# 2010 Progress Report
## Environmental and Health Results

The Clean Air Interstate Rule (CAIR) and the Acid Rain Program (ARP) are both cap and trade programs designed to reduce emissions of sulfur dioxide ($SO_2$) and nitrogen oxides ($NO_x$) from power plants.

The ARP, established under Title IV of the 1990 Clean Air Act (CAA) Amendments, requires major emission reductions of $SO_2$ and $NO_x$, the primary precursors of acid rain, from the power sector. The $SO_2$ program sets a permanent cap on the total amount of $SO_2$ that may be emitted by electric generating units (EGUs) in the contiguous United States. The program is phased in, with the final 2010 $SO_2$ cap set at 8.95 million tons, a level of about one-half of the emissions from the power sector in 1980. $NO_x$ reductions under the ARP are achieved through a program that applies to a subset of coal-fired EGUs and is closer to a traditional, rate-based regulatory system. Since the program began in 1995, the ARP has achieved significant emission reductions.

The $NO_x$ Budget Trading Program (NBP) operated from 2003 to 2008. The NBP was a cap and trade program that required $NO_x$ emission reductions from power plants and industrial units in the eastern U.S. during the summer months.

CAIR addresses regional interstate transport of ozone and fine particle ($PM_{2.5}$) pollution. CAIR requires certain eastern states to limit annual emissions of $NO_x$ and $SO_2$, which contribute to the formation of ozone and $PM_{2.5}$. It also requires certain states to limit ozone season $NO_x$ emissions, which contribute to the formation of smog during the summer ozone season (May to September). CAIR includes three separate cap and trade programs to achieve the required reductions: the CAIR $NO_x$ ozone season trading program, the CAIR $NO_x$ annual trading program, and the CAIR $SO_2$ annual 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 CAIR provides health benefits as well as improved visibility in national parks and improvements in freshwater aquatic ecosystems in the eastern U.S.

### At a Glance:
### Environmental and Health Results in 2010

By reducing the precursors ($SO_2$ and $NO_x$) to $PM_{2.5}$ and ozone formation, emission reductions achieved by the ARP, NPB, and CAIR significantly benefit human health and welfare.

**Air Quality:** Between 1989 to 1991 and 2008 to 2010, average ambient sulfate concentrations have decreased by 51 percent in the Mid-Atlantic, 52 percent in the Midwest, 57 percent in the Northeast, and 48 percent in the Southeast. In CAIR states, average 1-hour ozone concentrations decreased by 19 percent between the same three-year periods.

**Acid Deposition:** Between the 1989 to 1991 and 2008 to 2010 observation periods, regional decreases in wet deposition of sulfate across the Eastern United States averaged 51 percent.

**Surface Water Chemistry:** Levels of Acid Neutralizing Capacity (ANC), the ability of a water body to neutralize acid deposition, have increased significantly from 1990 in lake and stream long-term monitoring sites in the Adirondack Mountains and the Northern Appalachian Plateau. These increasing ANC levels indicate trends toward recovery from acidification.

On July 6, 2011, EPA finalized the Cross-State Air Pollution Rule (CSAPR) to replace CAIR. On December 30, 2011, the U.S. Court of Appeals for the District of Columbia Circuit stayed the CSAPR pending resolution of litigation challenging it. While the stay is in effect, the EPA will not be implementing the CSAPR. Pursuant to the Court's order, CAIR, which was to be replaced by the CSAPR as of January 1, 2012, will be in effect until the stay is lifted.

This report is part of a series of reports summarizing progress in 2010 under both CAIR and the ARP. EPA combined emissions and compliance data for both CAIR and the ARP to more holistically show reductions in power sector emissions of $SO_2$ and $NO_x$ and the effect of these regional programs on human health and the environment. While several other programs contribute to $NO_x$ and $SO_2$ emission reductions and improved air quality (e.g., mobile source emission control programs), this series of reports focuses on achievements related to emission reductions at power sector sources under CAIR, the ARP, and the former NBP.

The first report in this series, released in October 2011, presented 2010 data on combined emission reductions and compliance results for CAIR and the ARP. It also presented some historic NBP emissions data and evaluated shared progress under these programs in 2010 by analyzing emission reductions and market activity. This report, the second in the series, provides further 2010 trends analysis by comparing changes in emissions to changes in a variety of environmental indicators, particularly in the eastern United States.

For more information on CAIR, please visit <epa.gov/airmarkets/progsregs/cair/>. For more information on the ARP, please visit <epa.gov/airmarkets/progsregs/arp/>. For more information on the NBP, please visit <epa.gov/airmarkets/progsregs/nox/sip.html>.
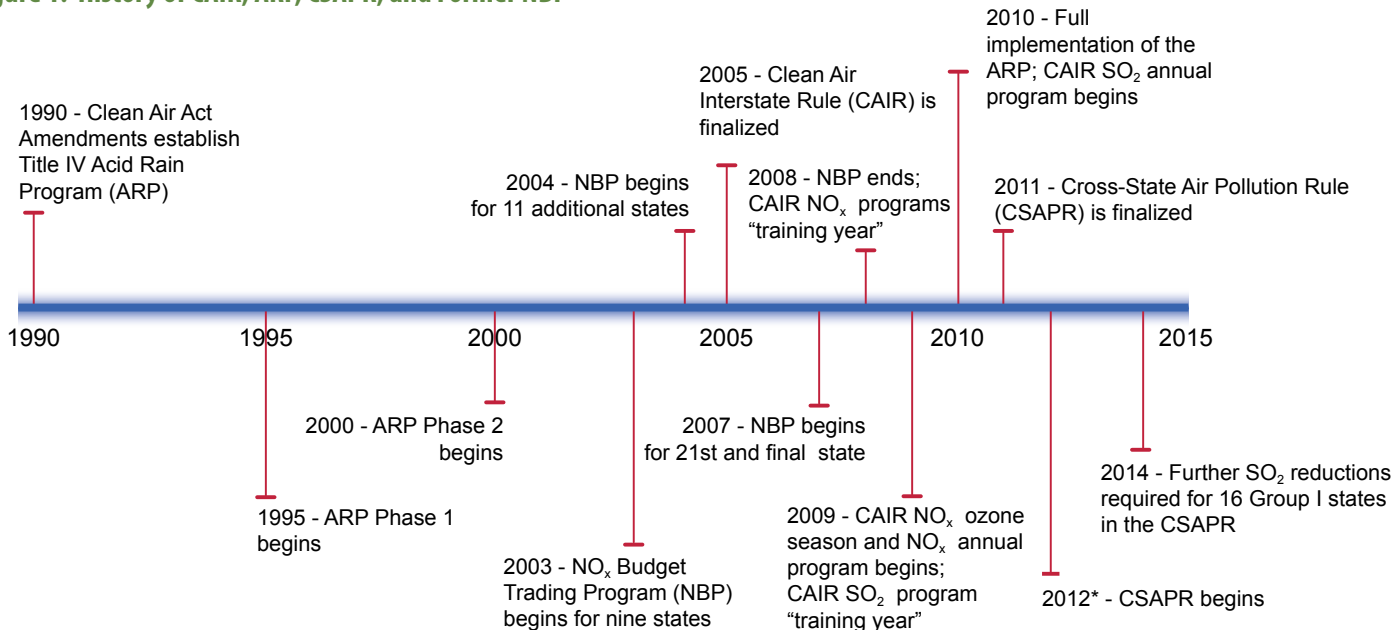
Figure 1 contains important milestones for CAIR, ARP, CSAPR, and the former NBP.

## CAIR Litigation and the Cross-State Air Pollution Rule

CAIR was finalized in 2005. However, in July 2008, the U.S. Court of Appeals for the D.C. Circuit granted several petitions for review of CAIR, finding significant flaws in the rule. Subsequently, in December 2008, the court issued a ruling to keep CAIR and the CAIR Federal Implementation Plans (FIPs)—including the CAIR trading programs—in place temporarily until EPA issued new rules to replace the CAIR and the CAIR FIPs.

