The NO_x Budget Trading Program: 2008 Environmental Results

The NO_x Budget Trading Program (NBP) was a market-based cap and trade program created to reduce the regional transport of emissions of nitrogen oxides (NO_x) from power plants and other large combustion sources that contribute to ozone nonattainment in the eastern United States. NO_x is a major precursor to the formation of ground-level ozone, a pervasive air pollution problem in many areas in the eastern United States. The NBP was designed to reduce NO_x emissions during the warm summer months, referred to as the ozone season, when ground-level ozone concentrations are highest. In 2009, the NBP was replaced by the Clean Air Interstate Rule (CAIR) NO_x ozone season program, which started requiring emission reductions from affected sources in an expanded geographic area on May 1, 2009.

Throughout the summer, the U.S. EPA is releasing a series of reports summarizing progress under the NBP. This is the third report in the series and it contains 2008 data on environmental results as well as analyses of the effects of reduced NO_x emissions on ozone and nitrate levels.

For more information on the NBP, visit: <www.epa.gov/airmarkets/progsregs/nox/sip.html>. Detailed emission results and other facility and allowance data are also publicly available on EPA's Data and Maps Web site at <camddataandmaps.epa.gov/gdm>. To view emission and other facility information in an interactive format using Google Earth or a similar three-dimensional platform, go to <www.epa.gov/airmarkets/progress/interactivemapping.html>.

The NBP and Ozone

EPA has developed more than a dozen programs to reduce NO_x and volatile organic compounds (VOCs) from mobile, industrial, and power sector sources since 1990. Between 1999 and 2002, states in the Northeast reduced NO_x emissions from electric generating units (EGUs) and industrial boilers through the OTC NO_x Budget Program. In addition, mobile source programs such as the Tier 2 Vehicle and Gasoline Sulfur Program, the Clean Air Diesel Trucks and Buses Program (also known as the Heavy-Duty Highway Diesel Program), the Clean Air Nonroad Diesel program, and the recently finalized Locomotive and Marine Vessel Compression-Engine Standards have started to reduce NO_x emissions from a variety of mobile source categories and will continue to do so into the future. These programs com-

At a Glance: NBP Results in 2008

Ozone: Ground-level ozone has decreased since implementation of the NBP in 2003

- Analyses of ozone trends using various metrics show regionwide ozone reductions ranging from 10-14 percent in the NBP region
- There is a strong association between areas with the greatest reductions in NO_x emissions and downwind sites exhibiting the greatest improvements in ozone

Nonattainment Areas: Based on 2006-2008 air monitoring data, ozone air quality improved in almost all of the 104 areas in the eastern U.S. designated to be in nonattainment for the 1997 8-hour National Ambient Air Quality Standards (NAAQS)

- 88 areas (85 percent) now have ozone air quality that is better than the level of the 1997 standard
- 13 areas continue to exceed the standard but have experienced an average of 10 percent improvement in ozone
- In total, over 103 million Americans in the East are living with cleaner air

Human Health Benefits: NO_x reductions due to the NBP have led to improvements in ozone and $PM_{2.5}$, saving an estimated 580-1,800 lives in 2008

Ecosystem Protection: Changes in ozone and nitrate concentrations due to the NBP have contributed to improvements in ecosystems in the East

- Decrease in areas with significant ozone damage to seven ozone-sensitive tree species
- 33 percent reduction in total nitrate concentrations

plement state and local efforts to improve ozone air quality and meet national standards.

While these programs, particularly the mobile source programs, have achieved dramatic decreases in NO_x emissions in recent years, the majority of NO_x reductions since 2003 were achieved under the NBP. Accordingly, the NBP is the most significant contributor to the improvements in ozone concentrations in the East.

To better understand how the NBP affected ozone formation in the atmosphere, this report examines changes in ozone concentrations before and after implementation of the NBP in the eastern United States. The report compares regional and geographic trends in ozone levels to changes in meteorological conditions (such as temperature) and NO_x emissions from NBP sources. This report also explores changes in human health and forest ecosystems due to ground-level ozone effects as well as changes in nitrate concentration.

Measuring and Evaluating Changes in Ozone

Two long-term monitoring networks measure ozone levels as well as meteorological and other air quality data throughout the United States. Monitoring sites used for regulatory compliance are located mainly in urban areas and report data to EPA's Air Quality System (AQS). Sites in EPA's Clean Air Status and Trends Network (CASTNET) measure trends in ozone at rural sites. The changes in eastern ozone concentrations presented in this report depict data from AQS and CASTNET monitoring sites located within both NBP and adjacent states. These analyses show a range of ozone reductions based on the metric used and the years examined.

Metrics for Assessing Ozone Concentrations

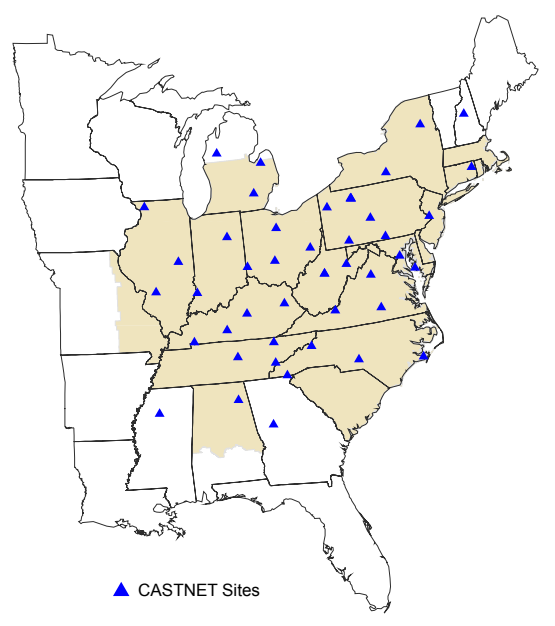
Two types of metrics are used to evaluate trends in ozone levels in this report. Both metrics indicate that ozone has decreased since implementation of the NBP. The two metrics are:

- *Meteorologically-adjusted daily maximum 8-hour ozone concentrations:* This metric is the maximum 8-hour rolling average for each day. It shows progress toward meeting the primary (health-based) ozone National Ambient Air Quality Standards (NAAQS). The seasonal average indicates general changes in daily maximum 8-hour concentrations in the NBP region. The three-year average of the fourth highest daily maximum 8-hour ozone concentration is used to designate non-attainment status in the United States.

