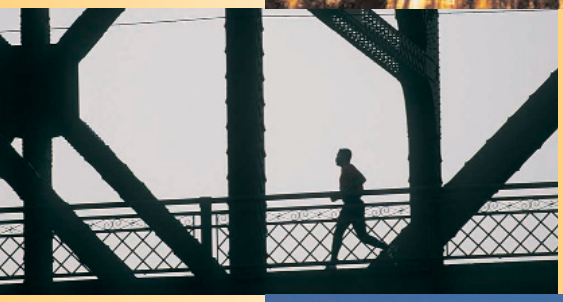
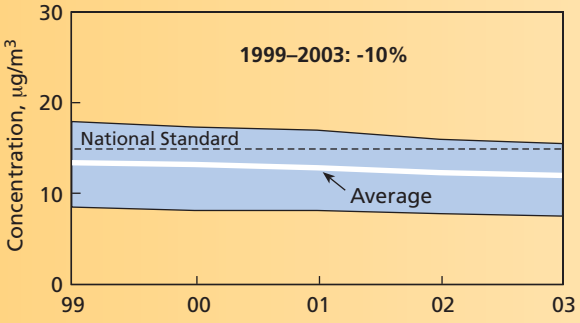
United States
Environmental Protection
Agency

The Particle Pollution Report

Current Understanding of Air Quality and Emissions through 2003



$PM_{2.5}$ Concentrations are Declining



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The Particle Pollution Report

Current Understanding of Air Quality and Emissions through 2003

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U.S. Environmental Protection Agency
Office of Air Quality Planning and Standards
Emissions, Monitoring, and Analysis Division
Research Triangle Park, North Carolina

Contents

Introduction

From the black puff of smoke from an old diesel bus to the haze that obscures the view in our national parks, particle pollution affects us all. This complex pollutant is present year-round, both in our cities and in the countryside, and it can cause health problems for millions of Americans.

EPA's national air quality standards for particle pollution are designed to protect public health and the environment. As this report shows, we are seeing progress: levels of particle pollution are decreasing on a national scale. Yet millions of people still live in areas of the country where particle pollution levels exceed national air quality standards. This harmful pollution affects not only people, but also visibility, ecosystems, and man-made materials.

EPA considers fine particle pollution its most pressing air quality problem, and the Agency is taking a number of steps that will reduce particle emissions and formation. These efforts range from EPA's Acid Rain program and regulations reducing emissions from fuels and diesel engines, to implementation of the Agency's first fine particle standards and a proposed rule to reduce particle-forming emissions from power plants.

In this report, EPA

- Explores characteristics of particle pollution in the United States
- Analyzes particle pollution for 2003 (the most recent year of data)
- Summarizes recent and long-term trends
- Investigates the relationship between air quality and emissions
- Reviews some current programs and future prospects for reducing particle pollution levels.

In addition, text boxes in this report present information on more specialized areas of interest, such as the PM Supersite project, episodic events, satellite monitoring, and the relationship of particle pollution to other air pollutants.

Major Findings

Air Quality Improvements

- Particulate matter (PM) air quality has been improving nationwide, both for $PM_{2.5}$ and PM_{10}.
- $PM_{2.5}$ concentrations
  - in 2003 were the lowest since nationwide monitoring began in 1999
  - have decreased 10% since 1999
  - are about 30% lower than EPA estimates they were 25 years ago.
- PM_{10} concentrations
  - in 2003 were the second lowest since nationwide monitoring began in 1988
  - have declined 7% since 1999
  - have declined 31% since 1988.
- In 2003, 62 million people lived in 97 U.S. counties with monitors showing particle pollution levels higher than the $PM_{2.5}$ air quality standards, the PM_{10} standards, or both.
- Monitored levels of both $PM_{2.5}$ and PM_{10} generally decreased the most in areas with the highest concentrations. For example, $PM_{2.5}$ levels decreased 20% in the Southeast from 1999 to 2003. The Northwest showed a 39% decrease in PM_{10} levels from 1988 to 2003.

Sources and Emissions

- Sulfates, nitrates, and carbon compounds are the major constituents of fine particle pollution. Sulfates and nitrates form from atmospheric transformation of sulfur dioxide and nitrogen oxide gases. Carbon compounds can be directly emitted, or they can form in the atmosphere from organic vapors.
- Approximately one-third of the $PM_{2.5}$ improvement observed in the eastern half of the country can be attributed to reduced sulfates; a large portion of the remaining $PM_{2.5}$ improvement is attributable to reductions in carbon-containing particles, especially in the Industrial Midwest and the Southeast.
- Power plant emissions of sulfur dioxide dropped 33% from 1990 to 2003, largely as a result of EPA's Acid Rain program. These reductions yielded significant regional reductions in sulfate concentrations, reducing acid deposition and improving visibility.
- Nationwide, reductions in industrial and highway vehicle emissions of fine particles and volatile organic compounds appear to have contributed to the improvement in $PM_{2.5}$.
- In the eastern half of the country
  - regional pollution accounts for more than half of the measured $PM_{2.5}$. This regional pollution comes from a variety of sources, including power plants, and can be transported hundreds of miles.
  - sulfates account for 25% to 55% of $PM_{2.5}$ levels. Sulfate levels are similar in urban and nearby rural areas. Power plants are the largest contributor to this sulfate formation.
- In the Industrial Midwest, Northeast, and southern California, nitrates make up a large portion of $PM_{2.5}$, especially in winter. Average nitrate concentrations in urban areas are generally higher than nearby rural levels. Power plants and highway vehicle emissions are large contributors to nitrate formation.
- EPA and states have put in place a number of control programs that will continue to reduce particle-forming emissions. EPA's 2004 Clean Air Nonroad Diesel Rule will significantly reduce emissions from nonroad diesel equipment across the country. EPA's proposed Clean Air Interstate Rule (proposed December 2003) will reduce PM-forming emissions from power plants in the eastern United States.

Understanding Particle Pollution

Particle Pollution Is…

Complex

Perhaps no other pollutant is as complex as particle pollution. Also called particulate matter or PM, particle pollution is a mixture of solid particles and liquid droplets found in the air. Some particles, such as dust, dirt, soot, or smoke, are large or dark enough to be seen with the naked eye. Others are so small, they can only be detected using an electron microscope.

These tiny particles come in many sizes and shapes and can be made up of hundreds of different chemicals. Some particles are emitted directly from a source, while others form in complicated chemical reactions in the atmosphere. And some can change back and forth from gas to particle form. Particle pollution also varies by time of year and by location and is affected by several aspects of weather, such as temperature, humidity, and wind.

A Continuum of Sizes

In general, particle pollution consists of a mixture of larger materials, called "coarse particles," and smaller particles, called "fine particles." Coarse particles have diameters ranging from about 2.5 micrometers (μm) to more than 40 μm, while fine particles, also known as known as $PM_{2.5}$, include particles with diameters equal to or smaller than 2.5 μm. EPA also monitors and regulates PM_{10}, which refers to particles less than or equal to 10 μm in diameter. PM_{10} includes coarse particles that are "inhalable" — particles ranging in size from 2.5 to 10 μm that can penetrate the upper regions of the body's respiratory defense mechanisms. "Ultrafine" particles are a subset of $PM_{2.5}$, measuring less than 0.1 μm in diameter.

Figure 1. Comparison of PM sizes.

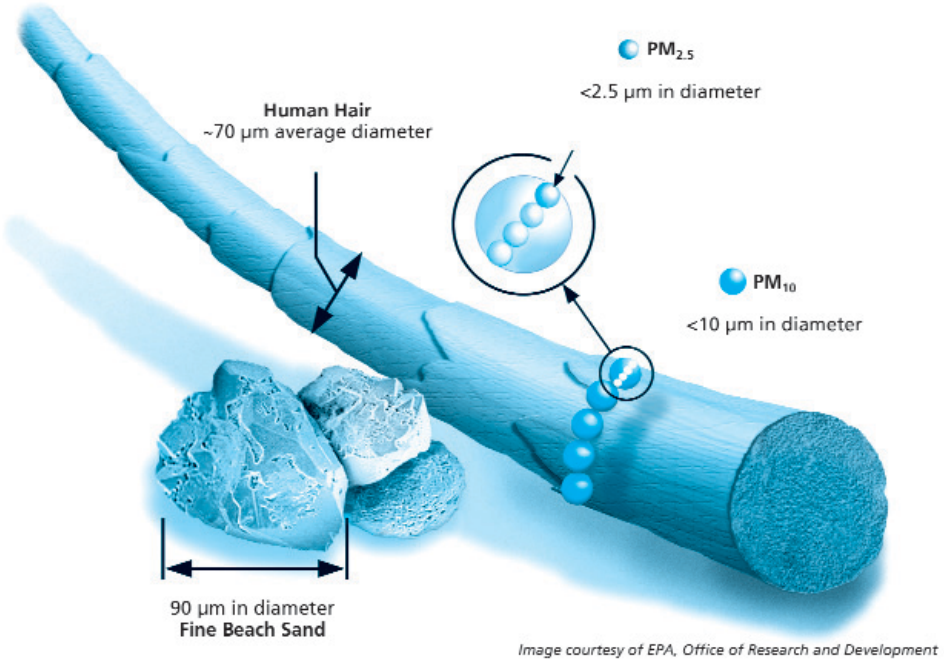


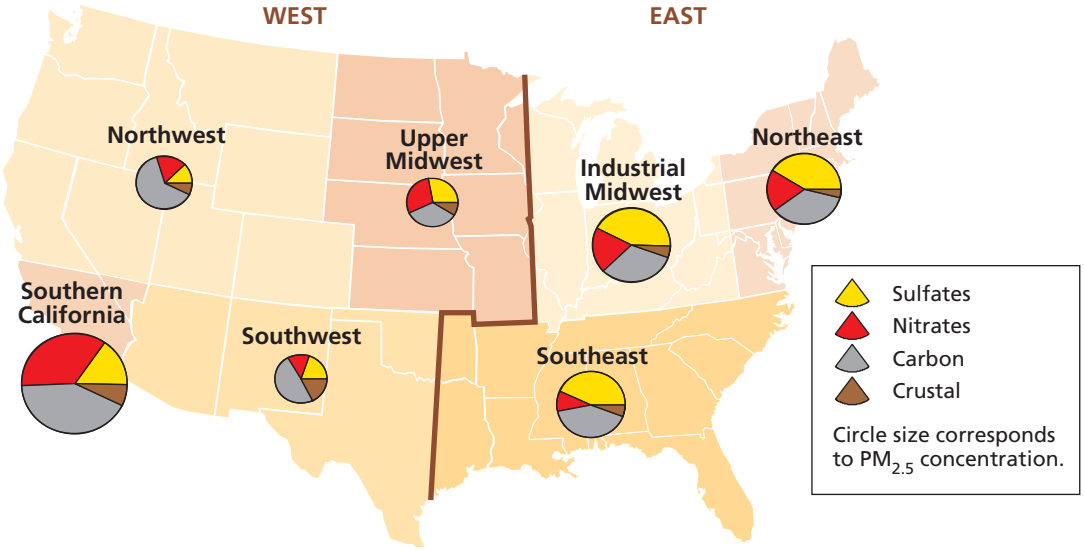
Image courtesy of EPA, Office of Research and Development

Note: In this report, particle size or diameter refers to a normalized measure called aerodynamic diameter, which accounts for the irregular shape and varying density of most particles.

Made Up of Many Species

Particles are made up of different chemical components. The major components, or species, are carbon, sulfate and nitrate compounds, and crustal materials such as soil and ash. The different components that make up particle pollution come from specific sources and are often formed in the atmosphere (see "Sources and Transport of Particle Pollution" on page 6). The chemical makeup of particles varies across the United States (see Figure 2). For example, fine particles in the eastern half of the United States contain more sulfates than those in the West, while fine particles in southern California contain more nitrates than other areas of the country. Carbon is a substantial component of fine particles everywhere. (For information on the composition of ultrafine and coarse particles in Los Angeles, see page 7.)

Figure 2. Average $PM_{2.5}$ composition in urban areas by region, 2003.



Note: In this report, the term "sulfates" refers to ammonium sulfate and "nitrates" refers to ammonium nitrate. "Carbon" refers to total carbonaceous mass, which is the sum of estimated organic carbon mass and elemental carbon. "Crustal" is estimated using the IMPROVE equation for fine soil at vista.cira.colostate.edu/improve.

This report summarizes analysis results using the geographic areas shown in this map. The area definitions correspond to the regions used in EPA's 1996 PM Criteria Document (www.epa.gov/ttn/naaqs).

In this report, "East" includes three regions: the Northeast, the Industrial Midwest, and the Southeast.

Health and Environmental Effects of Particulate Matter

Health Effects

Exposure to particles can lead to a variety of serious health effects. The largest particles do not get very far into the lungs, so they tend to cause fewer harmful health effects. Coarse and fine particles pose the greatest problems because they can get deep into the lungs, and some may even get into the bloodstream. Scientific studies show links between these small particles and numerous adverse health effects. Long-term exposures to PM, such as those experienced by people living for many years in areas with high particle levels, are associated with problems such as decreased lung function, development of chronic bronchitis, and premature death. Short-term exposures to particle pollution (hours or days) are associated with a range of effects, including decreased lung function, increased respiratory symptoms, cardiac arrythmias (heartbeat irregularities), heart attacks, hospital admissions or emergency room visits for heart or lung disease, and premature death. Sensitive groups at greatest risk include people with heart or lung disease, older adults, and children.

