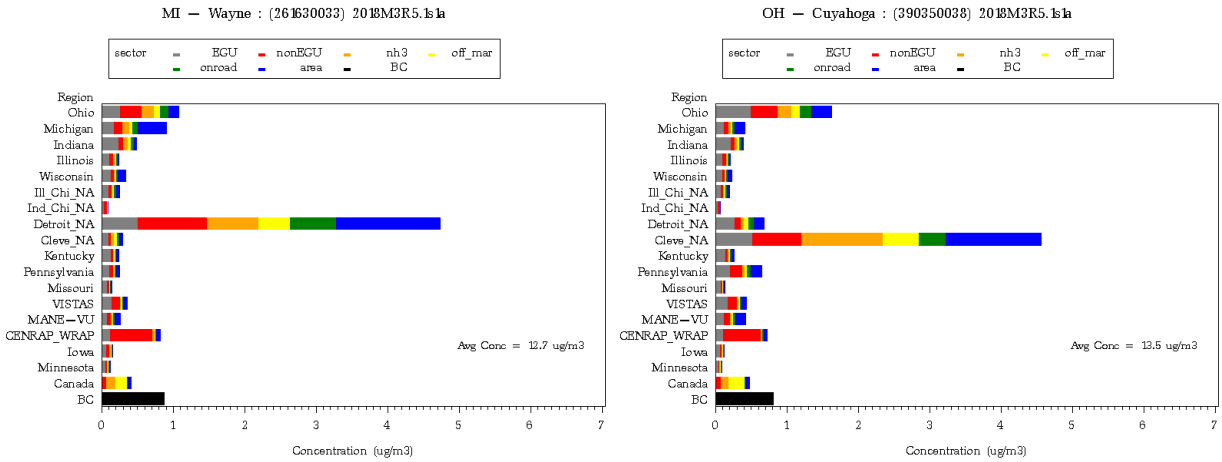


Figure 71. Source-region results for Detroit (left) and Cleveland (right) monitors – 2018 (Base M)

Summary: Air quality modeling and other supplemental analyses were performed to estimate future year $PM_{2.5}$ concentrations. Based on this information, the following general conclusions can be made:

- Existing ("on the books") controls are expected to produce significant improvement in $PM_{2.5}$ air quality.
- The choice of the base year affects the future year model projections. It is not clear how much of this is attributable to differences in meteorology, because, as noted in Section 3, $PM_{2.5}$ concentrations are not as strongly influenced by meteorology as ozone.
- Most sites are expected to meet the current $PM_{2.5}$ standard by the applicable attainment date, except for sites in Detroit, Cleveland, and Granite City.
- Current monitoring data show significant nonattainment in these areas (e.g., peak design values on the order of 16 – 17 ug/m^3). It is not clear whether sufficient emission reductions will occur in the next couple of years to provide for attainment. States are conducting local-scale analyses for Detroit, Cleveland, and Granite City, in particular, to identify appropriate additional local controls.
- Attainment by the applicable attainment date is dependent (possibly) on actual future year meteorology and (more likely) on actual future year emissions (e.g., if the emission reductions associated with the "on the books" controls are achieved, then attainment is likely). On the other hand, if either of these conditions is not met (especially, with respect to emissions), then attainment may be less likely.

Section 5. Reasonable Progress Assessment for Regional Haze

Air quality modeling and other information were used to assess the improvement in visibility that would be provided by existing ("on the books") controls and possible additional control programs. In determining reasonable progress for regional haze, Section 169A of the Clean Air Act and EPA's visibility rule requires states to consider five factors:

- costs of compliance
- time necessary for compliance
- energy and non-air quality environmental impacts of compliance
- remaining useful life of any existing source subject to such requirements
- uniform rate of visibility improvement needed to attain natural visibility conditions by 2064

The uniform rate of visibility improvement requirement can be depicted graphically in the form of a "glide path" (see Figure 72).

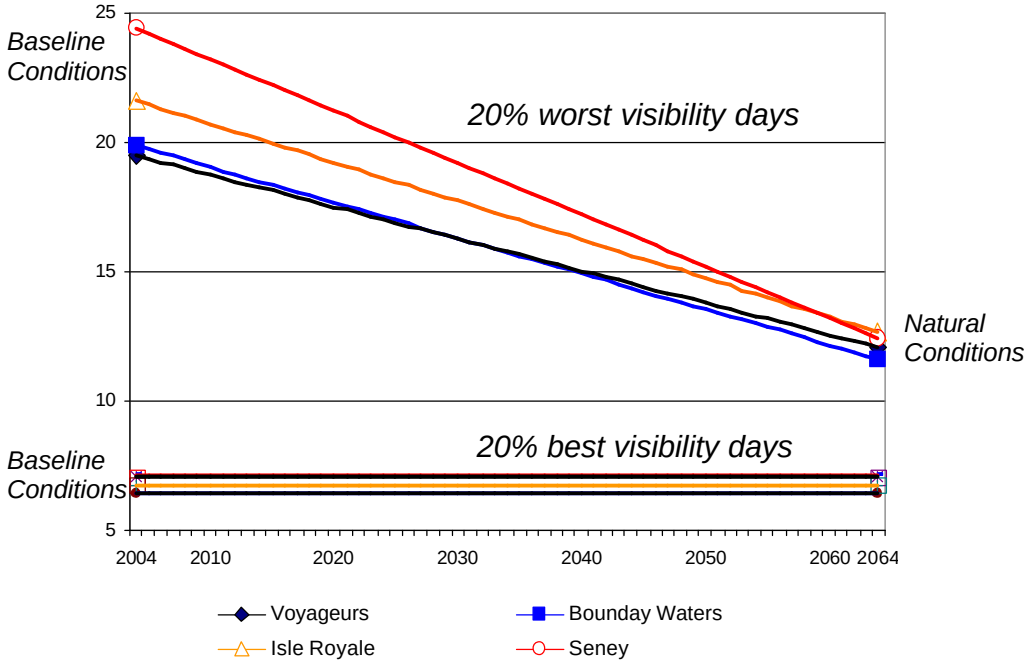


Figure 72. Visibility "glide paths" for northern Class I areas (units: deciviews)

5.1 Class I Areas Impacted

EPA's visibility rule requires a state to "address regional haze in each mandatory Class I Federal area located within the State and in each mandatory Class I Federal area located outside the State which may be affected by emissions from within the State." (40 CFR Part 51.308(d)) To meet this requirement, technical analyses conducted by the RPOs were consulted to obtain information on areas of influence and culpability for Class I areas in the eastern U.S. (MRPO, 2007). A summary of this information is provided in Table 1 (MRPO, 2007). The table shows that every LADCO State impacts multiple Class I areas in the eastern U.S.

Table 14. Draft List of Class I Areas Impacted by LADCO States

AREA NAME	IL	IN	MI	OH	WI
81.401 Alabama.					
Sipsey Wilderness Area	(1)	(1)			
81.404 Arkansas.					
Caney Creek Wilderness Area	(2), (4)	(2), (4)		(2), (4)	
Upper Buffalo Wilderness Area	(1),(2),(4),(5)	(2), (4)		(2), (4)	(2)
81.408 Georgia.					
Cohotta Wilderness Area					
Okefenokee Wilderness Area					
Wolf Island Wilderness Area					
81.411 Kentucky.					
Mammoth Cave NP	(1), (2), (5)	(1), (2), (5)	(1), (2)	(1), (2), (5)	
81.412 Louisiana.					
Breton Wilderness Area					
81.413 Maine.					
Acadia National Park	(3)	(3)	(3)	(3)	
Moosehorn Wilderness Area.	(3)	(3)	(3)	(3)	
81.414 Michigan.					
Isle Royale NP.	(1), (2)	(1), (2)	(1), (2)		(1), (2)
Seney Wilderness Area	(1), (2)	(1), (2)	(1), (2)	(1), (2)	(1), (2)
81.415 Minnesota.					
Boundary Waters Canoe Area Wilderness	(2)	(2)	(2)		(1), (2)
Voyageurs NP	(2)	(2)			(1), (2)
81.416 Missouri.					
Hercules-Glades Wilderness Area	(2), (4), (5)	(2), (4), (5)		(2), (4)	(2)
Mingo Wilderness Area	(2), (4), (5)	(2), (4), (5)	(2)	(2), (4)	(2)
81.419 New Hampshire.					
Great Gulf Wilderness Area	(3)	(3)	(3)	(1), (3)	
Pres. Range-Dry River Wilderness Area.					
81.42 New Jersey.					
Brigantine Wilderness Area	(3)	(3)	(1), (3)	(1), (3)	

81.422 North Carolina.					
Great Smoky Mountains NP{1}	(1)	(1)		(1)	
Joyce Kilmer-Slickrock Wilderness Area{2}					
Linville Gorge Wilderness Area.					
Shining Rock Wilderness Area.					
Swanquarter Wilderness Area					
81.426 South Carolina.					
Cape Romain Wilderness					
81.428 Tennessee.					
Great Smoky Mountains NP{1}.	(1)	(1)		(1)	
Joyce Kilmer-Slickrock Wilderness{2}					
81.431 Vermont.					
Lye Brook Wilderness	(2), (3)	(2), (3)	(2), (3)	(1), (2), (3)	
81.433 Virginia.					
James River Face Wilderness.	(2)	(2)	(2)	(2), (5)	
Shenandoah NP	(2), (3)	(1), (2), (3)	(2), (3)	(1),(2),(3),(5)	
81.435 West Virginia.					
Dolly Sods/Otter Creek Wilderness.	(2), (3)	(1), (2), (3)	(1), (2), (3)	(1),(2),(3),(5)	

Key
(1) MRPO Back Trajectory Analyses
(2) MRPO PSAT Modeling
(3) MANE-VU Contribution Assessment
(4) Missouri-Arkansas Contribution Assessment
(5) VISTAS Areas of Influence

5.2 Future Year Modeling Results

For regional haze, the calculation of future year conditions assumed:

- baseline concentrations based on 2000-2004 IMPROVE data, with updated (subsitituted) data for Mingo, Boundary Waters, Voyageurs, Isle Royale, and Seney (see Section 2.3);
- use of the new IMPROVE light extinction equation; and
- use of EPA default values for natural conditions, based on the new IMPROVE light extinction equation.

