PARTICLE POLLUTION

Particle pollution refers to two classes of particles—fine and coarse. These classes are based in part on long-established information about differences in sources, properties, and atmospheric behavior. EPA has set national standards to protect against the health and welfare effects associated with exposures to fine and coarse particles. Fine particles are generally considered to be less than or equal to 2.5 micrometers (µm) in aerodynamic diameter, or $PM_{2.5}$. Coarse particles are those between 2.5 and 10 µm in diameter. PM_{10} (particles generally less than or equal to 10 µm in diameter) is the indicator used for the coarse particle standard.

TRENDS IN $PM_{2.5}$ CONCENTRATIONS

There are two national air quality standards for $PM_{2.5}$: an annual standard (15 µg/m^3) and a 24-hour standard (35 µg/m^3). Nationally, annual and 24-hour $PM_{2.5}$ concentrations declined by 17 and 19 percent, respectively, between 2001 and 2008, as shown in Figure 13.

Annual

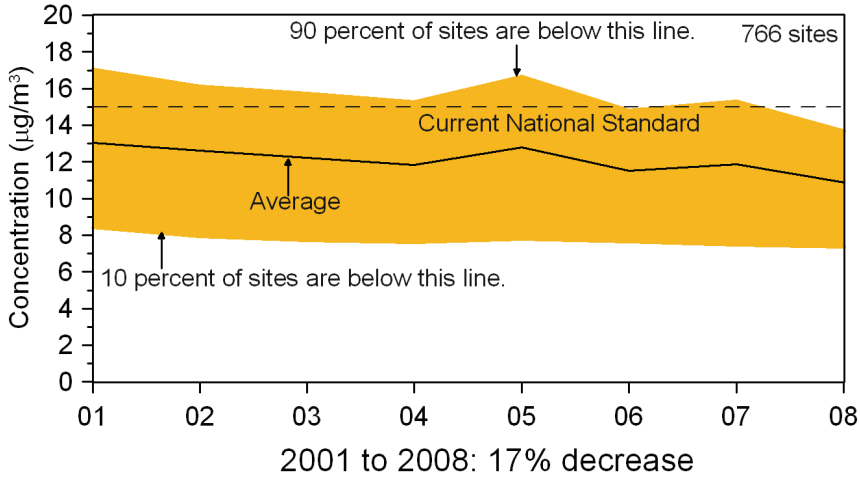
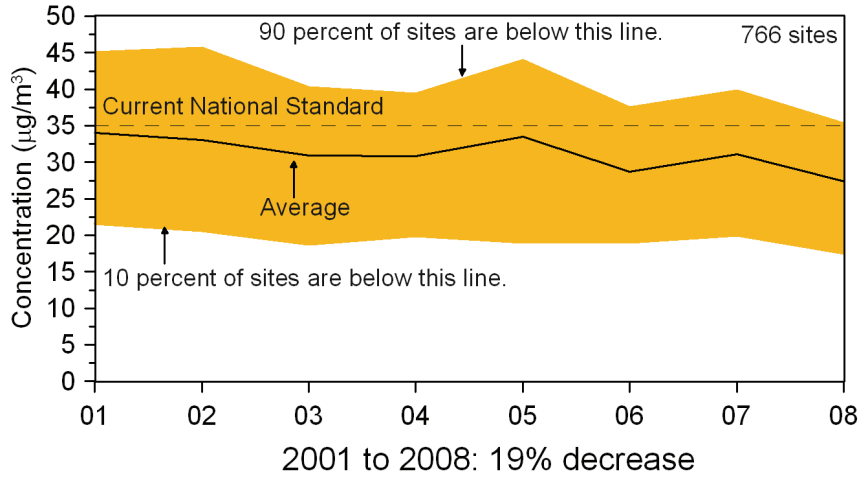


Figure 13. National $PM_{2.5}$ air quality trends, 2001-2008 (annual average concentration and 98th percentile of 24-hour concentration in µg/m^3).

24-hour



For each monitoring location, the maps in Figure 14 show whether annual and 24-hour $PM_{2.5}$ concentrations increased, decreased, or stayed about the same since the beginning of the decade. When comparing two three-year periods, 2001-2003 and 2006-2008, almost all of the sites show a decline or little change in $PM_{2.5}$ concentrations. Sixteen sites in California, Illinois, Indiana, Michigan, Ohio, Utah, and West Virginia showed the greatest decreases in annual $PM_{2.5}$ concentrations. Four of the 565 sites showed an increase in annual $PM_{2.5}$ concentrations greater than 1 μg/m³. These sites were located in Montana, Arizona, and Wisconsin. Of the four sites that showed an increase in annual $PM_{2.5}$ concentrations, none were above the level of the annual $PM_{2.5}$ standard for the most recent three-year period of data (2006-2008). Five sites in California, Montana, Oregon, Pennsylvania, and Utah showed decreases greater than 15 μg/m³ in 24-hour $PM_{2.5}$ concentrations. Nineteen sites showed an increase in 24-hour $PM_{2.5}$ concentrations greater than 3 μg/m³. Of the 19 sites that showed an increase for the most recent three-year period of data, seven measured concentrations above the level of the 24-hour $PM_{2.5}$ standard. These sites are located in or near the following metropolitan areas: Virginia Beach, VA; Butte-Silver Bow, MT; Nogales, AZ; Seattle, WA; Albany, GA; Redding, CA; and Chico, CA (note: Virginia Beach was above the standard due to the effects of a wildfire in North Carolina). Due to the influence of local sources, it is possible for sites in the same general area to show opposite trends, as in the case of the Denver area for the 24-hour standard.