Environmental Effects

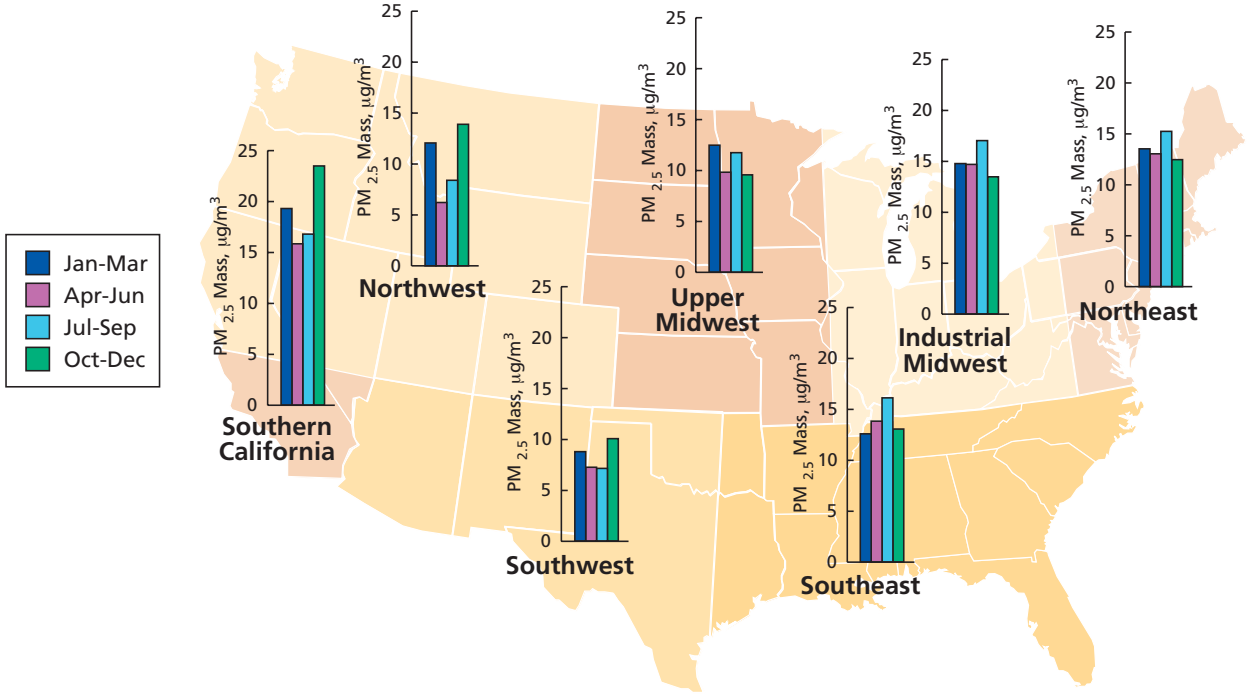
Fine particles are the major source of haze that reduces visibility in many parts of the United States, including our national parks. PM affects vegetation and ecosystems by settling on soil and water, upsetting delicate nutrient and chemical balances. PM also causes soiling and erosion damage to structures, including culturally important objects such as monuments and statues.

Seasonal

Fine particles often have a seasonal pattern. $PM_{2.5}$ values in the eastern half of the United States are typically higher in the third calendar quarter (July-September) when sulfates are more readily formed from sulfur dioxide (SO_2) emissions from power plants in that region. Fine particle concentrations tend to be higher in the fourth calendar quarter in many areas of the West, in part because fine particle nitrates are more readily formed in cooler weather, and wood stove and fireplace use produces more carbon.

The time of year also influences *daily* fine particle patterns. Unlike daily ozone levels, which are usually elevated in the summer, daily $PM_{2.5}$ values at some locations can be high at any time of the year. Figure 4 shows 2003 $PM_{2.5}$ levels for Fresno and Baltimore. The colors in the background of these charts correspond to the colors of the Air Quality Index (AQI), EPA's tool for informing the public about air pollution levels in their communities. As the Fresno graphic illustrates, fine particles can be elevated in the fall and winter in some areas, while ozone is elevated only in the summer. Contrast the Fresno graphic with the Baltimore graphic, which shows PM elevated year-round. Note: Elevated levels on the AQI do not indicate that an area is violating EPA's national air quality standards for any particular pollutant. The AQI is designed to help people reduce their individual exposure to pollution.

Figure 3. Seasonal averages of $PM_{2.5}$ concentration by region, 1999–2003.

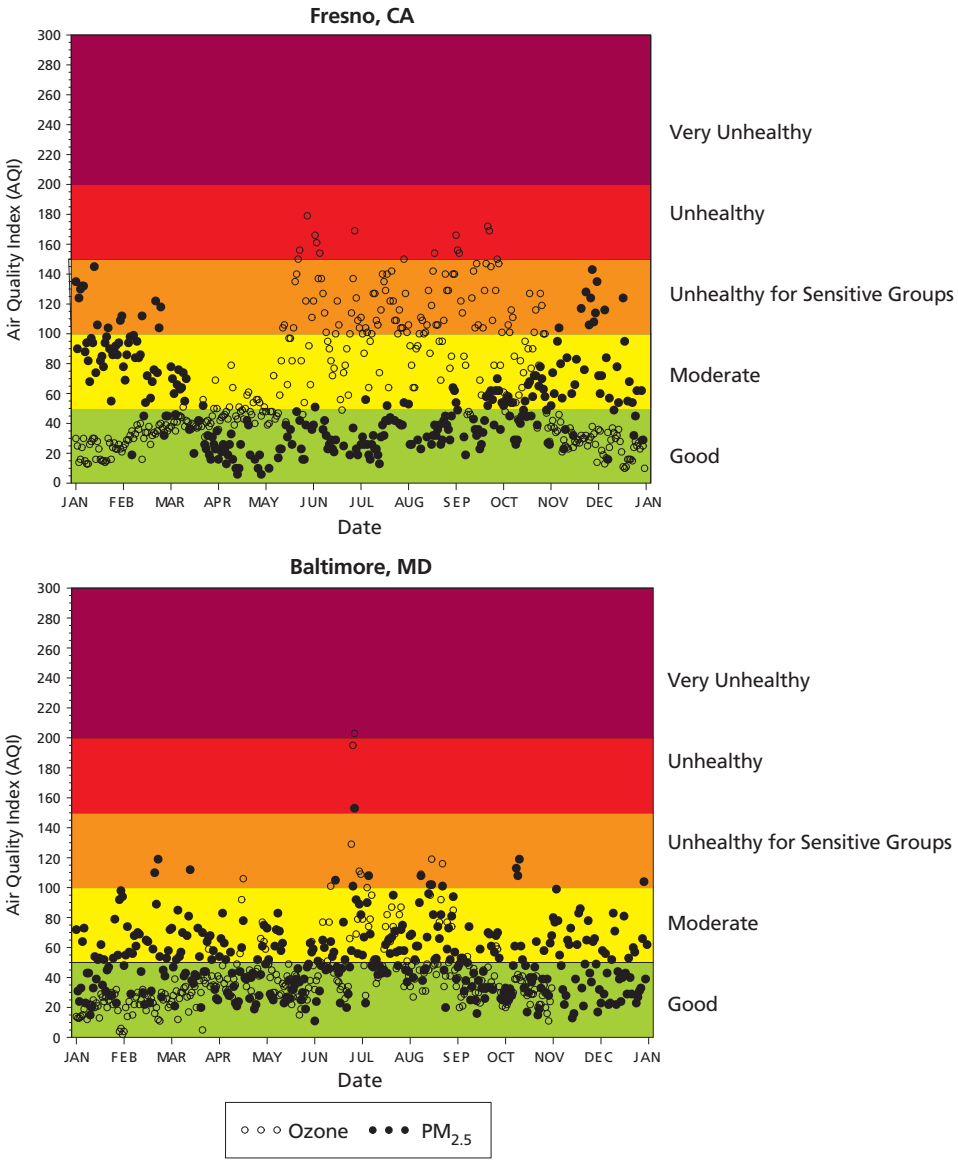


Air Quality Index (AQI) - Particulate Matter

The AQI is an index for reporting daily air quality. It tells how clean or polluted the air is and what associated health effects might be a concern. The AQI focuses on health effects people may experience within a few hours or days after breathing polluted air. EPA calculates the AQI for five major pollutants regulated by the Clean Air Act: particulate matter, ozone, carbon monoxide, sulfur dioxide, and nitrogen dioxide. The AQI values for particulate matter are shown here.

AQI	$PM_{2.5}$ ($\mu g/m^3$)	PM_{10} ($\mu g/m^3$)	Air Quality Descriptor
0–50	0.0–15.4	0–54	Good
51–100	15.5–40.4	55–154	Moderate
101–150	40.5–65.4	155–254	Unhealthy for Sensitive Groups
151–200	65.5–150.4	255–354	Unhealthy
201–300	150.5–250.4	355–424	Very unhealthy

Figure 4. Daily $PM_{2.5}$ and ozone AQI values, 2003.



Note: These graphs represent data from Federal Reference Method monitors. They do not show data from all monitors that report the Air Quality Index.

Sources and Transport of Particle Pollution

Sources

Particulate matter includes both "primary" PM, which is directly emitted into the air, and "secondary" PM, which forms indirectly from fuel combustion and other sources. Generally, coarse PM is made up of primary particles, while fine PM is dominated by secondary particles.

Primary PM consists of carbon (soot) — emitted from cars, trucks, heavy equipment, forest fires, and burning waste — and crustal material from unpaved roads, stone crushing, construction sites, and metallurgical operations.

Secondary PM forms in the atmosphere from gases. Some of these reactions require sunlight and/or water vapor. Secondary PM includes

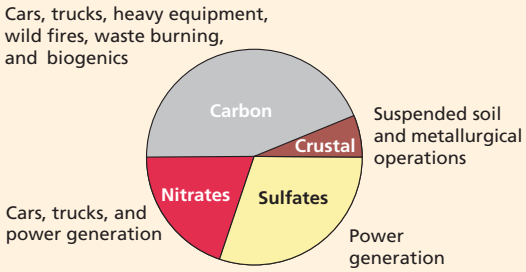
- *Sulfates* formed from sulfur dioxide emissions from power plants and industrial facilities
- *Nitrates* formed from nitrogen oxide emissions from cars, trucks, and power plants
- *Carbon* formed from reactive organic gas emissions from cars, trucks, industrial facilities, forest fires, and biogenic sources such as trees.

Note: For more information about the apportionment of fine particles to their sources, go to www.epa.gov/oar/oaqps/pm25/docs.html

Transport

In the atmosphere, coarse and fine particles behave in different ways. Larger coarse particles may settle out from the air more rapidly than fine particles and usually will be found relatively close to their emission sources. Fine particles, however, can be transported long distances by wind and weather and can be found in the air thousands of miles from where they were formed.

Automobiles, Power Generation, and Other Sources Contribute to Fine Particle Levels



Note: Ammonia from sources such as fertilizer and animal feed operations contributes to the formation of sulfates and nitrates that exist in the atmosphere as ammonium sulfate and ammonium nitrate.

Visibility

One of the most obvious effects of air pollution occurs both in urban areas and at the country's best-known and most-treasured national parks and wilderness areas. Visibility impairment occurs when fine particles scatter and absorb light, creating a haze that limits the distance we can see and that degrades the color, clarity, and contrast of the view. The particles that cause haze are the same particles that contribute to serious health problems and environmental damage.

Visibility impairment—and the concentration of particles that cause it—generally is worse in the eastern United States than it is in the West. Humidity can significantly increase visibility impairment by causing some particles to become more efficient at scattering light. Average relative humidity levels are higher in the East (70% to 80%) than in the West (50% to 60%).