The uniform rate of visibility improvement values for the 2018 planning year were derived (for the 20% worst visibility days) based on a straight line between baseline concentration value (plotted in the year 2004 -- end year of the 5-year baseline period) and natural condition value (plotted in the year 2064 -- date for achieving natural conditions). Plots of these "glide paths" with the Base M modeling results are presented in Figure 73 for Class I areas in the eastern U.S. A tabular summary of measured baseline and modeled future year deciview values for these Class I areas are provided in Table 15 (2002 base year) and Table 16 (2005 base year)[13].

The haze results show that several Class I areas in the eastern U.S. are expected to be greater than (less improved than) the uniform rate of visibility improvement values (in 2018), including those in northern Michigan and several in the northeastern U.S. Many other Class I areas in the eastern U.S. are expected to be less than (more improved than) the uniform rate of visibility improvement values (in 2018). As noted above, states should consider these results, along with information on the other four factors, in setting reasonable progress goals.

An assessment of the five factors was performed for LADCO and the State of Minnesota by a contractor (EC/R, 2007). Specifically, ECR examined reductions in SO2 and NOx emissions from EGUs and industrial, commercial and institutional (ICI) boilers; NOx emissions from mobile sources and reciprocating engines and turbines; and ammonia emissions from agricultural operations. The impacts of "on the books" controls were also examined to provide a frame of reference for assessing the impacts of the additional control measures.

The results of ECR's analysis of the five factors are summarized below:

Factor 1 (Cost of Compliance): The average cost effectiveness values (in terms of $M per ton) are provided in Table 16. For comparison, cost-effectiveness estimates previously provided for "on the books" controls include:

CAIR SO2: $700 - $1,200, NOx: $1,400 – $2.600 ($/T)

BART SO2: $300 - $963, NOx: $248 - $1,770

MACT SO2: $1,500, NOx: $7,600

Most of the cost-effectiveness values for the additional controls are within the range of cost-effectiveness values for "on the books" controls.

[13] Model results reflect the grid cell where the IMPROVE monitor is located.

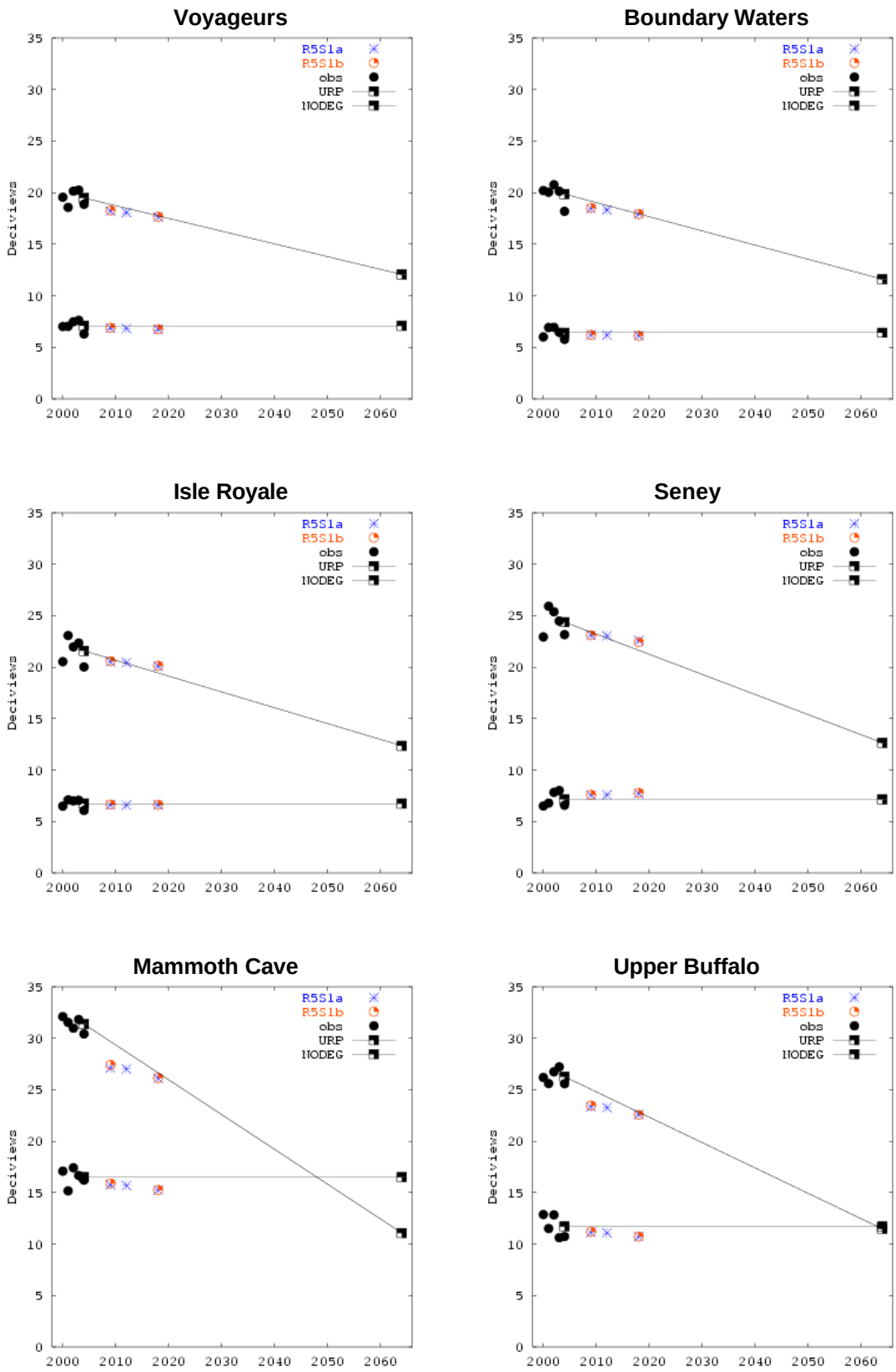


Figure 73. Visibility modeling results for Class I areas in eastern U.S.