CASTNET

The Clean Air Status and Trends Network (CASTNET) is a long-term monitoring network designed to assess trends in regional (rural) ozone levels and acidic dry deposition. Sites are equipped with an ozone analyzer and a three-stage filter pack to collect total weekly gaseous (i.e., nitric acid) and particulate (i.e., nitrate) concentrations. Many of the monitoring sites have been running continuously for over 15 years, making the network ideal for long-term trends analyses. Regional trends in ozone levels from CASTNET sites have been used to assess emission reduction programs, such as the NBP and the Acid Rain Program (ARP). Figure 1 shows the 43 CASTNET sites used in this report's analysis of trends in rural ozone and nitrate concentrations. These sites met data completeness criteria and are located in NBP states or within 200 kilometers (km) of an NBP state's border.

Figure 1: Location of CASTNET Sites



Note: States in the NBP region are shaded.

Source: EPA, 2009

- *Unadjusted 99th percentile of 1-hour and 8-hour ozone concentrations:* This metric shows changes in the highest concentrations of ozone and provides a broad picture of ozone in the eastern United States. The 99th percentile is used in this report because it is statistically similar to the 4th highest daily maximum 8-hour ozone concentration—the ozone NAAQS. This metric is representative of true, measured ozone concentrations without meteorological adjustments.

Although they differ in the amount of ozone reduced, all of the analyses presented in this report show substantial overall improvements in the NBP region since implementation of the program in 2003. These results are further supported by several studies investigating the impact of NO_x emission reductions from NBP sources on ozone in the region.[1]

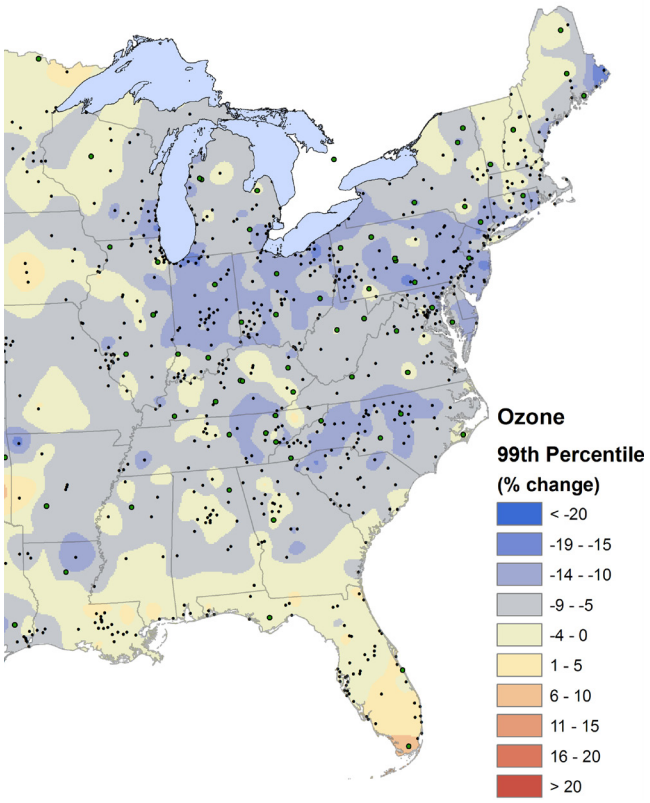
Weather

Weather plays an important role in determining ozone levels. EPA often uses a statistical model to account for the weather-related variability in seasonal ozone concentrations to provide a trend that is more representative of changes in emissions. Averaging ozone concentrations across multi-year periods is another way to account for the effects of weather on ozone formation. Both methods are used in the analyses that follow.

Changes in 1-Hour Ozone Concentrations in the East

EPA examined changes in regional 1-hour ozone concentrations, as measured at urban (AQS) and rural (CASTNET) sites. Results demonstrate how NO_x emission reduction policies have affected ozone concentrations in the eastern United States. Figure 2 shows changes in the 99th percentile of 1-hour ozone concentrations between 2000–2002 (before implementation of the NBP) and 2006-2008 (under the NBP). Using this metric, an overall regional reduction in ozone levels was observed between these two time periods, with an average reduction in ozone concentrations in NBP states of 11 percent.

Figure 2: Percent Change in 1-Hour Ozone Concentrations during the Ozone Season, 2000-2002 versus 2006-2008



Note: AQS and CASTNET monitoring sites used for this analysis are shown as black dots on this map.

Source: EPA, 2009

Changes in Rural Ozone Concentrations

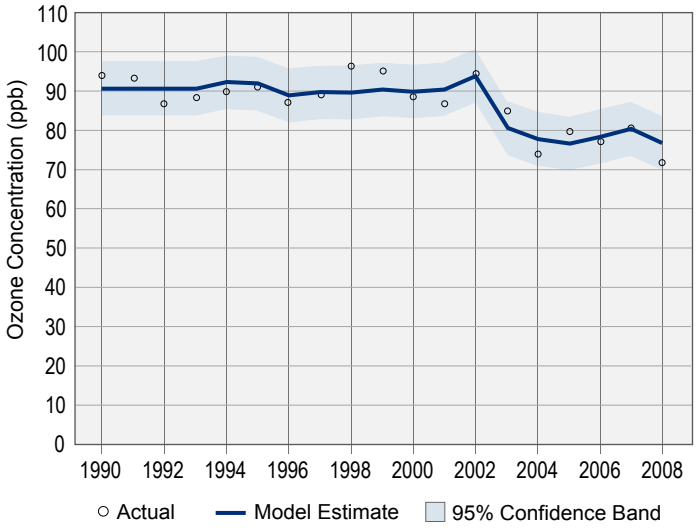
Rural ozone measurements are useful in assessing the impacts on air quality resulting from regional NO_x emission reductions because these monitoring sites are typically less affected by local sources of NO_x (e.g., industrial, automotive, and power generation sources) than urban measurements. Consequently, the formation of ozone in these areas is particularly sensitive to changes in levels of regional NO_x emissions. The majority of reductions in rural ozone concentrations can therefore be attributed to reductions in regional NO_x emissions and transported ozone.

While ozone levels vary by season and location, regional trends reveal notable drops in ambient ozone levels since the NBP began in 2003. EPA investigated trends in both rolling 8-hour and 1-hour ozone concentrations as measured at CASTNET monitoring sites within the NBP region and in adjacent states (states within 200 km of an NBP state's borders).