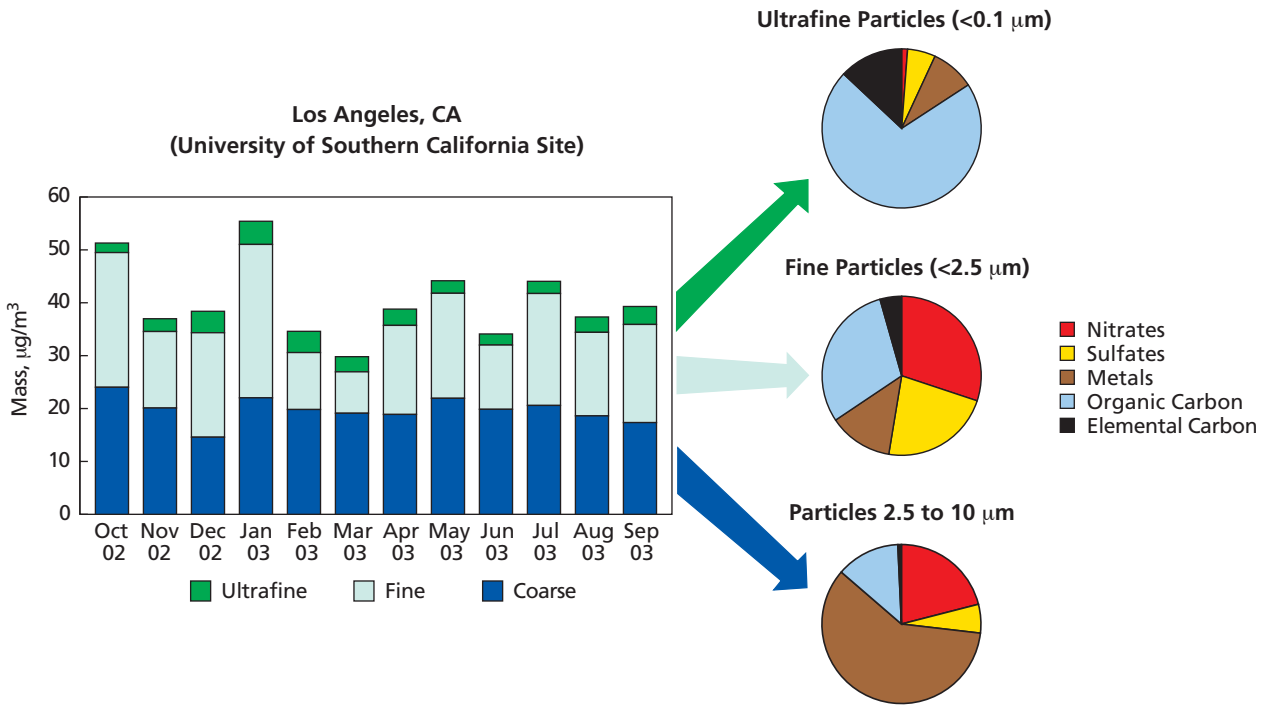
In the East, reduced visibility is mainly attributable to sulfates, organic carbon, and nitrates. Poor summertime visibility is primarily the result of high sulfate concentrations, combined with high humidity. Sulfates, which dominate the composition of these visibility-impairing particles, have been found to contribute even more to light extinction than they do to fine particle concentrations. In the West, organic carbon, nitrates, and crustal material make up a larger portion of total particle concentrations than they do in the East.

Through its 1999 regional haze rule, EPA, states, and other federal agencies are working to improve visibility in 156 national parks and wilderness areas such as the Grand Canyon, Yosemite, the Great Smokies, and Shenandoah. Five multistate regional planning organizations are working together to develop and implement regional haze reduction plans. For more information, see www.epa.gov/airtrends/vis.html.

Yosemite National Park (California) under bad and good visibility conditions. Visual range is 111 kilometers (km) in the left photo and greater than 208 km in the right photo.

Shenandoah National Park (Virginia) under bad and good visibility conditions. Visual range is 25 km in the left photo and 180 km in the right photo.

PM Supersites



Note: "Crustal materials" include windblown soil, industrial process emissions, sea salt, and flyash from combustion.

After issuing the nation's first $PM_{2.5}$ standards in 1997, EPA developed the PM Supersites project, a monitoring research program, to address a number of scientific issues associated with particulate matter. Program goals focus on obtaining atmospheric measurements to

- Characterize PM, its constituents, atmospheric transport, and source categories that affect PM in any region
- Compare and evaluate different PM measurement methods (e.g., emerging sampling methods, routine monitoring techniques)
- Support exposure and health effects research concerning the relationships between sources, ambient PM concentrations, and human exposures and health effects and the biological basis for these relationships.

EPA selected eight locations for Supersites, including Los Angeles. Atmospheric measurements taken at the Los Angeles site between October 2002 and September 2003 show that ultrafine particles make up a small portion of the PM concentration compared to inhalable coarse and fine particles. However, the *number* of ultrafine particles is significantly larger than the number of coarse or fine particles. EPA is studying this from a health perspective.

The Los Angeles data also show that coarse, fine, and ultrafine PM have different compositions. For each type of PM, there is a difference in the relative amounts of nitrates, sulfates, crustal materials, and carbon. Carbon, shown here as organic and elemental carbon, makes up a large fraction of ultrafine and fine PM in Los Angeles.

For more information, see www.epa.gov/ttn/amtic/supersites.html and www.epa.gov/ttn/amtic/laprog.html

Both Local and Regional

Both local and regional sources contribute to particle pollution. Figure 5 shows how much of the $PM_{2.5}$ mass can be attributed to local versus regional sources for 13 selected urban areas (arranged west to east). In each of these urban areas, monitoring sites were paired with nearby rural sites. When the average rural concentration is subtracted from the measured urban concentration, the estimated local and regional contributions become apparent.

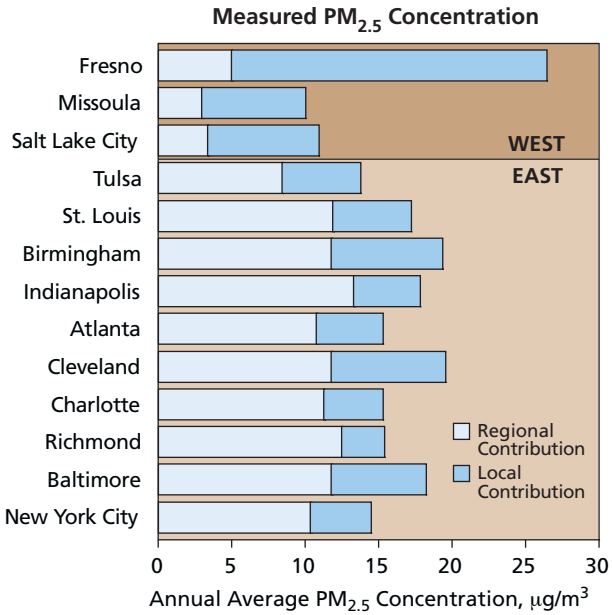
In the East, regional pollution contributes more than half of total $PM_{2.5}$ concentrations. Rural background $PM_{2.5}$ concentrations are high in the East and are somewhat uniform over large geographic areas. These regional concentrations come from emission sources such as power plants, natural sources, and urban pollution and can be transported hundreds of miles.

For the cities shown in Figure 5, local contributions range from 2 to 20 micrograms per cubic meter ($\mu g/m^3$), with the West generally showing larger local contributions than the East. In the East, local contributions are generally greatest in cities with the highest annual average $PM_{2.5}$ concentrations.

Figure 6 shows the local and regional contributions for the major chemical components that make up urban $PM_{2.5}$: sulfates, carbon, and nitrates. In the eastern United States, the local contribution of sulfates is generally small. Most sulfates in the East are converted from regional SO_2 emissions and are transported long distances from their sources.

Carbon has the largest local contribution of the three major chemical components. These local emissions come from a combination of mobile and stationary combustion sources. The regional

Figure 5. Local and regional contribution to urban $PM_{2.5}$.

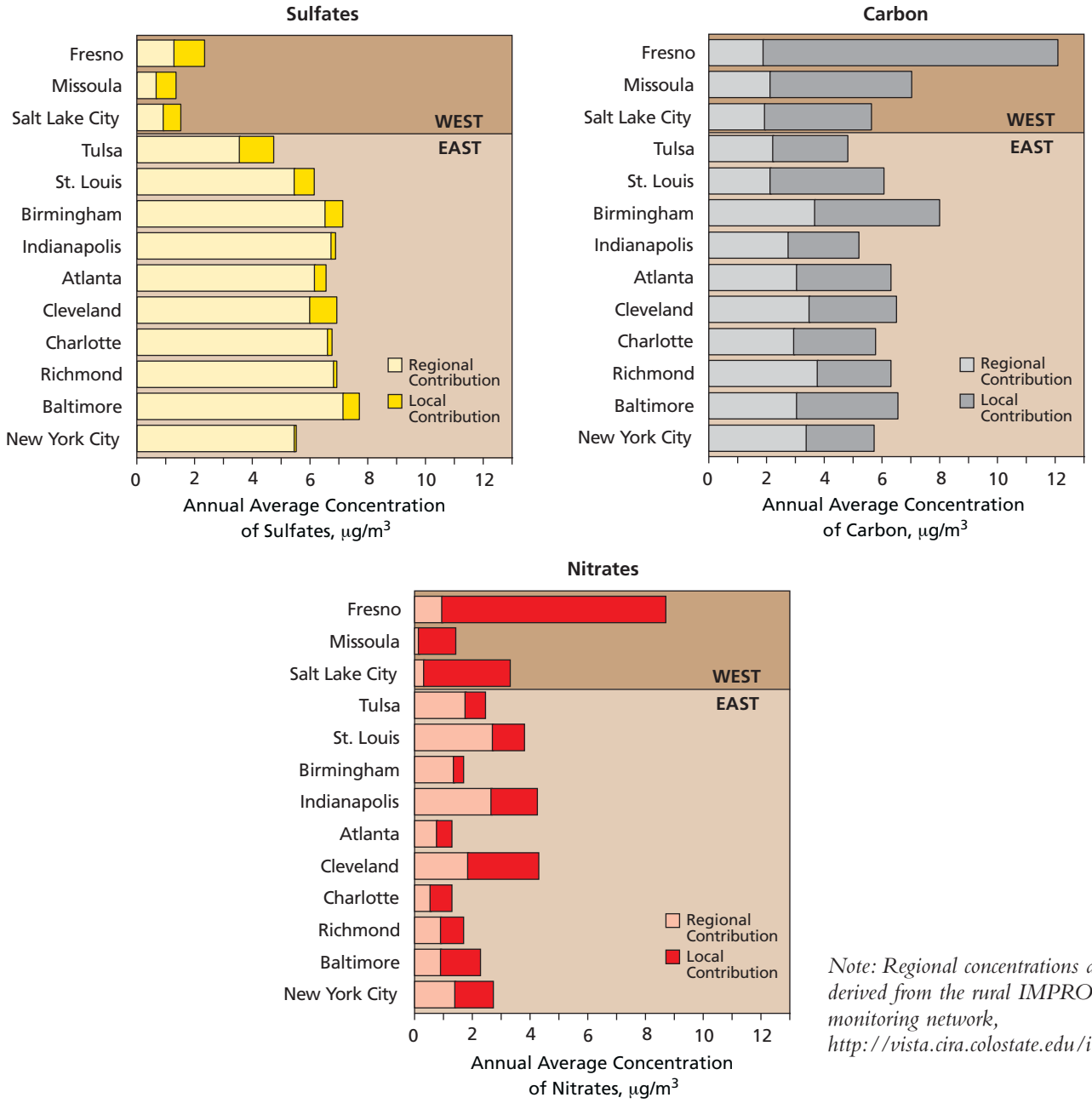


Note: Urban and nearby rural $PM_{2.5}$ concentrations suggest substantial regional contributions to fine particles in the East. The measured $PM_{2.5}$ concentration is not necessarily the maximum for each urban area. Regional concentrations are derived from the rural IMPROVE monitoring network, http://vista.cira.colostate.edu/improve.

contribution, which varies from 30% to 60% of the total carbon at urban locations, is from rural emission sources such as vegetation and wildfires, as well as region-wide sources such as cars and trucks.

Nitrates represent only about 10% to 30% of annual average $PM_{2.5}$, and urban concentrations are higher than the nearby regional levels. This is likely due to local nitrogen sources such as cars, trucks, and small stationary combustion sources.

Figure 6. Local and regional contribution of major $PM_{2.5}$ chemical components.



Note: Regional concentrations are derived from the rural IMPROVE monitoring network, http://vista.cira.colostate.edu/improve.

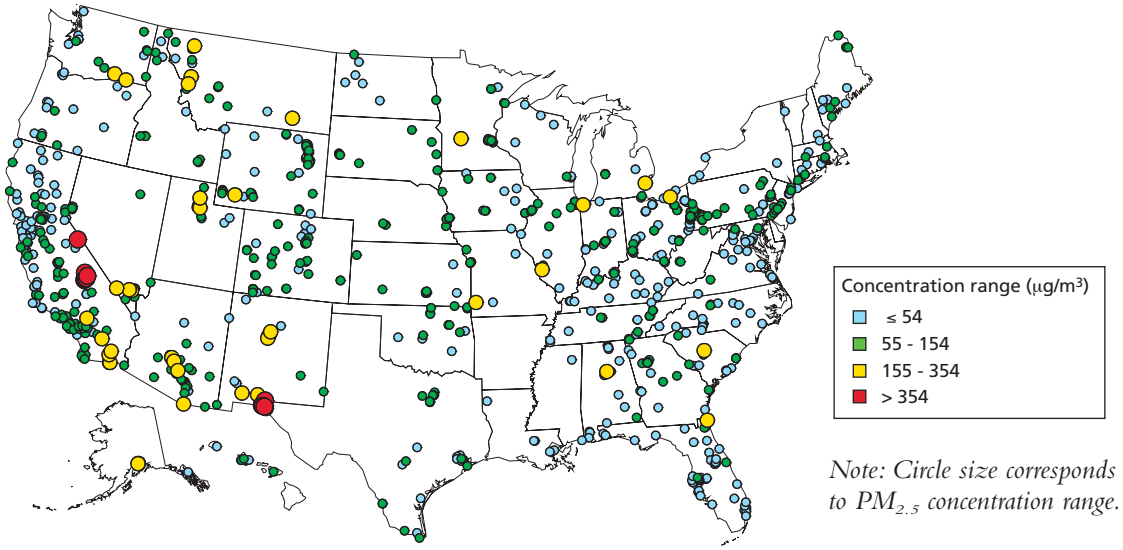
Particle Pollution in 2003

Nationally, fine particle concentrations in 2003 were the lowest since nationwide $PM_{2.5}$ monitoring began in 1999. Compared with 2002, the biggest decreases occurred in the Industrial Midwest and parts of California — areas with relatively high $PM_{2.5}$ concentrations. PM_{10} concentrations were slightly higher in 2003 than the previous year, but they are still the second lowest since nationwide PM_{10} monitoring began in 1988.