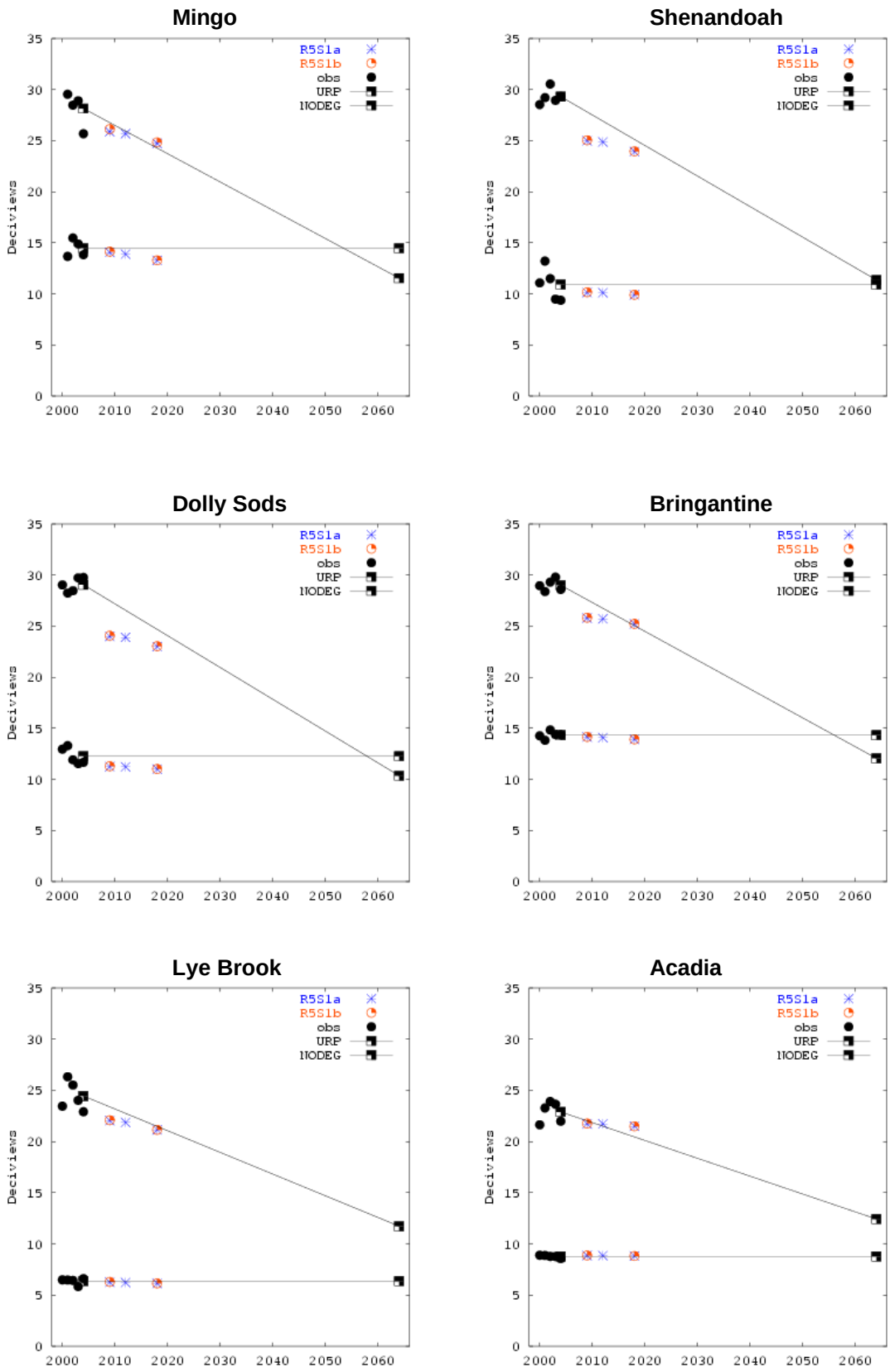


Figure 73 (cont.) Visibility modeling results for Class I areas in eastern U.S.

Table 15. Haze Results - Round 4 (Based on 2000-2004)							
Worst 20%		**2018**	**2009**	**2012**	**2018**	**2018**	**2018**
Site	**Baseline**	**URP**	**OTB**	**OTB**	**OTB**	**EGU2 (5-state region)**	**EGU2 (12-state region)**
BOWA1	19.86	17.70	19.05	19.01	**18.94**	**18.40**	17.72
VOYA2	19.48	17.56	19.14	19.19	**19.18**	**18.94**	**18.38**
SENE1	24.38	21.35	22.98	22.71	**22.38**	21.26	20.63
ISLE1	21.59	19.21	20.46	20.28	**20.04**	19.09	18.64
HEGL1	26.75	22.76	24.73	24.34	**23.85**	**23.01**	22.04
MING1	28.15	24.08	25.18	24.67	24.01	22.53	21.45
CACR1	26.36	22.55	24.01	23.55	**22.99**	22.43	21.57
UPBU1	26.27	22.47	24.02	23.58	**23.06**	22.31	21.38
MACA1	31.37	26.14	28.06	27.03	25.52	24.27	22.57
DOSO1	29.04	24.23	24.86	23.59	22.42	21.60	20.15
SHEN1	29.31	24.67	24.06	22.79	21.57	20.43	19.42
JARI1	29.12	24.48	24.81	23.79	22.42	21.59	20.88
BRIG1	29.01	24.68	25.87	25.25	24.39	23.91	23.45
LYBR1	24.45	21.16	21.80	21.32	20.69	20.18	19.79
Best 20%		**2018**	**2009**	**2012**	**2018**	**2018**	**2018**
Site	**Baseline**	**URP**	**OTB**	**OTB**	**OTB**	**EGU2 (5-state region)**	**EGU2 (12-state region)**
BOWA1	6.42	6.42	6.71	6.73	6.87	6.83	6.81
VOYA2	7.09	7.09	7.21	7.25	7.34	7.31	7.26
SENE1	7.14	7.14	7.19	7.19	7.23	7.06	6.91
ISLE1	6.75	6.75	6.57	6.51	6.47	6.20	6.06
HEGL1	12.84	12.84	12.61	12.62	12.61	12.43	12.02
MING1	14.46	14.46	13.96	13.93	13.94	13.74	13.33
CACR1	11.24	11.24	10.91	10.92	10.90	10.75	10.42
UPBU1	11.71	11.71	11.47	11.46	11.42	11.28	11.01
MACA1	16.51	16.51	16.06	15.91	15.54	15.18	14.75
DOSO1	12.28	12.28	11.72	11.45	11.19	10.93	10.67
SHEN1	10.93	10.93	9.73	9.53	9.17	9.05	8.90
JARI1	14.21	14.21	13.56	13.33	12.97	12.65	12.46
BRIG1	14.33	14.33	13.74	13.69	13.47	13.32	13.21
LYBR1	6.36	6.36	6.12	6.05	5.96	5.88	5.82

Table 16. Haze Results - Round 5.1 (Based on 2000-2004)						
Worst 20%		**2018**	**2009**	**2012**	**2018**	**2018**
Site	**Baseline**	**URP**	**OTB**	**OTB**	**OTB**	**OTB+Will DO**
BOWA1	19.86	17.94	18.45	18.33	17.94	17.92
VOYA2	19.48	17.75	18.20	18.07	17.63	17.66
SENE1	24.38	21.64	23.10	23.04	**22.59**	**22.42**
ISLE1	21.59	19.43	20.52	20.43	**20.09**	**20.13**
ISLE9	21.59	19.43	20.33	20.22	**19.84**	**19.82**
HEGL1	26.75	23.13	24.72	24.69	**24.22**	**24.17**
MING1	28.15	24.27	25.88	25.68	**24.74**	**24.83**
CACR1	26.36	22.91	23.39	23.29	22.44	22.40
UPBU1	26.27	22.82	23.34	23.27	22.59	22.55
MACA1	31.37	26.64	27.11	27.01	26.10	26.15
DOSO1	29.05	24.69	24.00	23.90	23.00	23.04
SHEN1	29.31	25.12	24.99	24.87	23.92	23.95
JARI1	29.12	24.91	25.17	25.01	24.06	24.12
BRIG1	29.01	25.05	25.79	25.72	**25.21**	**25.22**
LYBR1	24.45	21.48	22.04	21.86	21.14	21.14
ACAD1	22.89	20.45	21.72	21.72	**21.49**	**21.49**
Best 20%		**2018**	**2009**	**2012**	**2018**	**2018**
Site	**Baseline**	**Max**	**OTB**	**OTB**	**OTB**	**OTB+Will DO**
BOWA1	6.42	6.42	6.21	6.19	6.14	6.12
VOYA2	7.09	7.09	6.86	6.83	6.75	6.76
SENE1	7.14	7.14	7.57	7.58	7.71	7.78
ISLE1	6.75	6.75	6.62	6.59	6.60	6.62
ISLE9	6.75	6.75	6.56	6.55	6.52	6.50
HEGL1	12.84	12.84	12.51	12.32	11.66	11.64
MING1	14.46	14.46	14.07	13.89	13.28	13.29
CACR1	11.24	11.24	10.88	10.85	10.52	10.52
UPBU1	11.71	11.71	11.13	11.08	10.73	10.74
MACA1	16.51	16.51	15.76	15.69	15.25	15.25
DOSO1	12.28	12.28	11.25	11.23	11.00	11.01
SHEN1	10.93	10.93	10.13	10.11	9.91	9.91
JARI1	14.21	14.21	13.38	13.38	13.14	13.14
BRIG1	14.33	14.33	14.15	14.08	13.92	13.92
LYBR1	6.37	6.37	6.25	6.23	6.14	6.15
ACAD1	8.78	8.78	8.86	8.86	8.82	8.82