On July 6, 2011, EPA finalized the Cross-State Air Pollution Rule (CSAPR) to replace CAIR. This rule responds to the court's concerns and fulfills the "good neighbor" provision of the Clean Air Act by addressing the problem of air pollution that is transported across state boundaries. The CSAPR will require 28 states in the eastern half of the U.S. to improve air quality significantly by reducing power plant emissions of $SO_2$ and $NO_x$ that cross state lines and contribute to smog (ground-level ozone) and soot (fine particle pollution) in other states.
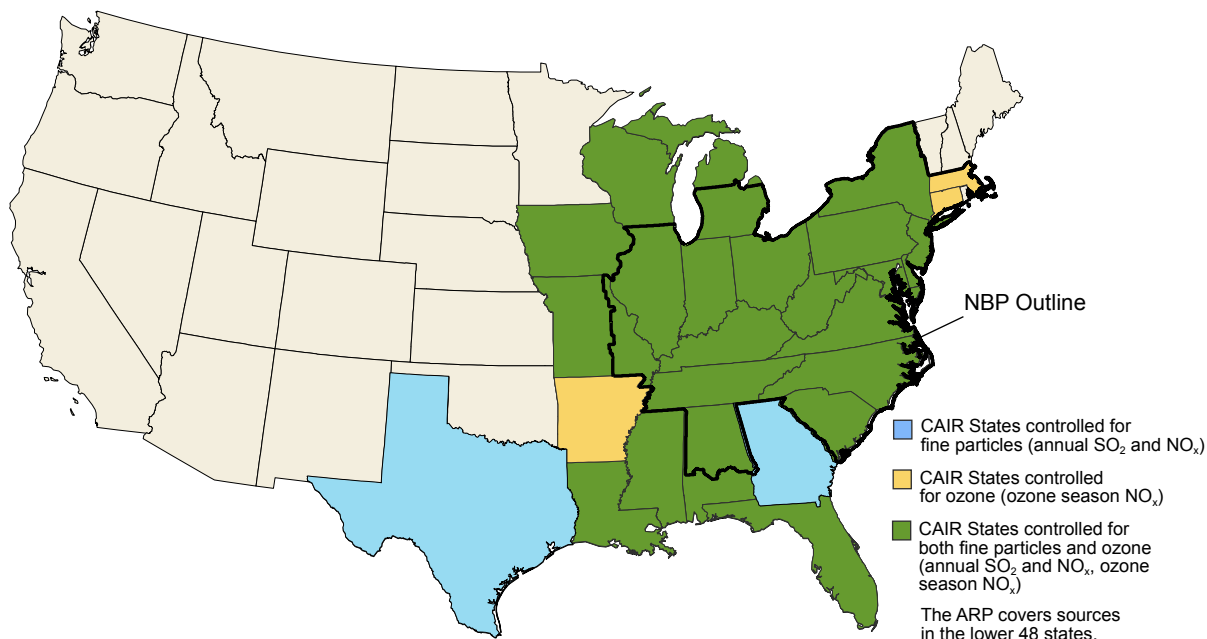
**Figure 1:  History of CAIR, ARP, CSAPR, and Former NBP**



1990 - Clean Air Act Amendments establish Title IV Acid Rain Program (ARP)

2004 - NBP begins for 11 additional states

2005 - Clean Air Interstate Rule (CAIR) is finalized

2010 - Full implementation of the ARP; CAIR $SO_2$ annual program begins

2008 - NBP ends; CAIR $NO_x$ programs "training year"

2011 - Cross-State Air Pollution Rule (CSAPR) is finalized

2000 - ARP Phase 2 begins

2007 - NBP begins for 21st and final state

1995 - ARP Phase 1 begins

2014 - Further $SO_2$ reductions required for 16 Group I states in the CSAPR

2009 - CAIR $NO_x$ ozone season and $NO_x$ annual program begins; CAIR $SO_2$ program "training year"

2003 - $NO_x$ Budget Trading Program (NBP) begins for nine states

2012* - CSAPR begins

1990    1995    2000    2005    2010    2015

* On December 30, 2011, the U.S. Court of Appeals for the District of Columbia Circuit stayed the CSAPR pending resolution of litigation challenging it. While the stay is in effect, the EPA will not be implementing the CSAPR. Pursuant to the Court's order, CAIR, which was to be replaced by the CSAPR as of January 1, 2012, will be in effect until the stay is lifted.

Source: EPA, 2011

## Figure 2: CAIR, ARP, and NBP States



Note: In November 2009, EPA finalized a rule staying the requirements of CAIR for Minnesota. Minnesota is therefore not currently included in the CAIR annual $SO_2$ and $NO_x$ programs.

Source: EPA, 2011

On December 30, 2011, the U.S. Court of Appeals for the District of Columbia Circuit stayed the CSAPR pending resolution of litigation challenging it. While the stay is in effect, the EPA will not be implementing the CSAPR. Pursuant to the Court's order, CAIR, which was to be replaced by the CSAPR as of January 1, 2012, will be in effect until the stay is lifted. Visit <epa.gov/crossstaterule/> for more information.

## CAIR, ARP, and NBP Affected States and Units

### Affected States

The ARP is a nationwide program affecting large fossil fuel-fired power plants across the country. CAIR covers 27 eastern states and the District of Columbia (D.C.) and requires reductions in annual emissions of $SO_2$ and $NO_x$ from 24 states and D.C. (to achieve improvements in fine particle pollution in downwind areas) and emission reductions of $NO_x$ during the ozone season from 25 states and D.C. (to achieve improvements in ozone pollution in downwind areas). The former NBP affected 20 eastern states and D.C. State coverage for CAIR, ARP, and NBP is shown in Figure 2.

## Air Quality

### Sulfur Dioxide

$SO_2$ is one of a group of highly reactive gasses known as "oxides of sulfur." The largest sources of $SO_2$ emissions are from fossil fuel combustion at power plants (65 percent) and other industrial facilities (16 percent). Smaller sources of $SO_2$ emissions include industrial processes such as extracting metal from ore, and the burning of high sulfur containing fuels by locomotives, large ships, and non-road equipment. $SO_2$ is linked with a number of adverse effects on the respiratory system.
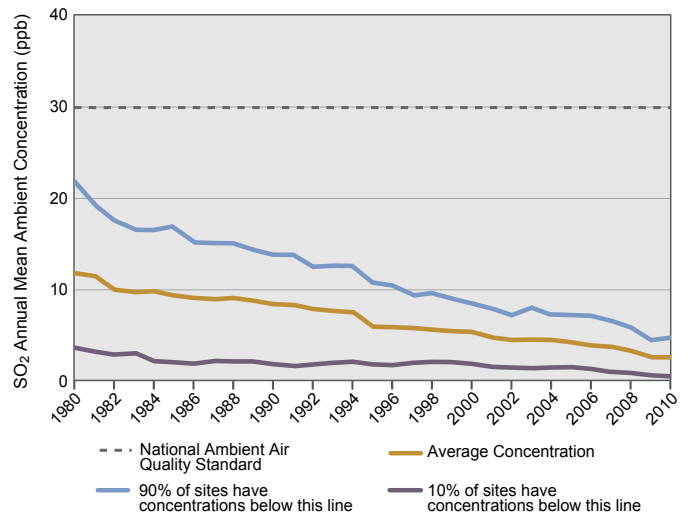
Data collected from monitoring networks show that the decline in $SO_2$ emissions from the power industry has improved air quality. Based on EPA's latest air trends data, the national composite average of $SO_2$ annual mean ambient concentrations decreased 83 percent between 1980 and 2010, as shown in Figure 3 on page 4 (based on state, local, and EPA monitoring sites located primarily in urban areas). The largest single-year reduction (20.5 percent) occurred in the first year of the ARP, between 1994 and 1995. The second largest single-year reduction (20 percent) occurred recently between 2008 and 2009, just prior to the start of the CAIR $SO_2$ program. These trends are consistent with the regional ambient air quality trends observed in the Clean Air Status and Trends Network (CASTNET).

Dramatic regional improvements in $SO_2$ and ambient sulfate concentrations were observed following implementation of Phase I of the ARP during the late 1990s at CASTNET sites throughout the eastern United States, and these improvements continue today. Analyses of regional monitoring data from CASTNET show the geographic pattern of $SO_2$ and airborne sulfate in the eastern United States. Three-year mean annual concentrations of $SO_2$ and sulfate from CASTNET long-term monitoring sites are compared from 1989 to 1991 (before implementation of the ARP) and 2008 to 2010 (most recent available data) in tabular form in Table 1 on page 5.

The average annual ambient concentrations of $SO_2$ from 1989 to 1991 were highest in western Pennsylvania and along the Ohio River Valley. There was a significant decline in those concentrations in nearly all affected areas after implementation of the ARP and other programs.

Like $SO_2$ concentrations, the highest average annual ambient sulfate concentrations from 1989 to 1991 were observed in

**Figure 3: National $SO_2$ Air Quality , 1980–2010**



Source: EPA, 2011

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### About Long-term Ambient and Deposition Monitoring Networks

To evaluate the impact of emission reductions on the environment, scientists and policymakers use data collected from long-term national monitoring networks such as CAST-NET and the National Atmospheric Deposition Program/ National Deposition Trends Network (NADP/NTN). Data from long-term regulatory networks, such as State and Local Air Monitoring Stations (SLAMS) and Chemical Speciation Network (CSN), are stored in EPA's Air Quality System (AQS) database. These complementary, long-term monitoring networks provide information on a variety of indicators necessary for tracking temporal and spatial trends in regional air quality and acid deposition.

CASTNET provides long-term monitoring of air quality in rural areas to determine trends in regional atmospheric nitrogen, sulfur, and ozone concentrations and deposition fluxes (the rate of particles and gases being deposited to a surface) of sulfur and nitrogen pollutants in order to evaluate the effectiveness of national and regional air pollution control programs. CASTNET operates more than 80 regional sites throughout the contiguous United States, Alaska, and Canada. Sites are located in areas where urban influences

are minimal. Information and data from CASTNET are available at the CASTNET website at <www.epa.gov/castnet>.