Regional Trends in Ozone

An Autoregressive Integrated Moving Average (ARIMA) model was used to determine the trend in ozone concentrations since the inception of the NBP. The ARIMA model is an advanced statistical analysis tool that can evaluate trends over time (time series analysis). The average of the 99th percentile of the 8-hour daily maximum ozone concentrations (the highest daily levels of ozone) measured at CASTNET sites during the NBP ozone season were modeled (Figure 3). The ARIMA model shows that between 1990 and 2003, the average of the 99th percentile of ozone concentration was 91 parts per billion (ppb). After 2004, a statistically significant shift occurred and a new trend was established, with an average ozone level of 79 ppb. The ARIMA model shows a statistically significant, 13 percent (12 ppb) decrease in ozone concentrations beginning at the start of the NBP, suggesting that this program is a major contributor to these regional improvements in ozone.

Figure 3: Shift in 8-Hour Seasonal Ozone Concentrations in the NBP Region, 1990-2008



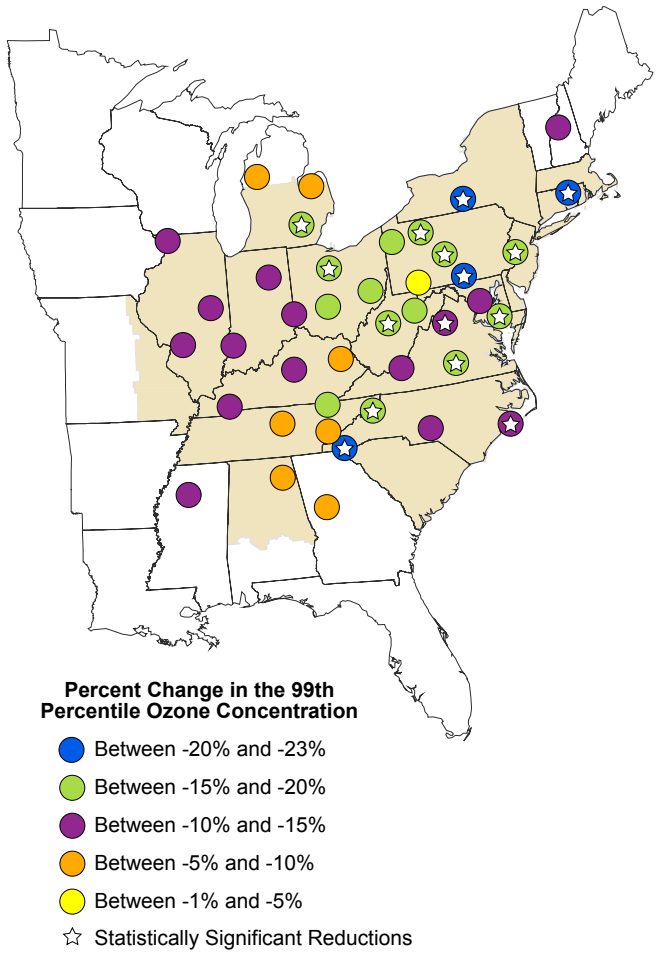
Notes: Total ozone concentration data are from CASTNET sites that met completeness criteria and are located in and adjacent to the NBP region.

Source: EPA, 2009

Site-Specific Changes in Ozone

Similar trends in rural ozone concentrations were observed at individual CASTNET monitoring sites. As expected, there was variation across the region. The largest and most significant decreases in ozone were observed at sites downwind of the Ohio River Valley (Ohio, West Virginia, and Pennsylvania), where NBP sources reduced NO_x emissions most dramatically. Figure 4 displays the average percent reduction in the 99th percentile of 1-hour ozone concentrations at individual rural CASTNET sites between 2000–2002 and 2006–2008. Between the two time periods, ozone levels fell by an average of 14 percent in the NBP region. A total of four CASTNET sites (in Connecticut, New York, Pennsylvania, and North Carolina) measured ozone reductions greater than 20 percent. The largest reduction

Figure 4: Percent Reduction in Rural 1-Hour Ozone during the Ozone Season, 2000-2002 versus 2006-2008



Notes:

- States in the NBP region are shaded.
- The change in ozone concentration is the percent change of the average of the 99th percentile of 1-hour ozone concentrations between each three-year period.
- Ozone data are from CASTNET sites that met completeness criteria and are located in or adjacent to the NBP region.

Source: EPA, 2009

in ozone (23 percent) was measured at the Abington site (ABT147) in Connecticut. Furthermore, at many sites in the NBP region, the decrease in ozone between the two time periods was significant and statistically different.

Changes in the Monthly Distribution of Ozone

An additional statistical analysis shows that the monthly distribution of 8-hour daily maximum ozone concentrations has shifted to lower concentrations. This shift has occurred in the NBP region during the ozone season since implementation of the program. Figure 5 depicts every 8-hour daily maximum value measured in January and June (where January represents months outside the ozone season and June represents months within the ozone season) for two time periods. The blue lines represent ozone concentrations before implementation of the NPB (2000-2002), while the red lines represents ozone concentrations after implementation of the NBP (2006-2008). The y-axis represents the percent of the total number of days in a month with measurements at a specific ozone ppb level.

As the right-hand graph in Figure 5 shows, there is a noticeable shift toward lower ozone concentration during the ozone season (represented by the red arrow). As NO_x emission controls were turned on at sources subject to the NBP, there have been fewer days with high levels of ozone during the ozone season. In months outside the ozone season (represented by the month of January), there is little to no shift.

As Table 1 shows, the 99th percentile of 8-hour ozone dropped by 3-10 ppb during the ozone season, while there were no significant changes in the months outside of the ozone season (except for October).

The downward shift in the monthly distribution of ozone levels in the NBP region is indicative of broader, substantial change in ozone concentrations due in significant part to the program.