Although average concentrations have declined nationally, many areas still exceed the level of the PM standards. In 2003, monitors in 97 counties (home to 62 million people) showed concentrations greater than the PM_{10} or $PM_{2.5}$ national air quality standards. Thirty-seven counties (21 million people) measured concentrations in excess of the national PM_{10} standards, and 72 counties (53 million people) exceeded the national $PM_{2.5}$ standards. These numbers do not include other areas outside of these counties that might *contribute* to levels above the standards.

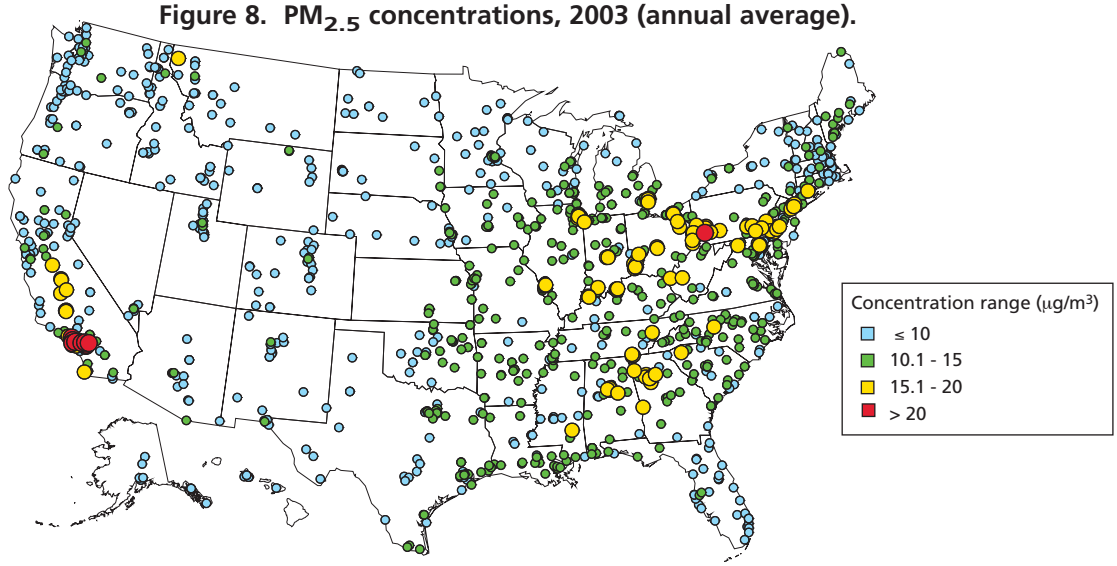
Figure 7 shows the range of PM_{10} concentrations across the country in 2003. The highest concentrations were recorded in Inyo and Mono counties, California; El Paso County, Texas; and Dona Ana County, New Mexico. Figure 8 shows the

Figure 7. PM_{10} concentrations, 2003 (second maximum 24-hour).



Note: Circle size corresponds to $PM_{2.5}$ concentration range.

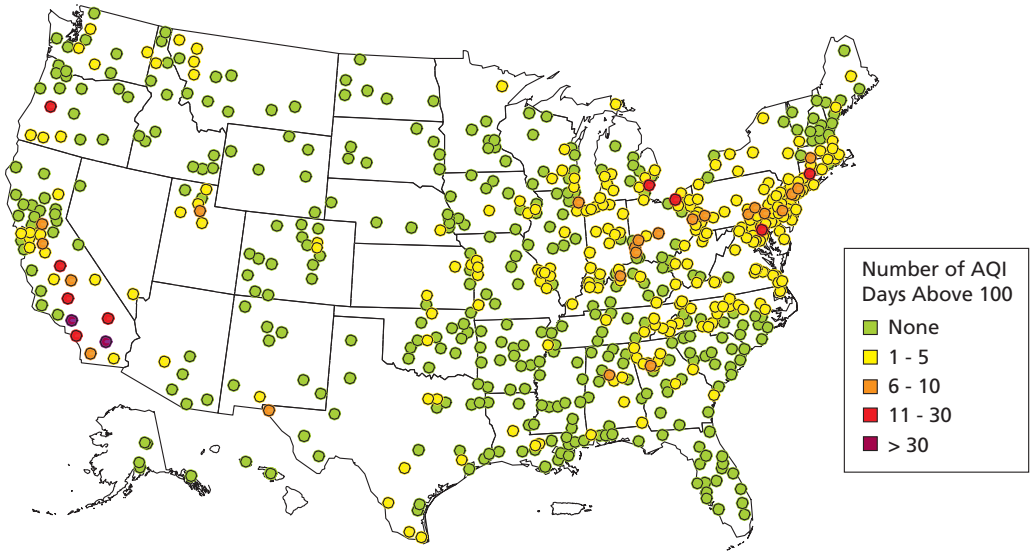
Figure 8. $PM_{2.5}$ concentrations, 2003 (annual average).



range of 2003 $PM_{2.5}$ annual averages across the country. The highest annual averages occurred in southern California and Pittsburgh. High levels are also seen in many urban areas in the Southeast, Northeast, and Industrial Midwest. See www.epa.gov/airtrends/pm.html for county-level maps of PM.

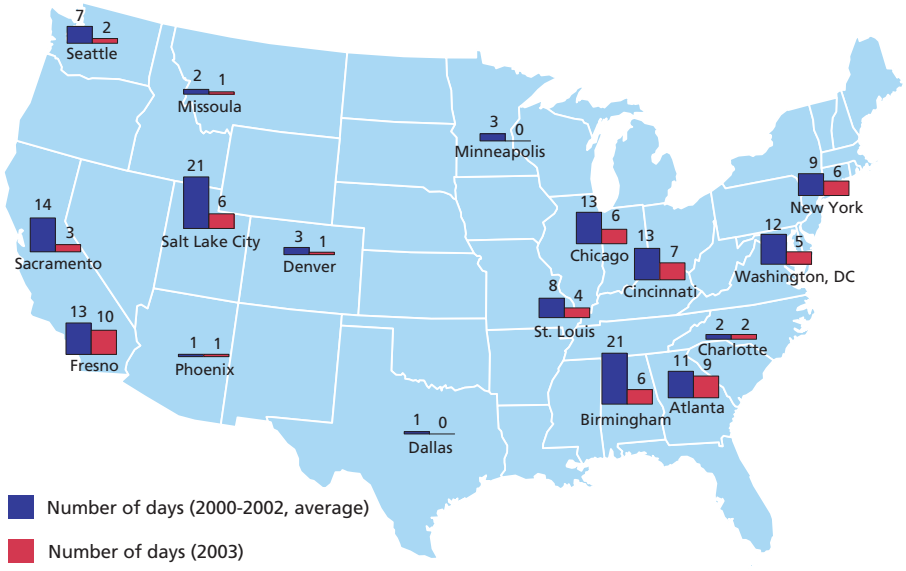
$PM_{2.5}$ concentrations can reach unhealthy levels even in areas that meet the annual standard. In 2003, there were 277 counties with at least 1 unhealthy day based on $PM_{2.5}$ AQI values, as shown in Figure 9. Nearly two-thirds of those counties had annual averages below the level of the standard. Figure 10 shows how several major metropolitan areas fared in 2003 relative to previous years. Most metropolitan areas had fewer unhealthy $PM_{2.5}$ days in 2003 compared to the average from the previous 3 years, which reflects the improvements observed in 2003.

Figure 9. $PM_{2.5}$ AQI days above 100 (≥40.5 µg/m³) in 2003.



Note: This map represents data from Federal Reference Method monitors. It does not show data from all monitors that report the Air Quality Index. As such, it may not provide a complete picture of days above the AQI in some cities.

Figure 10. Number of days with $PM_{2.5}$ AQI levels above 100, 2003 versus average 2000–2002.

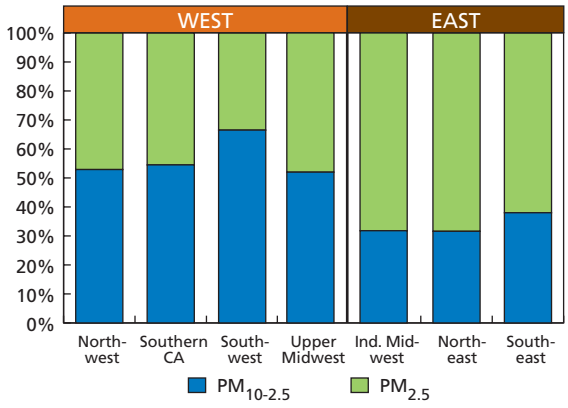


PM_{10} – $PM_{2.5}$

Particulate matter varies greatly in size. "Coarse" particles can be as large as 40 micrometers (μm) in diameter or even larger. EPA's National Ambient Air Quality Standards (NAAQS) for particulate matter, however, have focused on particles that are 10 μm in diameter or smaller. These particles are the most likely to be inhaled and can penetrate into the lower respiratory tract. EPA has had air quality standards for particles 10 μm and smaller since 1987. In 1997, EPA also established an NAAQS for fine particles — those particles 2.5 μm in diameter or smaller. EPA is now in the process of reviewing the PM NAAQS.

As shown in Figure 11, the size distribution of particles smaller than 10 μm but larger than 2.5 μm varies by geographic location. Levels of $PM_{10-2.5}$ are generally higher in the West, particularly the Southwest. $PM_{10-2.5}$ typically comprises more than half of the PM_{10} mass in the West. Data also suggest that concentrations of particles between 2.5 and 10 μm in size are lower in the mid-Atlantic and Southeast. Overall, while directly emitted $PM_{2.5}$ and its precursors can come from both local and regional sources, the larger particles that are part of PM_{10} tend to come from local sources.

Figure 11. Percent of 2003 annual average concentration of particles smaller than 10 μm but larger than 2.5 μm, by region.



National Standards for Particulate Matter

EPA first established National Ambient Air Quality Standards (NAAQS) for total suspended particulate (TSP) in 1971. When the standards were revised in 1987, TSP was replaced by PM_{10}. In 1997, EPA revised the primary (health) and secondary (welfare) PM NAAQS by adding standards for $PM_{2.5}$. EPA added $PM_{2.5}$ standards because fine particles are more closely associated with serious health effects.

The NAAQS for PM_{10} and $PM_{2.5}$ include both short-term (24-hour) and long-term (annual) standards:

NAAQS	$PM_{2.5}$	PM_{10}
Short-term (24-hour average)	65 μg/m³	150 μg/m³
Long-term (annual average)	15 μg/m³	50 μg/m³

Compliance

Each PM standard carries a separate threshold for compliance:

- For the long-term standards for both $PM_{2.5}$ and PM_{10}, compliance is determined based on the average of three consecutive annual average values.
- Compliance with the short-term $PM_{2.5}$ standard is determined by the 3-year average of the annual 98th percentile of 24-hour concentrations.
- The short-term standard for PM_{10} is not to be exceeded more than once per year, averaged over 3 years.

EPA reviews the NAAQS on a regular basis. The standards for PM_{10} and $PM_{2.5}$ are currently under review, to be completed in 2006.

Note: μg/m³ = micrograms per cubic meter.