AQS contains ambient air pollution data collected by EPA, state, local, and tribal air pollution control agencies from thousands of monitoring stations. AQS also contains meteorological data, descriptive information about each monitoring station (including its geographic location and its operator), and data quality assurance/quality control information. Information and data from AQS are available at the Air Quality System website at <epa.gov/ttn/airs/airsaqs>.

NADP/NTN is a nationwide, long-term network tracking the chemistry of precipitation. NADP/NTN provides concentration and wet deposition data on hydrogen ion (acidity as pH), sulfate, nitrate, ammonium, chloride, and base cations. NADP/NTN has grown to more than 250 sites spanning the continental United States, Alaska, Puerto Rico, and the Virgin Islands. Information and data from NADP/NTN are available at the NADP's website at <nadp.sws.uiuc.edu>.

**Table 1: Regional Changes in Air Quality and Deposition of Sulfur and Nitrogen Compounds, 1989–1991 versus 2008–2010, from Rural Monitoring Networks**

| Measurement | Region | Annual Average, 1989–1991 | Annual Average, 2008–2010 | Percent Change | Number of Sites |
|---|---|---|---|---|---|
| Ambient $SO_2$ Concentration (micrograms per cubic meter, $\mu g/m^3$) | Mid-Atlantic | **13** | **4** | **-69** | 12 |
| | Midwest | **11** | **3.5** | **-68** | 10 |
| | Northeast | 5.5 | 1.3 | -76 | 3 |
| | Southeast | **5.1** | **1.7** | **-67** | 8 |
| Ambient Particulate Sulfate Concentration ($\mu g/m^3$) | Mid-Atlantic | **6.3** | **3.1** | **-51** | 12 |
| | Midwest | **5.8** | **2.8** | **-52** | 10 |
| | Northeast | **3.5** | **1.5** | **-57** | 3 |
| | Southeast | **5.4** | **2.8** | **-48** | 8 |
| Ambient Total Nitrate Concentration (Nitrate + Nitric Acid) ($\mu g/m^3$) | Mid-Atlantic | **3.3** | **1.8** | **-45** | 12 |
| | Midwest | **4.6** | **3.1** | **-33** | 10 |
| | Northeast | 1.8 | 0.9 | -50 | 3 |
| | Southeast | **2.2** | **1.4** | **-36** | 8 |
| Dry Inorganic Nitrogen Deposition (kilograms nitrogen per hectare, kg-N/ha) | Mid-Atlantic | **2.4** | **1.3** | **-46** | 10 |
| | Midwest | **2.5** | **1.7** | **-32** | 7 |
| | Northeast | 1.8 | 0.8 | -56 | 2 |
| | Southeast | 0.7 | 0.5 | -29 | 1 |
| Total Inorganic Nitrogen Deposition (kg-N/ha) | Mid-Atlantic | **8.8** | **5.4** | **-39** | 10 |
| | Midwest | **8.9** | **7.2** | **-19** | 7 |
| | Northeast | 6.8 | 4 | -41 | 2 |
| | Southeast | 5.8 | 4.1 | -29 | 1 |
| Dry Sulfur Deposition (kilograms sulfur per hectare, kg-S/ha) | Mid-Atlantic | **6.9** | **2.7** | **-61** | 10 |
| | Midwest | **7.2** | **2.7** | **-63** | 7 |
| | Northeast | 4.1 | 1.1 | -73 | 2 |
| | Southeast | 0.9 | 0.5 | -44 | 1 |
| Total Sulfur Deposition (kg-S/ha) | Mid-Atlantic | **17** | **7** | **-59** | 10 |
| | Midwest | **16** | **8** | **-50** | 7 |
| | Northeast | 11 | 4.1 | -63 | 2 |
| | Southeast | 8.8 | 4.3 | -51 | 1 |
| Wet Nitrogen Deposition from Inorganic Nitrogen (kg-N/ha) | Mid-Atlantic | **6.2** | **3.9** | **-37** | 11 |
| | Midwest | **5.8** | **4.6** | **-21** | 27 |
| | Northeast | **5.6** | **3.7** | **-34** | 17 |
| | Southeast | **4.4** | **3.5** | **-20** | 23 |
| Wet Sulfur Deposition from Sulfate (kg-S/ha) | Mid-Atlantic | **9.2** | **4.1** | **-55** | 11 |
| | Midwest | **7.1** | **3.5** | **-51** | 27 |
| | Northeast | **7.5** | **3.6** | **-52** | 17 |
| | Southeast | **6.1** | **3.3** | **-46** | 23 |

Notes:

• Averages are the arithmetic mean of all sites in a region that were present and met the completeness criteria in both averaging periods. Thus, average concentrations for 1989 to 1991 may differ from past reports.

• Total deposition is estimated from raw measurement data, not rounded, and may not equal the sum of dry and wet deposition.

• Percent change and values in bold indicates that differences were statistically significant at the 95 percent confidence level. Changes that are not statistically significant may be unduly influenced by measurements at only a few locations or large variability in measurements.

Source: EPA, 2011

western Pennsylvania and along the Ohio River Valley. Most of the eastern United States experienced annual ambient sulfate concentrations greater than 5 micrograms per cubic meter ($\mu g/m^3$).

Ambient sulfate concentrations have also decreased since the program was implemented, with average concentrations decreasing by 48 to 57 percent in regions of the East (see Table 1 on page 5). Both the magnitude and spatial extent of the highest concentrations have dramatically declined, with the largest decreases observed along the Ohio River Valley.

### Nitrogen Oxides

$NO_x$ is a group of highly reactive gasses including nitrogen dioxide, nitrous acid, and nitric acid. In addition to contributing to the formation of ground-level ozone and $PM_{2.5}$, $NO_x$ is linked with a number of adverse effects on the respiratory system.

Although the ARP and CAIR $NO_x$ programs have contributed to significant $NO_x$ reductions, emissions from other sources (such as motor vehicles and agriculture) contribute to ambient nitrate concentrations in many areas. Ambient nitrate levels can also be affected by emissions transported via air currents over wide regions.

From 2008 to 2010, reductions in $NO_x$ emissions during the ozone season from power plants under the $NO_x$ SIP Call, ARP, and CAIR have continued to contribute to significant regional improvements in ambient total nitrate ($NO_3$- plus $HNO_3$) concentrations. For instance, annual mean ambient total nitrate concentrations for 2008 to 2010 in the Mid-Atlantic region were 45 percent less than the annual mean concentration in 1989 to 1991 (see Table 1 on page 5). These improvements can be partly attributed to added $NO_x$ controls installed for compliance with the $NO_x$ SIP Call and CAIR.

### Acid Deposition

National Atmospheric Deposition Program/National Deposition Trends Network (NADP/NTN) monitoring data show significant improvements in the primary acid deposition indicators. For example, wet sulfate deposition (sulfate that falls to the earth through rain, snow, and fog) has decreased since the implementation of the ARP in much of the Ohio River Valley and northeastern United States. Some of the greatest reductions have occurred in the mid-Appalachian region, including Maryland, New York, West Virginia, Virginia, and most of Pennsylvania. Other less dramatic reductions have been observed across much of New England, portions of the southern Appalachian Mountains, and some areas of the Midwest. Between the 1989 to 1991 and 2008 to 2010 observation periods, average decreases in wet deposition of sulfate averaged more than 46 percent for the eastern United States (see Table 1 on page 5 and Figure 4).

### Figure 4: Three-Year Mean Wet Sulfate Deposition

1989–1991



2008–2010



Source: EPA, 2011

Along with wet sulfate deposition, wet sulfate concentrations have also decreased by similar percentages. A strong correlation between large-scale $SO_2$ emission reductions and large reductions in sulfate concentrations in precipitation has been noted in the Northeast, one of the areas most affected by acid deposition. The reduction in total sulfur deposition (wet plus dry) has been of similar magnitude as that of wet deposition in the Mid-Atlantic and Midwest, with reductions of 59 and 50 percent, respectively (see Table 1 on page 5). Because continuous data records are available from only a few sites in the Northeast and Southeast, it is unclear if the observed reductions in total deposition are representative for those regions.