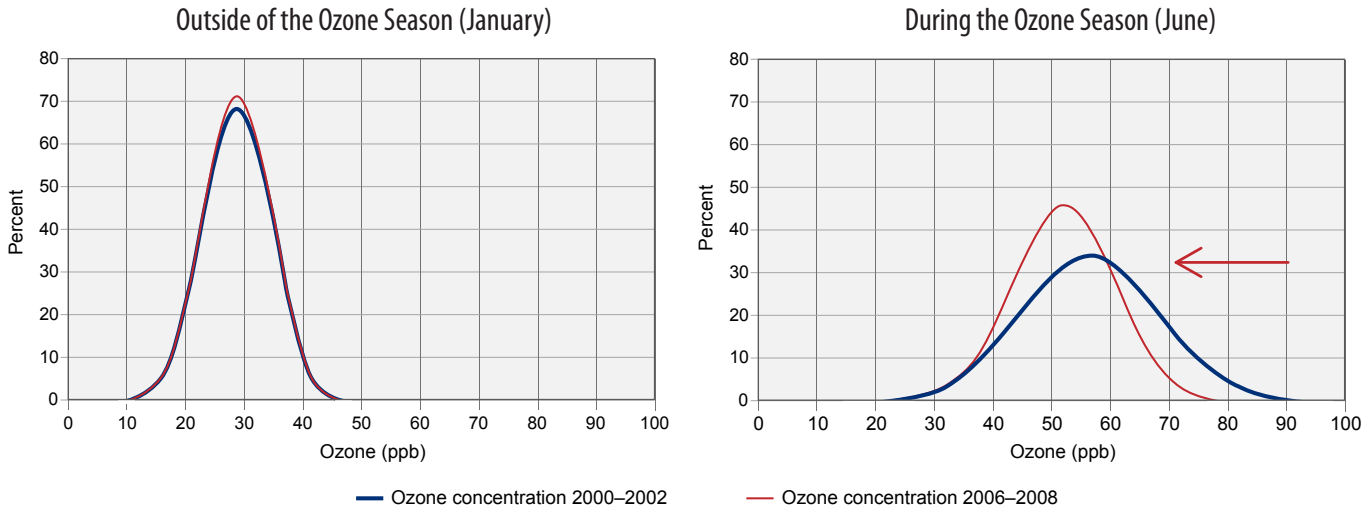
Table 1: Shift in 8-Hour Ozone Concentration by Month, 2000-2002 versus 2006-2008

Month	Change in 99th Percentile 8-Hour Ozone Concentration
January	No statistically significant shift
February	No statistically significant shift
March	No statistically significant shift
April	No statistically significant shift
May	Down 3 ppb
June	Down 10 ppb
July	Down 9 ppb
August	Down 8 ppb
September	Down 8 ppb
October	Down 10 ppb
November	No statistically significant shift
December	No statistically significant shift

Note: Months within the ozone season are shaded.

Source: EPA, 2009

Figure 5: Monthly Distribution of 8-Hour Ozone Concentrations, 2000-2002 versus 2006-2008



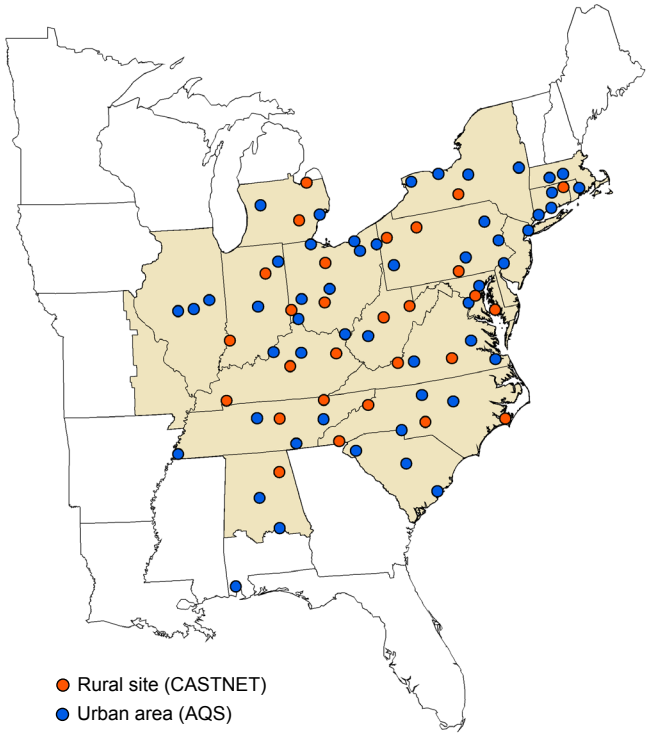
Note: Ozone data are from CASTNET sites that met completeness criteria and are located in or adjacent to the NBP region.

Source: EPA, 2009

Changes in 8-Hour Ozone Concentrations

Daily maximum 8-hour ozone concentration data were assessed from 52 urban AQS areas and 28 rural CASTNET sites located in the NBP region. For a monitor or area to be included in this trend analysis, it had to provide complete and valid data for 50 percent of the ozone season days for each of the years from 1997–2008. In addition, urban AQS areas often include more than one monitoring site. In these cases, the site with the highest observed ozone concentration for each day was used. Figure 6 shows the AQS and CASTNET monitoring sites in the NBP region that met these completeness criteria.

Figure 6: Location of Urban and Rural Ozone Monitoring Sites



Notes:

- States in the NBP region are shaded.
- Urban areas are represented by multiple monitoring sites. Rural areas are represented by a single monitoring site. For more information on AQS, visit <www.epa.gov/ttn/airs/airsaqs>. For more information about CASTNET, visit <www.epa.gov/CASTNET>.

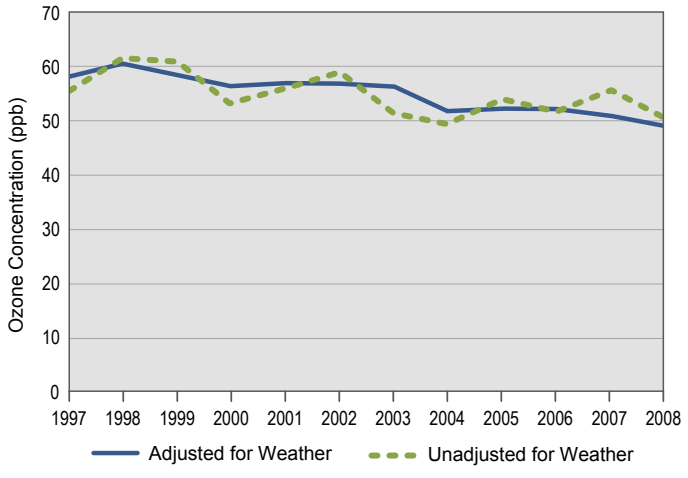
Source: EPA, 2009

Ozone Changes after Adjusting for Meteorology

As noted earlier, weather plays an important role in determining ozone levels. Accordingly, EPA uses a generalized linear model to describe the relationship between daily ozone and several meteorological parameters.[2] The model also accounts for the variation in seasonal ozone across different years by correcting for meteorological fluctuations. The most important meteorological parameters considered in this model are daily maximum 1-hour temperature and midday (10 a.m. to 4 p.m.) relative humidity. This methodology and the subsequent ozone estimates are provided by EPA's Office of Air Quality Planning and Standards (OAQPS), Air Quality Assessment Division <www.epa.gov/airtrends/weather.html>.

