


EPA's NO_x Reduction Program and Clean Air Interstate Rule
2009 Environmental and Health Results

Program Basics

The Clean Air Interstate Rule (CAIR) was designed to address interstate transport of ozone and fine particulate matter ($PM_{2.5}$) pollution. To do so, CAIR required certain states to limit emissions of nitrogen oxides (NO_x) and sulfur dioxide (SO_2), which contribute to the formation of ozone and $PM_{2.5}$. CAIR developed three separate cap and trade programs that could be used to achieve the required reductions — the CAIR NO_x ozone season trading program, the CAIR annual NO_x trading program, and the CAIR SO_2 trading program. The CAIR NO_x ozone season and annual programs began in 2009, while the CAIR SO_2 annual program began in 2010. The reduction in ozone and $PM_{2.5}$ formation resulting from implementation of the CAIR programs provides health benefits as well as improved visibility in national parks and improved ecosystem protection in the eastern U.S.

2009 Progress Reports

EPA released a series of reports over several months summarizing the first year of CAIR implementation, including the transition from the ozone season NO_x Budget Program (NBP) to the CAIR NO_x ozone season program. Previous online reports presented and analyzed emission reductions, compliance results, and market activity in 2009. This is the third and final report in the series and contains 2009 data on environmental results as well as analyses of the effects of reduced NO_x emissions on ozone and nitrate levels and reduced NO_x and SO_2 emissions on $PM_{2.5}$. Detailed emission results and other facility and allowance data are also publicly available on EPA's Data and Maps website 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 EPA's Interactive Mapping site at <www.epa.gov/airmarkets/progress/interactivemapping.html>.

Litigation and Rules to Replace CAIR

On July 11, 2008, the U.S. Court of Appeals for the D.C. Circuit issued a ruling vacating CAIR in its entirety. EPA and other parties requested a rehearing, and on December 23, 2008, the Court revised its decision and remanded CAIR to EPA without vacatur. This ruling leaves CAIR and the CAIR Federal Implementation Plans (FIPs) — including the CAIR trading programs — in place until EPA issues new rules to replace CAIR.

At a Glance: CAIR Benefits in 2009

Ozone: Ground-level ozone decreased under the first year of the CAIR NO_x ozone season program, continuing the marked improvements achieved by the NO_x SIP (State Implementation Plan) Call program.

- Regional 1-hour ozone concentrations in CAIR states decreased by an average of 16 percent between 2000–2002 (before implementation of the NBP) and 2007–2009 (under the NBP and first year of CAIR NO_x ozone season program implementation)
- Between 2002 and 2009, 8-hour average ozone concentrations decreased by an average of 18 percent across all states controlled for ozone under the CAIR NO_x ozone season program
- Based on data gathered from 2007–2009, 86 percent of the original eastern nonattainment areas for the 8-hour ozone standard now have ozone air quality that is better than the standard

Particulate Matter: The CAIR NO_x annual program and CAIR SO_2 program were established to reduce the interstate transport of fine particulate matter ($PM_{2.5}$)

- Concentrations of $PM_{2.5}$ have decreased by approximately 18 percent in the warm season (May through September) and 12 percent in the cool season (October through April) across states controlled for PM under the CAIR rules
- Based on data gathered from 2007–2009, 92 percent of the areas in the east originally designated nonattainment for the 24-hour average $PM_{2.5}$ standard now have $PM_{2.5}$ air quality that is better than the standard

Human Health Benefits: An estimated 10,000 to 26,000 lives are saved annually due to the reductions in $PM_{2.5}$ from the CAIR rules

EPA is committed to issuing rules to replace CAIR that will help states address the interstate air emissions transport problem in a timely way and that fully comply with the requirements of the Clean Air Act and the opinions of the D.C. Circuit. EPA has developed a proposed Transport Rule which, if finalized as proposed, would replace CAIR after the end of the 2011 control periods. The proposed rule was signed in July 2010, and is available online at <epa.gov/airtransport/>.

Ozone

Ozone pollution forms when NO_x and volatile organic compounds (VOCs) react in the presence of sunlight. Ozone itself is rarely emitted directly into the air. Major sources of NO_x and VOC emissions include motor vehicles, solvents, industrial facilities, and electric power plants.

Meteorology plays a significant role in ozone formation. Dry, hot, sunny days are most favorable for ozone production. In general, ozone concentrations increase during the daylight hours, peak in the afternoon when the temperature and sunlight intensity are highest, and drop in the evening. Because ground-level ozone concentrations are highest when sunlight is most intense, the warm summer months (May 1 to September 30) are known as the ozone season.

Ozone Impacts on Human Health and Ecosystems

Exposure to ozone has been linked to a variety of health effects, the severity of which depends on concentration, length of exposure, and breathing rate. At levels found in many urban areas, ozone can aggravate respiratory diseases such as asthma, emphysema, and bronchitis, and can increase susceptibility to respiratory infections. More serious effects include emergency department visits, hospital admissions, and premature mortality.

Scientific evidence also continues to show that repeated exposure to ozone damages sensitive vegetation, including some tree, crop, and native plant species. Such effects can include reduced growth and productivity, damaged foliage, and increased susceptibility to disease, insect pests, and other stresses (e.g., harsh weather). Ozone-related damage can lead to ecosystem-level changes such as loss of diversity.

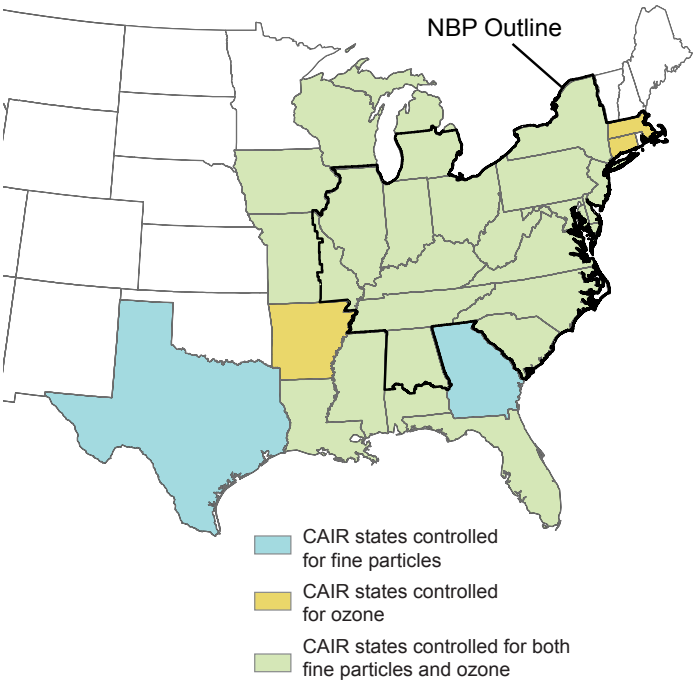
For more information on the health and environmental effects of ground-level ozone, visit <www.epa.gov/ozonepollution>.

Ozone Standards

The Clean Air Act (CAA) requires EPA to set National Ambient Air Quality Standards (NAAQS) for ground-level ozone and five other criteria pollutants. The CAA established two types of national air quality standards for ground-level ozone. Primary standards set limits to protect public health, including the health of "sensitive" populations such as asthmatics, children, and the elderly. Secondary standards set limits to protect public welfare, including protection against visibility impairment and damage to animals, crops, vegetation, and buildings. The CAA requires EPA to review the latest scientific information and standards every five years.

In the 1970s, EPA established the NAAQS for ozone. A 1-hour standard of 0.08 parts per million (ppm) was set in 1971 and revised to 0.12 ppm in 1979. In 1997, a new, more stringent 8-hour ozone standard of 0.08 ppm was promulgated, revising the 1979 standard. In March 2008, EPA changed the 8-hour ozone standard to 0.075 ppm. However, in September 2009, EPA announced it would reconsider its 2008 decision. EPA is reconsidering the standards to ensure they are clearly grounded in science, protect public health with an adequate margin of safety, and are sufficient to protect the environment. In January 2010, EPA proposed stricter standards for ground-level ozone — in the range of 0.060 to 0.070 ppm measured over eight hours. As part of

Figure 1: Transition from the NBP to CAIR



Note: In a November 2009 rule, EPA stayed the effectiveness of CAIR for Minnesota, which had previously been among the states controlled for fine particles.
Source: EPA, 2010

EPA's extensive review of the science, Administrator Jackson has asked the Clean Air Scientific Advisory Committee (CASAC) for further interpretation of the epidemiological and clinical studies they used to make their recommendation. To ensure EPA's decision is grounded in the best science, EPA will review the input CASAC provides before the new standard is selected. Given this ongoing scientific review, EPA intends to set a final standard in the range recommended by the CASAC by the end of July 2011.