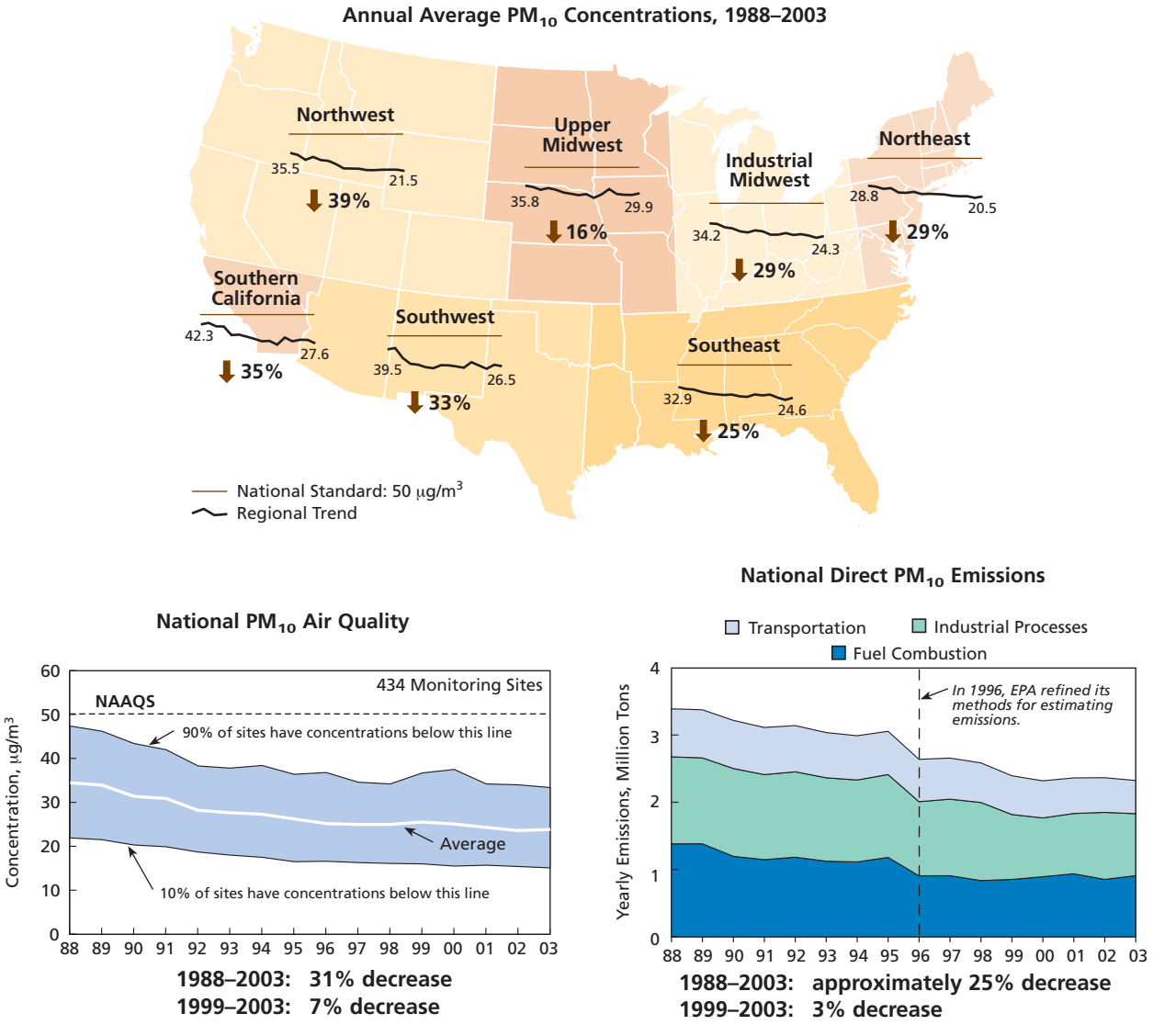
Looking at Trends

PM_{10} National and Regional Trends

Nationally, PM_{10} concentrations have decreased 31% since 1988, as shown in Figure 12. Regionally, PM_{10} decreased most in areas with historically higher concentrations — the Northwest (39%), the Southwest (33%), and southern California (35%).

Programs aimed at reducing direct emissions of particles have played an important role in reducing PM_{10} concentrations, particularly in western areas. Some examples of PM_{10} controls include paving unpaved roads, replacing wood and coal with cleaner-burning fuels like natural gas, and using best management practices for agricultural sources of resuspended soil. Additionally, EPA's Acid Rain Program has substantially reduced SO_2 emissions from power plants since 1995 in the eastern United States, contributing to lower PM concentrations. Direct emissions of PM_{10} have decreased approximately 25% nationally since 1988.

Figure 12. Regional and national trends in annual average PM_{10} concentrations and emissions, 1988–2003.

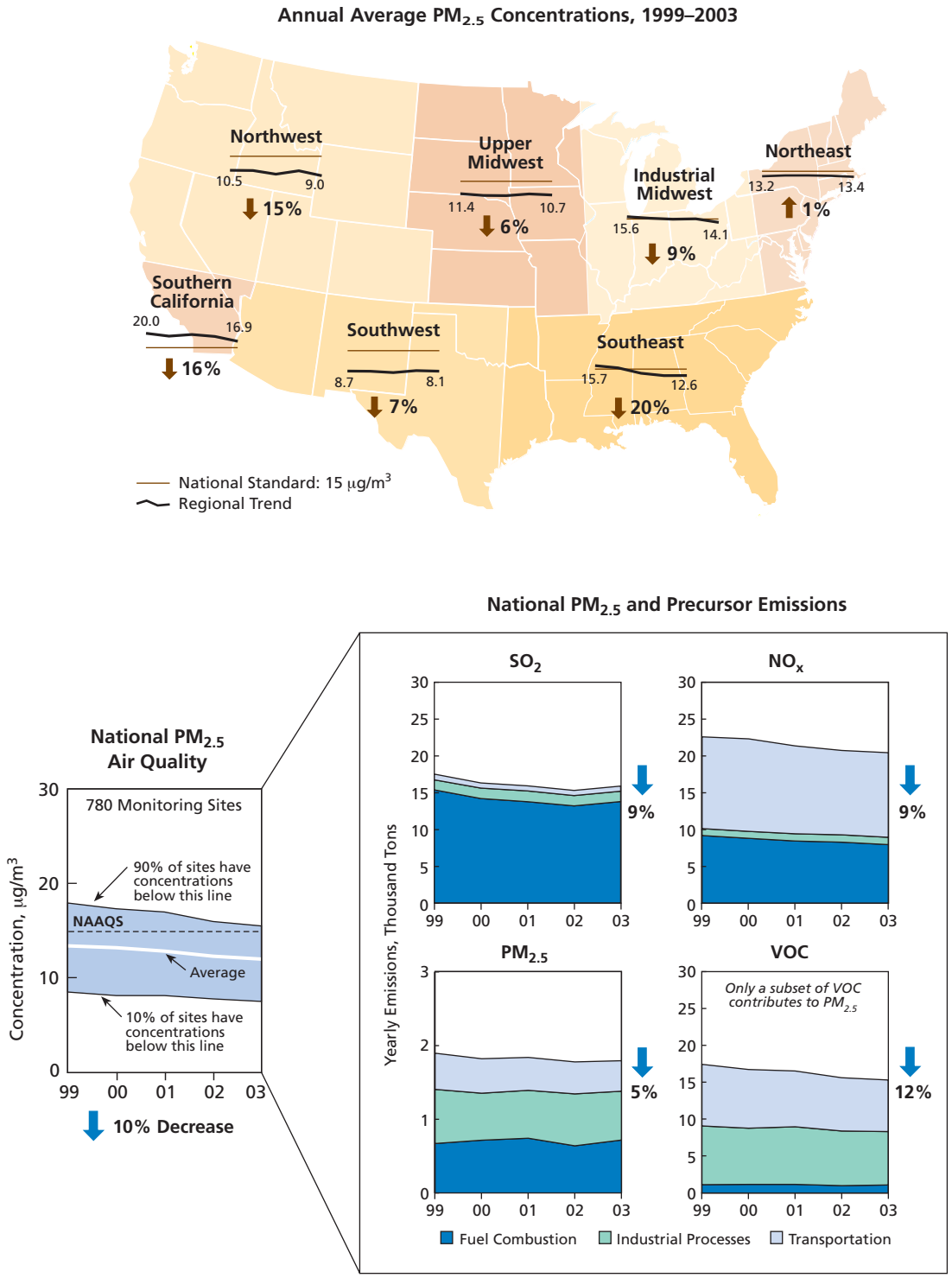


$PM_{2.5}$ National and Regional Trends

$PM_{2.5}$ concentrations have decreased 10% nationally since 1999. Generally, $PM_{2.5}$ has decreased the most in regions with the highest concentrations — the Southeast (20%), southern California (16%), and the Industrial Midwest (9%), as shown in Figure 13. With the exception of the Northeast, the remaining regions posted modest declines in $PM_{2.5}$ from 1999 to 2003.

A variety of local and national programs have resulted in a 5% decrease in estimated direct emissions of $PM_{2.5}$ over the past 5 years. In addition, programs that reduce the gaseous emissions that can form particles in the atmosphere have yielded additional reductions. National programs that affect regional emissions — including EPA's Acid Rain Program — have contributed to lower sulfate concentrations and, consequently, to lower $PM_{2.5}$ concentrations, particularly in the Industrial Midwest and Southeast. National ozone-reduction programs designed to reduce emissions of volatile organic compounds (VOCs) and nitrogen oxides (NO_x) also have helped reduce carbon and nitrates, both of which are components of $PM_{2.5}$. Nationally, SO_2, NO_x, and VOC emissions decreased 9%, 9%, and 12%, respectively, from 1999 to 2003. In eastern states affected by the Acid Rain Program, sulfates decreased 7% over the same period.

Figure 13. Regional and national trends in annual average $PM_{2.5}$ concentrations and emissions related to $PM_{2.5}$ formation, 1999–2003.



Note: Ammonia is a contributor to $PM_{2.5}$ formation. However, because of uncertainty in ammonia emission estimates, its trends are not shown here.

25-Year $PM_{2.5}$ Trends

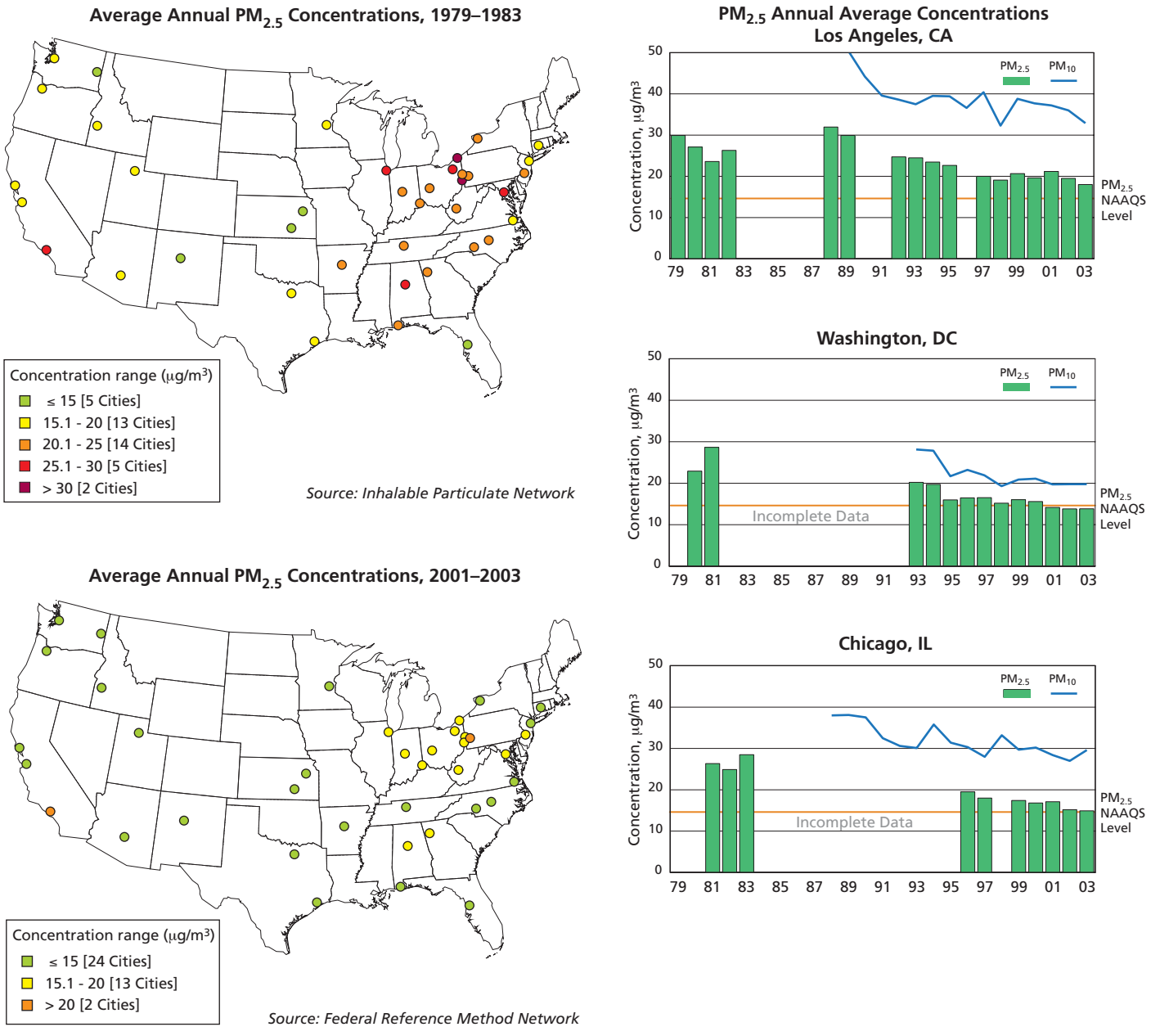
Because EPA's national $PM_{2.5}$ monitoring network is just 5 years old, we use data from older $PM_{2.5}$ monitoring networks to assess longer-term trends. Although the earlier networks are more limited in geographic scope and years of coverage, their data do provide historical perspective. The maps in Figure 14 show how $PM_{2.5}$ concentrations 25 years ago compare with $PM_{2.5}$ concentrations today in 39 major cities. Reductions vary among the 39 cities. Generally, the largest reductions occurred in the areas with the highest concentrations. On average, today's levels are about 30% lower than they were 25 years ago.

The following examples, illustrated in Figure 14, show how $PM_{2.5}$ concentrations have improved over the past 25 years in three cities. Figure 14 also shows PM_{10} concentrations for comparison (where available). $PM_{2.5}$ accounts for more than half of the PM_{10} levels in these areas.