Figure 7 shows trends in the seasonal average 8-hour ozone concentrations in the NBP region with and without considering the influence of weather.[3] It is important to account for meteorological variations when comparing two years with notably different weather conditions and ozone-forming potential (e.g., 2004 versus 2007). In general, lower temperatures in the NBP region during the 2004 ozone season dampened ozone formation, while higher temperatures in the 2007 ozone season increased ozone formation. Removing the effects of weather results in a higher-than-observed ozone estimate for 2004 and a lower-than-observed ozone estimate for 2007. Consequently, despite weather condi-

Figure 7: Seasonal Average 8-Hour Ozone Concentrations in the NBP Region, 1997-2008



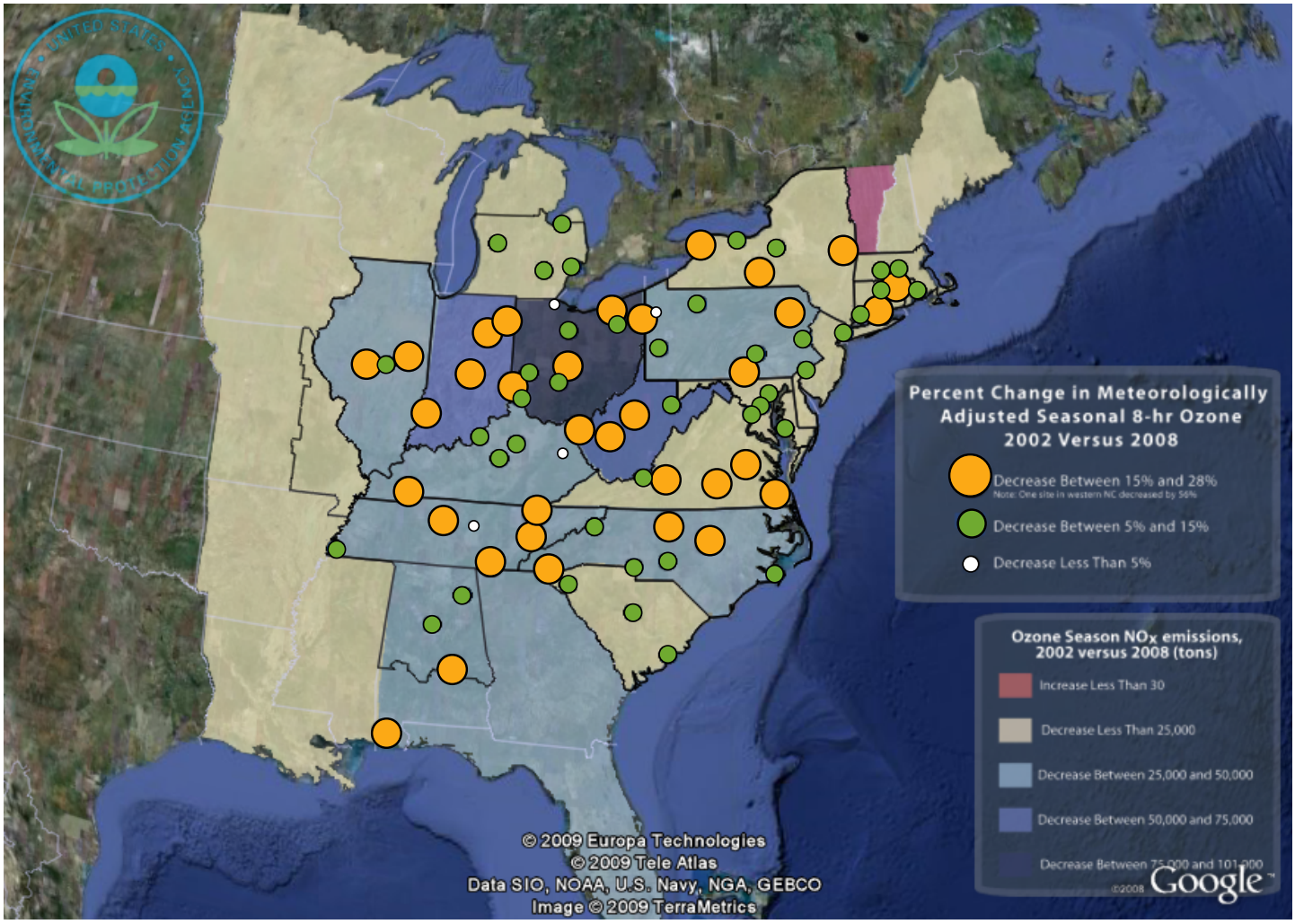
Note: Data presented in this figure are averages of 8-hour daily maximum ozone concentrations during the ozone season for AQS and CASTNET sites within the NBP region.

Source: EPA, 2009

tions conducive to ozone formation in 2008, average ozone concentrations in the NBP region were lower than in 2002, before implementation of the NBP.

A closer look at the meteorologically-adjusted ozone trends since the start of the NBP in 2003 indicates that these reductions are substantive and sustainable. The average reduction in seasonal 8-hour ozone concentrations measured in the NBP region in the 2000-2002 and 2006-2008 time periods was about 6 percent. After considering the influence of weather, the improvement in 8-hour ozone concentrations between these three-year periods was 11 percent. A comparison of single year meteorologically-adjusted ozone reveals a 14 percent reduction between 2002 and 2008.

Figure 8: Reductions in Seasonal NO_x Emissions from NBP Sources and Changes in 8-Hour Ozone, 2002 versus 2008



Notes:

- From 1999 to 2002, states in the Northeast reduced emissions from EGUs and industrial boilers under the OTC NO_x Budget Program. OTC states include Connecticut, Delaware, the District of Columbia, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and Virginia.
- Meteorologically-adjusted ozone data are from AQS and CASTNET sites that met completeness criteria.
- Google Earth was used to display the information shown in this figure. To access the data layers shown here as well as other data, including unit-level emissions and controls, visit the Clean Air Market Division's interactive mapping site at <www.epa.gov/airmarkt/progress/interactivemapping.html>.