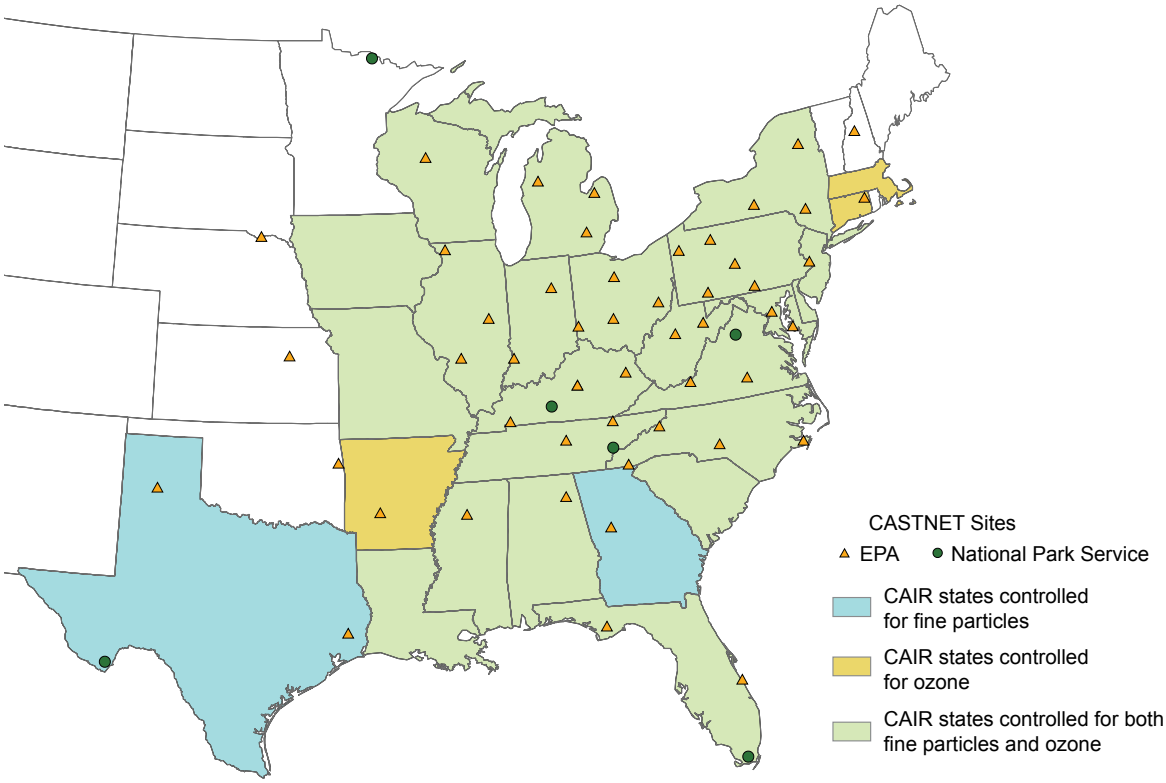
CAIR NO_x Ozone Season Program

The CAIR NO_x ozone season program was established to reduce interstate transport of ozone during the summer months and help eastern U.S. counties attain the 1997 ozone standard. The CAIR NO_x ozone season program applies to electric generating units (EGUs) as well as, in some states, large industrial units that produce electricity or steam primarily for internal use and were carried over from the NBP. The CAIR NO_x ozone season requirements apply to all states from the former NBP except Rhode Island, and to six additional eastern states (Arkansas, Florida, Iowa, Louisiana, Mississippi, and Wisconsin). In addition, while only parts of Alabama, Michigan, and Missouri were in the NBP, the CAIR NO_x ozone season requirements apply to these states in their entirety. In Figure 1 on page 2 the states colored yellow and green are those that are subject to the CAIR NO_x ozone season program.

CASTNET

The Clean Air Status and Trends Network (CASTNET) is the only 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. Each site also measures a suite of meteorological parameters which are used to model dry deposition fluxes of the acidic pollutants. 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 Acid Rain Program (ARP). CASTNET data will now be used to determine baselines and regional ozone trends for CAIR and future reduction programs. Figure 2 shows the 59 CASTNET sites used in this report's analysis of trends in rural ozone, sulfate and nitrate concentrations. These sites met data completeness criteria and are located in CAIR states or within 200 kilometers (km) of a CAIR state's border.

Figure 2: CASTNET Monitoring Stations



Source: EPA, 2010

The first year of implementation of the CAIR NO_x ozone season program was 2009. In 2009, there were 3,279 EGUs and industrial facility units in the program and NO_x emissions from those sources were approximately 495,000 tons.

To better understand how the CAIR NO_x ozone season program affected ozone formation in the atmosphere, this report examines changes in ozone concentrations before and after implementation of CAIR. The report compares regional and geographic trends in ozone levels to changes in meteorological conditions (such as temperature) and NO_x emissions from CAIR 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.

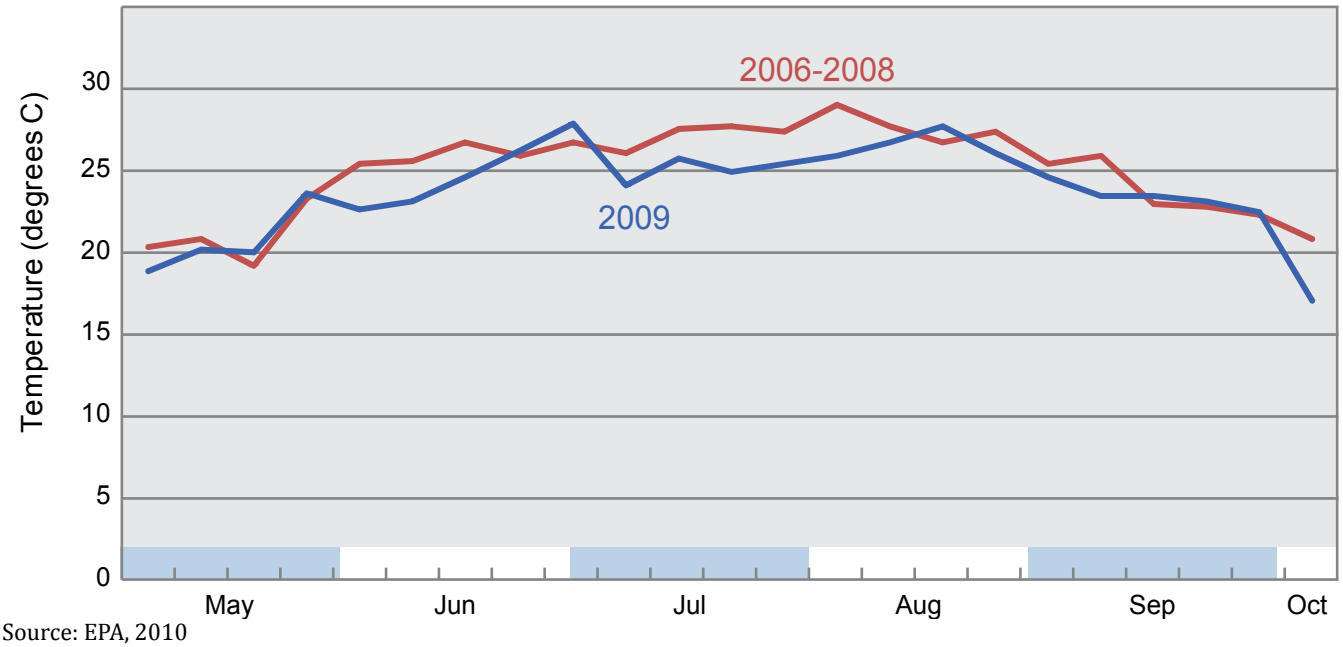
Measuring and Evaluating Changes in Ozone

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 CAIR and adjacent states. These analyses show a range of ozone reductions based on the metric used and the years examined.

Meteorological Effects on Environmental Trends

Detecting trends or causal effects in air quality requires several data points or multiple-year averages because of natural variability in environmental measurements and meteorology. EPA uses a regression model for trends analysis that partially adjusts for the variability in weather. Figure 3 shows the weekly average of maximum daily temperatures during the NO_x ozone season at CASTNET sites included in the CAIR region that met the data completeness criteria. During the first year of CAIR, 2009, the ozone season months were cooler on average than those months during the 2006–2008 time period, making it important to account for meteorological effects when assessing any trends in air pollution after CAIR was implemented (see page 8 for an analysis of ozone trends using meteorologically adjusted data).

Figure 3: Weekly Average of Maximum Ozone Season Daily Temperatures, 2006–2009

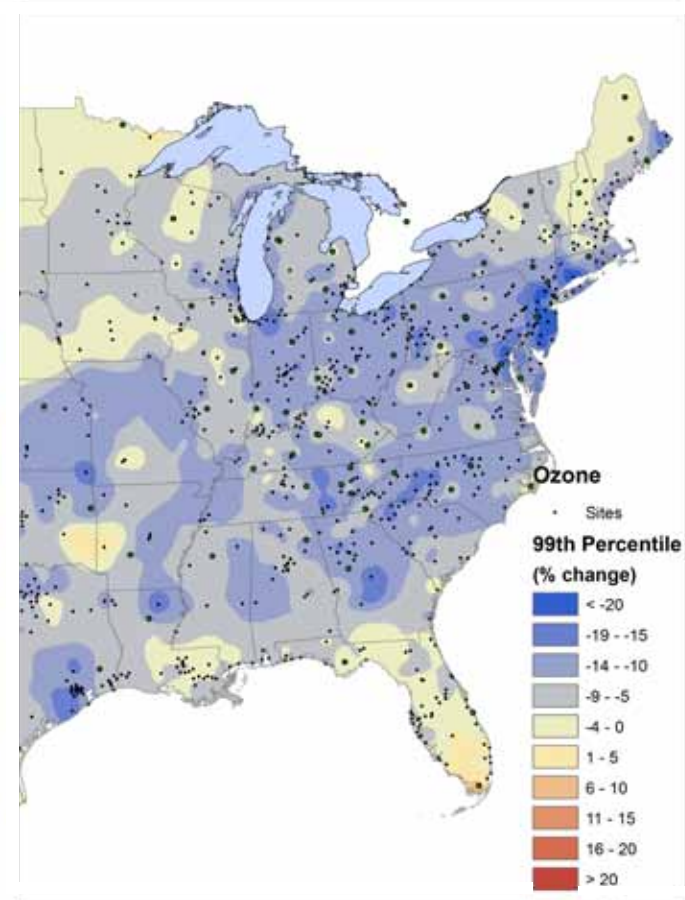


Source: EPA, 2010

Changes in 1-Hour Ozone Concentrations in the East

EPA examined changes in unadjusted 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 4 shows changes in the 99th percentile of 1-hour ozone concentrations between 2000–2002 (before implementation of the NBP) and 2007–2009 (under the NBP and first year of CAIR NO_x ozone season program implementation). 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 CAIR states of 16 percent. This reduction represents the greatest three-year average decrease in ozone concentrations since the NBP program began in 2003.