Table 17. Estimated Cost Effectiveness for Potential Control Measures

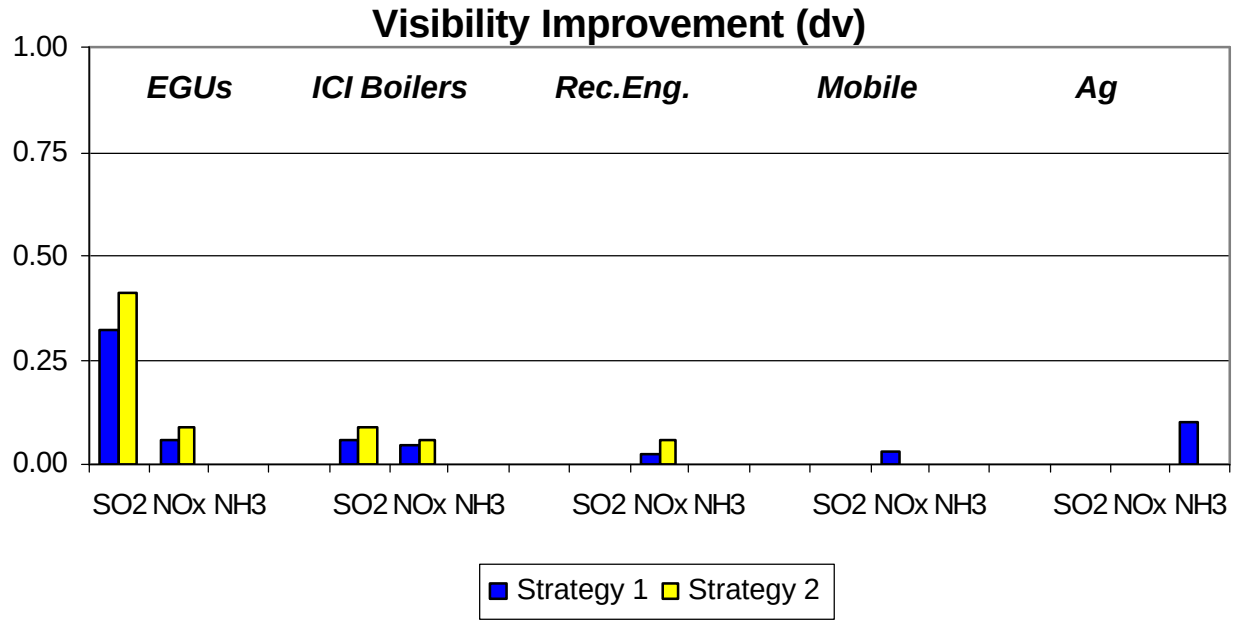
			Average Cost effectiveness ($/ton)		
Emission category	Control strategy	Region	SO2	NOX	NH3
EGU	EGU1	3-State	1,540	2,037	
		9-State	1,743	1,782	
	EGU2	3-State	1,775	3,016	
		9-State	1,952	2,984	
ICI boilers	ICI1	3-State	2,992	2,537	
		9-State	2,275	1,899	
	ICI Workgroup	3-State	2,731	3,814	
		9-State	2,743	2,311	
Reciprocating engines and turbines	Reciprocating engines emitting 100 tons/year or more	3-State		538	
		9-State		506	
	Turbines emitting 100 tons/year or more	3-State		754	
		9-State		754	
	Reciprocating engines emitting 10 tons/year or more	3-State		1,286	
		9-State		1,023	
	Turbines emitting 10 tons/year or more	3-State		800	
		9-State		819	
Agricultural sources	10% reduction	3-State			31 - 2,700
		9-State			31 - 2,700
	15% reduction	3-State			31 - 2,700
		9-State			31 - 2,700
Mobile sources	Low-NOX Reflash	3-State		241	
		9-State		241	
	MCDI	3-State		10,697	
		9-State		2,408	
	Anti-Idling	3-State		(430) - 1,700	
		9-State		(430) - 1,700	
	Cetane Additive Program	3-State		4,119	
		9-State		4,119	
Cement Plants	Process Modification	Michigan		-	
	Conversion to dry kiln	Michigan		9,848	
	LoTox™	Michigan		1,399	
Glass Manufacturing	LNB	Wisconsin		1,041	
	Oxy-firing	Wisconsin		2,833	
	Electric boost	Wisconsin		3,426	
	SCR	Wisconsin		1,054	
	SNCR	Wisconsin		1,094	
Lime Manufacturing	Mid-kiln firing	Wisconsin		688	
	LNB	Wisconsin		837	
	SNCR	Wisconsin		1,210	
	SCR	Wisconsin		5,037	
	FGD	Wisconsin		128 - 4,828	
Oil Refinery	LNB	Wisconsin		3,288	
	SNCR	Wisconsin		4,260	
	SCR	Wisconsin		17,997	
	LNB+FGR	Wisconsin		4,768	
	ULNB	Wisconsin		2,242	
	FGD	Wisconsin		1,078	

Factor 2 (Time Necessary for Compliance): All of the control measures can be implemented by 2018. Thus, this factor can be easily addressed.

Factor 3 (Energy and Non-Air Quality Environmental Impacts): The energy and other environmental impacts are believed to be manageable. For example, the increased energy demand from add-on control equipment is less than 1% of the total electricity and steam production in the region, and solid waste disposal and wastewater treatment costs are less than 5% of the total operating costs of the pollution control equipment. It should also be noted that the SO2 and NOx controls would have beneficial environmental impacts (e.g., reduced acid deposition and nitrogen deposition).

Factor 4 (Remaining Useful Life): The additional control measures are intended to be market-based strategies applied over a broad geographic region. It is not expected that the control requirements will be applied to units that will be retired prior to the amortization period for the control equipment. Thus, this factor can be easily addressed.

Factor 5 (Visibility Impacts): The estimated incremental improvement in 2018 visibility levels for the additional measures is shown in Figure 74, along with the cost-effectiveness expressed in $M per deciview improvement). These results show that although EGU and ICI boiler controls have higher cost-per-deciview values (compared to some of the other measures), their visibility impacts are larger.



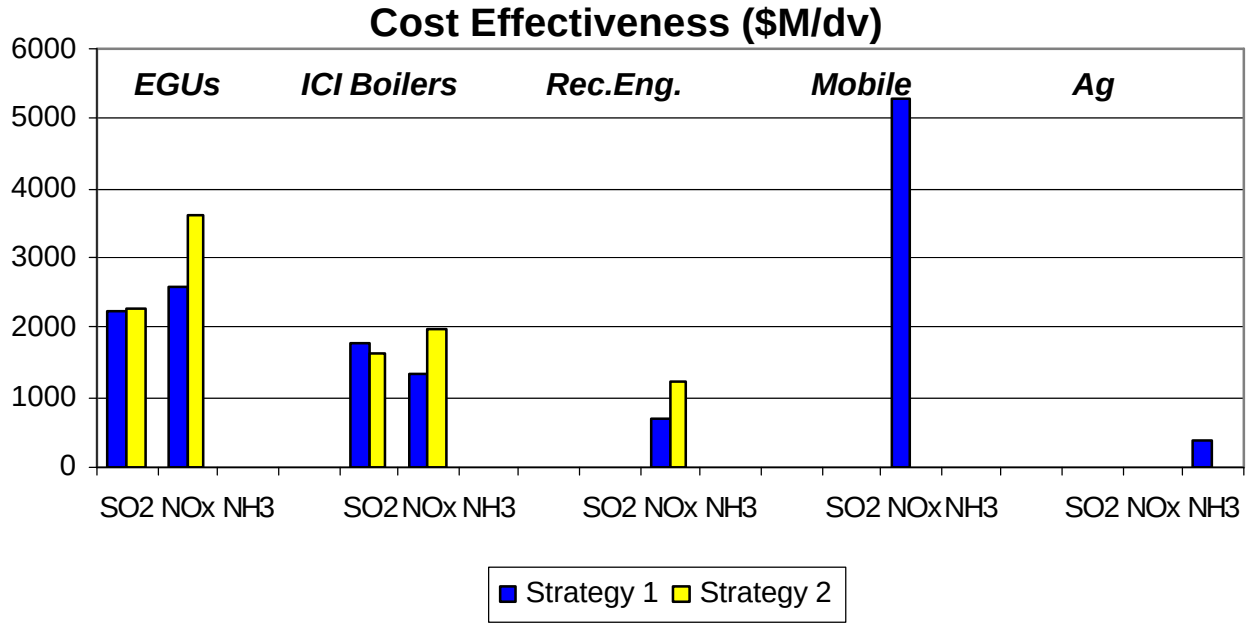


Figure 74. Results of ECR analysis of reasonable progress factors – visibility improvement (Factor 5) is on top, and cost effectiveness (Factor 1) is on bottom

5.3 Weight-of-Evidence Determination for Haze

The WOE determination for haze consists of the primary modeling and other supplemental analyses. A summary of this information is provided below.

Primary (Guideline) Modeling: The results of the guideline modeling are presented in Section 4.1. Key findings from this modeling include:

- Base M modeling results show that the northern Minnesota Class I areas are close to the glide path, whereas the northern Michigan Class I areas are above the glide path in 2018. Other sites in the eastern U.S. are close to (or below) the glide path, except for Mingo (MO), Brigantine (NJ), and Acadia (ME).

- Base K modeling results show that the northern Minnesota and northern Michigan Class I areas are above the glide path in 2018. Other sites in the eastern U.S. are close to (or below) the glide path.

- The difference in the two modeling analyses is due mostly to differences in future year emission projections, especially for EGUs (e.g., use of IPM2.1.9 v. IPM3.0).

- Base K and Base M modeling analyses are considered "SIP quality", so the attainment demonstration for haze should reflect a weight-of-evidence approach, with consideration of monitoring based information.

Additional Modeling: Two additional modeling analyses were considered: (1) the primary modeling redone with different baseline values, and (2) modeling by the State of Minnesota which looked at different receptor locations in the northern Class I areas (MPCA, 2008). Each of these analyses is described below.

First, the primary modeling analysis (Base M) was revised using an alternative baseline value. Specifically, the data for the period 2000-2005 were used to calculate the baseline, given that the Base M modeling reflects a 2005 base year. The results of this alternative analysis (see Table 18) are generally consistent with the primary modeling (see Table 16).