Source: EPA, 2009

Furthermore, the pace of these reductions has increased since implementation of the NBP. Between 1997 and 2002, ozone fell by 3 percent, while between 2002 and 2008, ozone dropped by 14 percent. On average, across the NBP region, meteorologically-adjusted ozone levels have been fairly stable since 2004, indicating that the majority of the progress made in reducing ozone levels since 2003 is being maintained. This is also consistent with the downward trend in NO_x emissions.

Linking Ozone and NO_x Emissions

Figure 8 on the previous page is a Google Earth snapshot depicting the relationship between reductions in NO_x emissions from NBP sources and reductions in 8-hour average ozone after implementation of the NBP. As indicated previously, between 2002 and 2008, ozone decreased across all NBP states (after adjusting for meteorology) by an average of 14 percent. The largest reductions occurred in New York, Ohio, Virginia, North Carolina, and Pennsylvania.

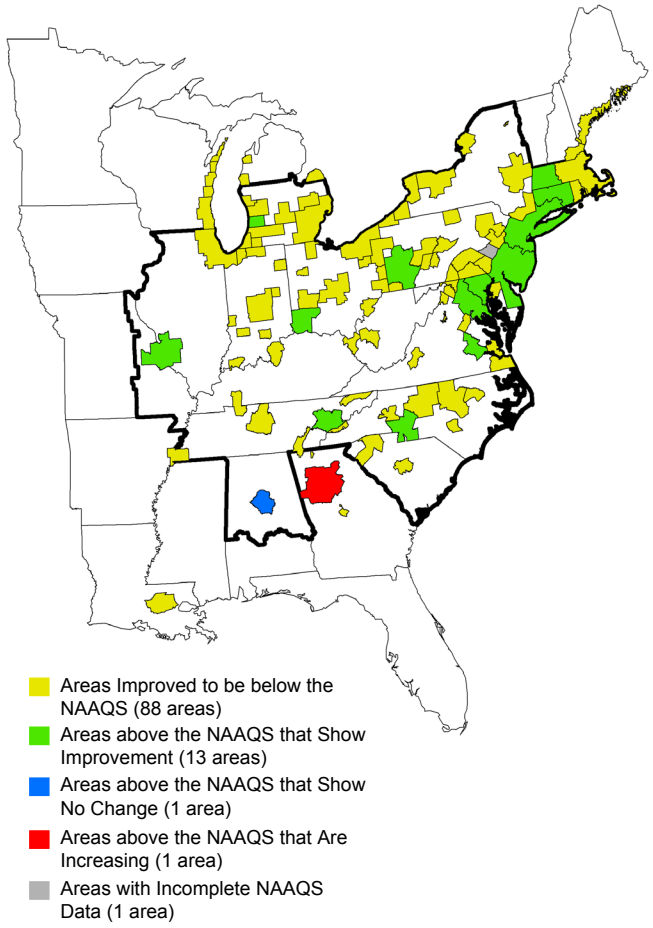
Generally, there is a strong association between areas with the greatest NO_x emission reductions from NBP sources and downwind monitoring sites measuring the greatest improvements in ozone. This suggests that, as a result of the NBP, transported NO_x emissions have been reduced in the East, contributing to ozone reductions that have occurred after 2002.[4]

Changes in Ozone Nonattainment Areas

In April 2004, EPA designated 126 areas as nonattainment for the 8-hour ozone standard adopted in 1997.[5] These designations were made using data from 2001-2003. Of those areas, 104 are in the East (as shown in Figure 9) and are home to about 108 million people.[6] Based on data gathered from 2006-2008, 88 of these original nonattainment areas show concentrations below the level of the 1997 ozone standard (0.08 ppm), indicating improvements in ozone. Improvements in these 88 areas mean that 85 percent of the original nonattainment areas in the East now have ozone air quality that is better than the standard under which they were originally designated nonattainment. These improvements bring cleaner air to over 57 million people. The majority of these areas have officially been redesignated to attainment or maintenance, as described in Section 107 of the Clean Air Act.

Fifteen of the original 104 areas in the East continue to exceed the level of the standard. In 13 of these areas, however, ozone concentrations have fallen by an average of 10 percent. Because of these reductions in ozone, over 46 million Americans living in these areas are experiencing better air quality.

Figure 9: Changes in Ozone Nonattainment Areas in the East, 2001-2003 (Original Designations) versus 2006-2008



Note: States in the NBP region are shown inside the black boundary line.

Source: EPA, 2009

Given that the majority of relevant NO_x emission reductions occurring after 2003 are attributable to the NBP, it is clear that the NBP is the most significant contributor to these improvements in ozone air quality.

Human Health Benefits from NBP Implementation

Epidemiological studies[7] continue to show a significant link between exposure to air pollution, particularly $PM_{2.5}$ and ozone, and adverse health effects, including respiratory and cardiovascular effects as well as incidences of premature mortality. The analysis presented here is a screening-level estimate of the annual human health benefits (the number of premature deaths avoided annually) from NO_x emission reductions achieved under the NBP.

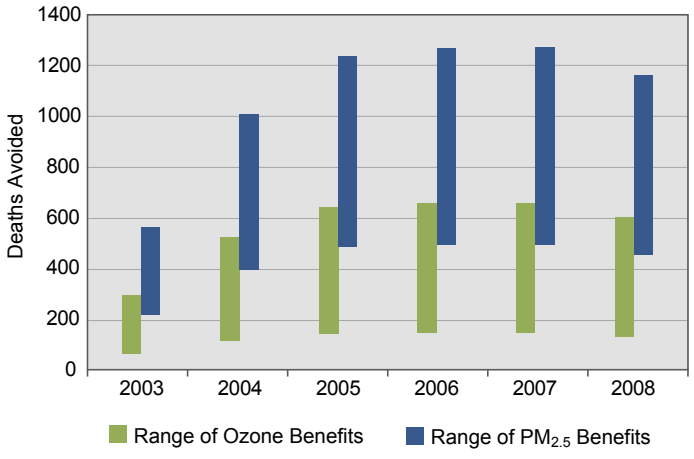
In order to calculate the amount of NO_x emissions reduced as a result of NBP implementation, EPA compared NO_x emission levels under the program with estimates of what emissions would have been without the program. In this analysis, actual monitored NO_x emission data were used for most years to represent NO_x emissions as a result of the program.[8] The amount of NO_x emitted from affected units in the absence of the NBP was estimated using historical, unit-level NO_x rates (from 2000, where available) and yearly measured heat input from 2003 through 2008.