Figure 4: Percent Change in 1-Hour Ozone Concentrations during the Ozone Season, 2000–2002 versus 2007–2009



Source: EPA, 2010

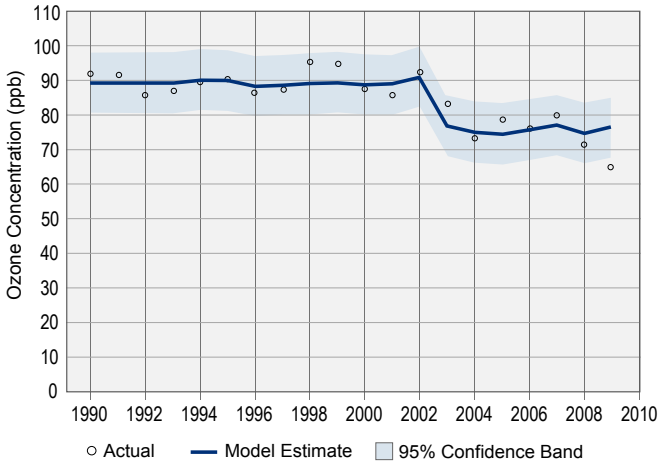
Changes in Rural Ozone Concentrations

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. EPA investigated trends in both rolling 8-hour and 1-hour ozone concentrations as measured at CASTNET monitoring sites within the CAIR NO_x ozone season region and in adjacent states (states within 200 km of a CAIR NO_x ozone season 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 various programs geared towards reducing NO_x emissions. 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 CAIR NO_x ozone season was modeled (Figure 5). The ARIMA model shows that between 1990 and 2003, the average of the 99th percentile of ozone concentration was 89 parts per billion (ppb). After 2004, the year by which the majority of NBP affected states began

Figure 5: Shift in 8-Hour Seasonal Rural Ozone Concentrations in the CAIR NO_x Region, 1990–2009



Note: Ozone concentration data are from CASTNET sites that met completeness criteria and are located in and adjacent to the CAIR NO_x region.
Source: EPA, 2010

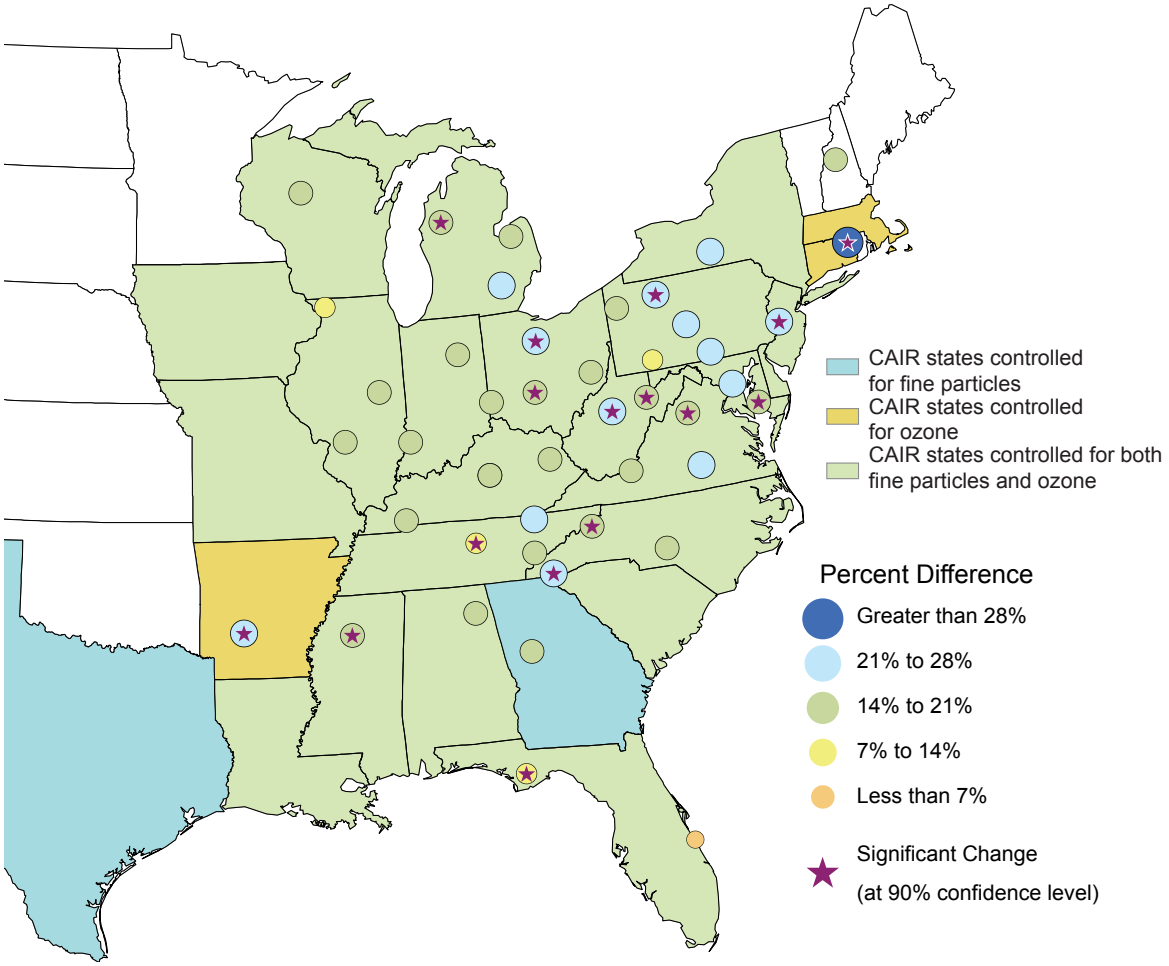
compliance, a statistically significant shift occurred and a new trend was established, with an average ozone level of 74 ppb. The ARIMA model shows a statistically significant, 17 percent (15 ppb) decrease in ozone concentrations beginning at the start of the NBP, suggesting that this program is a major contributor to these regional improvements in ozone. In 2009, the first compliance year of the new CAIR NO_x programs, ozone concentrations were the lowest over the 20-year period. Ozone concentrations were down 27 ppb (29 percent) in 2009 versus 1990.

The large improvements in ozone concentrations shown in Figure 5 on page 5 result from the establishment of the NBP in 2003, which CAIR now carries forward. Emission controls in place primarily from the NBP are responsible for these improvements. The significant decrease in ozone levels evident in Figure 5 is not the result of the recent economic downturn, given that the large drop in ozone concentrations predated the economic downturn. Moreover, emission rates for fossil generation have declined remarkably to capped levels established under the NBP and have been to shown to be binding in a viable trading market.

Site-Specific Changes in Rural Ozone

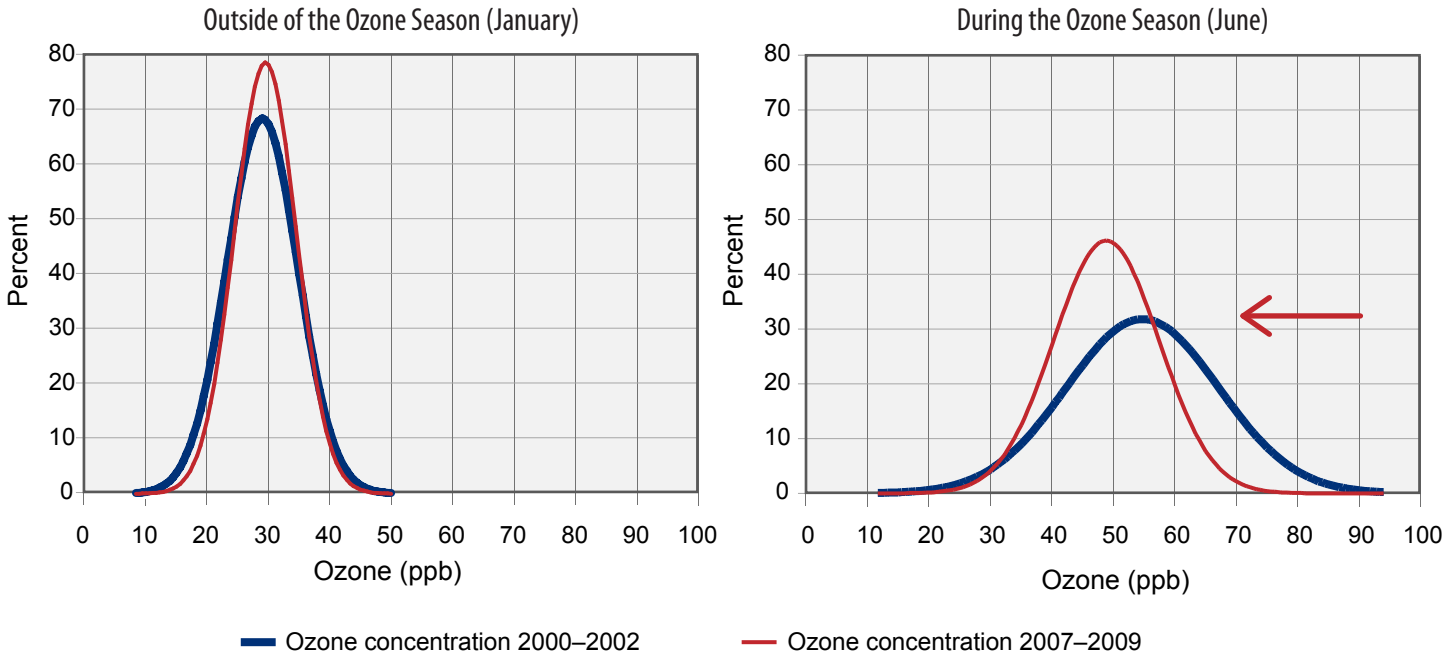
Changes in hourly ozone concentrations at CASTNET sites located in or within 200 km of a state's border which participates in the CAIR NO_x ozone season program are shown in Figure 6. The percent difference in the average of the 99th percentile for 2000–2002 versus 2007–2009 was calculated for each site which met the completeness criteria. The 99th percentile is used to represent the change in extreme ozone concentrations. The largest reductions occurred downwind of the Ohio River Valley where the greatest reductions in NO_x emissions were realized. There are a total of 19 CASTNET sites with reductions greater than 20 percent. Abington, CT (ABT147) showed the greatest decrease in 99th percentile average ozone concentration with a 31 percent reduction between 2000–2002 and 2007–2009. To determine whether the percent difference was statistically significant, a p-value was calculated using a Student's t-test. Sites with significant changes at the 90 percent confidence level are noted with a star.

Figure 6: Percent Difference in 99th Percentile Hourly Ozone Values during the Ozone Season, 2000–2002 versus 2007–2009



Source: EPA, 2010

Figure 7: Changes in the Monthly Distribution of Ozone



Source: EPA, 2010

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 CAIR region during the ozone season since implementation of the NBP and CAIR program. Figure 7 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 NBP and CAIR program (2000–2002), while the red lines represent ozone concentrations after implementation of the NBP and CAIR Program (2007–2009). 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 7 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 and CAIR program, 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 6-15 ppb during the ozone season, while there were very little (February and March) to 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 CAIR region is indicative of broader, substantial change in ozone concentrations due in significant part to the NBP and CAIR programs.