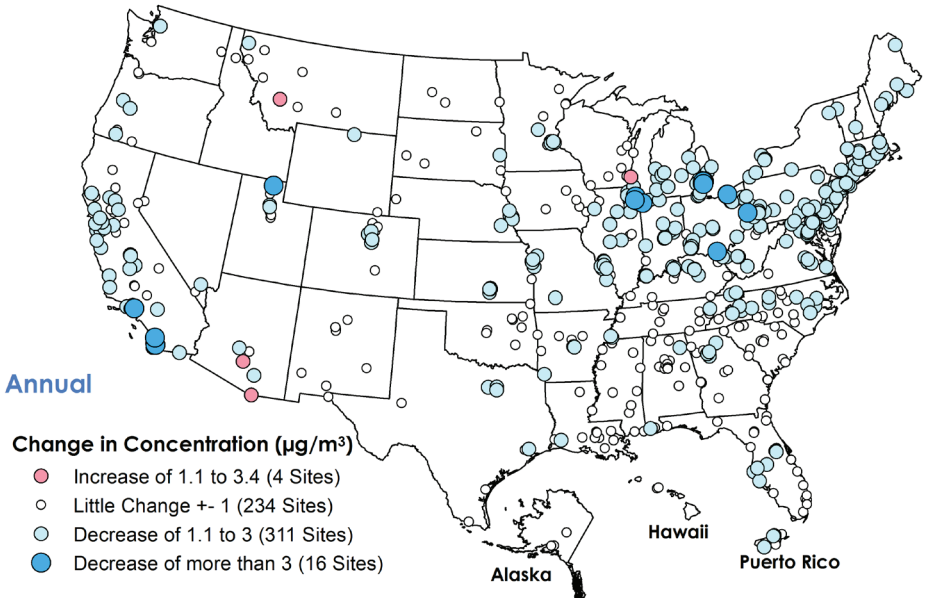
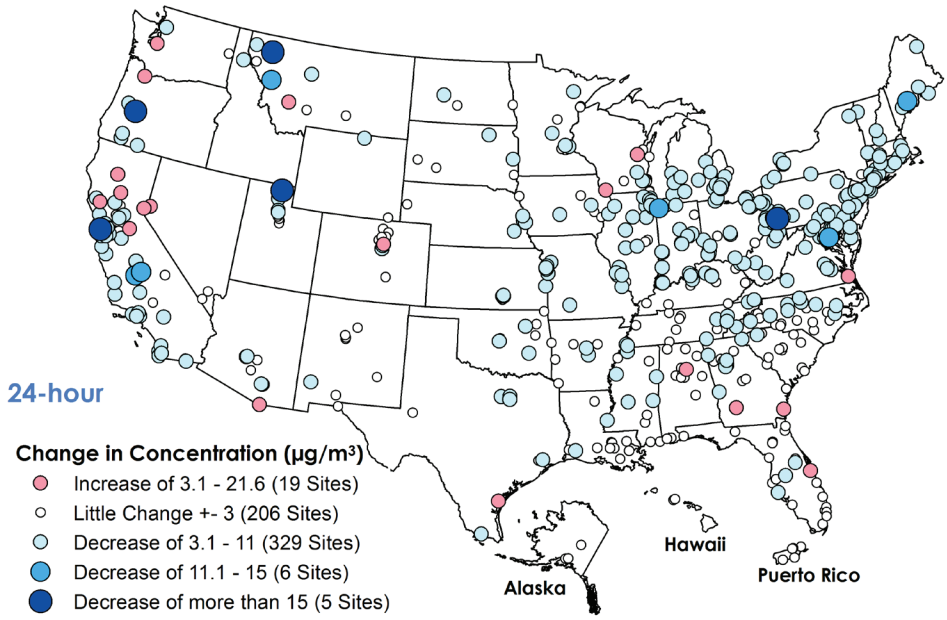
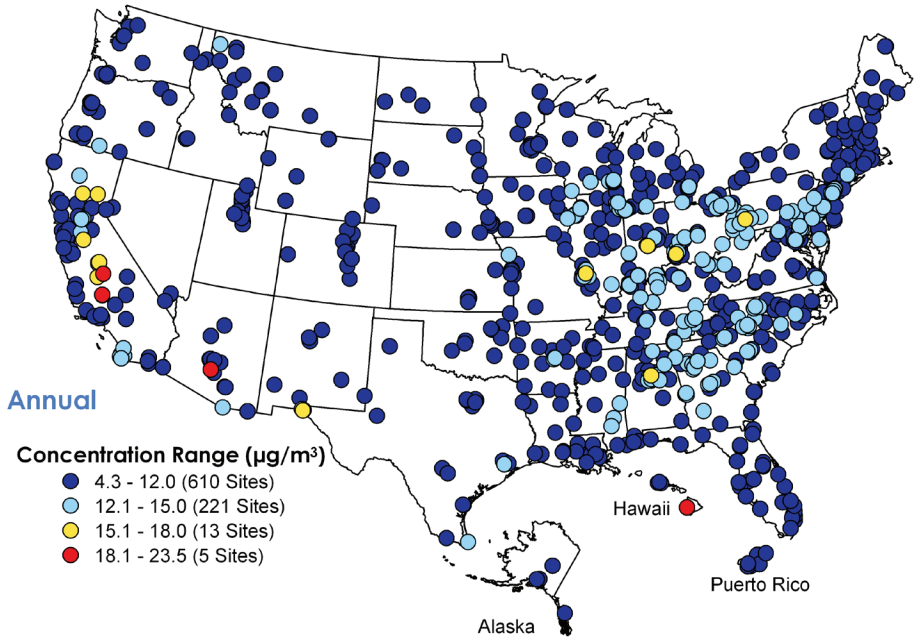