EPA's Response Surface Model (RSM) and Benefits Mapping and Analysis Program (BenMAP) were used to estimate the human health benefits per ton of NO_x emissions reduced for both ozone[9] and $PM_{2.5}$[10]. RSM scenarios were run to develop "benefit per ton" estimates, specifically for NO_x emission reductions in the power sector.

Figure 10 illustrates how many lives were estimated to be saved annually because of air quality improvements in ozone and $PM_{2.5}$ as a result of the NBP. The results of this health benefits assessment are influenced by the amount of NO_x emissions reduced by NBP sources in a given year, the pollutant affected (ozone or $PM_{2.5}$), and the health function that relates exposure to that pollutant with incidences of premature mortality. In addition, results are presented as a range in order to capture the variation across the 8 studies used in this analysis.

This analysis shows that improvements in ozone air quality have led to fewer premature deaths annually. For example, in 2008 alone, between 130 and 600 lives were estimated to be saved because of decreases in ozone. In addition to these ozone benefits, improvements in $PM_{2.5}$ protected an additional 450 to 1,200 lives in 2008. Therefore, as a result of reductions in NO_x emissions due to the NBP, total human health benefits (for ozone and $PM_{2.5}$) range from 580 to 1,800 incidences of premature deaths avoided in 2008.

Figure 10: Annual Incidences of Premature Mortality Avoided, 2003-2008



Notes:

- Ozone benefits were calculated using Ito, Schwartz, Bell 2004, Bell 2005, Levy, and Huang.[11]
- $PM_{2.5}$ benefits were calculated using Laden and Pope.[12]

Source: EPA, 2009

Changes in Ozone and Nitrate Impacts on Ecosystems

Ozone Impacts on Forests

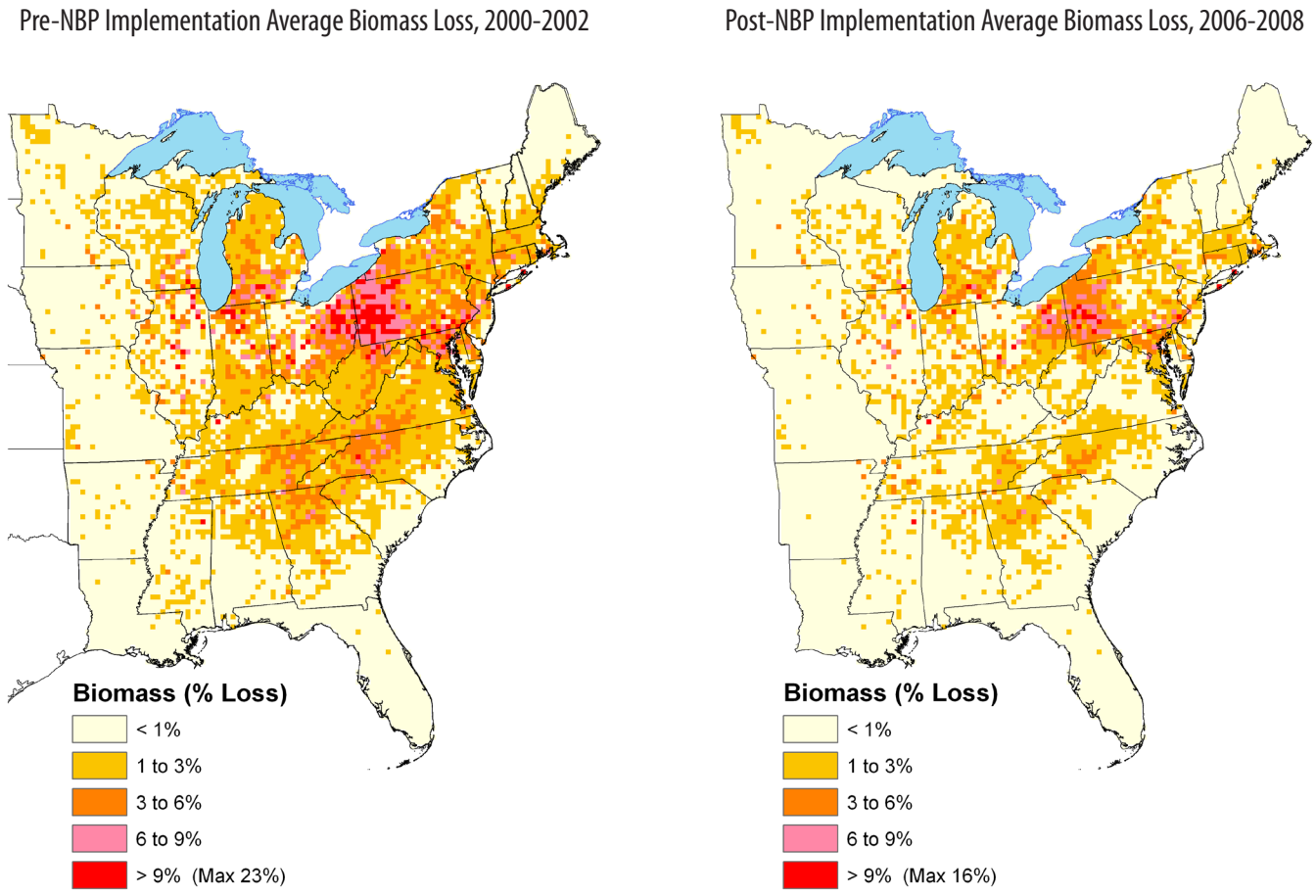
Air pollution can impact the environment and affect ecological systems, leading to changes in the ecological community and influencing the diversity, health, and vigor of individual species. Ozone has been shown in numerous studies to have a strong effect on the health of many plants, including a variety of commercial and ecologically important forest tree species throughout the United States.[13]

When ozone is present in the air, it can enter a plant through pores in its leaves and cause significant cellular damage. This damage can compromise the ability of the plant to produce energy during photosynthesis. The remaining energy resources of the plant are then depleted as leaves attempt to repair or replace damaged tissue. This loss of energy resources can lead to reduced growth and/or reproduction of plants. Ozone stress also increases the susceptibility of plants to disease, insects, fungus, and other environmental stresses (e.g., harsh weather). Because ozone damage can also cause visible injury to leaves, it can reduce the aesthetic value of ornamental vegetation and trees, and negatively affect scenic vistas in protected natural areas.