Table 1: Shift in 8-Hour Ozone Concentration by Month, 2000–2002 versus 2007–2009

Month	Change in 99th Percentile 8-Hour Ozone Concentration
January	No statistically significant shift
February	Down 3 ppb
March	Down 2 ppb
April	No statistically significant shift
May	Down 6 ppb
June	Down 12 ppb
July	Down 15 ppb
August	Down 11 ppb
September	Down 7 ppb
October	Down 12 ppb
November	No statistically significant shift
December	No statistically significant shift

Note: Months within the ozone season are shaded.

Source: EPA, 2010

Changes in 8-Hour Ozone Concentrations

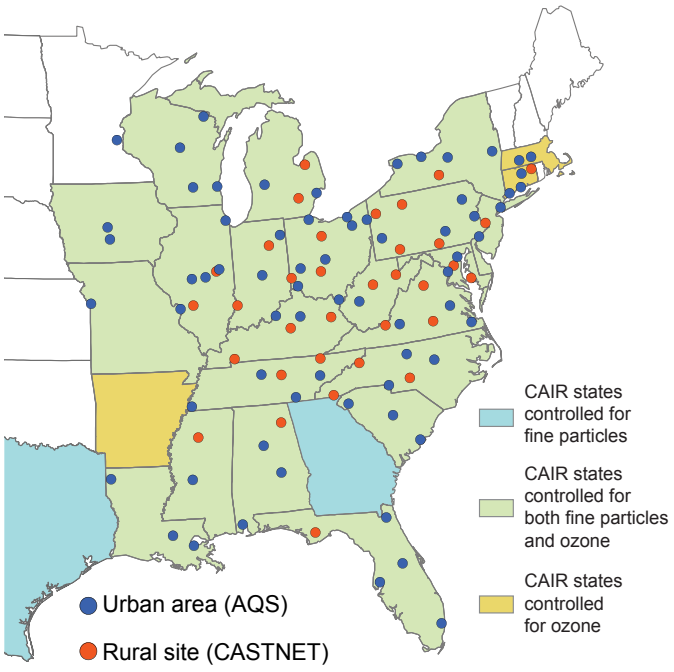
Daily maximum 8-hour ozone concentration data were assessed from 70 urban AQS areas and 34 rural CASTNET sites located in the CAIR NO_x ozone season program region. For a monitor or area to be included in this trend analysis, it had to provide complete and valid data for 50 percent of the ozone season 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 8 shows the AQS and CASTNET monitoring sites in the CAIR NO_x ozone season program region that met these completeness criteria.

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.[1] The model 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.

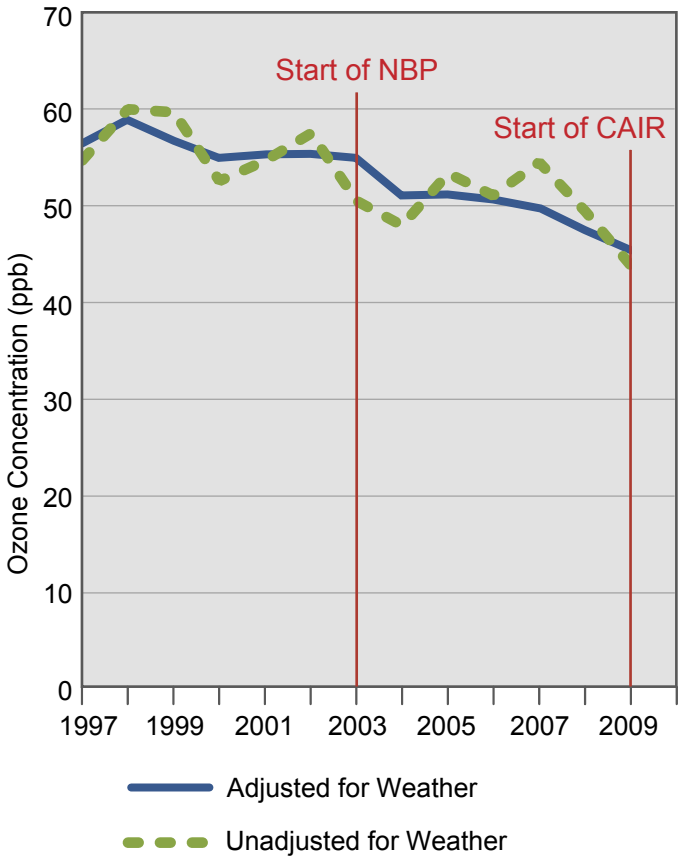
Figure 9 shows trends in the seasonal average daily maximum 8-hour ozone concentrations in the CAIR NO_x ozone season region before and after adjusting for the influence of weather.[2] For example, lower temperatures and higher relative humidity in the CAIR NO_x ozone season region during the 2004 ozone season dampened ozone formation, while higher temperatures and lower relative humidity 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. The first year of CAIR, 2009, was a cooler year than the 2006–2008 time period, however the meteorologically-adjusted trend still indicates a decrease in ozone concentrations. Therefore, decreases in ozone concentrations in 2009 are due not only to cooler temperatures, but also to emission reductions. Three-year averages will be used in 2011 to assess the air quality impact of the CAIR NO_x reductions with more confidence.

Figure 8: Location of Urban and Rural Ozone Monitoring Sites



Note: Urban areas represent multiple monitoring sites. Rural areas represent single monitoring sites.
Source: EPA, 2010

Figure 9: Seasonal Average of 8-hour Ozone Concentrations in CAIR States before and after Adjusting for Weather



Source: EPA, 2010

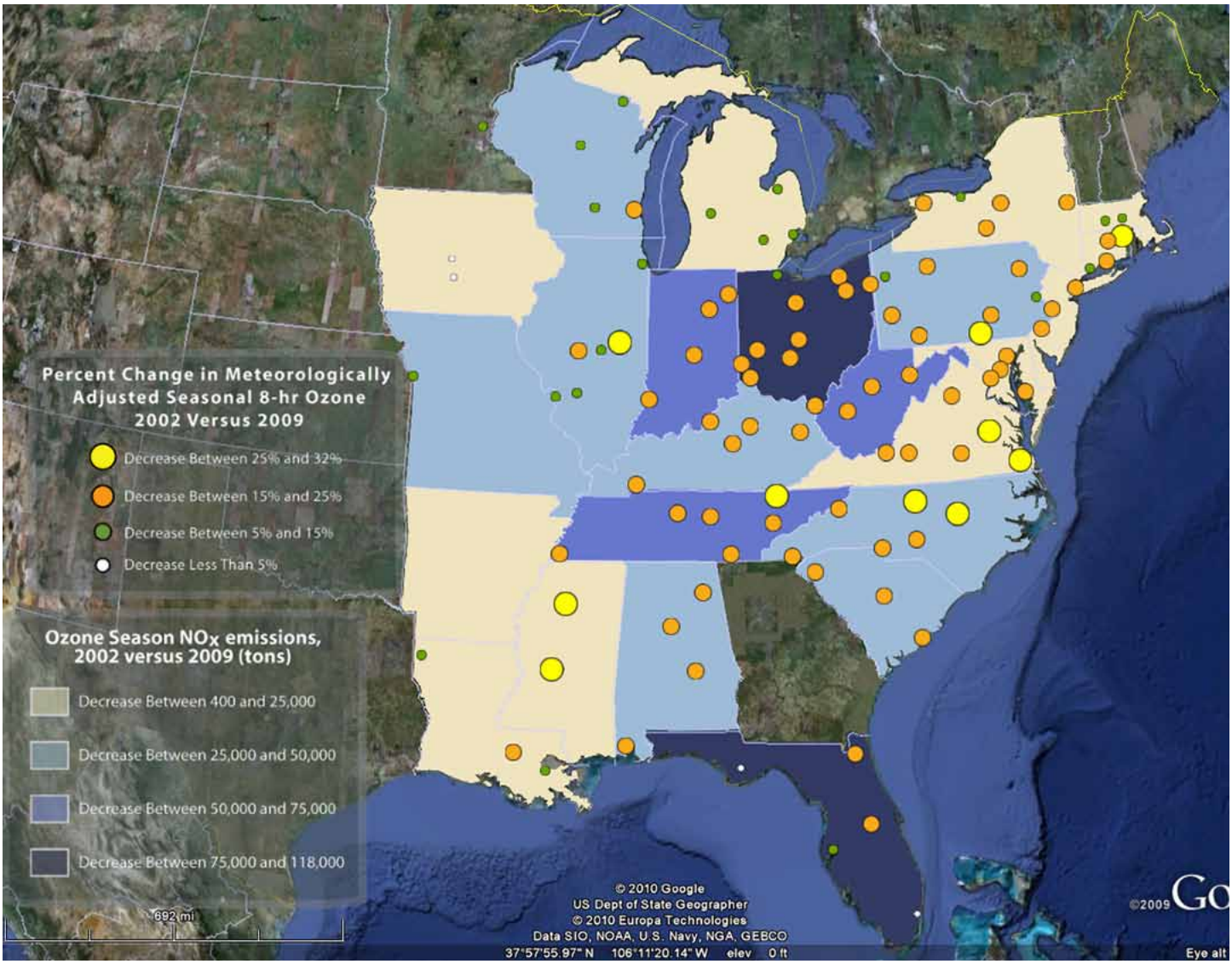
A closer look at the meteorologically-adjusted ozone trends since the start of the NBP in 2003 indicates that these reductions are substantive and sustainable. The average reduction in seasonal daily maximum 8-hour ozone concentrations measured in the CAIR NO_X region in the 2000–2002 and 2007–2009 time periods was about 9 percent. After considering the influence of weather, the improvement in daily maximum 8-hour ozone concentrations between these three-year periods was 13.5 percent. A comparison of single year meteorologically-adjusted ozone reveals an 18 percent reduction between 2002 and 2009.

Furthermore, the pace of these reductions has increased since implementation of the NBP and subsequent CAIR NO_X ozone season program. Between 1997 and 2002, ozone fell by 3 percent, while between 2002 and 2009, ozone dropped by 18 percent. This is consistent with the downward trend in NO_X emissions.