A principal reason for reduced sulfate deposition in the Northeast is a reduction in the long-range transport of sulfate from emission sources located in the Ohio River Valley. The reductions in sulfate documented in the Northeast, particularly across New England and portions of New York, were also affected by $SO_2$ emission reductions in eastern Canada. NADP data indicate that similar reductions in precipitation acidity, expressed as hydrogen ion (H+) concentrations, occurred concurrently with sulfate reductions, with reductions of 30 to 40 percent over much of the East.
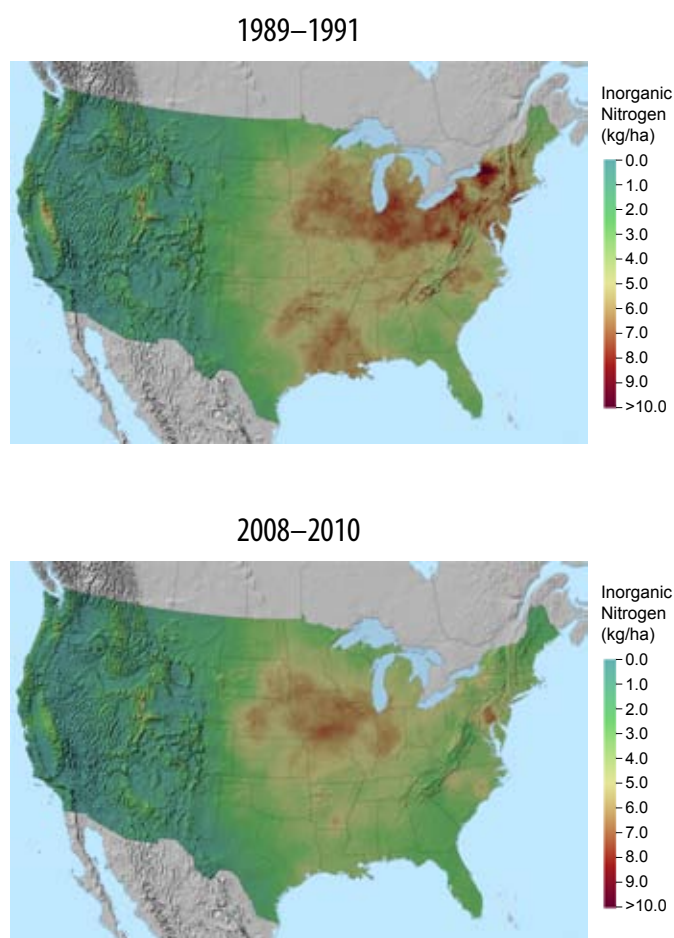
### Interpolation of Wet Deposition Fluxes

Total deposition is calculated as the sum of the wet deposition flux (as measured or interpolated by nearby NADP/NTN sites) and dry deposition flux estimated by the CASTNET measured pollutant concentration and modeled deposition velocity. Historically, wet deposition has been interpolated over large areas in the Western U.S. due to the sparse number of sites. This problem is exacerbated due to the rugged terrain. CASTNET and NADP are now using PRISM (Parameter-elevation Regressions on Independent Slopes Model), a model which uses point measurements, temperature and climatic factors to produce precipitation grids. The PRISM precipitation data sets are used to interpolate wet deposition between NADP/NTN sites. There has been a large improvement in the resolution of the graphs and improved accuracy in the data output. All historical maps and data will be updated using the new interpolation technique and will be available on the CASTNET website.

Reductions in nitrogen deposition recorded since the early 1990s have been less pronounced than those for sulfur. As noted earlier, emission changes from source categories other than ARP sources significantly affect air concentrations and deposition of nitrogen. Inorganic nitrogen in wet deposition decreased commensurately in the Mid-Atlantic and Northeast (see Figure 5).

Decreases in dry and total inorganic nitrogen deposition at CASTNET sites have generally been greater than that of wet deposition, with a 39 and 19 percent decrease in total nitrogen deposition for the Mid-Atlantic and Midwest, respectively (see Table 1 on page 5).

### Figure 5: Three-Year Mean Wet Inorganic Nitrogen Deposition



1989–1991



2008–2010

Source: EPA, 2011

### 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 deaths. Air pollution can impact the environment and affect ecological systems, leading to changes in the biological community, both in the diversity of species and in the health and vigor of individual species.

For more information on the health and environmental effects of ground-level ozone, visit EPA's Ground-level Ozone website at <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. 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.

### $NO_x$ Reduction Programs and Ozone

To better understand how the CAIR, NBP, and ARP $NO_x$ programs affected ozone formation in the atmosphere, this report examines changes in ozone concentrations before and after implementation of the NBP and 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.

### 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). CASTNET sites measure trends in ozone at rural sites and these data are also reported to AQS. 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.
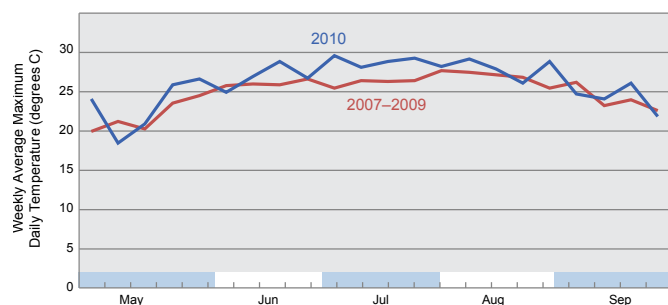
## Meteorological Effects on Environmental Trends

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 6 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 ozone season months in 2010, the average of maximum daily temperatures were typically higher than the three-year average from 2007 to 2009, making it important to account for meteorological effects when assessing any trends in air pollution after CAIR was implemented (see "Changes in 8-Hour Ozone Concentrations," below, for an analysis of ozone trends using meteorologically adjusted data).
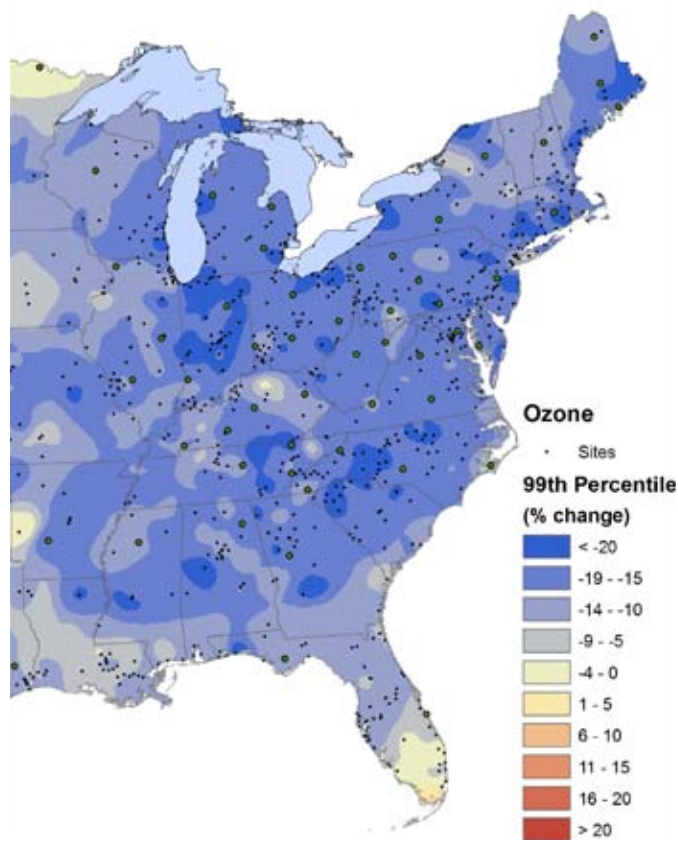
## Changes in Rural Ozone Concentrations

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).

**Figure 6: Weekly Average of Maximum Ozone Season Daily Temperatures, 2007–2010**



Source: EPA, 2011

**Figure 7: Percent Change in Unadjusted 1-Hour Ozone Concentrations during the Ozone Season, 2000–2002 versus 2008–2010**



Note: Data are from AQS and CASTNET monitoring sites with two or more years of data within each three-year monitoring period.

Source: EPA, 2011

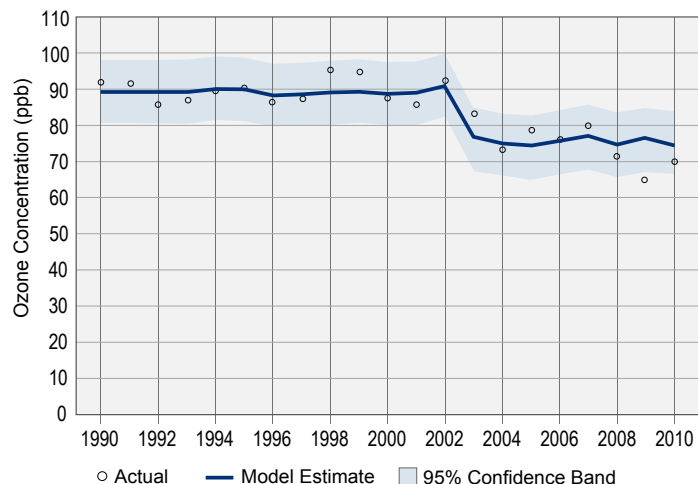## Changes in 1-Hour Ozone Concentrations in the East

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 7 shows changes in the 99th percentile of unadjusted 1-hour ozone concentrations between 2000 to 2002 (before implementation of the NBP) and 2008 to 2010 (under the last year of the NBP and first year two years of the CAIR $NO_x$ ozone season program). 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 19 percent. To date, this reduction represents the greatest three-year average decrease in ozone concentrations since the NBP began in 2003.