Assessing the impact of ozone on forests in the eastern United States involves understanding the risk to tree species from ambient ozone concentrations and accounting for the prevalence of those species within the forest. As a way to quantify the risk to particular trees, scientists have developed concentration-response (C-R) functions which relate ozone exposure to tree response. Tree C-R functions are determined by exposing tree seedlings to different ozone levels and measuring reductions in growth as "biomass loss." In areas where certain species dominate the forest community, the biomass loss from ozone can be significant. In this analysis, biomass loss is used as an indicator for the effects of ozone on the forest ecosystem.

Some of the common tree species in the eastern United States that are sensitive to ozone are black cherry (*Prunus serotina*), yellow-poplar (*Liriodendron tulipifera*), sugar maple (*Acer saccharum*), eastern white pine (*Pinus strobus*), Virginia pine (*Pinus virginiana*), red maple (*Acer rubrum*), and quaking aspen (*Populus trenuloides*). To estimate the

Figure 11: Estimated Black Cherry, Yellow Poplar, Sugar Maple, Eastern White Pine, Virginia Pine, Red Maple, and Quaking Aspen Biomass Loss due to Ozone Exposure, 2000-2002 versus 2006-2008



Note: Sources of uncertainty include the ozone-exposure/plant-response functions, the tree abundance index, and other factors (e.g., soil moisture). Although these factors were not considered, they can affect ozone damage.[14]

Source: EPA, 2009

biomass loss for forest ecosystems across the eastern United States, the biomass loss for each of the seven tree species was calculated using the three-month, 12-hour W126 exposure metric[15] at each location, along with each tree's individual C-R functions. The W126 exposure metric was calculated using monitored ozone data from CASTNET and AQS sites, and a three-year average was used to mitigate the effect of variations in meteorological and soil moisture conditions. The biomass loss estimate for each species was then multiplied by its prevalence in the forest community using the U.S. Department of Agriculture (USDA) Forest Service IV index of tree abundance calculated from Forest Inventory and Analysis (FIA) measurements.[16] This analysis compared two time periods: 2000-2002 (before the NBP) and 2006-2008 (under the NBP) and demonstrates the benefit to forest ecosystems from decreasing ozone concentrations.

Since implementation of the NBP, the number of areas with significant biomass loss[17] due to ozone has decreased for all seven tree species across their range in the East (see Figure 11). Of these seven species, the black cherry and yellow poplar are the most sensitive to ozone. Comparing data from 2000-2002 versus 2006-2008, EPA found that the total land area in the Eastern U.S. with significant biomass loss has decreased by 5 percent for black cherry and by 4 percent for yellow poplar. In addition, areas with significant biomass loss for the remaining five species (red maple, sugar maple, quaking aspen, Virginia pine, and eastern white pine) now make up less than 1 percent of their total range. While this change in biomass loss cannot be exclusively attributed to the implementation of the NBP, it is likely that NO_x emission reductions achieved under the NBP and the corresponding decreases in ozone concentration contributed to this environmental improvement.

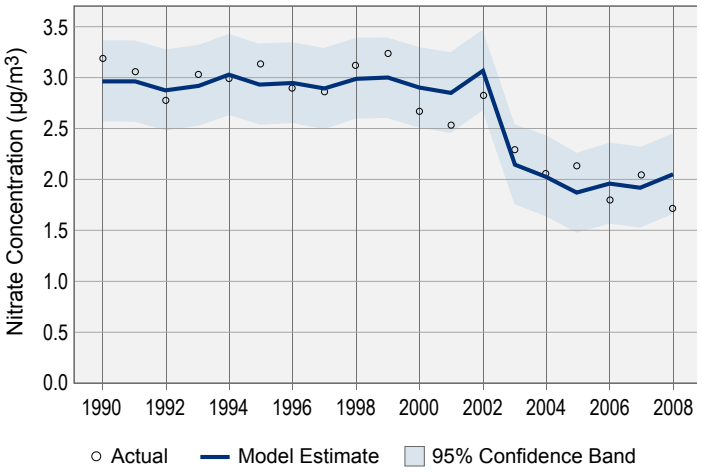
Changes In Nitrate

NO_x is emitted from a source as nitric oxide (NO) and nitrogen dioxide (NO_2). Once in the air, several chemical reactions occur, depending on meteorological conditions and concentrations of other pollutants in the atmosphere. NO_x contributes to the formation of many secondary pollutants, including particulate nitrate (NO_3), nitric acid (HNO_3), ozone, and organic compounds. For example, ozone is produced when NO_2, volatile organic compounds (VOCs), and sunlight are present.

Generally, NO_x is removed directly from the atmosphere by dry deposition of nitric acid and particulate nitrates, and wet deposition of dissolved nitrates. Nitrate deposition can be harmful to sensitive ecosystems, vegetation, and water bodies by causing eutrophication, changes in biological communities, and an increased sensitivity to changes in the environment. Because the majority of NO_x in the NBP region is removed from the atmosphere over a period of four to nine days, nitrogen deposition from transported NO_x emissions may still affect areas that are considerable distances from NO_x emission sources.[18]

As facilities install and use control technologies, reducing the amount of NO_x emitted in the NBP region, the amount of NO_x secondary pollutants also decreases. To determine the trend in total nitrate since the start of the NBP, an ARIMA model was used to assess changes in the average of median total nitrate concentrations as measured at CASTNET sites located in the NBP region during the ozone season (Figure 12). The ARIMA model illustrates that between 1990 and 2003, total nitrate concentrations averaged about 3 µg/m^3. After 2004, a statistically significant shift occurred and a new trend was established with an average concentration of 2 µg/m^3. Similar to the shift observed for ozone concentrations, the ARIMA model shows a statistically significant, 33 percent (1 µg/m^3) decrease in total nitrate since the start of the NBP, suggesting that the NBP was a significant contributor to these improvements in total nitrate.

Figure 12: Shift in Seasonal Nitrate Concentrations in the NBP Region, 1990-2008



Notes: Total nitrate concentration data are from CASTNET sites that met completeness criteria and are located in and adjacent to the NBP region.

Source: EPA, 2009

Endnotes

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