- **Los Angeles:** $PM_{2.5}$ concentrations have decreased substantially since 1980. Although concentrations have leveled off in recent years, average $PM_{2.5}$ levels in 2003 were the lowest on record. Low-sulfur gasoline use and ozone reduction programs designed to control NO_x and VOC emissions may have contributed to the $PM_{2.5}$ decrease observed in the 1990s.
- **Washington, DC:** $PM_{2.5}$ concentrations are currently (2003) at their lowest levels. The relatively large drop from 1994 to 1995 corresponds to decreases in sulfates (21%) and organic carbon (30%). The decrease in sulfates is attributable in part to the Acid Rain Program, which substantially reduced SO_2 emissions from power plants during this time. The decrease in organic carbon is attributable in part to the use of reformulated gasoline.
- **Chicago:** $PM_{2.5}$ concentrations at this site have dropped substantially since the early 1980s, reaching their lowest levels in 2003.

For additional information on long-term trends, see www.epa.gov/airtrends/pm.html.

Figure 14. Comparison of historical $PM_{2.5}$ and PM_{10} annual average concentrations, 1979–2003.



Note: The 1979–1983 data are from the Inhalable Particulate Network (IPN). The 1984–1999 data are from EPA's Air Quality System. The 1999–2003 data are from the Federal Reference Method (FRM) network. The 1993–2003 data for Washington, DC, are from the IMPROVE network.

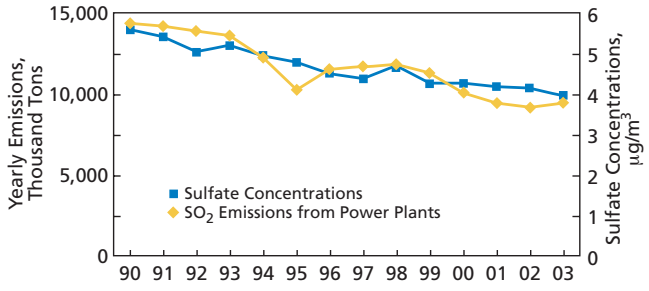
Rural Sulfate Trends

In the eastern half of the United States, sulfates account for 25% to 55% of $PM_{2.5}$ annually. Power plants are the largest contributor to sulfate formation in the East, where they were responsible for more than 75% of sulfur dioxide emissions in 2003.

In the East, power plants reduced sulfur dioxide emissions 33% between 1990 and 2003. As Figure 15 shows, this downward trend matches well with the trend in concentrations of rural sulfates (a 29% decrease). Because sulfates have such a large regional component (shown in Figure 6), these trends in sulfate concentration can also be used to help explain urban $PM_{2.5}$ trends.

The reductions shown in Figure 15 are primarily attributable to implementation of EPA's Acid Rain program. Phase I compliance began in 1995, affecting large coal-burning power plants in 21 eastern and midwestern states. Phase II implementation began in 2000, tightening emission limits on the Phase I power plants and setting restrictions on smaller coal-, oil-, and gas-fired plants. As the figure shows, sulfur dioxide emissions and sulfate concentrations decreased following implementation of both phases. A slight increase in SO_2 emissions in the latter half of the 1990s was likely due to power plants not affected until Phase II began in 2000. The small increase from 2002 to 2003 resulted from increased electricity production by coal-fired and oil-fired units. These units emit much more SO_2 than natural gas units that generated less power in 2003. This annual variation does not affect the total limit on SO_2 emissions under the Acid Rain Program. (For more information, see www.epa.gov/air/oap.html and www.epa.gov/acidrainreport/.)

Figure 15. Eastern annual trends of sulfur dioxide emissions from power plants and sulfate concentrations.



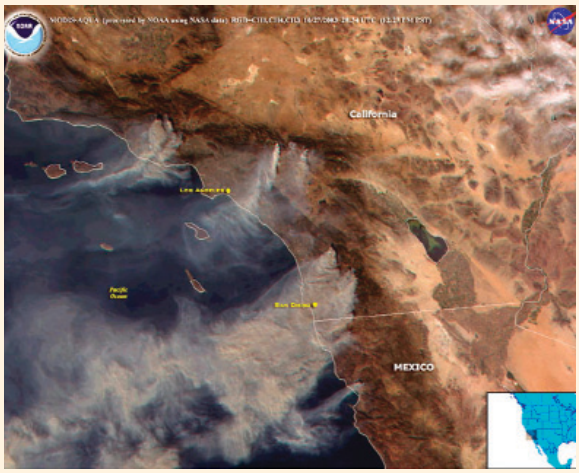
Note: Sulfate concentrations are from EPA's CASTNET monitoring network, www.epa.gov/castnet

Episodic Events

PM concentrations can increase dramatically due to human-caused or natural episodic events, such as biomass burning, meteorological inversions, dust storms, and volcanic and seismic activity. These events are rare, affecting less than 1% of reported $PM_{2.5}$ concentrations between 2001 and 2003. Episodic events can affect people's short-term PM exposure, briefly pushing hourly and daily PM levels into the unhealthy ranges of the Air Quality Index. However, these events rarely have a significant effect on annual or longer averages of PM.

Biomass burning can be either a human-initiated event, as in the burning of vegetation for land clearing or land use change, or a natural event, as in the wild fires resulting from lightning. Biomass burning can significantly increase PM levels in local areas and sometimes more distant areas. Air currents can carry smoke from forest fires half-way around the earth. Organic carbon compounds usually dominate the $PM_{2.5}$ concentration profile during these fire episodes.

Topography and meteorological conditions make some areas more susceptible to episodic events. In mountain regions, temperature inversions sometimes trap polluted air during the winter. Wintertime $PM_{2.5}$ and PM_{10} can be more than three times higher than other seasonal averages. Woodstove smoke, containing large amounts

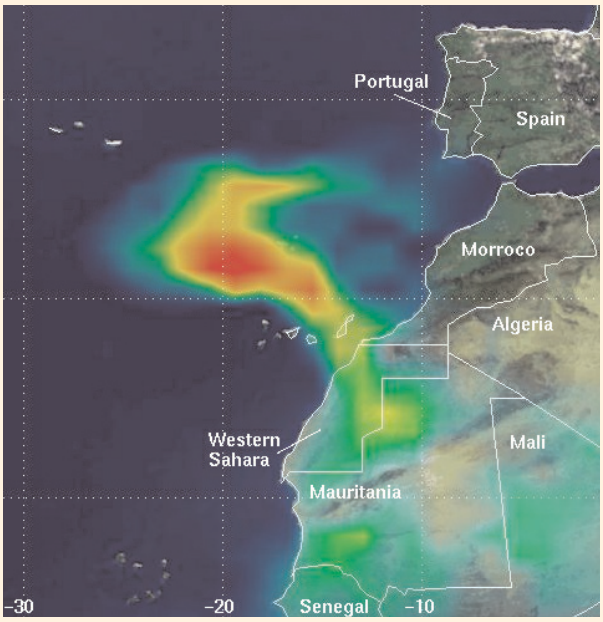


Satellite photo of forest fires, southern California, October 27, 2003.

of organic carbon, is often identified as a significant source of the elevated wintertime PM concentrations.

Arid desert conditions in the southwestern United States make this region more vulnerable to wind-blown dust than other regions of the nation. Most dust events are caused by passage of weather fronts and troughs and downmixing of upper-level winds. Cyclone development and thunderstorms result in the most dramatic dust clouds with the lowest visibilities. Dust-related events are typically dominated by large, coarse particles, but fine particle levels also increase.

The effects of dust storms can also be seen globally. Giant sand storms originating in the Sahara Desert can blow across the Atlantic to South America, the Caribbean, and the southeastern United States, transporting several hundred million tons of dust each year. Movement of dust from Africa has increased since 1970 because of an increase of dry weather in the Saharan region. Satellite pictures also confirm that sandstorms originating in China's Gobi Desert occasionally cross the Pacific to the United States. Transport from Africa typically occurs in the summer, and transport from Asia typically occurs in the spring.



Satellite photo of giant cloud of dust originating in North Africa moving westward.

Temperature inversion, Salt Lake Valley, Utah, January 13, 2004.

Dust storm, Phoenix, Arizona, August 19, 1999.

Explaining the Trends

$PM_{2.5}$ Trends in Three Regions (1999–2003)

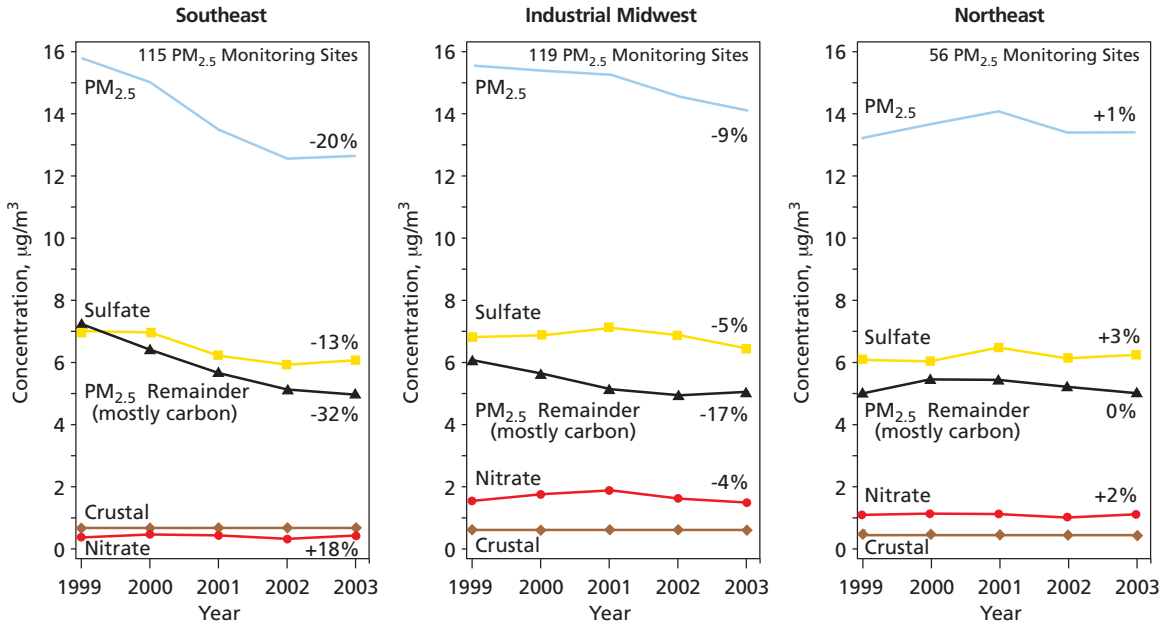
To better understand ambient air quality, it is helpful to examine trends and the factors that contribute to those trends in specific regions. This section explores, in detail, trends in three regions in the eastern half of the country from 1999 to 2003.

Figure 16 shows the 5-year regional trends in urban $PM_{2.5}$ and its major chemical constituents. In the Southeast, $PM_{2.5}$ declined sharply from 1999 to 2002, with little further change to 2003. Overall, the Southeast shows a 20% decrease in $PM_{2.5}$ from 1999 to 2003. In the Industrial Midwest, there is a gradual downward $PM_{2.5}$ trend from 1999 to 2001 and a more pronounced decrease from 2001 to 2003. Overall, $PM_{2.5}$ decreased 9% over the 5-year period. In the Northeast, $PM_{2.5}$ increased slightly from 1999 through 2001, then decreased through 2003, for an overall increase of 1%. Trends in PM components indicate that reductions in sulfates appear to be responsible for approximately one-third of the reductions in $PM_{2.5}$ in the Industrial Midwest and the Southeast. Trends in sulfate concentrations in the eastern United States match well with trends in SO_2 emissions from power plants over the past 14 years (based on analyses discussed in the previous section; see Figure 15).

Figure 17 shows that, on smaller subregional scales, the relationship between sulfate concentrations and power plant SO_2 emissions can vary among the subregions. Although trends in sulfate concentrations and SO_2 emissions match best overall in the Southeast (SO_2 emissions down 15%, sulfate concentrations down 13%, from 1999 to 2003), the year-to-year comparisons for the Industrial Midwest and the Northeast do not show such a close match. Sulfur dioxide emissions in the Industrial Midwest declined 19%, while sulfate concentrations declined 5%. In the Northeast, sulfur dioxide emissions were down 6%, and sulfate concentrations were up 3%.