## 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 8). 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 compliance, a statistically significant shift occurred and a new trend was established, with an average ozone level of 73 ppb. The ARIMA model shows a statistically significant, 18 percent (16 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 2010, the second compliance year of the CAIR $NO_x$ programs, ozone concentrations were at the second lowest over the 21-year period. Ozone concentrations were down 22 ppb (24 percent) in 2010 versus 1990.

The large decrease in ozone concentrations shown in Figure 8 results in part 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 8 is not the result of the recent economic downturn, given that the large drop in ozone concentrations predated the economic downturn.

## Figure 8: Shift in 8-Hour Seasonal Rural Ozone Concentrations in the CAIR $NO_x$ Region, 1990–2010



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, 2011
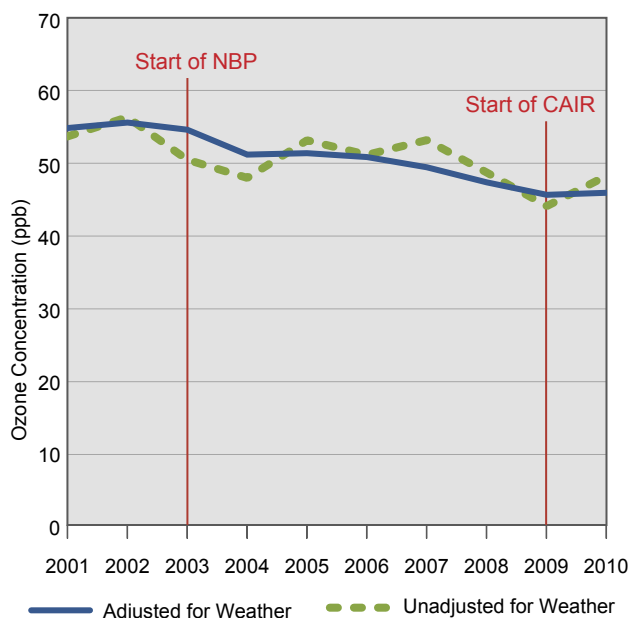
## Changes in 8-Hour Ozone Concentrations

Daily maximum 8-hour ozone concentration data were assessed from 84 urban AQS areas and 46 rural CASTNET sites located in the CAIR $NO_x$ ozone season program region. 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.

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 second year of CAIR, 2010, was warmer than the 2007 to 2009 time period, however the meteorologically-adjusted trend remained stable from 2009 to 2010. Therefore, the warmer temperatures explain some of the increase in ozone concentrations in 2010. Three-year averages will be used in 2011 to assess the air quality impact of the CAIR $NO_x$ reductions with more confidence.

A closer look at the meteorologically-adjusted ozone trends since the start of the NBP in 2003 indicates that these reductions are substantive and sustained. The average reduction in seasonal daily maximum 8-hour ozone concentrations measured in the CAIR $NO_x$ region in the 2001 to 2003 and 2008 to 2010 time periods was about 12 percent. After considering the influence of weather, the improvement in daily maximum 8-hour ozone concentrations between these three-year periods was almost 16 percent. A comparison of single year meteorologically-adjusted ozone between 2001 and 2010 also reveals a 16 percent reduction.

Furthermore, the pace of these reductions has increased with implementation of the NBP and subsequent CAIR $NO_x$ ozone season program. Between 2001 and 2005, ozone fell by six percent, while between 2005 and 2010, ozone dropped by over ten percent. This is consistent with the general downward trend in $NO_x$ emissions observed over this time period.

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



Note: 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 2001 to 2010. 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.

Source: EPA, 2011

**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 to 2003. Of those areas, 91 are in the East (as shown in Figure 10) and are home to about 103 million people.[4] Based on data gathered from 2008 to 2010, 90 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 90 areas mean that over 98 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. The Baltimore, Maryland area is the only one of the original 91 areas in the East that continues to exceed the level of the standard. In this area, however, ozone concentrations have fallen by over 13 percent. Because of the reductions in all 91 areas, millions of Americans living in these areas are experiencing better air quality.

Given that the majority of power sector $NO_x$ 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.
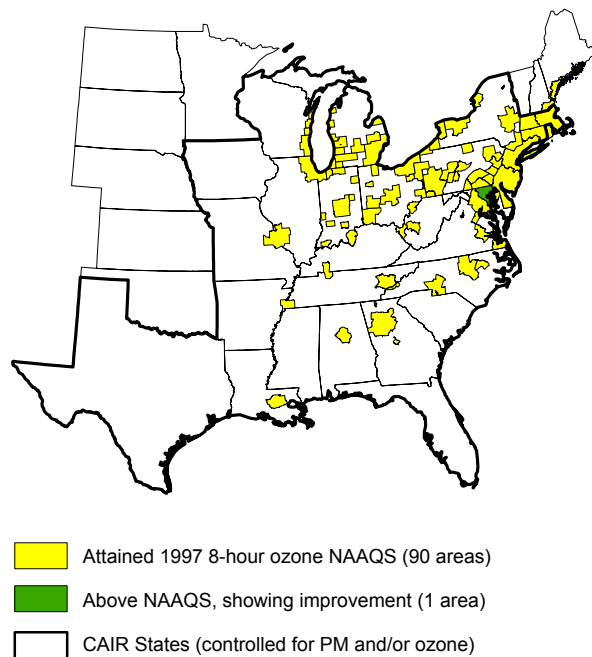
**Particulate Matter**

"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.

**Figure 10: Changes in Nonattainment Areas in the CAIR Region, 2001–2003 (Original Designations) versus 2008–2010**



☐ (yellow) Attained 1997 8-hour ozone NAAQS (90 areas)

☐ (green) Above NAAQS, showing improvement (1 area)

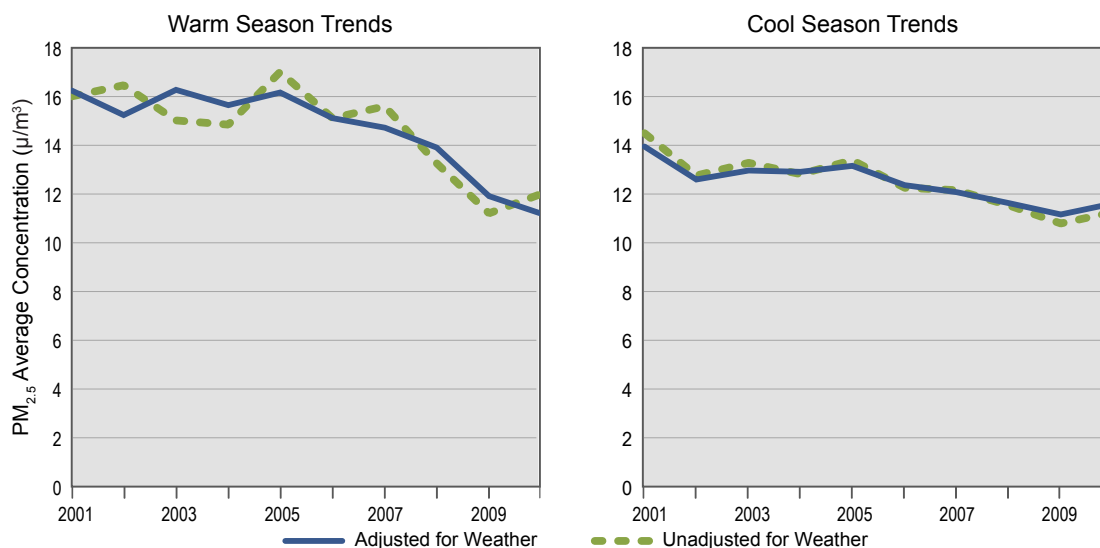☐ CAIR States (controlled for PM and/or ozone)

Source: EPA, 2011

For more information on the health and environmental effects of particulate matter, visit EPA's Particulate Matter website at <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 ($\mu g/m^3$) measured as the three-year average of the 98th percentile for 24-hour exposure, and at 15 $\mu g/m^3$ for annual exposure measured as the three-year annual mean. 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 $\mu g/m^3$.

**Figure 11: PM$_{2.5}$ Seasonal Trends**



Note: 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 to 2010. 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.

Source: EPA, 2011

**Annual Emission Reduction Programs and PM$_{2.5}$**

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. To better understand how emission reductions under CAIR and ARP affected the formation of PM$_{2.5}$, this report presents regional and geographic trends in PM$_{2.5}$ levels prior to implementation of any of the CAIR annual programs, and for 2010. More information on emissions reductions achieved in 2010 under the CAIR annual programs and ARP can be found in the CAIR, ARP, and Former NBP 2010 SO$_2$ and NO$_X$ Emissions, Compliance, and Market Analyses Report at <epa.gov/airmarkets/progress/ARPCAIR10_01.html>.

**Trends in PM$_{2.5}$ Concentrations**

Average PM$_{2.5}$ concentration data were assessed from 108 urban AQS areas located in the CAIR NO$_x$ and SO$_2$ annual program region.