Linking Ozone and NO_X Emissions

Figure 10 is a snapshot depicting the relationship between reductions in NO_X emissions from CAIR NO_X ozone season program sources and reductions in 8-hour average ozone after implementation of the NBP and CAIR. As indicated previously, between 2002 and 2009, ozone decreased across all CAIR NO_X ozone season program states (after adjusting for meteorology) by an average of 18 percent. The largest reductions occurred in Tennessee, Illinois, Virginia, Mississippi, North Carolina, Pennsylvania, and Connecticut.

Figure 10: NO_X Emission Reductions and Adjusted Seasonal 8-hour Ozone Concentration Changes in CAIR NO_X Ozone Season States

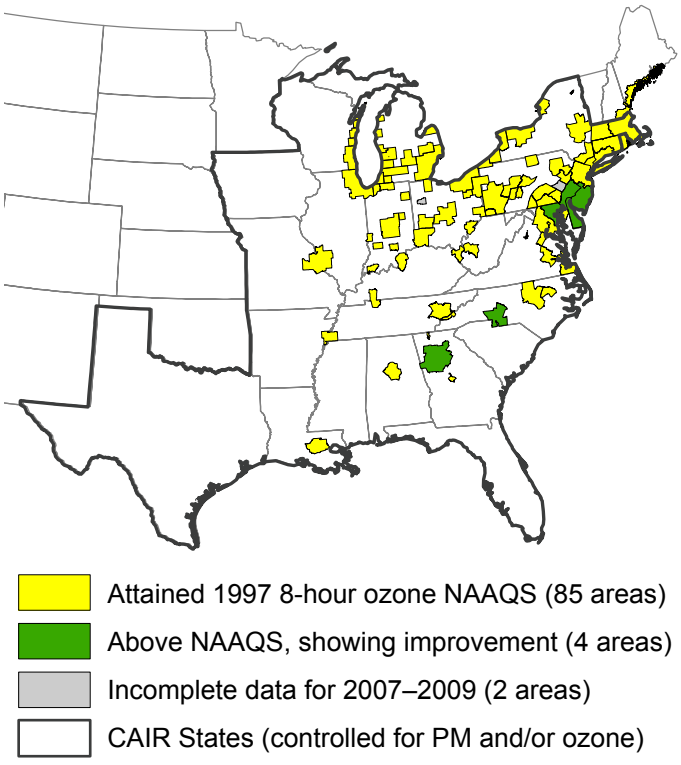


Source: EPA, 2010

Changes in Ozone Nonattainment Areas

In April 2004, EPA designated 126 areas as nonattainment for the 8-hour ozone standard adopted in 1997, of which 113 designations took legal effect.[3] These designations were made using data from 2001–2003. Of those areas, 92 are in the East (as shown in Figure 11) and are home to about 103 million people.[4] Based on data gathered from 2007–2009, 86 of these original eastern nonattainment areas show concentrations below the level of the 1997 ozone standard (0.08 ppm), indicating improvements in ozone. Improvements in these 86 areas mean that 93 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 87 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.

Figure 11: Changes in Nonattainment Areas in the CAIR Region, 2001–2003 (Original Designations) versus 2007–2009



Note: Previous NBP progress reports included Early Action Compact (EAC) areas as areas of nonattainment. Those areas were switched to attainment/unclassified status before the nonattainment designation took legal effect and are not included in this analysis of CAIR nonattainment areas. For more information on EACs please visit <www.epa.gov/oar/eac/>
Source: EPA, 2010

Six of the original 92 areas in the East continue to exceed the level of the standard. In the four largest of these areas, however, ozone concentrations have fallen by an average of 13 percent. Because of the reductions in these four areas, over 15 million Americans living in these areas are experiencing better air quality. The other two areas do not have sufficient recent ozone data to quantify their change in ozone.

Given that the majority of relevant NO_x emission reductions occurring after 2003 are attributable to the NBP and CAIR, it is reasonable to conclude that these NO_x reduction programs have been a significant contributor to these improvements in ozone air quality.

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. Ground-level 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.[5]

When ozone is present in the air, it can enter a plant through pores in its leaves known as stomata and cause significant cellular damage. This damage can compromise the ability of the plant to produce sugars during photosynthesis. The remaining energy resources of the plant are further depleted as leaves attempt to repair or replace damaged tissue. This loss of energy resources can lead to reduced growth and/or reproduction and health 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.

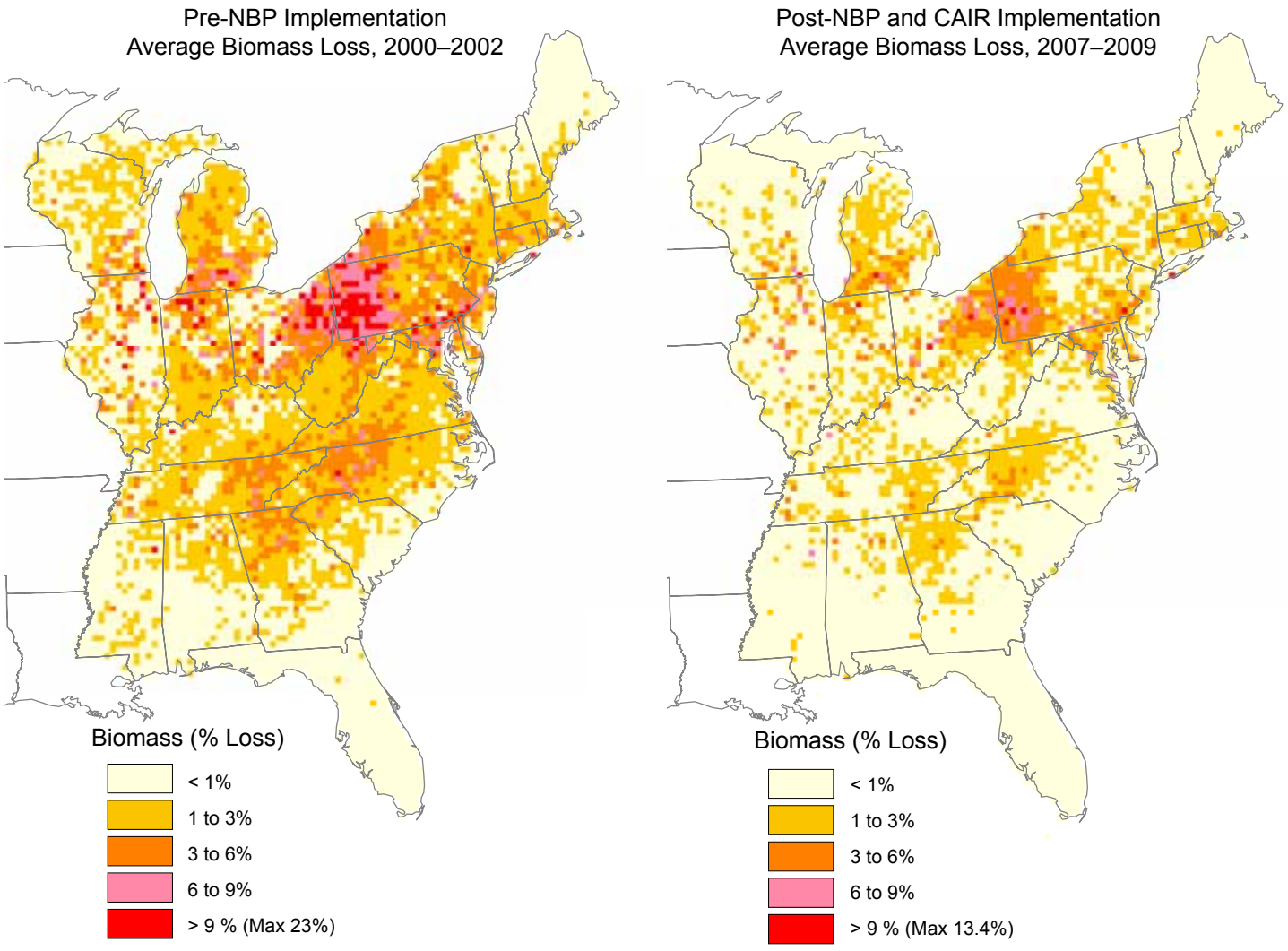
Assessing the impact of ground-level ozone on forests in the eastern United States involves understanding the risk to tree species from ambient ozone concentrations and accounting for the prevalence of those species within the forest. The more abundant ozone-sensitive tree species are in a community, the larger the impact on the community as a whole. 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 seedling 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 or tulip-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 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[6] 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 minimize 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.[7] This analysis compared two time periods: 2000–2002 (before the NBP) and 2007–2009 (under the NBP and first year of the CAIR NO_x ozone season program) and demonstrates the benefit to forest ecosystems from decreasing ozone concentrations during these two time periods.

Since implementation of the NBP and CAIR, the number of areas with significant biomass loss (more than 2 percent)[8] due to ozone was 16 percent for the period of 2007–2009, down from 37 percent for the period of 2000–2002 for all seven tree species across their range in the East (see Figure 12). Of these seven species, the black cherry, yellow poplar, eastern white pine, and quaking aspen are the most sensitive to ozone. For these species' individual response,

Figure 12: Estimated Average Biomass Loss of Selected Species due to Ozone Exposure, 2000–2002 versus 2007–2009



Source: EPA, 2010

the areas with significant biomass loss decreased on average by 17 percent, with quaking aspen and eastern white pine showing the most improvement. The remaining three tree species — red maple, sugar maple and Virginia pine — are no longer predicted to experience significant biomass loss across their range. While this change in biomass loss cannot be exclusively attributed to the implementation of the NBP and CAIR, it is likely that NO_x emission reductions and the corresponding decreases in ozone concentration occurring under the NBP and CAIR contributed to this environmental improvement. Also, other environmental factors, such as soil moisture, that can affect ozone damage were not considered in this analysis.[9]

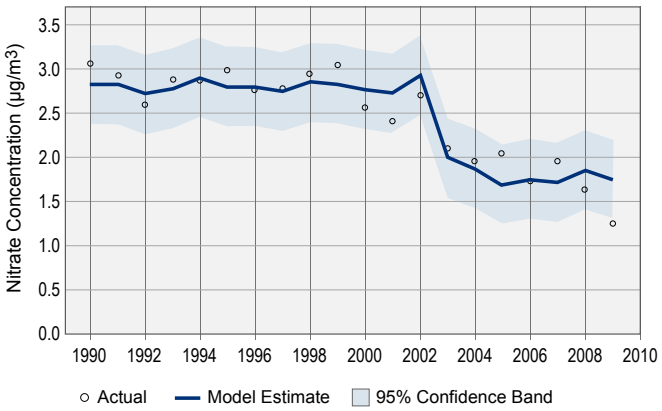
Changes in Nitrate

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 CAIR NO_x 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.