Second, Minnesota's modeling reflects a 2002 base year and much of the data developed by LADCO for its modeling. (Note, Minnesota conducted modeling for LADCO's domain at 36 km, and for a statewide domain at 12 km.) The purpose of the 12 km modeling was to address local scale impacts on the northern Class I areas at several locations, not just the location of the IMPROVE monitor. Results for the Boundary Waters on the 20% worst days range from 18.3 – 19.0 dv, with an average value of 18.7 dv, which is consistent with Minnesota's 36 km modeling results at the IMPROVE monitor. This variability in visibility levels should be kept in mind when reviewing the values presented in Tables 15, 16, and 18, which reflect results at the IMPROVE monitor locations.

Table 18. Haze Results - Round 5.1 (Based on 2000-2005)						
Worst 20%			**2009**	**2012**	**2018**	**2018**
Site	**Baseline**	**URP**	**OTB**	**OTB**	**OTB**	**OTB+Will DO**
BOWA1	20.10	18.12	18.63	18.51	18.12	18.09
VOYA2	19.62	17.86	18.27	18.15	17.70	17.72
SENE1	24.77	21.94	23.44	23.39	**22.94**	**22.77**
ISLE1	21.95	19.71	20.84	20.76	**20.41**	**20.44**
ISLE9	21.95	19.71	20.65	20.55	**20.15**	**20.13**
HEGL1	27.45	23.67	25.30	25.27	**24.79**	**24.73**
MING1	28.92	24.86	25.88	25.68	24.74	24.83
CACR1	27.05	23.44	23.88	23.78	22.92	22.86
UPBU1	26.97	23.36	23.92	23.85	23.14	23.09
MACA1	31.76	26.93	27.42	27.32	26.39	26.44
DOSO1	29.36	24.92	24.20	24.11	23.19	23.23
SHEN1	29.45	25.23	25.06	24.94	23.98	24.01
JARI1	29.40	25.13	25.32	25.17	24.22	24.28
BRIG1	29.12	25.14	25.84	25.77	**25.26**	**25.26**
LYBR1	24.71	21.69	22.22	22.06	21.36	21.36
ACAD1	22.91	20.47	21.72	21.72	**21.49**	**21.49**
Best 20%			**2009**	**2012**	**2018**	**2018**
Site	**Baseline**	**URP**	**OTB**	**OTB**	**OTB**	**OTB+Will DO**
BOWA1	6.40	6.40	6.20	6.17	6.13	6.10
VOYA2	7.05	7.05	6.82	6.78	6.71	6.71
SENE1	7.20	7.20	7.60	7.61	7.73	7.80
ISLE1	6.80	6.80	6.67	6.64	6.65	6.66
ISLE9	6.80	6.80	6.62	6.61	6.57	6.55
HEGL1	13.04	13.04	12.71	12.51	11.85	11.82
MING1	14.68	14.68	14.07	13.89	13.28	13.29
CACR1	11.62	11.62	11.24	11.20	10.86	10.86
UPBU1	11.99	11.99	11.41	11.36	11.01	11.02
MACA1	16.64	16.64	15.88	15.82	15.37	15.38
DOSO1	12.24	12.24	11.21	11.19	10.96	10.97
SHEN1	10.85	10.85	10.04	10.02	9.82	9.83
JARI1	14.35	14.35	13.51	13.51	13.27	13.27
BRIG1	14.36	14.36	14.17	14.10	13.94	13.94
LYBR1	6.21	6.21	6.11	6.09	6.01	6.01
ACAD1	8.57	8.57	8.67	8.66	8.62	8.62

Observational Models and Diagnostic Analyses: The observation-based modeling (i.e., application of thermodynamic equilibrium models) is presented in Section 3. The key findings from this modeling are that $PM_{2.5}$ mass is sensitive to reductions in sulfate, nitric acid, and ammonia concentrations. Even though sulfate reductions cause more ammonia to be available to form ammonium nitrate (PM-nitrate increases slightly when sulfate is reduced), this increase is generally offset by the sulfate reductions, such that $PM_{2.5}$ mass decreases and visibility improves. Under conditions with lower sulfate levels (i.e., proxy of future year conditions), $PM_{2.5}$ is more sensitive to reductions in nitric acid compared to reductions in ammonia.

As discussed in Section 2, thermodynamic equilibrium modeling based on data collected at Seney indicates that $PM_{2.5}$ there is most sensitive to reductions in sulfate, but also responsive to reductions in nitric acid (Blanchard, 2004). An analysis using data from the Midwest ammonia monitoring network for a site in Minnesota (i.e., Great River Bluffs, which is the closest ammonia monitoring site to the northern Class I areas) suggested that reductions in sulfate, nitric acid, and ammonia concentrations will lower $PM_{2.5}$ concentrations and improve visibility levels in the northern Class I areas.

Trajectory analyses for the 20% worst visibility days for the four northern Class I areas are provided in Figure 75. (Note, this figure is similar to Figure 34, but the trajectory results for each Class I area are displayed separately here.) The orange areas are where the air is most likely to come from, and the green areas are where the air is least likely to come from. Darker shading represents higher frequency. As can be seen, bad air days are generally associated with transport from regions located to the south, and good air days with transport from Canada.

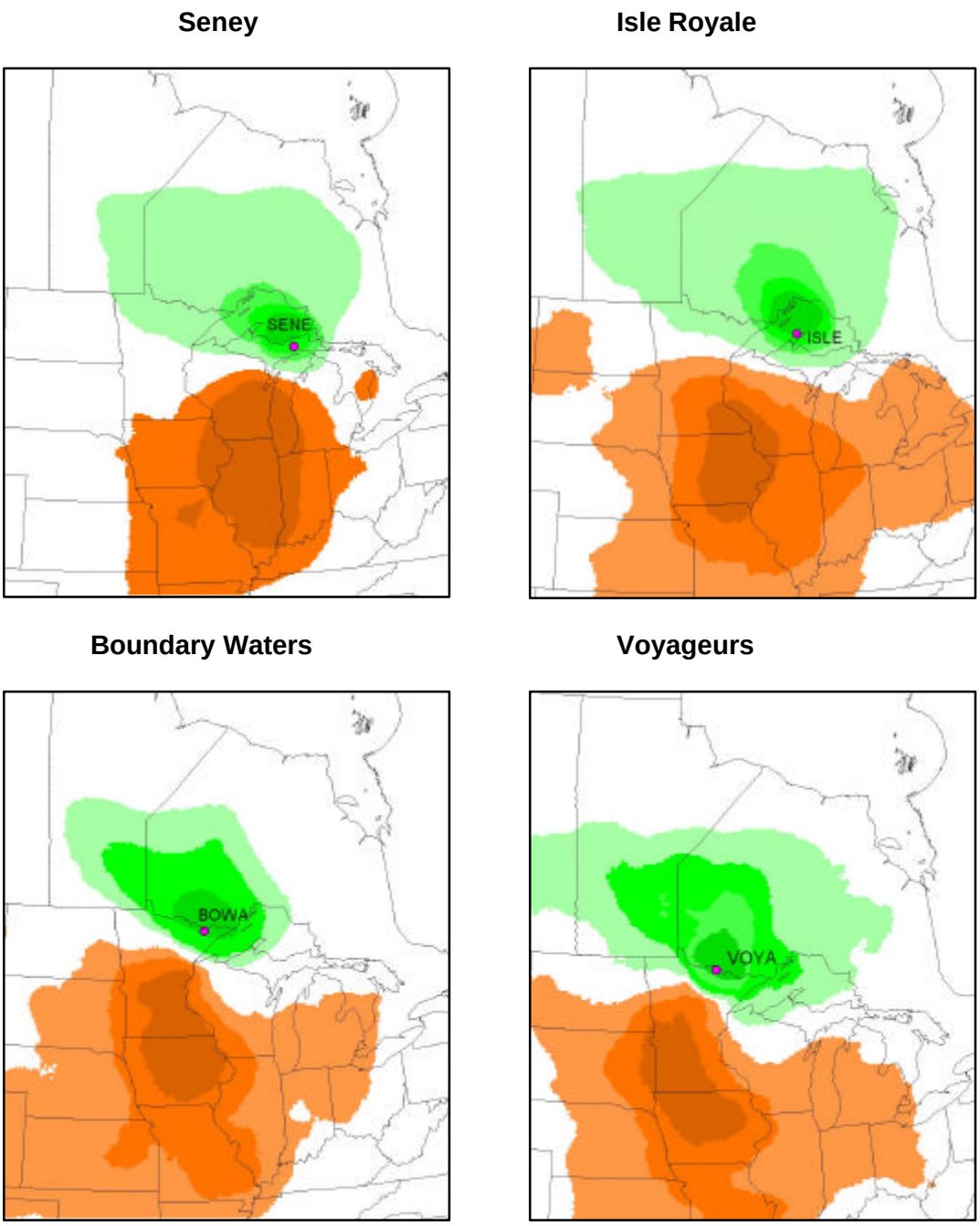


Figure 75. Trajectory analysis results for northern Class I areas on 20% worst visibility days

The primary diagnostic analysis is source apportionment modeling with CAMx to provide more quantitative information on source region (and source sector) impacts (Baker, 2007b). Specifically, the CAMx model was applied to provide source contribution information. Specifically, the model estimated the impact of 18 geographic source regions (which are identified in Figure 76) and 6 source se ctors (EGU point, non-EGU point, on-road, off-road, area, and ammonia sources) at visibility/haze monitoring sites in the eastern U.S.