As with ozone, weather plays an important role in the formation of PM (see Figure 6 on page 9 for weather trends). For this report, 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.

Figure 11 shows separate trends in PM$_{2.5}$ concentrations in the CAIR NO$_x$ and SO$_2$ 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$_{2.5}$. After adjusting for weather, PM$_{2.5}$ concentrations have decreased by over 22 percent in the warm season and 13 percent in the cool season between the 2001 to 2003 and 2008 to 2010 monitoring periods.
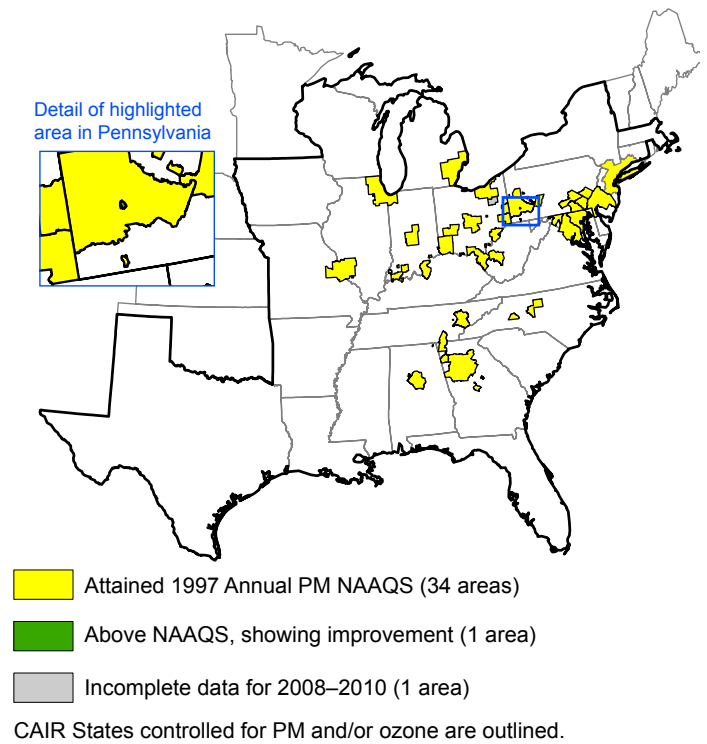
**Changes in PM$_{2.5}$ Nonattainment Areas**

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.[5] These designations were made using data from 2001 to 2003. Of those areas, 36 are in the East (as shown in Figure 12) and are home to about 88 million people.[6] Based on data gathered from 2008 to 2010, 34 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 34 areas mean that 94 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.

The Liberty-Clairton (Pennsylvania) area is the only one of the original 36 areas in the East that continues to exceed the level of the PM$_{2.5}$ standard (see inset in Figure 12). However, PM$_{2.5}$ concentrations in that area have fallen by almost 25 percent since the original designation. The Canton-Massillion area does not have sufficient recent PM$_{2.5}$ data to quantify its change in air quality.

Given that the majority of power sector 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.

**Figure 12: Changes in PM Nonattainment Areas in the CAIR Region, 2001–2003 (Original Designations) versus 2008–2010**



Detail of highlighted area in Pennsylvania

☐ Attained 1997 Annual PM NAAQS (34 areas)

☐ Above NAAQS, showing improvement (1 area)

☐ Incomplete data for 2008–2010 (1 area)

CAIR States controlled for PM and/or ozone are outlined.

Source: EPA, 2011

## Health Benefits of the ARP, NBP, and CAIR

By reducing precursors ($SO_2$ and $NO_x$) to $PM_{2.5}$ formation and a precursor ($NO_x$) to ground-level ozone formation, emission reductions achieved by the ARP, NPB, and CAIR significantly benefit human health and welfare. Exposure to $PM_{2.5}$ and ozone is linked to premature death as well as a variety of non-fatal effects including heart attacks, hospital and emergency department visits for respiratory and cardiovascular symptoms, acute bronchitis, aggravated asthma, and days when people miss work or school.[7,8] In addition to these impacts on human health, $PM_{2.5}$ contributes to visibility impairment and materials damage and ozone negatively impacts agriculture and forestry.

Moreover, $SO_2$ and $NO_x$ pollution contribute to aquatic and terrestrial acidification while $NO_x$ pollution can cause nutrient enrichment and $SO_2$ deposition can lead to the conversion of mercury to methylated mercury—a more toxic form of this potent neurotoxin.[9]
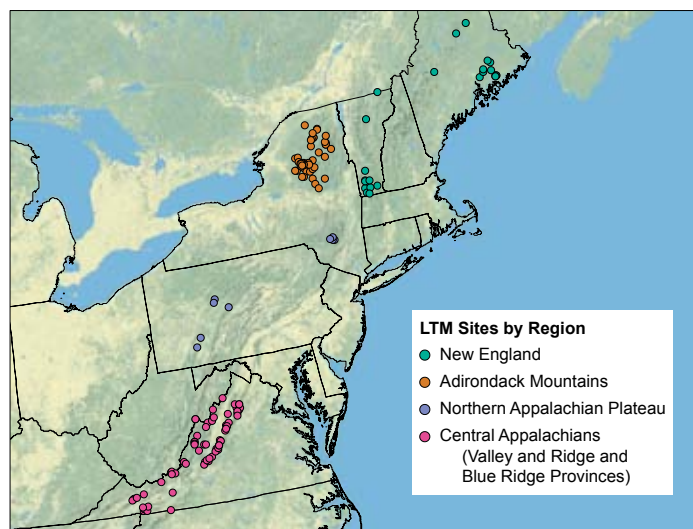
**Figure 13: Long-term Monitoring Program Sites**



LTM Sites by Region
- New England
- Adirondack Mountains
- Northern Appalachian Plateau
- Central Appalachians (Valley and Ridge and Blue Ridge Provinces)

Source: EPA, 2011

## Ecosystems

### Improvements in Surface Water Chemistry

Acid rain resulting from $SO_2$ and $NO_x$ emissions negatively affects the health of lakes and streams in the U.S. Surface water chemistry provides direct indications of the potential effects of acidic deposition on the overall health of aquatic ecosystems. Two EPA-administered monitoring programs provide information on the impacts of acidic deposition on otherwise protected aquatic systems: Temporally Integrated Monitoring of Ecosystems (TIME) and Long-term Monitoring (LTM) programs. These programs are designed to track changes in surface water chemistry in the four acid sensitive regions shown in Figure 13: New England, the Adirondack Mountains, the Northern Appalachian Plateau, and the central Appalachians (the Valley and Ridge and Blue Ridge Provinces).

Table 2 on page 16 shows regional trends in acidification from 1990 (before implementation of the ARP) to 2009 (most recent available data) in lakes and streams through the LTM program. Five indicators of aquatic ecosystem response to emission changes are presented: measured ions of sulfate, nitrate, base cations (sum of calcium, magnesium, sodium, and potassium ions), acid neutralizing capacity (ANC), and dissolved organic carbon (DOC). These indicators provide information regarding the surface water sensitivity to acidification. Trends in these measured chemical receptors allow for the determination of whether the conditions of the water bodies are improving and heading towards recovery or if the conditions are still acidifying.

Sulfate is the primary negatively charged ion in most acid-sensitive waters and has the potential to acidify drainage waters and leach aluminum and base cations from the soils. Nitrate has the same potential as sulfate to acidify drainage waters. However, nitrogen is a limiting nutrient for plant growth and a large portion of nitrogen inputs from deposition are quickly incorporated into plants as organic nitrogen, leaving less leaching of nitrate into surface waters. Base cations are the positively charged ions in surface waters that buffer both sulfate and nitrate ions, thereby preventing surface water acidification.

ANC is a measure of acidification, which results in the diminishing ability of surface waters to neutralize strong acids that enter aquatic systems. Water bodies with ANC values less than or equal to 0 microequivalents per liter (μeq/L) are defined as being of acute concern for acidification. Lakes and streams having springtime ANC values less than 50 μeq/L are generally considered of elevated concern for acidification. Lakes and streams with ANC higher than 50 μeq/L are generally considered of moderate to low concern for acidification. When ANC is low, and especially when it is negative, stream water pH is also low (less than pH 6), and there may be adverse impacts on fish and other animals essential for a healthy aquatic ecosystem. Movement toward recovery of an aquatic ecosystem is indicated by increasing trends in ANC and decreasing trends in sulfate and nitrate concentrations. Dissolved organic carbon (DOC) is essentially organic material that is an important part of the acid-base chemistry of most low-ANC freshwater systems. While a host of factors control DOC dynamics in surface waters, increased concentrations of DOC can be indicative of reduced acidification from acid deposition and/or a sign of increased decomposition of organic matter in the watershed.