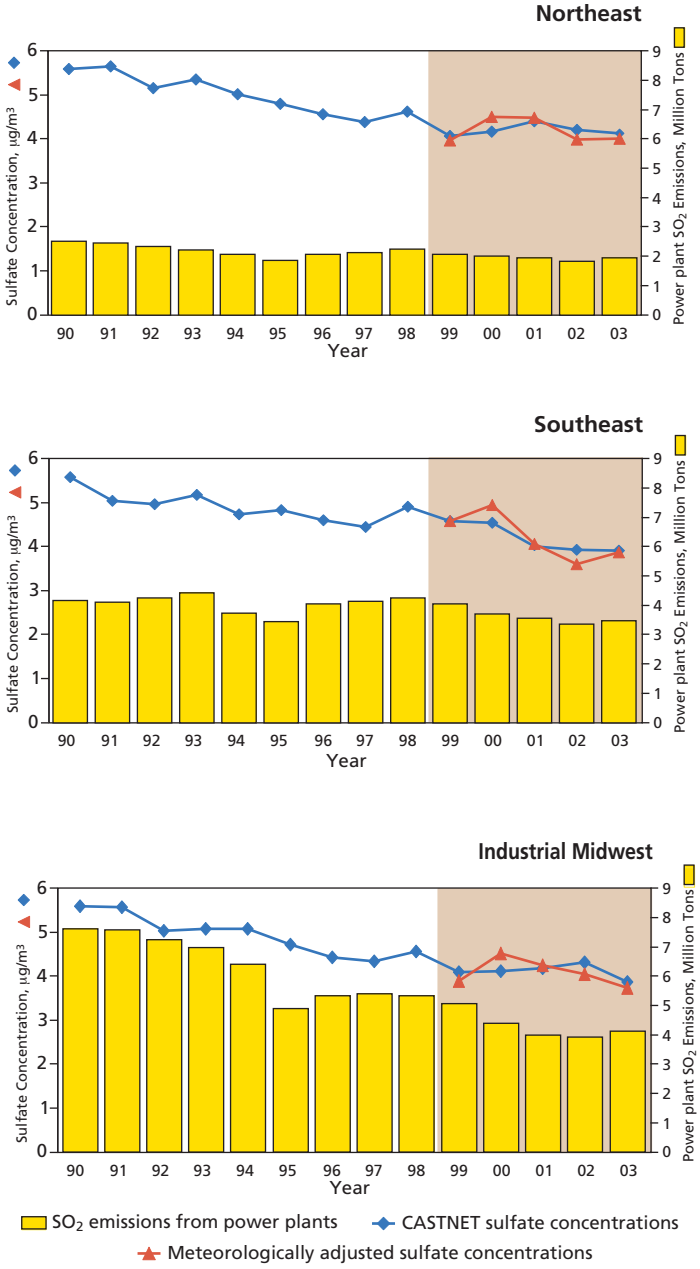
These subregional differences may be caused by several factors, the most important of which is likely to be transport. As Figure 17 shows, the ratio of sulfate concentrations to SO_2 emissions is higher in the Northeast than in the other regions. This suggests that transport of emissions

Figure 16. Trends in $PM_{2.5}$ and its chemical constituents, 1999–2003.



Note: Sulfate and nitrate concentrations from the CASTNET monitoring network were adjusted to represent mass in $PM_{2.5}$ and include ammonium as well as water. Trends for crustal were not available so constant values based on 2002–2003 data for each region were used. See www.epa.gov/airtrends/pm.html for further details.

Figure 17. Meteorologically adjusted sulfate concentrations, 1999–2003.



from other regions contributes to sulfate formation in the Northeast. Other factors that may contribute to the subregional differences in these trends include variations in meteorological conditions that are important to sulfate formation and transport, contributions to the Northeast from Canada, and subregional differences in the contributions of sources other than power plants.

Effect of Meteorology

Weather plays a role both in the atmospheric formation of $PM_{2.5}$ and in the quantity of emissions that contribute to this pollution. For this report, we examined the effect of meteorology on sulfates, which are a major component of $PM_{2.5}$, especially in the eastern half of the United States. To assess the effect of meteorology on annual average sulfate concentrations, EPA has conducted a preliminary analysis, adjusting sulfate levels based on weather conditions. (The blue line in Figure 17 represents measured sulfate concentrations; the red line represents the meteorologically adjusted sulfate concentrations.) One of the main parameters driving these preliminary adjustments is temperature. In the eastern half of the United States, 1999, 2001, and 2003 were near-normal meteorological years, so only minimal adjustments to sulfate concentrations were needed. In 2000, however, a cool summer may well have caused sulfur dioxide emissions to be lower than average, resulting in lower amounts of sulfates in the air. Adjusting for weather in 2000 raised estimated sulfate levels in all three regions to the level expected during a year with average weather conditions.

Conversely, the summer of 2002 in the eastern United States was one of the hottest in recent years. Sulfur dioxide emissions were higher that year, likely due (at least in part) to increased demand for electricity for cooling. The meteorological adjustment for 2002 reduces the amount of sulfates in all three regions to levels expected during a normal meteorological year.

In two of the three regions, the variations in power plant SO_2 emissions (illustrated by the yellow bars in Figure 17) generally correlate more closely with the meteorologically adjusted sulfates (the red line) than the unadjusted sulfates (the blue line). In the Industrial Midwest, however, adjusting for weather causes the sulfate trend to move farther away from the sulfur dioxide emission trend in 2002-2003. More refined meteorological analyses and emission inventories are necessary to fully understand these results.

The $PM_{2.5}$ Remainder

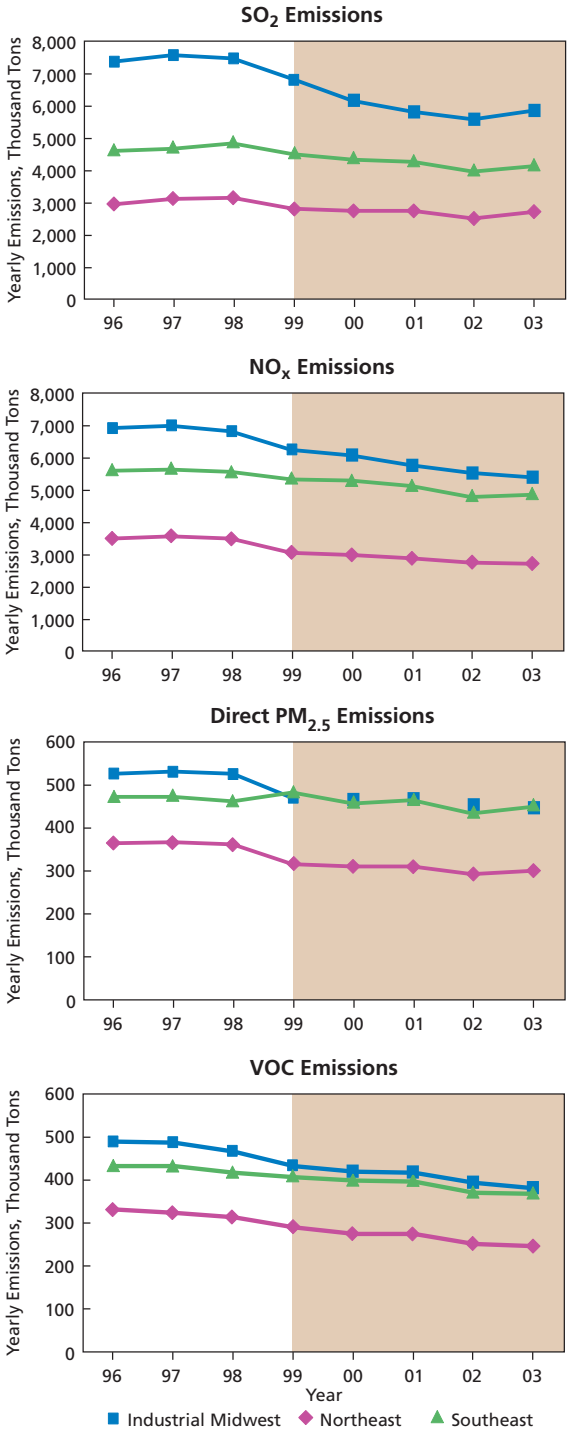
Figure 16 (page 20) also shows the estimated trend in the "$PM_{2.5}$ remainder" for each of the three regions. The remainder is estimated by subtracting all known $PM_{2.5}$ components from the total $PM_{2.5}$ mass. Some uncertainties exist in our interpretations of these data; however, the $PM_{2.5}$ remainder appears to consist mostly of carbon-containing particles. Some small contributions to the $PM_{2.5}$ remainder trend shown in Figure 16 include

- Trends in crustal material
- Local contributions for nitrates and sulfates (see the discussion on pages 8 and 9)
- Any changes in data quality or the operation of EPA's $PM_{2.5}$ Federal Reference Method monitoring network during its first few years of operation.

Despite the uncertainties, the reductions in the $PM_{2.5}$ remainder for the Industrial Midwest and Southeast appear to be due, in large part, to reductions in emissions that contribute to the formation of carbon-containing particles. The relative importance of various man-made emissions sources to these trends is uncertain and may vary by region and urban area. Important sources of carbon-containing particles in urban air include direct emissions from sources such as motor vehicles, fuel combustion, and fires and atmospheric transformation of certain organic gases, including both regional biogenic emissions and some components of man-made VOCs.

It is interesting to note that, in Figure 18, the decrease in the estimated $PM_{2.5}$ remainder corresponds either to reductions in directly emitted fine particles or reductions in man-made VOC emissions. The Northeast region, however, shows virtually no net change in $PM_{2.5}$ or in any of its estimated components. Yet both direct $PM_{2.5}$ emissions and VOC emissions decreased from 1999 to 2003. EPA is continuing to conduct research and analysis to better identify and quantify key direct emission sources in addition to the relative contribution of man-made VOC emissions to atmospheric formation of carbon-containing particles.

Figure 18. $PM_{2.5}$ emission trends.



Percent Change in Emissions from 1999 to 2003

	Industrial Midwest	Northeast	Southeast
SO_2	-15	-3	-9
NO_x	-14	-10	-9
$PM_{2.5}$	-5	-5	-7
VOC	-12	-15	-9

For more details on the $PM_{2.5}$ remainder, see ww.epa.gov/airtrends/pm.html. For information on EPA's monitoring networks, see www.epa.gov/ttn/amtic/.

Control Programs

Many programs have been put in place to reduce levels of particulate matter. Table 1 lists the major emission control programs that have contributed to reductions in PM since 1995 and will continue to reduce PM in the future. These programs control direct PM emissions and/or the emissions that contribute to PM formation, such as SO_2, NO_x, and VOCs. The control programs consist of a series of regulations that reduce emissions from many stationary and mobile source sectors. For example, beginning in 2008, states will be required to attain the National Ambient Air Quality Standards for fine particles. EPA's proposed Clean Air Interstate Rule (proposed in December 2003) will help states meet those requirements by reducing SO_2 and NO_x emissions in the eastern United States thus reducing particle pollution transported across state boundaries. Another regulation, the Best Available Retrofit Technology (BART) program, will require the older, existing power plants to control PM emissions with retrofit pollution control equipment. Also, national mobile source rules are in place to strengthen the emission requirements for virtually all types of mobile sources. Many localities also have pollution reduction requirements for diesel engine retrofits as well as sulfur limits in diesel and gasoline engines.

Table 1. A Selection of Emission Control Programs Contributing to PM Emission Reductions, 1995–2015

Program	Sector	Direct PM[a] Reductions	PM Precursors SO_2 Reductions	PM Precursors NO_x Reductions	PM Precursors VOC Reductions	Implementation Date
Clean Air Nonroad Diesel Rule	Mobile sources	X	X	X		2004-2015
Clean Air Interstate Rule (proposed December 2003)	Electric Utilities	X	X	X		2010-2015
Acid Rain Program	Electric Utilities		X	X		1995-2010
NO_x SIP Call	Electric Utilities		X	X		2004
Regional Haze Rule/ Best Available Retrofit Technology	Electric Utilities[b]	X	X	X		2013-2015
$PM_{2.5}$ Implementation[c]	Stationary/Area/ Mobile sources	X	X	X	X	2008-2015
PM_{10} SIPs (e.g., San Joaquin Valley)	Stationary/Area/ Mobile sources	X	X	X	X	Ongoing
Maximum Achievable Control Technology (MACT) Standards[d]	Stationary/Area	X			X	1996-2003
Various Mobile Source Programs[e]		X	X	X	X	Ongoing

[a] Includes elemental and organic carbon, metals, and other direct emissions of PM.

[b] Also applies to industrial boiler and the other source categories also covered under Prevention of Significant Deterioration (PSD).

[c] Includes Reasonably Available Control Technology (RACT) and Reasonably Available Control Measures (RACM).

[d] Includes a variety of source categories such as Boilers and Process heaters, Pulp and Paper, Petroleum Refineries, various minerals and ores, and others. While these standards are for hazardous air pollutants (HAPs) such as metals, measures to reduce HAPs in many cases also reduce PM emissions.

[e] Includes such programs as onroad diesel and gasoline engines, nonroad gasoline engines, Low Sulfur Diesel and Gasoline Fuel Limits for onroad and offroad engines, Motorcycles, Land-based recreational vehicles, and Marine diesel engines.