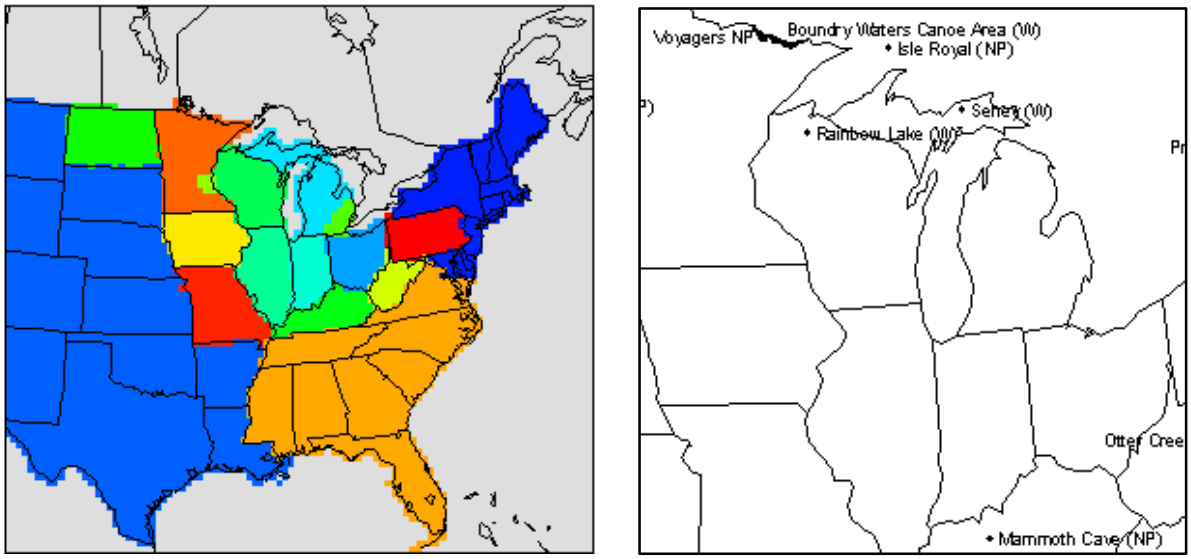


Figure 76. Source regions (left) and key monitoring sites (right) for haze modeling analysis

Modeling results for 2018 (Base K and Base M) are provided in Appendix IV for several key monitoring sites (Class I areas). For each monitoring site, there are two graphs: one showing sector-level contributions, and one showing source region and sector-level contributions in terms of absolute modeled values.

The sector-level results (see, for example, Figure 77) show that EGU sulfate, non-EGU-sulfate, and ammonia emissions generally have the largest contributions at the key monitor locations. The source group contributions vary by receptor location due to emissions inventory differences.

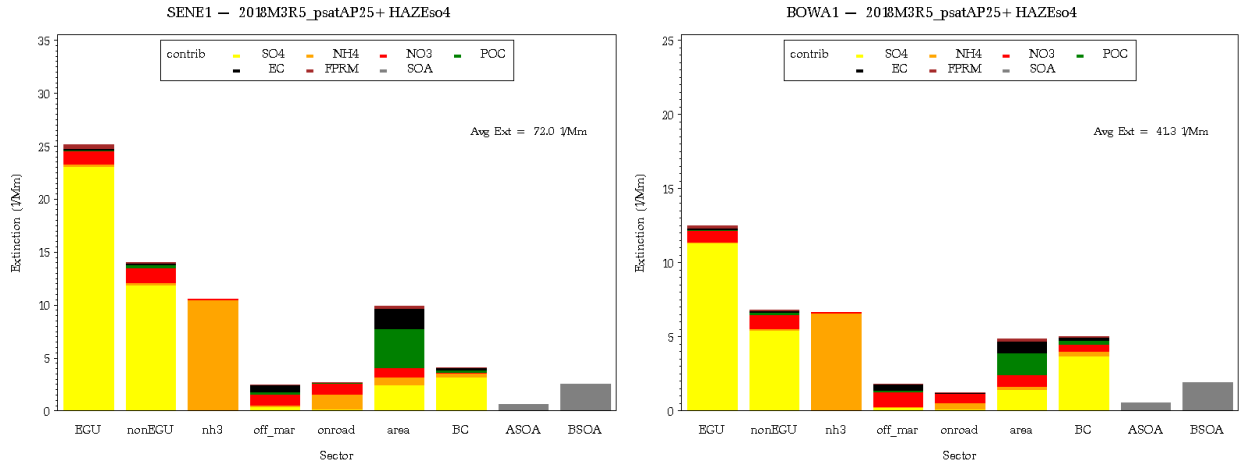


Figure 77. Source-sector results for Seney (left) and Boundary Waters (right) – 2018 (Base M)

The source region results (see, for example, Figure 78) show that emissions from a number of nearby states contribute to regional haze levels.

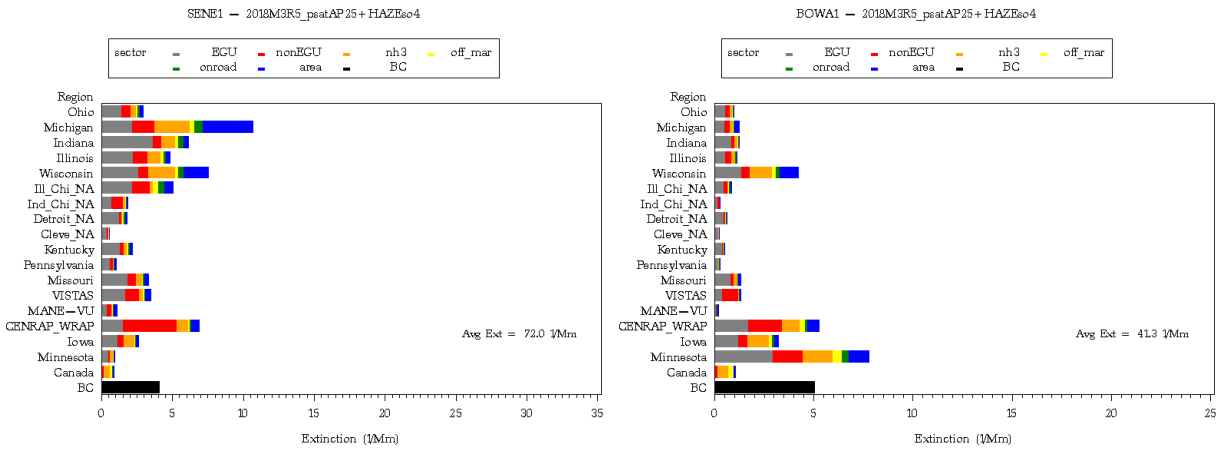


Figure 78. Source-region results for Seney (left) and Boundary Waters (right) – 2018 (Base M)

Table 19 provides a summary of the estimated state-level culpabilities based on the LADCO back trajectory analyses and the PSAT analyses for 2018.

Summary: Air quality modeling and other supplemental analyses were performed to estimate future year visibility levels. Based on this information, the following general conclusions can be made:

- Existing ("on the books") controls are expected to improve visibility levels in the northern Class I areas.
- Visibility levels in a few Class I areas in the eastern U.S. are expected to be greater than (less improved than) the uniform rate of visibility improvement values in 2018, including those in northern Michigan and some in the northeastern U.S.
- Visibility levels in many other Class I areas in the eastern U.S. are expected to be less than (more improved than) the uniform rate of visibility improvement values in 2018.

Table 19. State Culpabilities Based on PSAT Modeling and Trajectory Analyses

	Boundary Waters						Seney			
	LADCO - Round 4 PSAT	**LADCO - Round 5 PSAT**	**MPCA- PSAT**	**CENRAP - PSAT**	**LADCO - Traj. Analysis**		**LADCO - Round 4 PSAT**	**LADCO - Round 5 PSAT**	**CENRAP - PSAT**	**LADCO - Traj. Analysis**
Michigan	3.4%	4.8%	3.0%	1.9%	0.7%		13.8%	18.1%		14.7%
Minnesota	30.5%	23.5%	28.0%	30.6%	37.6%		4.8%	1.6%		3.8%
Wisconsin	10.4%	10.9%	10.0%	6.4%	10.6%		12.6%	10.9%		8.4%
Illinois	5.2%	5.1%	6.0%	3.5%	2.7%		13.0%	14.3%		7.4%
Indiana	2.9%	3.9%	3.0%	1.8%	1.2%		9.6%	11.6%		2.2%
Iowa	7.6%	8.3%	8.0%	2.5%	7.4%		6.2%	3.8%		5.7%
Missouri	5.2%	3.4%	6.0%	2.1%	3.3%		6.5%	4.8%		3.2%
N. Dakota	5.7%	1.1%	6.0%	4.6%	5.9%		1.5%	0.1%		0.6%
Canada	1.9%	2.7%	3.0%	12.5%	15.1%		2.1%	1.2%		11.1%
CENRAP-WRAP	10.9%	13.5%		4.2%	10.1%		13.1%	10.0%		7.0%
	83.6%	**77.2%**	**73.0%**	**70.2%**	**94.6%**		**83.3%**	**76.4%**		**64.1%**
	Voyageurs						**Isle Royale**			
	LADCO - Round 4 PSAT	**LADCO - Round 5 PSAT**	**MPCA- PSAT**	**CENRAP - PSAT**	**LADCO - Traj. Analysis**		**LADCO - Round 4 PSAT**	**LADCO - Round 5 PSAT**	**CENRAP - PSAT**	**LADCO - Traj. Analysis**
Michigan	2.0%	4.9%	2.0%	1.0%	1.6%		12.7%	13.4%		
Minnesota	35.0%	20.2%	31.0%	31.5%	36.9%		14.1%	9.5%		
Wisconsin	6.3%	7.9%	6.0%	3.7%	9.7%		16.3%	14.7%		
Illinois	3.0%	7.1%	3.0%	1.8%	1.2%		7.0%	8.7%		
Indiana	1.6%	4.6%	2.0%	0.8%			5.6%	5.2%		
Iowa	7.4%	7.1%	7.0%	2.4%	10.2%		6.9%	8.3%		
Missouri	4.3%	4.0%	4.0%	1.6%	0.3%		3.9%	4.6%		
N. Dakota	10.3%	1.7%	13.0%	6.1%	7.1%		3.6%	0.3%		
Canada	2.7%	3.3%	5.0%	17.2%	13.3%		2.2%	1.7%		
CENRAP-WRAP	10.2%	13.7%		6.1%	16.5%		12.5%	12.6%		
	82.7%	**74.5%**	**73.0%**	**72.2%**	**96.8%**		**84.9%**	**79.0%**		