As facilities install and use control technologies, reducing the amount of NO_x emitted in the CAIR NO_x region, the amount of NO_x secondary pollutants also decreases. To determine the trend in total nitrate since the inception of various programs geared towards reducing NO_x emissions, an ARIMA model was used to assess changes in the average of median total nitrate concentrations as measured at CASTNET sites located in the CAIR NO_x region during the ozone season (see Figure 13). The ARIMA model illustrates that between 1990 and 2003, total nitrate concentrations averaged about 3 µg/m^3. After 2004, the year by which the majority of NBP affected states began compliance, 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. In 2009, the first compliance year of the new CAIR NO_x programs, nitrate concentrations were the lowest over the 20-year period.

Figure 13: Shift in Seasonal Nitrate Concentrations at Rural Sites in the CAIR Region, 1990–2010



Note: Total nitrate concentration data are from CASTNET sites that met completeness criteria and are located in and adjacent to the NBP region.
Source: EPA, 2010

Particulate Matter

"Particulate matter," also known as particle pollution or PM, is a complex mixture of extremely small particles and liquid droplets. Particle pollution is made up of a number of components, including acids (such as nitrates and sulfates), organic chemicals, metals, and soil or dust particles. Fine particles ($PM_{2.5}$) can form when gases emitted from power plants, industrial sources, automobiles, and other sources react in the air.

Particulate Matter Impacts on Human Health and Ecosystems

Particle pollution — especially fine particles — contains microscopic solids or liquid droplets that are so small that they can get deep into the lungs and cause serious health problems. Numerous scientific studies have linked particle pollution exposure to a variety of problems, including: increased respiratory symptoms, such as irritation of the airways, coughing, or difficulty breathing; decreased lung function; aggravated asthma; development of chronic bronchitis; irregular heartbeat; nonfatal heart attacks; and premature death in people with heart or lung disease.

Particles can be carried over long distances by wind and then settle on ground or water. The effects of this settling include: making lakes and streams acidic; changing the nutrient balance in coastal waters and large river basins; depleting the nutrients in soil; damaging sensitive forests and farm crops; and affecting the diversity of ecosystems.

For more information on the health and environmental effects of particulate matter, visit <www.epa.gov/air/particlepollution/>.

Particulate Matter Standards

The CAA requires EPA to set NAAQS for particle pollution. The first PM standard for fine particles was set by EPA in 1997 at 65 micrograms per cubic meter ($\mu g/m^3$) for 24-hour exposure and at 15 $\mu g/m^3$ for annual exposure. EPA revised the air quality standards for particle pollution in 2006. The 2006 standards tighten the 24-hour fine particle standard from the current level of 65 micrograms per cubic meter ($\mu g/m^3$) to 35 $\mu g/m^3$, and retain the current annual fine particle standard at 15 $\mu g/m^3$.

CAIR Annual Programs

The CAIR NO_x annual program and CAIR SO_2 program were established to address the interstate transport of $PM_{2.5}$ pollution throughout the year and help eastern U.S. counties attain the $PM_{2.5}$ annual standard. These programs generally apply to large electric generating units (EGUs) — boilers, turbines, and combined cycle units used to generate electricity for sale. The CAIR annual programs apply in all of the CAIR NO_x ozone season states except Connecticut, Massachusetts, and Arkansas, and also in Texas and Georgia. In Figure 1 on page 2, the states colored blue and green are those that are subject to the CAIR annual programs and controlled for fine particles.

The first year of implementation of the CAIR NO_x annual program was 2009. In 2009, there were 3,321 EGUs in the program and NO_x emissions from those sources were approximately 1.3 million tons. Implementation of the CAIR SO_2 program began in 2010. However, all the CAIR SO_2 program facilities participated in a monitoring and reporting training year in 2009. With the exception of a small number of facilities with pending applicability questions, all participating units reported data in 2009. Their total SO_2 emissions in 2009 were approximately 5.0 million tons.

Several factors contributed to early reductions in SO_2 prior to implementation of the CAIR SO_2 program in 2010. The ability to use SO_2 allowances from the ARP to comply with the CAIR SO_2 program served as a strong incentive from 2005–2009 for units subject to both programs to lower SO_2 emissions in order to bank allowances for future use under CAIR. For example, in 2009 37 EGUs subject to the ARP added scrubbers to reduce SO_2 emissions. Thirty-four of those units are also in the CAIR SO_2 program, suggesting that the controls were installed to meet the emission reductions that were required in 2010, the CAIR SO_2 program's first compliance year. Another factor influencing early SO_2 reductions was the recent economic downturn that lowered demand for electric power. Between 2008 and 2009 there was a 7.5 percent drop in heat input, a surrogate measure of electricity generation. Additionally, several state programs and new source review (NSR) settlements contributed to early SO_2 reductions.

To better understand how the CAIR annual programs will affect $PM_{2.5}$ formation in the atmosphere, this report presents regional and geographic trends in $PM_{2.5}$ levels prior to implementation of any of the CAIR annual programs, and for 2009, the first year of the CAIR NO_x annual program implementation.

Measuring and Evaluating Changes in Particulate Matter

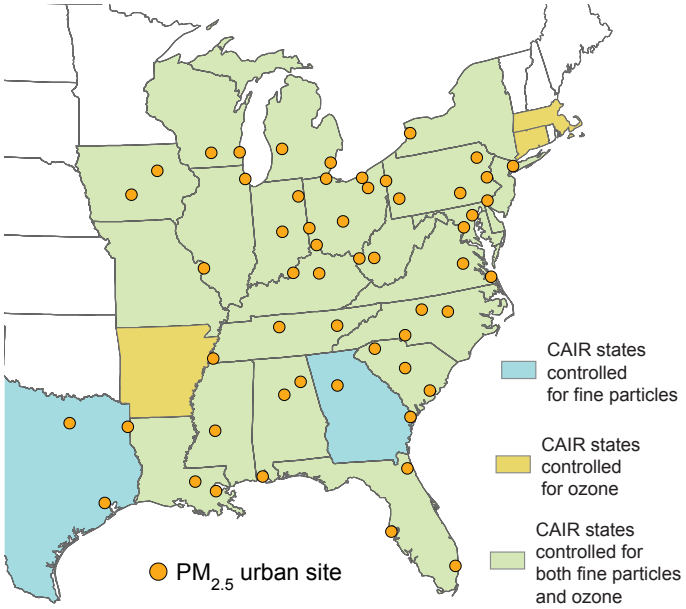
Average $PM_{2.5}$ concentration data were assessed from 55 urban AQS areas located in the CAIR NO_x annual program region. For a monitor or area to be included in this trend analysis, it had to provide complete and valid data for at least 60 days in each of the years from 2001–2009. In addition, urban AQS areas often include more than one monitoring site. In these cases, the site with the highest observed $PM_{2.5}$ concentration for each day was used. Figure 14 shows the AQS monitoring sites in the CAIR NO_x annual program region that met these completeness criteria.

Trends in $PM_{2.5}$ Concentrations

As with ozone, weather plays an important role in the formation of PM (see Figure 3 for 2008 and 2009 weather trends). EPA uses a statistical model to account for the weather-related variability of $PM_{2.5}$ concentrations to provide a more accurate assessment of the underlying trend in the precursor emissions that cause $PM_{2.5}$ formation. This methodology and the subsequent $PM_{2.5}$ estimates are provided by EPA's Office of Air Quality Planning and Standards (OAQPS), Air Quality Assessment Division.

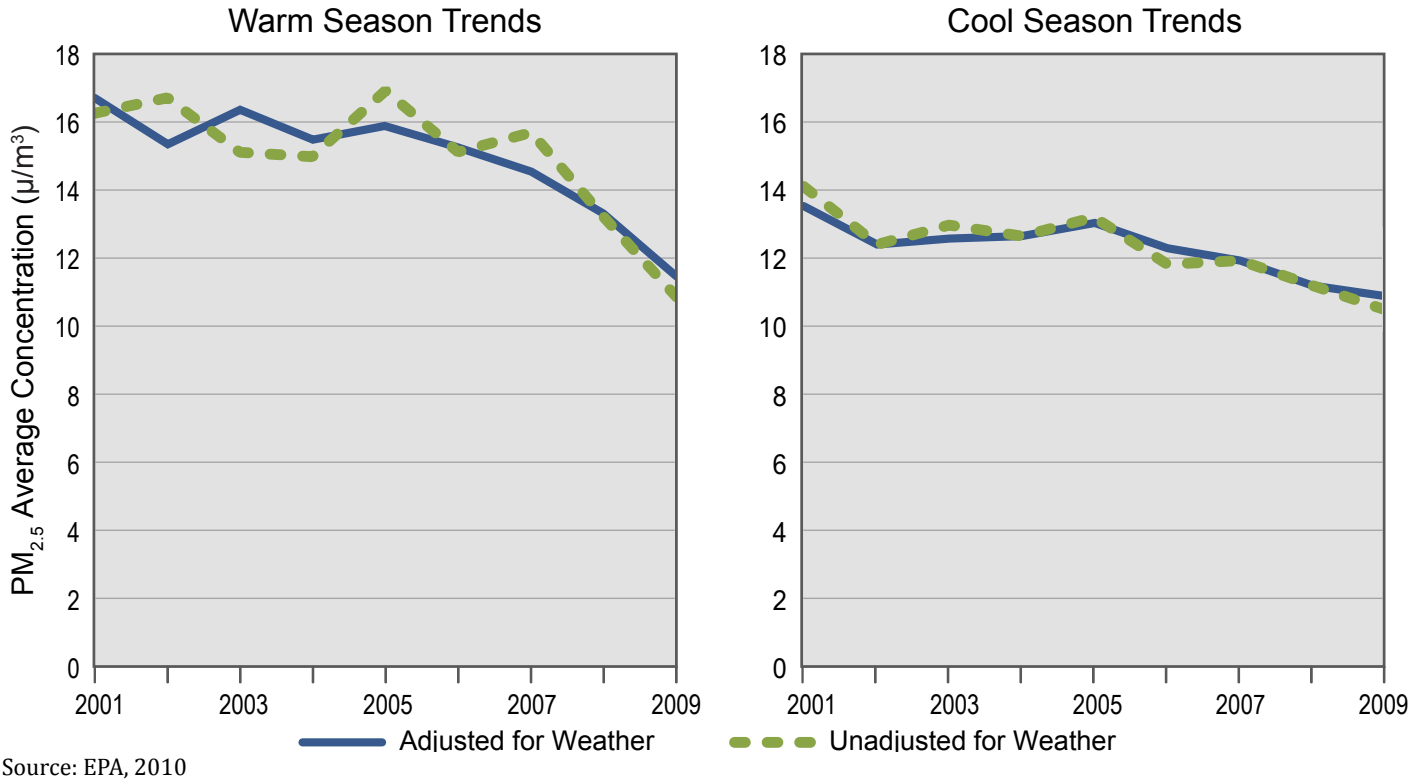
Figure 15 shows separate trends in $PM_{2.5}$ concentrations in the CAIR NO_x annual program region for the warm months (May to September) and cool months (October to April). These separate graphs are shown due to the seasonal variability of the components that make up $PM_{2.5}$ (explained in more depth in the following section). After adjusting for weather, $PM_{2.5}$ concentrations have decreased by approximately 18 percent in the warm season and 12 percent in the cool season between the 2001–2003 and 2007–2009 monitoring periods.