As seen in Table 2, significant improving trends in sulfate concentrations from 1990 to 2009 are found at nearly all monitoring sites in New England, Adirondacks, and the Catskill mountains/Northern Appalachian Plateau. However, in the Central Appalachians only 12 percent of monitored streams showed a decreasing sulfate trend, while 14 percent of monitored streams actually increased, despite decreasing sulfate deposition. The highly weathered soils of the Central Appalachians are able to store large amounts of deposited sulfate, but as long-term sulfate deposition exhausts the soil's ability to store more sulfate, a decreasing proportion of the deposited sulfate is retained in the soil and an increasing proportion is exported to surface waters.

Surface nitrate concentrations trends are decreasing at some of the sites in all four regions, but some sites also indicate flat or slightly increasing nitrate trends. Improving trends for nitrate concentration were noted at 37 percent of all monitored sites, but this improvement may only be partially explained by decreasing deposition. Ecosystem factors, such as vegetation disturbances and soil retention are also known to contribute to declining surface water nitrate concentrations.

Reductions in sulfate deposition levels likely result in many of the improving ANC trends. From 1990 to 2009, monitoring sites in the Adirondacks (60 percent), and the Catskills/northern Appalachian Plateau (55 percent) showed the strongest improvement in ANC trends. However, sites in New England (20 percent) and the Central Appalachians (17 percent) had few sites with improving ANC trends. Relatively flat trends in sulfate in the Central Appalachians likely account for why so few sites have improving ANC. In New England, hydrology and declining trends of base cation concentration may delay the onset of recovery. Decreasing base cation levels can balance out reductions of sulfate and nitrate, thereby preventing ANC from increasing. DOC is increasing at only 30 percent of all monitored lakes and streams. This is likely linked to declines in sulfate concentrations as well as warmer seasonal and annual temperatures.

## Table 2: Regional Trends in Sulfate, Nitrate, ANC, and DOC at Long-term Monitoring Sites, 1990–2009

| Region | Water Bodies Covered | % of Sites with Improving Sulfate Trend | % of Sites with Improving Nitrate Trend | % of Sites with Improving ANC Trend | % of Sites with Improving Base Catons Trend | % of Sites with Improving DOC Trend |
|---|---|---|---|---|---|---|
| Adirondack Mountains | 50 lakes in NY | 94% | 48% | 60% | 74% | 48% (29 sites) |
| Catskills/N. Appalachian Plateau* | 9 streams in NY and PA | 80% | 30% | 55% | 80% | 25% (9 sites) |
| New England | 26 lakes in ME and VT | 96% | 33% | 20% | 57% | 26% (15 sites) |
| Central Appalachians | 66 streams in VA | 12% | 50% | 17% | 12% | NA |

Notes:
- Trends are determined by multivariate Mann-Kendall tests.
- Trends are significant at the 95 percent confidence interval (p < 0.05).
- DOC was only examined in low-ANC waterbodies (ANC less than 25 μeq/L).
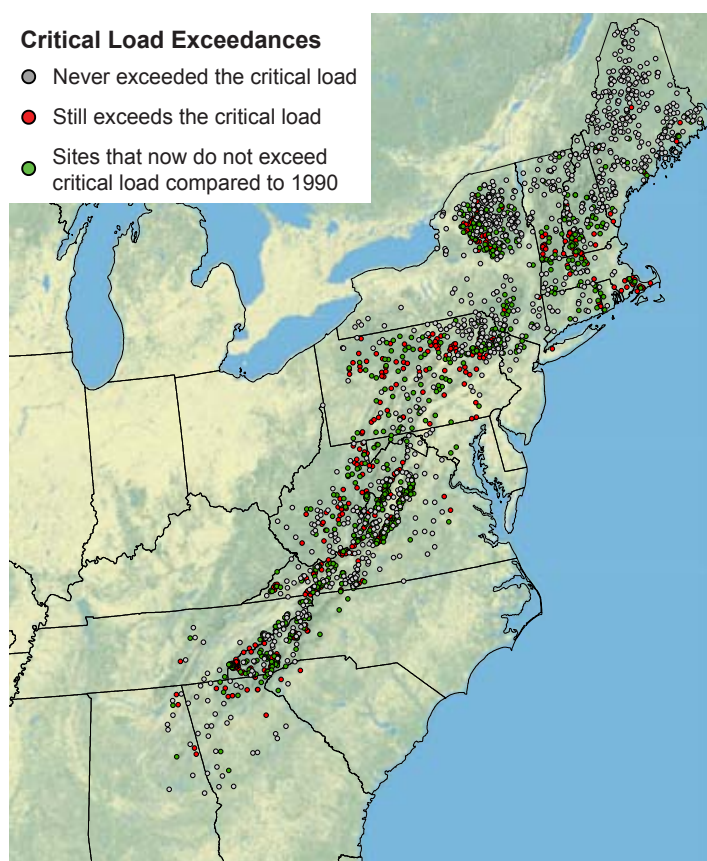- DOC is not currently measured in Central Appalachian streams.

*Data for streams in N. Appalachian Plateau is only through 2008.

Source: EPA, 2011

**Critical Loads and Exceedances**

Since the early 1980s, acidic deposition has acidified many lakes and many miles of streams in the eastern United States.[10] However, with the implementation of the ARP, CAIR, and other emission reduction programs, acidic deposition has decreased throughout the eastern United States as emissions of $NO_x$ and $SO_2$ have declined (see CAIR, ARP, and Former NBP 2010 Emissions, Compliance, and Market Analyses Report). The critical load approach is an assessment tool that can be used to determine the degree to which air pollution may be affecting ecological health. A critical load is a quantitative estimate of exposure to one or more pollutants below which significant harmful effects on specific sensitive elements of the environment do not occur according to present knowledge.[11] This approach provides a useful lens through which to assess the results of emission reduction programs such as the ARP and CAIR.

### Figure 14: Lake and Stream Exceedances of Estimated Critical Loads for Total Nitrogen and Sulfur Deposition, 1989–1991 vs. 2008–2010

**Critical Load Exceedances**

⊙ Never exceeded the critical load

🔴 Still exceeds the critical load

🟢 Sites that now do not exceed critical load compared to 1990
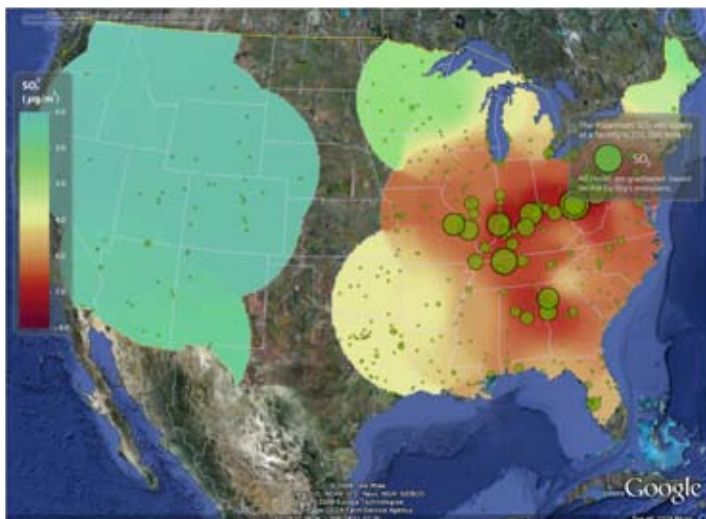


Source: EPA, 2011

Drawing on the methods from the peer-reviewed scientific literature,[12, 13] critical loads were calculated for over 2,300 lakes and streams using the Steady-State Water Chemistry (SSWC) model. These critical load estimates represent only lakes and streams where surface water samples have been collected through programs such as National Surface Water Survey (NSWS), Environmental Monitoring and Assessment Program (EMAP), the TIME program, and the LTM program. The lakes and streams associated with these programs consist of a subset of lakes and streams that are located in areas most affected by acid deposition, but are not intended to represent all lakes in the eastern US.

For this particular analysis, the critical load represents the combined deposition loads of sulfur and nitrogen to which a lake or stream could be subjected and still have a calculated ANC of 50 µeq/L or higher. While a critical load can be calculated for any ANC level, this level was chosen because it tends to support healthy aquatic ecosystems and protect most fish and other aquatic organisms, although systems can become episodically acidic and some sensitive species still may be lost. Critical loads of combined total sulfur and nitrogen deposition are expressed in terms of ionic charge balance as milliequivalents per square meter per year ($meq/m^2/yr$).

If pollutant exposure is less than the critical load, adverse ecological effects (e.g., reduced reproductive success, stunted growth, loss of biological diversity) are not anticipated, and recovery is expected over time if an ecosystem has been damaged by past exposure. A critical load exceedance is the measure of pollutant exposure above the critical load. This means pollutant exposure is higher than, or "exceeds," the critical load and the ecosystem continues to be exposed to damaging levels of pollutants. In order to assess the extent to which regional lake and stream ecosystems are protected by the emission reductions achieved by the ARP and CAIR so far, this case study compares the amount of deposition systems can receive—the critical load—to measured deposition for the period before implementation of the ARP (1989 to 1991) and for a recent period after ARP and CAIR implementation (2008 to 2010).