Section 6. Summary

To support the development of SIPs for ozone, $PM_{2.5}$, and regional haze in the States of Illinois, Indiana, Michigan, Ohio, and Wisconsin, technical analyses were conducted by LADCO, its member states, and various contractors. The analyses include preparation of regional emissions inventories and meteorological modeling data for two base years, evaluation and application of regional chemical transport models, and review of ambient monitoring data.

Analyses of monitoring data were conducted to produce a conceptual model, which is a qualitative summary of the physical, chemical, and meteorological processes that control the formation and distribution of pollutants in a given region. Key findings of the analyses include:

Ozone

- Current monitoring data show about 20 sites in violation of the 8-hour ozone standard of 85 ppb. Historical ozone data show a steady downward trend over the past 15 years, especially since 2001-2003, due likely to federal and state emission control programs.

- Ozone concentrations are strongly influenced by meteorological conditions, with more high ozone days and higher ozone levels during summers with above normal temperatures.

- Inter- and intra-regional transport of ozone and ozone precursors affects many portions of the five states, and is the principal cause of nonattainment in some areas far from population or industrial centers

$PM_{2.5}$

- Current monitoring data show 30 sites in violation of the annual $PM_{2.5}$ standard of 15 ug/m^3. Nonattainment sites are characterized by an elevated regional background (about 12 – 14 ug/m^3) and a significant local (urban) increment (about 2 – 3 ug/m^3). Historical $PM_{2.5}$ data show a slight downward trend since deployment of the $PM_{2.5}$ monitoring network in 1999.

- $PM_{2.5}$ concentrations are also influenced by meteorology, but the relationship is more complex and less well understood compared to ozone.

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

Haze

- Current monitoring data show visibility levels in the Class I areas in northern Michigan are on the order of 22 – 24 deciviews. The goal of EPA's visibility program is to achieve natural conditions, which is on the order of 12 deciviews for these Class I areas, by the year 2064.

- Visibility impairment is dominated by sulfate and nitrate.

Air quality models were applied to support the regional planning efforts. Two base years were used in the modeling analyses: 2002 and 2005. EPA's modeling guidance recommends using

2002 as the baseline inventory year, but also allows for use of an alternative baseline inventory year, especially a more recent year. Initially, LADCO conducted modeling with a 2002 base year (i.e., Base K modeling, which was completed in 2006). A decision was subsequently made to conduct modeling with a 2005 base year (i.e., Base M, which was completed in 2007). Statistical analyses showed that 2002 and 2005 both had above normal ozone-conducive conditions, although 2002 was more severe compared to 2005. Examination of multiple base years provides for a more complete technical assessment. Both sets of model runs are discussed in this document.

Basecase modeling was conducted to evaluate model performance (i.e., assess the model's ability to reproduce the observed concentrations). This exercise was intended to assess whether, and to degree, confidence in the model is warranted (and to assess whether model improvements are necessary). Model performance for ozone and $PM_{2.5}$ was generally acceptable and can be characterized as follows:

Ozone

- Good agreement between modeled and monitored concentration for higher concentration levels (> 60 ppb) – i.e., bias within 30%

- Regional modeled concentrations appear to be underestimated in the 2002 base year, but show better agreement (with monitored data) in the 2005 base year due to model and inventory improvements.

- Day-to-day and hour-to-hour variation in and spatial patterns of modeled concentrations are consistent with monitored data

- Model accurately simulates the change in monitored ozone concentrations due to reductions in precursor emissions.

$PM_{2.5}$

- Good agreement in the magnitude of fine particle mass, but some species are overestimated and some are underestimated
    - Sulfates: good agreement in the 2002 base year, but underestimated in the summer in the 2005 base year due probably to meteorological factors
    - Nitrates: slightly overestimated in the winter in the 2002 base year, but good agreement in the 2005 base year as a result of model and inventory improvements
    - Organic Carbon: grossly underestimated in the 2002 and 2005 base years due likely to missing primary organic carbon emissions

- Temporal variation and spatial patterns of modeled concentrations are consistent with monitored data

Future year strategy modeling was conducted to determine whether existing ("on the books") controls would be sufficient to provide for attainment of the standards for ozone and $PM_{2.5}$ and if not, then what additional emission reductions would be necessary for attainment. Traditionally, attainment demonstrations involved a "bright line" test in which a single modeled value (based on EPA guidance) was compared to the ambient standard. To provide a more robust assessment of expected future year air quality, other information was considered. Furthermore, according to EPA's modeling guidance, if the future year modeled values are "close" to the

standard (i.e., 82 – 87 ppb for ozone and 14.5 – 15.5 ug/m^3 for $PM_{2.5}$), then the results of the primary modeling should be reviewed along with the supplemental information in a "weight of evidence" (WOE) assessment of whether each area is likely to achieve timely attainment. Key findings of the WOE determination include:

- Existing controls are expected to produce significant improvement in ozone and $PM_{2.5}$ concentrations and visibility levels.

- The choice of the base year affects the future year model projections. A key difference between the base years of 2002 and 2005 is meteorology. 2002 was more ozone conducive than 2005. The choice of which base year to use as the basis for the SIP is a policy decision (i.e., how much safeguard to incorporate).

- Most sites are expected to meet the current 8-hour standard by the applicable attainment date, except for sites in western Michigan and, possibly, in eastern Wisconsin and northeastern Ohio.

- Most sites are expected to meet the current $PM_{2.5}$ standard by the applicable attainment date, except for sites in Detroit, Cleveland, and Granite City.

  The regional modeling for $PM_{2.5}$ does not reflect air quality benefits expected from local controls. States are conducting local-scale analyses and will use these results, in conjunction with the regional-scale modeling, to support their attainment demonstrations for $PM_{2.5}$.

- These findings of residual nonattainment for ozone and $PM_{2.5}$ are supported by current (2005 – 2007) monitoring data which show significant nonattainment in the region (e.g., peak ozone design values on the order of 90 – 93 ppb, and peak $PM_{2.5}$ design values on the order of 16 - 17 ug/m^3). It is unlikely that sufficient emission reductions will occur in the next few of years to provide for attainment at all sites.

- Attainment at most sites by the applicable attainment date is dependent on actual future year meteorology (e.g., if the weather conditions are consistent with [or less severe than] 2005, then attainment is likely) and actual future year emissions (e.g., if the emission reductions associated with the existing controls are achieved, then attainment is likely). If either of these conditions is not met, then attainment may be less likely.

- The new $PM_{2.5}$ 24-hour standard and the new lower ozone standard will not be met at several sites, even by 2018, with existing controls.

- Visibility levels in a few Class I areas in the eastern U.S. are expected to be greater than (less improved than) the uniform rate of visibility improvement values in 2018 based on existing controls, including those in northern Michigan and some in the northeastern U.S. Visibility levels in many other Class I areas in the eastern U.S. are expected to be less than (more improved than) the uniform rate of visibility improvement values in 2018.

Section 7. References

Alpine Geophysics, 2007, “Emissions Inventory Assistance: 2005 Base Year Biogenic and Other (non-LADCO) State Emissions, Preparation and Delivery of Non-MRPO Emission Files< March 12, 2007.

AER, 2004, “Analysis of Recent Regional Haze Data”, Atmospheric and Environmental Research, Inc., August 2004.

Baker, K., “Hot Spot Test (Draft), Lake Michigan Air Directors Consortium, March 23, 2005

Baker, K. 2007a, “Ozone Source Apportionment Results for Receptors in Non-Attainment Counties in the Great Lakes Region”, Lake Michigan Air Directors Consortium, October 2007.