Figure 14: CAIR $PM_{2.5}$ Monitoring Sites



Source: EPA, 2010

Figure 15: $PM_{2.5}$ Seasonal Trends



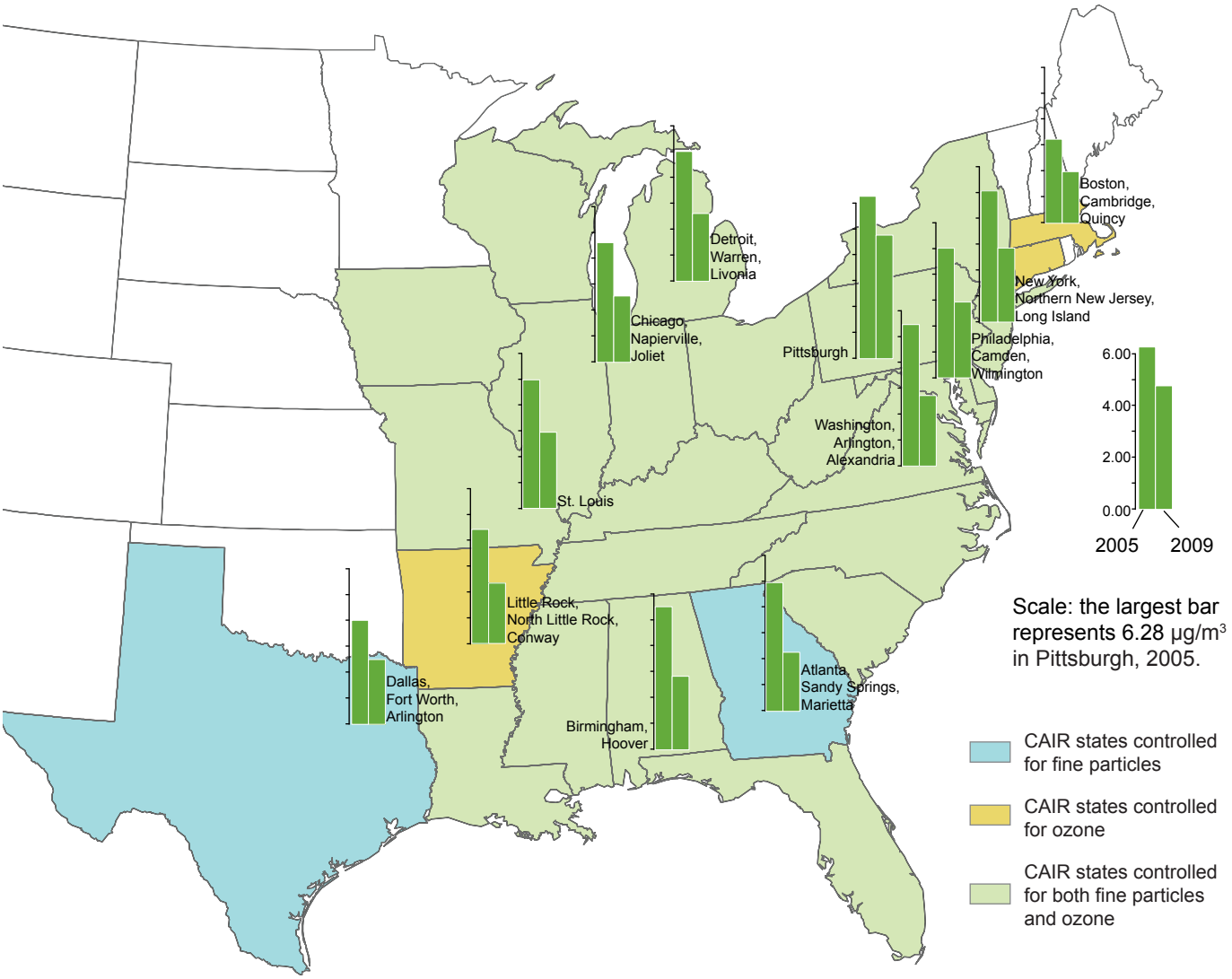
Source: EPA, 2010

Changes in $PM_{2.5}$ Composition

The chemical composition of $PM_{2.5}$ is characterized in terms of five major components that generally comprise the mass of $PM_{2.5}$: sulfate, nitrate, organic carbon, elemental carbon, and crustal material. On average, sulfate is the largest component by mass in the eastern U.S. and generally the largest sources of sulfate in the east are EGUs and industrial boilers.

Composition of $PM_{2.5}$ was analyzed in 91 metropolitan and micropolitan areas (i.e., Core Based Statistical Areas) within the CAIR region in 2005 and 2009. Results of this analysis indicate that all of the areas studied, with complete data, showed a decline in sulfate concentration as a portion of $PM_{2.5}$ between 2005 and 2009 (see Figure 16 for results in select cities). The CAIR annual SO_2 program was not implemented until 2010, but results from the 2009 monitoring training year indicate that many sources made emissions reductions early (see the Clean Air Interstate Rule 2009 Emission, Compliance, and Market Analyses report at <www.epa.gov/airmarkets/progress/CAIR_09/CAIR_2.html>). Nitrate concentrations as a portion of $PM_{2.5}$ decreased in about 87 percent of the areas between 2005 and 2009. In total, $PM_{2.5}$ mass was down in all but two of the areas studied (El Paso, Texas and Tallahassee, Florida).

Figure 16: 2005 and 2009 Sulfate Concentration in $PM_{2.5}$



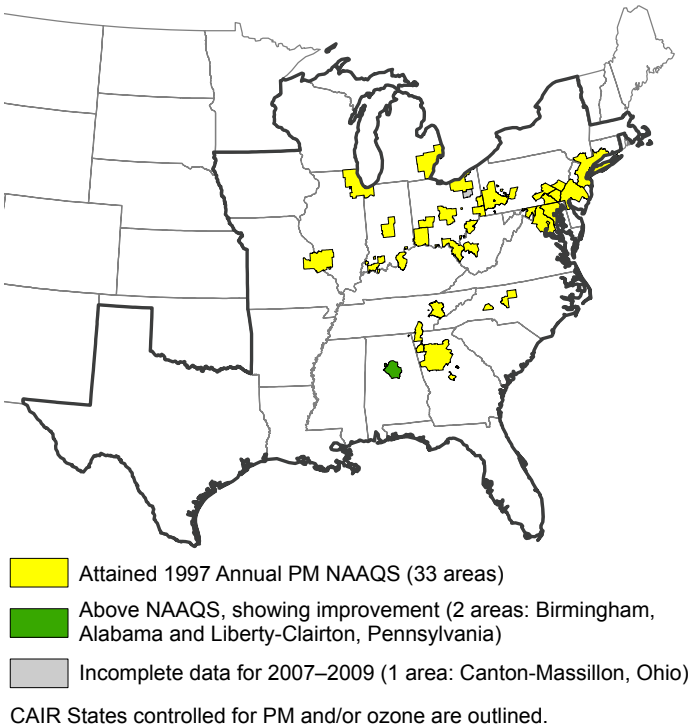
Source: EPA, 2010

Changes in $PM_{2.5}$ Nonattainment Areas

In January 2005, EPA designated 39 areas as nonattainment for the annual average $PM_{2.5}$ standard adopted in 1997, one of which was also designated nonattainment for the 24-hour average $PM_{2.5}$ standard.[10] These designations were made using data from 2001–2003. Of those areas, 36 are in the East (as shown in Figure 17) and are home to about 88 million people.[11] Based on data gathered from 2007–2009, 33 of these original eastern areas show concentrations below the level of the 1997 $PM_{2.5}$ standard (15.0 µg/m^3), indicating improvements in $PM_{2.5}$ air quality. Improvements in these 33 areas mean that 92 percent of the areas originally designated nonattainment in the East now have $PM_{2.5}$ air quality that is better than the standard under which they were originally designated nonattainment. These improvements bring cleaner air to over 69 million people. Many of these areas have applied to be officially redesignated to maintenance, as described in Section 107 of the CAA.

Three of the original 36 areas in the East continue to exceed the level of the $PM_{2.5}$ standard. In two of these areas, however, $PM_{2.5}$ concentrations have fallen by an average of 16 percent. Because of these reductions in $PM_{2.5}$, over 800,000 Americans living in these areas are experiencing better air quality. The other area does not have sufficient recent $PM_{2.5}$ data to quantify its change in air quality.

Figure 17: Changes in PM Nonattainment Areas in the CAIR Region, 2001–2003 (Original Designations) versus 2007–2009



Source: EPA, 2010

Given that the majority of relevant NO_x and SO_2 emission reductions occurring after 2003 are attributable to the Acid Rain Program, NBP, and CAIR, it is reasonable to conclude that these emission reduction programs have been a significant contributor to these improvements in $PM_{2.5}$ air quality.