Overall, this critical load analysis shows that emission reductions achieved by the ARP and CAIR so far have contributed significantly to improved environmental conditions and increased ecosystem protection in the eastern United States. For the period from 2008 to 2010, 30 percent of the lakes and streams examined received levels of combined sulfur and nitrogen deposition that exceeded the critical load (Figure 14). This is an improvement when compared to the 1989 to 1991

**Figure 15: U.S. SO$_2$ Emissions and Sulfate Concentrations, 1990**



Note: This example depicts 1990 SO$_2$ emissions from ARP sources along with 1990 sulfate concentration data as measured by the CASTNET monitoring program.
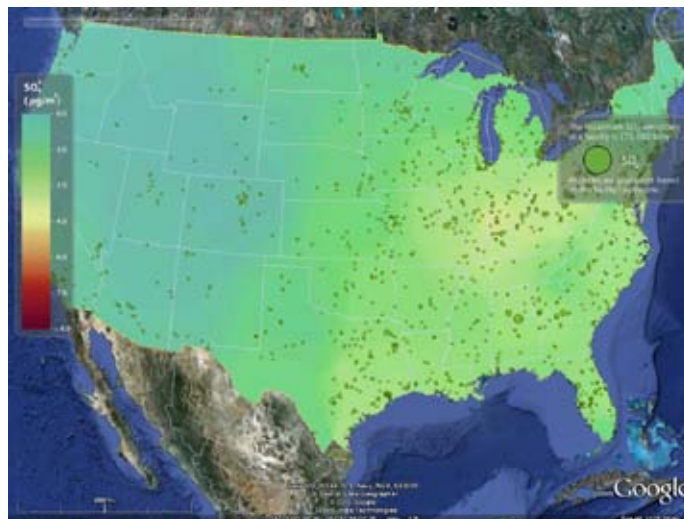
Source: EPA, 2011

**Figure 16: U.S. SO$_2$ Emissions and Sulfate Concentrations, 2010**
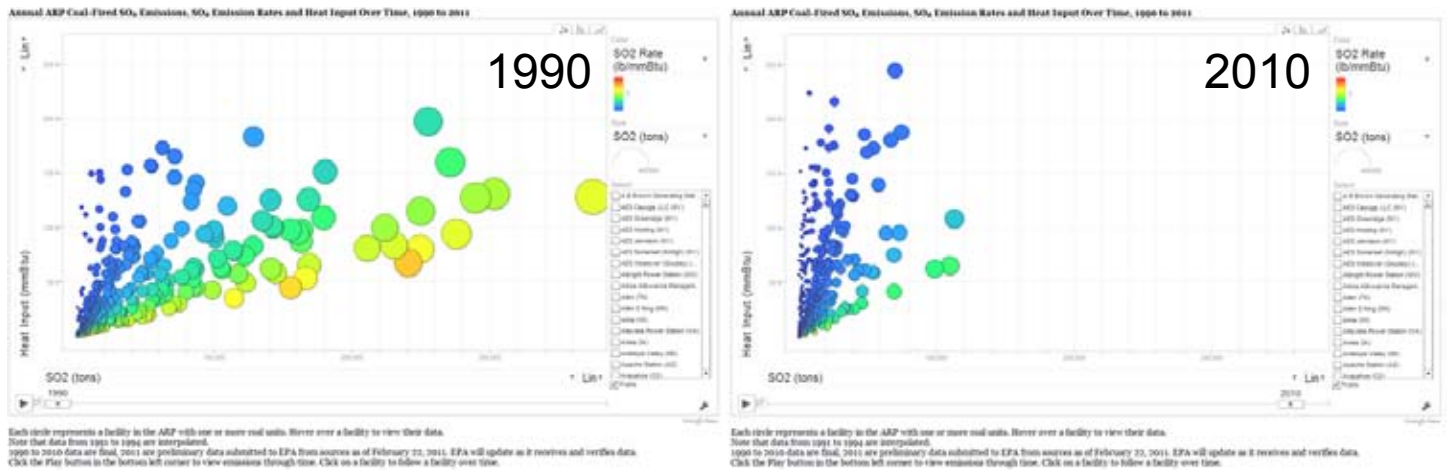


Note: This example depicts 2010 SO$_2$ emissions from ARP sources along with 2010 sulfate concentration data as measured by the CASTNET monitoring program.

Source: EPA, 2011

period, during which 55 percent of lakes and streams exceeded the critical load. Areas with the largest concentration of lakes where acid deposition currently is greater than—or exceeds—estimated critical loads include the southern Adirondack mountain region in New York, southern New Hampshire and Vermont, Cape Cod Massachusetts, and along the Appalachian Mountain spine from Pennsylvania to North Carolina.

### Online Information, Data, and Resources

The availability and transparency of data, from emission measurement to allowance trading to deposition monitoring, is a cornerstone of effective cap and trade programs. CAMD, in the Office of Air and Radiation's Office of Atmospheric Programs, develops and manages programs for collecting these data and assessing the effectiveness of cap and trade programs, including the ARP, NBP, and CAIR. CAMD then makes these data available to the public in readily usable and interactive formats. The CAMD website at <epa.gov/airmarkets> provides a public resource for general information on how market-based programs work and what they have accomplished, along with the processes, information, and tools necessary to participate in any of these market-based programs.

To increase data transparency, EPA has created supplementary maps that allow the user to display air market program data geospatially on an interactive 3D platform. Figure 15 and Fig-

ure 16 are examples of these maps. The maps come in the form of a KMZ file (a compressed KML file) that is downloaded directly to the user's computer. Data can be explored in new and meaningful ways by turning different layers on and off, overlaying data points and satellite imagery, and using navigation tools to change the view of the Earth's surface. KMZ/KML files are supported by programs such as Google Earth, ESRI Arc Explorer, and NASA WorldWind View. These interactive mapping applications provide a unique way to identify environmental trends and track the progress of various EPA programs, such as the ARP. For more information or to utilize this tool, visit the Interactive Mapping website at <epa.gov/airmarkets/progress/interactivemapping.html>.

In another effort to increase data transparency, EPA regularly posts updates of quarterly SO$_2$ and NO$_x$ emissions data from coal-fired power plants controlled under the ARP and other programs to make it easy for the public to track changes in emissions from these sources (available at the Quarterly Emissions Tracking website at <epa.gov/airmarkets/quarterlytracking.html>). The data presented on the quarterly emissions tracking website compare emissions, emission rates, and heat input from power plant units in the ARP. These files graphically and spatially compare quarterly emission data from the most recent completed quarter of 2011 with data for the same quarter from 2010.

**Figure 17: Motion Charts of Annual ARP Coal-fired Power Plant Emissions, SO₂ Emission Rates and Heat Input over Time, 1990 and 2010**



Source: EPA, 2011

Interactive motion charts are a key feature on the quarterly tracking website. Figure 17 shows examples of motion charts created to show changes in ARP SO₂ emissions and SO₂ emission rates over time (from 1990 to 2010). These motion charts show, historically, how coal-fired power plants have responded to the ARP. Each circle on the motion chart represents a facility in the ARP with one or more units that burn coal to create electricity. The size and color of these circles tell us something about the facility. To the right of the motion chart you will find two legends. The color spectrum at the top represents the emissions generated per unit of fuel (also known as the SO₂ emission rate), with warmer colors (yellow through red) representing a high emission rate and cooler colors (green through blue) representing a low emission rate. The size of the circle on the chart is proportional to the emissions from that plant. On the interactive mapping website, the user can watch this data move through time by clicking the play button.

## 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 CAIR ozone season 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.  40 CFR Part 81. Designation of Areas for Air Quality Planning Purposes.

6.  U.S. Census. 2000.

7.  U.S. Environmental Protection Agency (U.S. EPA). 2009. 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 <http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=216546>.

8.  U.S. Environmental Protection Agency (U.S. EPA). 2006. 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 <http://cfpub.epa.gov/ncea/CFM/recordisplay.cfm?deid=149923>.

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

10. Stoddard, J.L.; et al. (2003) Response of Surface Water Chemistry to the Clean Air Act Amendments of 1990; EPA/620/R-03/001; U.S. EPA: Washington, DC.

11. Nilsson, J. & Grennfelt, P. (Eds) (1988) Critical loads for sulphur and nitrogen. UNECE/Nordic Council workshop report, Skokloster, Sweden. March 1988. Nordic Council of Ministers: Copenhagen.

12. EPA, 2008 and DuPont J., T.A. Clair, C. Gagnon, D.S. Jeffries, J.S. Kahl, and S.J. Nelson, and J. M. Peckenham. (2005). Environmental Monitoring and Assessment 109: 275–291

13. Sullivan T.J., B.J. Cosby, J.R. Webb, R.L. Dennis, A.J. Bulger, and F.A. Deviney, Jr. 2007. Streamwater acid-base chemistry and critical loads of atmospheric sulfur deposition in Shenandoah National Park, Virginia. Environmental Monitoring and Assessment 137:85 99