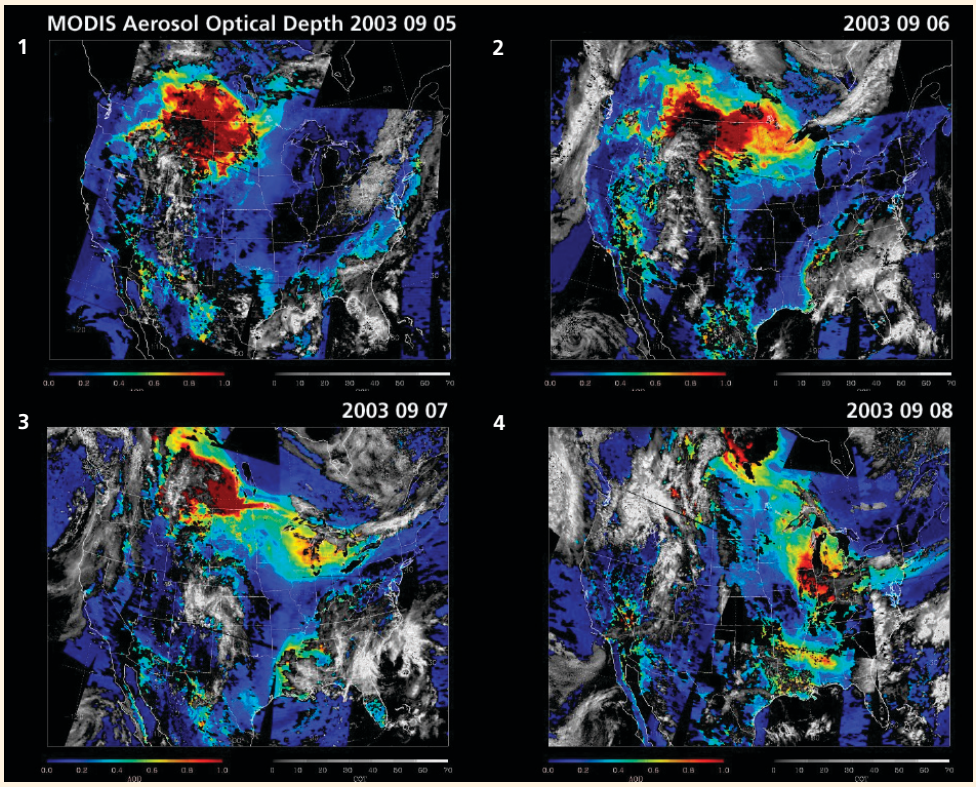
Using Satellites to Track Particulate Matter

The most direct way to obtain surface concentration data for particles is from the routine measurements made at surface monitoring stations across the United States. This approach has some limitations, however, because large regions of the country do not have surface monitors, and coastal regions are often influenced by polluted air approaching over water. In addition, pollution may be transported aloft, undetected by surface monitors, and then descend to influence air at the ground. New work being done through a collaborative partnership between EPA, the National Aeronautics and Space Administration (NASA), and the National Oceanic and Atmospheric Administration (NOAA) uses satellite observations to augment the surface network monitoring data with satellite data.

The NASA MODIS (Moderate Resolution Imaging Spectroradiometer) instruments on board the EOS (Earth Observing System) satellites EOS-Terra and EOS-Aqua provide twice-daily measurements of aerosol optical depth (AOD), a measure of how much light airborne particles prevent from passing through a column of atmosphere. Scientists use these measurements to estimate the relative amount of aerosols suspended in the atmosphere.

IDEA (Infusing satellite Data into Environmental Applications) is a partnership between EPA, NASA, and NOAA. These agencies are working to improve air quality assessment, management, and prediction by infusing satellite measurements from NASA into EPA and NOAA analyses for public benefit.

Initial research shows that MODIS-derived data are suitable for tracking air quality events on a regional scale and may be a good surrogate for estimating the intensity of surface $PM_{2.5}$ concentrations. More research and data are needed to help show how aerosol loads are distributed vertically in the atmosphere so that MODIS-derived AOD can be put into the proper context. For more information on the MODIS-derived AOD and $PM_{2.5}$ pollution events, go to the Cooperative Institute for Meteorological Satellite Studies/Space Science and Engineering Center at the University of Wisconsin-Madison website: http://idea.ssec.wisc.edu.



Composites of MODIS-derived AOD (color) and cloud optical thickness (black-white) from September 5 to 8, 2003. The majority of the high AOD seen in the images (yellow-red) was the result of several very large wildfires in western North America from British Columbia to Oregon. MODIS-derived AOD tracked the movement of the plume, which eventually affected surface $PM_{2.5}$ concentrations throughout the midwestern United States.

The Future

National and regional regulations will make major reductions in ambient $PM_{2.5}$ levels over the next 10 to 20 years. In particular, the proposed Clean Air Interstate Rule (CAIR) and the existing NO_x SIP Call, will reduce SO_2 and NO_x emissions from certain electric generating units and industrial boilers across the eastern half of the United States. Regulations to implement the ambient air quality standards for $PM_{2.5}$ will require direct $PM_{2.5}$ and $PM_{2.5}$ precursor controls in nonattainment areas. New national mobile source regulations affecting heavy-duty diesel engines, highway vehicles, and other mobile sources will reduce emissions of NO_x, direct $PM_{2.5}$, SO_2, and VOCs.

EPA estimates that current and proposed regulations for stationary and mobile sources will cut SO_2 emissions by 6 million tons annually in 2015 from 2001 levels. NO_x emissions will be cut 9 million tons annually in 2015 from 2001 levels. VOC emissions will drop by 3 million tons, and direct $PM_{2.5}$ emissions will be cut by 200,000 tons in 2015, compared to 2001 levels. Figure 19 shows anticipated emission reductions. Most of the SO_2 reductions are associated with electric generating sources, while NO_x and VOC reductions for mobile sources are associated with continuing improvements in onroad and nonroad vehicles.

Models predicting the effect of these emission reductions on air quality show that all areas in the eastern United States will have lower $PM_{2.5}$ concentrations in 2015 relative to present-day conditions. In most cases, the predicted improvement in $PM_{2.5}$ ranges from 10% to 20%. EPA estimates that the proposed CAIR combined with existing regulations will bring the majority of the counties in the East into attainment for the $PM_{2.5}$ standards. As Figure 20 shows, 99 eastern counties are estimated to have exceeded the annual $PM_{2.5}$ standard in the 1999–2002 period, but only 13 of those counties are projected to exceed the $PM_{2.5}$ standard by 2015. More information on CAIR can be found at: www.epa.gov/interstateairquality/.

Figure 19. Projected emission reductions by 2015.

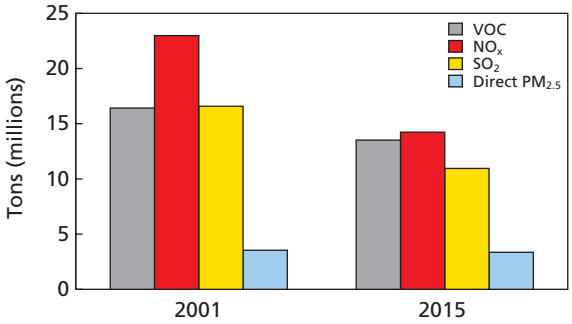
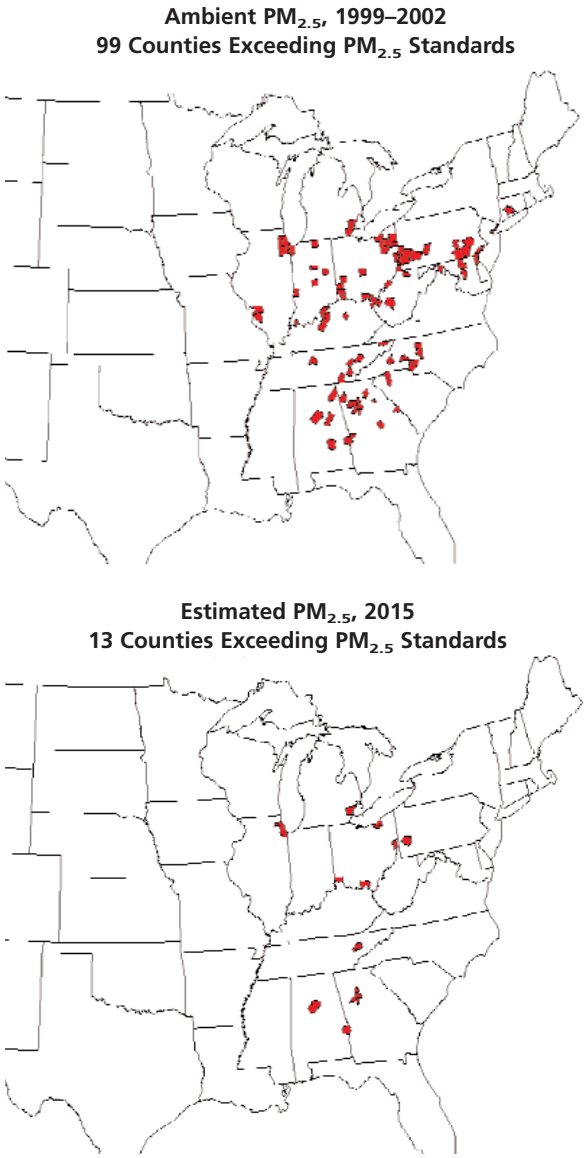


Figure 20. Estimated reduction in number of counties exceeding $PM_{2.5}$ standards from 2001 (99) to 2015 (13), based on current programs plus the Clean Air Interstate Rule as proposed in December 2003.



Upcoming $PM_{2.5}$ Designations

EPA designates areas as attaining or not attaining the National Ambient Air Quality Standards for fine particulate matter ($PM_{2.5}$). EPA designates an area as "nonattainment" if it has violated the annual or 24-hour national $PM_{2.5}$ standard (assessed over a 3-year period) or if it has contributed to a violation of one of the standards. Once designated, nonattainment areas must take actions to improve their $PM_{2.5}$ air quality on a certain timeline. Designations are a crucial first step in the efforts of states, tribes, and local governments to reduce harmful levels of fine particles. For more details on $PM_{2.5}$ designations, visit www.epa.gov/pmdesignations.

Note: Designations are based on 3 years of data, and the boundaries of defined nonattainment areas may differ from the county boundaries used in this report.

$PM_{2.5}$ and Other Pollutants

Areas that experience $PM_{2.5}$ concentrations that exceed the National Ambient Air Quality Standards can also have air quality problems associated with other pollutants. This association in the presence of different pollutants is not unexpected. A 2004 report by the National Academies of Sciences *(Air Quality Management in the United States)* indicates that air pollutants "often share similar precursors and similar chemical reactions once in the atmosphere." For example, nitrogen oxides, which contribute to $PM_{2.5}$ formation, are also a key ingredient in ground-level ozone.

Pollutants may also be emitted from the same types of sources. Industries that emit air toxics may also emit chemicals that contribute to ozone or PM formation. Data indicate that millions of people likely live in areas where particle pollution levels are elevated along with ozone and/or air toxics. EPA will continue to analyze this information as we work to protect public health across the country.

Acronyms

AOD	aerosol optical depth
AQI	Air Quality Index
BART	best available retrofit technology
CAA	Clean Air Act
CAIR	Clean Air Interstate Rule
CASTNET	Clean Air Status and Trends Network
EOS	Earth Observing System
EPA	U.S. Environmental Protection Agency
FRM	Federal Reference Method
HAP	hazardous air pollutants
IDEA	Infusing satellite Data into Environmental Applications
IMPROVE	Interagency Monitoring of Protected Visual Environments
IPN	Inhalable Particulate Network
km	kilometer
MACT	maximum achievable control technology
MODIS	moderate resolution imaging spectroradiometer
NAAQS	National Ambient Air Quality Standards
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
NO_x	oxides of nitrogen
PM	particulate matter
PM_{10}	particulate matter 10 μm or less in size
$PM_{2.5}$	particulate matter (fine) 2.5 μm or less in size
$PM_{10-2.5}$	particulate matter (coarse) between 10 and 2.5 μm in size
PSD	prevention of significant deterioation
RACM	reasonably available control measures
RACT	reasonably available control technology
SIP	State Implementation Plan
SO_2	sulfur dioxide
TCM	total carbonaceous mass
TSP	total suspended particulate
$\mu g/m^3$	micrograms per cubic meter
μm	micrometers
VOC	volatile organic compound

For Further Information

Web Sites

Additional technical information: www. epa.gov/airtrends/pm.html

Air Quality Index (AQI): www.epa.gov/airnow

Clean Air Interstate Rule: www.epa.gov/interstateairquality/

CASTNET: www.epa.gov/castnet/

Emissions: www.epa.gov/ttn/chief/

EPA 1996 PM Criteria Document: www.epa.gov/ttn/naaqs

EPA Monitoring Networks: www.epa.gov/ttn/amtic/

Health and Ecological Effects: www.epa.gov/air/urbanair/pm/index.html

IMPROVE: vista.cira.colostate.edu/improve

National Academies: www4.nationalacademies.org/nas/nashome.nsf

Office of Air and Radiation: www.epa.gov/oar

Office of Air Quality Planning and Standards: www.epa.gov/oar/oaqps

Office of Atmospheric Programs: www.epa.gov/air/oap.html

Office of Transportation and Air Quality: www.epa.gov/otaq

Online Air Quality Data: www.epa.gov/air/data/index.html

PM Supersites: www.epa.gov/ttn/amtic/supersites.html and www.epa.gov/ttn/amtic/laprog.html

$PM_{2.5}$ Designations: www.epa.gov/pmdesignations

Report on Acid Rain: www.epa.gov/acidrainreport/

Satellite information: idea.ssec.wisc.edu

Source apportionment: www.epa.gov/oar/oaqps/pm25/docs.html

Visibility: www.epa.gov/airtrends/vis.html

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