Health Benefits

With 2009 ushering in the CAIR annual and ozone season NO_x programs, coupled with electricity generators preparing for compliance with the CAIR annual SO_2 program, 2009 saw significant reductions in emissions of both NO_x and SO_2 by EGUs in the CAIR program. These reductions in pollutants that are precursors to ground-level ozone and ambient particulate matter can be expected to improve air quality and human health.

Exposure to ground-level ozone and particulate matter has been shown to adversely impact human health and welfare. The 2009 $PM_{2.5}$ Integrated Science Assessment[12] and the 2006 ozone criteria document[13] identify the human health effects associated with these ambient pollutants, which include premature mortality and a variety of morbidity effects associated with acute and chronic exposures. PM welfare effects include visibility impairment and materials damage. Ozone welfare effects include damages to agricultural and forestry sectors. NO_x welfare effects include aquatic and terrestrial acidification and nutrient enrichment.[14] SO_2 welfare effects include aquatic and terrestrial acidification and increased mercury methylation.[14] Though models exist for quantifying these ecosystem impacts, time and resource constraints precluded quantifying those effects in this analysis.

Emission reductions for summer NO_x were estimated as the reduction in NO_x emissions from CAIR units between 2008 and 2009, scaled by the reduction in heat input (to account for reduced demand). It is difficult to discern emission reductions prior to 2008 because many states were complying with the NBP at that time. SO_2 reductions attributable to CAIR were estimated as the difference between 2005 and 2009 monitored SO_2 emissions, scaled by the reduction in heat input (electricity demand) between those two assessment years. While these two approaches differ, they are both believed to be the most appropriate screening-level estimates available for each pollutant.

In order to assess the order of magnitude of CAIR benefits in 2009, EPA performed a screening level assessment combining reductions in SO_2 and NO_x emissions that can largely be attributed to CAIR with benefit per ton factors derived from EPA's recent analysis of the proposed Transport Rule. Summer NO_x reductions were combined with summer NO_x

Table 2: Estimated Quantifiable $PM_{2.5}$ Human Health Benefits Largely Attributable to CAIR in 2009

$PM_{2.5}$ Benefits	Incidences Avoided	Value (2006 $)
Premature Mortality		
Pope et al. (2002) (age > 30)	10,000	
3% Discount Rate		$ 77,000,000,000
7% Discount Rate		$ 71,000,000,000
Laden et al. (2006) (age > 25)	26,000	
3% Discount Rate		$ 200,000,000,000
7% Discount Rate		$ 180,000,000,000
Infant (< 1 year)	43	$ 360,000,000
Chronic Bronchitis	6,400	$ 2,900,000,000
Non-fatal heart attacks (age > 18)	15,000	$ 1,700,000,000
Hospital admissions—respiratory (all ages)	2,400	$ 33,000,000
Hospital admissions—cardiovascular (all ages)	5,100	$ 140,000,000
Emergency room visits for asthma (age < 18)	9,600	$ 3,500,000
Acute Bronchitis (age 8-12)	15,000	$ 6,300,000
Lower Respiratory Symptoms (age 7-14)	170,000	$ 3,200,000
Upper Respiratory Symptoms (age 9-18)	130,000	$ 3,800,000
Minor restricted-activity days (ages 18-65)	7,400,000	$ 440,000,000
Lost work days (ages 18-65)	1,200,000	$ 150,000,000
Asthma exacerbation (asthmatics 6-18)	160,000	$ 8,600,000

Source: EPA, 2010

Table 3: Estimated Quantifiable Ozone Human Health Benefits Largely Attributable to CAIR in 2009

Ozone Benefits	Incidences Avoided	Value (2006 $)
Premature Mortality		
Multi-city and NMMAPS		
Bell et al. (2004) (all ages)	39	$ 320,000,000
Schwartz et al. (2005) (all ages)	60	$ 500,000,000
Huang et al. (2005) (all ages)	65	$ 540,000,000
Meta-analyses		
Ito et al. (2005) (all ages)	180	$ 1,500,000,000
Bell et al. (2005) (all ages)	130	$ 1,100,000,000
Levy et al. (2005) (all ages)	180	$ 1,500,000,000
Hospital admissions—respiratory (ages > 65)	280	$ 6,700,000
Hospital admissions—respiratory (ages < 2)	220	$ 2,200,000
Emergency room visits for asthma (all ages)	180	$ 65,000
School absence days	80,000	$ 7,200,000
Minor restricted-activity days (ages 18-65)	230,000	$ 14,000,000

Source: EPA, 2010

benefit per ton factors for ground-level ozone health endpoints to estimate CAIR benefits attributable to reductions in ozone while annual SO_2 reductions were combined with annual SO_2 benefit per ton factors for ambient $PM_{2.5}$ health endpoints to estimate CAIR benefits attributable to reductions in ambient $PM_{2.5}$. Although annual reductions in NO_x would also contribute to reductions in $PM_{2.5}$, EPA did not develop annual NO_x benefit per ton factors for ambient $PM_{2.5}$ for the proposed Transport Rule. Therefore, these benefits were not quantified, adding to the conservative scope of this assessment.

This analysis includes several independent estimates of the relationship between premature mortality and exposure to $PM_{2.5}$ or ozone. The use of multiple estimates stems from the conclusions of EPA's 2006 ozone criteria document[13] and recommendations from the EPA Science Advisory Board, the National Research Council, and the National Academy of Sciences. For $PM_{2.5}$ mortality, this analysis uses two epidemiological studies, Pope *et al.* 2002 and Laden *et al.* 2006 to represent the low end and high end respectively of premature mortality estimates. For ozone mortality, this analysis uses six epidemiological studies including: three multi-city studies (including the National Morbidity, Mortality and Air Pollution Study [NMMAPS]) and three meta-analyses of multi-city and single-city studies. For more information on the selected estimates, please refer to EPA's Regulatory Impact Analysis for the Proposed Federal Transport Rule at <http://www.epa.gov/ttnecas1/regdata/RIAs/proposaltrria_final.pdf>.

The results of this screening-level assessment, shown in Table 2, indicate that the total assessed human health benefits of CAIR in 2009 due to changes in $PM_{2.5}$ from reductions in annual SO_2 emissions were between $83 and $200 billion annually using a 3 percent discount rate and between $76 and $190 billion annually using a 7 percent discount rate (all benefits are cited in 2006 dollars).[15] Benefits from decreased ground-level ozone due to reductions in summer NO_x emissions attributable to CAIR are expected to have added between $0.35 billion and $1.5 billion (see Table 3). A majority of this monetized benefit comes from incidences of premature mortality avoided — 10,000 to 26,000 incidences annually due to $PM_{2.5}$ benefits and 39 to 180 incidences annually due to ozone benefits. Other endpoints evaluated in this assessment include nonfatal heart attacks, hospital and emergency room visits, bronchitis, and asthma.

Notes

1 Cox, W. M. & Chu, S.H. 1996. Assessment of interannual ozone variation in urban areas from a climatological perspective. *Atmospheric Environment.* 30:16, 2615–2625.

Camalier, L., Cox, W.M. & Dolwick, P. 2007. The effects of meteorology on ozone in urban areas and their use in assessing ozone trends. *Atmospheric Environment.* 41:33, 7127–7137.

2 The seasonal average ozone concentration is calculated as the average of the daily maximum 8-hour ozone levels during the ozone season. These results provide a combined seasonal average for NBP states and do not show variations in ozone concentrations for specific urban or rural areas.

3 40 CFR Part 81. Designation of Areas for Air Quality Planning Purposes.

4 U.S. Census. 2000.

5 U.S. EPA. 2007. Review of the National Ambient Air Quality Standards for Ozone, Policy Assessment of Scientific and Technical Information. OAQPS Staff Paper. EPA-452/R-07-003. This document is available in Docket EPA-HQ-OAR-2003-0190 and online at <www.epa.gov/ttn/naaqs/standards/ozone/s_o3_cr_sp.html>.

6 The W126 exposure metric is a cumulative (not average) exposure index that is biologically based and places a greater weight on the higher hourly ozone concentrations.

7 Prasad, A.M. and Iverson, L.R. 2003. Little's range and FIA importance value database for 135 eastern U.S. tree species. <www.fs.fed.us/ne/delaware/4153/global/littlefia/index.html>, Northeastern Research Station, USDA Forest Service.

8 Areas with more than 2 percent biomass loss are defined here as significant based on a consensus workshop on ozone effects, which reported that a 2 percent annual biomass loss causes harm because of the potential for compounding effects over multiple years as short-term negative effects on seedlings affect long-term forest health. See:

Heck, W.W. &Cowling E.B. 1997. The need for a long term cumulative secondary ozone standard – an ecological perspective. *Environmental Management*, January, 23–33.

9 Chappelka, A.H. and Samuelson, L.J. 1998. Ambient ozone effects on forest trees of the eastern United States: A review. *New Phytologist* 139: 91–108.

10 40 CFR Part 81. Designation of Areas for Air Quality Planning Purposes.

11 U.S. Census. 2000.

12 U.S. Environmental Protection Agency (U.S. EPA). 2009d. Integrated Science Assessment for Particulate Matter (Final Report). EPA-600-R-08-139F. National Center for Environmental Assessment – RTP Division. December. Available on the Internet at <cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=216546>.

13 U.S. Environmental Protection Agency (U.S. EPA). 2006a. Air Quality Criteria for Ozone and Related Photochemical Oxidants (Final). EPA/600/R-05/004aF-cF. Washington, DC: U.S. EPA. February. Available on the Internet at <cfpub.epa.gov/ncea/CFM/recordisplay.cfm?deid=149923>.

14 U.S. Environmental Protection Agency (U.S. EPA). 2008f. Integrated Science Assessment for Oxides of Nitrogen and Sulfur –Ecological Criteria National (Final Report). National Center for Environmental Assessment, Research Triangle Park, NC. EPA/600/R-08/139. December. Available on the Internet at <cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=201485>.

15 Results reflect the use of 3 percent and 7 percent discount rates consistent with EPA and OMB guidelines. Further discussion of the choice of discount rate appears in EPA's Guidelines for Preparing Economic Analyses. EPA 240-R-00-003. National Center for Environmental Economics, Office of Policy Economics and Innovation. Washington, DC. September. Available on the Internet at <http://yosemite.epa.gov/ee/epa/eed.nsf/webpages/Guidelines.html/$file/cover.pdf>.