Baker, K., 2007b, “Source Apportionment Results for $PM_{2.5}$ and Regional Haze at Receptors in the Great Lakes Region”, Lake Michigan Air Directors Consortium, November 2007.

Baker, K. and D. Kenski, 2007, “Diagnostic and Operational Evaluation of 2002 and 2005 8-Hour Ozone to Support Model Attainment Demonstrations”, Lake Michigan Air Directors Consortium, October 2007.

Blanchard, C.L., and S. Tanenbaum, 2003, “VOC and NO_x Limitation of Ozone Formation at Monitoring Sites in Illinois, Indiana, Michigan, Missouri, Ohio, and Wisconsin, 1998-2002”, Report to LADCO, February 2003..

Blanchard, C.L., and S. Tanenbaum, 2004, “The Effects of Changes in Sulfate, Ammonia, and Nitric Acid on Fine PM Composition at Monitoring Sites in Illinois, Indiana, Michigan, Missouri, Ohio, and Wisconsin, 2000-2002”, Report to LADCO, February 2004.

Blanchard, C.L., and S. Tanenbaum, 2005a, “Weekday/Weekend Differences in Ambient Concentrations of Primary and Secondary Air Pollutants in Atlanta, Baltimore, Chicago, Dallas-Fort Worth, Denver, Houston, New York, Phoenix, Washington, and Surrounding Areas”, Prepared for National Renewable Energy Laboratory, NREL Project ES04-1, July 30, 2005.

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

Breiman, L., J. Friedman, R. Olshen, and C. Stone, 1984, “Classification and Regression Trees”, Chapman & Hall (1984).

Camalier, L., Cox, W., Dolwick, P., 2007. The effects of meteorology on ozone in urban areas and their use in assessing ozone trends. Atmospheric Environment 41, 7127-7137

Cox, W.M, and S.-H. Chu, 1993, Meteorologically Adjusted Ozone Trends in Urban Areas: A Probabililistic Approach, Atmospheric Environment 27B(4):425-434 (1993).

DeBell, L.J., K. Gebhart, J. Hand, W. Malm, M. Pitchford, B. Schichtel, and W. White, 2006, “Spatial and Seasonal Patterns and Temporal Variability of Haze and its Constituents in the United States, Report IV”, Cooperative Institute for Research in the Atmosphere, November 2006

DRI, 2005, “Source Apportionment Analysis of Air Quality Monitoring Data: Phase II”, Desert Research Institute. March 2005

EC/R, Incorporated, 2004, “Fire Emissions Inventory Development for the Midwest Regional Planning Organization”, Final Report, September 30, 2004.

EC/R, Incorporated, 2007, “Reasonable Progress for Class I Areas in the Northern Midwest – Factor Analysis”, Draft Final Technical Memorandum, July 18, 2007.

E.H. Pechan, 2004, “LADCO Nonroad Emissions Inventory Project – Development of Local Data for Construction and Agricultural Equipment”, Final Report, September 10, 2004

E.H. Pechan, 2005, “Development of Updated Growth and Control Factors for Lake Michigan Air Directors Consortium (LADCO)”, Draft Report, December 29, 2005.

E. H. Pechan, 2007, “Development of 2005 Base Year Growth and Control Factors for Lake Michigan Air Directors Consortium (LADCO)”, Final Report, September 2007.

Environ, 2004, “LADCO Nonroad Emissions Inventory Project for Locomotive, Commercial Marine, and Recreational Marine Emission Sources, Final Report, December 2004.

Environ, 2007a, “Modeling Weekend and Weekday Ozone in Southeast Michigan”, Draft Final Report, Prepared for National Renewable Energy Laboratory, July 30, 2007.

Environ, 2007b, “LADCO 2005 Locomotive Emissions”, Draft, February 2007.

Environ, 2007c, “LADCO 2005 Commercial Marine Emissions”, Draft, March 2, 2007.

Environ, 2008, “LADCO On-Road Emission Inventory Development Using CONCEPT MV”, January 2008..

Hollander, M. and D. Wolfe, 1973, “Nonparametric Statistical Methods”, John Wiley & Sons, New York (1973).

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

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

Kenski, D.M., 2007a, “CART Analysis for Ozone Trends and Meteorological Similarity”, May 10, 2007.

Kenski, D.M., 2007b, “Impact of Missing Data on Worst Days at Midwest Northern Class 1 Areas”, Donna Kenski, Midwest RPO, March 12, 2007 (revised 6/19/07).

Kenski, D.M., 2008a, “Updated Cox Trends Analysis”, February 2008.

Kenski, D.M. 2008b, “Updated CART Analysis for Ozone through 2007”, January 30, 2008.

LADCO, 2005, “Meteorological Modeling Performance Summary for Applications to $PM_{2.5}$/Haze/Ozone Modeling Projects”, February 18, 2005.

LADCO, 2006a, “Base K/Round 4 Strategy Modeling” Emissions”, May 16, 2006.

LADCO, 2006b, “Base K/Round 4 Modeling: Summary”, August 31, 2006.

LADCO, 2007a, “Modeling Protocol: 2002 Basecase Technical Details”, October 17, 2007

LADCO, 2007b, “Modeling Protocol: 2005 Basecase Technical Details”, October 19, 2007

LADCO, 2007c, “An Evaluation of an Annual 2005 MM5 Simulation to Support Photochemical and Emissions Modeling Applications”, January 10, 2007.

LADCO, 2007d, “Base M/Round 5 Modeling: Summary (DRAFT), October 10, 2007

LADCO, 2008a, “Base M Strategy Modeling: Emissions (Revised)”, February 27, 2008

LADCO, 2008b, “Critique: Modeled Attainment Probability (i.e., Bob Lopez’ analysis)”, January 10, 2008

Lopez, 2007, “Assessing the Site-Specific and Region-wide Probability of Attainment Level Ozone Air Quality under varying seasonal conditions using the results of 2002 (Round 4) and 2005 (Round 5) Regional Modeling”, Draft 2, Bob Lopez, WDNR, December 12, 2007

Mansell, G, Z. Wang, R. Zhang, J. Fadel, T. Ramsey, H. Xin, Y. Liang, and J. Arogo, 2005, “An Improved Process-Based Ammonia Emissions Model for Agricultural Sources – Emission Estimates”

MPCA, 2008, “Technical Support Document for the Minnesota State Implementation Plan for Regional Haze”, Draft, March 4, 2008.

MRPO, 2001, “Principles for Regional Planning”, March 9, 2001.

MRPO, 2007, “Draft List of Class I Areas Located Within (or Impacted by) Midwest RPO States”, June 26, 2007.

MRPO, 2008, “Regional Haze in the Upper Midwest: Summary of Technical Information”, Version 2.2, February 22, 2008.

Millstein, D.E., R.A. Harley, and S.V. Hering, 2007, “Weekly cycles in fine particulate matter”, Atmospheric Environment (2007), doi:10.1016/j.atmosenv.2007.10.010.

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

Sheesley, R.J., J.J. Schauer, E. Bean, and D. Kenski, Trends in Secondary Organic Aerosol at a Remote Site in Michigan’s Upper Peninsula, Env. Sci. and Tech. *38*(24); 6491-6500 (Oct 2004).

STI, 2004, “Data Processing and Analysis of Aloft Air Quality Data Collected in the Upper Midwest”, Executive Summary, STI-903470-2568-ES3, Sonoma Technology, Inc, August 5, 2004.

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

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

EPA, 1999, Regional Haze Regulations, 64 FR 35714, July 1, 1999.

EPA, 2003, “Guidance for Estimating Natural Visibility Conditions Under the Regional Haze Rule”, EPA-454/B-03-005, September 2003.

EPA, 2002, “Recommended Approach for Performing Mid-Course Review of SIPs to Meet the 1-Hour NAAQS for Ozone”, January 2002.

EPA, 2005, Final Rule to Implement the 8-Hour Ozone National Ambient Air Quality Standard, 70 FR 71612, November 29, 2005

EPA, 2006, “Regulatory Impact Analysis of the Revisions to the National Ambient Air Quality Standards”, September 2006 (http://www.epa.gov/ttn/ecas/ria.html#ria2007)

EPA, 2007a, "Guidance for on the Use of Models and Other Analyses for Demonstrating Attainment of Air Quality Goals for Ozone, $PM_{2.5}$, and Regional Haze”, EPA-454/B07-002, April 2007.

EPA, 2007b, “Regulatory Impact Analysis of the Proposed Revisions to the National Ambient Air Quality Standards”, EPA-452/R-07-008, July 2007 (http://www.epa.gov/ttn/ecas/ria.html#ria2007)

EPA, 2007c, Clean Air Fine Particle Implementation Rule, 72 FR 20586, April 25, 2007

Zhang, R, T. Ramsey, J. Fadel, J. Arogo, Z. Wang, G. Mansell, and H. Xin, 2005, “An Improved Process-Based Ammonia Emissions Model for Agricultural Sources – Model Development”

Web Sites:
http://www.ladco.org/tech/emis/basem/canada/index.htm

http://www.ladco.org/tech/emis/basek/BaseK_Reports.htm

http://www.ladco.org/tech/emis/r5/round5_reports.htm

http://vista.cira.colostate.edu/views/