Figure 14. Change in $PM_{2.5}$ concentrations in μg/m³, 2001-2003 vs. 2006-2008 (3-year average of annual average and 98th percentile of 24-hour concentrations).



In 2008, the highest annual average $PM_{2.5}$ concentrations were in California, Arizona, and Hawaii, as shown in Figure 15. The highest 24-hour $PM_{2.5}$ concentrations were in California and Virginia. Wildfires played a role in both state's $PM_{2.5}$ levels.

Some sites showed high 24-hour $PM_{2.5}$ concentrations but low annual $PM_{2.5}$ concentrations, and vice versa. Sites that show high 24-hour concentrations but low or moderate annual concentrations exhibit substantial variability from season to season. For example, sites in the Northwest generally show low concentrations in warm months but are prone to much higher concentrations in the winter. Factors that contribute to the higher levels in the winter are extensive woodstove use coupled with prevalent cold temperature inversions that trap pollution near the ground. Nationally, more sites exceeded the level of the 24-hour $PM_{2.5}$ standard than the annual $PM_{2.5}$ standard, as indicated by yellow and red dots on the maps below. Of the 18 sites that exceeded the annual standard and 55 sites that exceeded the 24-hour standard, 14 sites exceeded both.



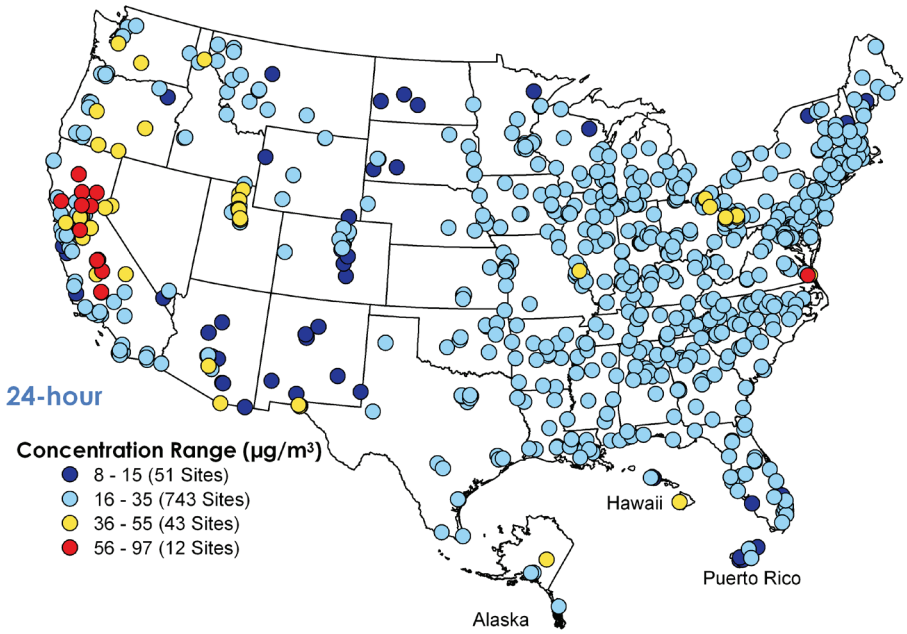


Figure 15. Annual average and 24-hour (98th percentile of 24-hour concentrations) $PM_{2.5}$ concentrations in µg/m³, 2008.

WEATHER INFLUENCES $PM_{2.5}$

In addition to emissions, weather plays an important role in the formation of $PM_{2.5}$. Figure 16 shows trends in $PM_{2.5}$ from 2001 through 2008, before and after adjusting for weather. $PM_{2.5}$ levels are monitored throughout the year, and separate graphs are shown for the warm and cool months. These separate graphs are shown due to the seasonal variability of the components that make up $PM_{2.5}$, as described in the next section. After adjusting for weather, $PM_{2.5}$ concentrations have decreased by approximately 17 percent in both the warm and cool seasons between 2001 and 2008.

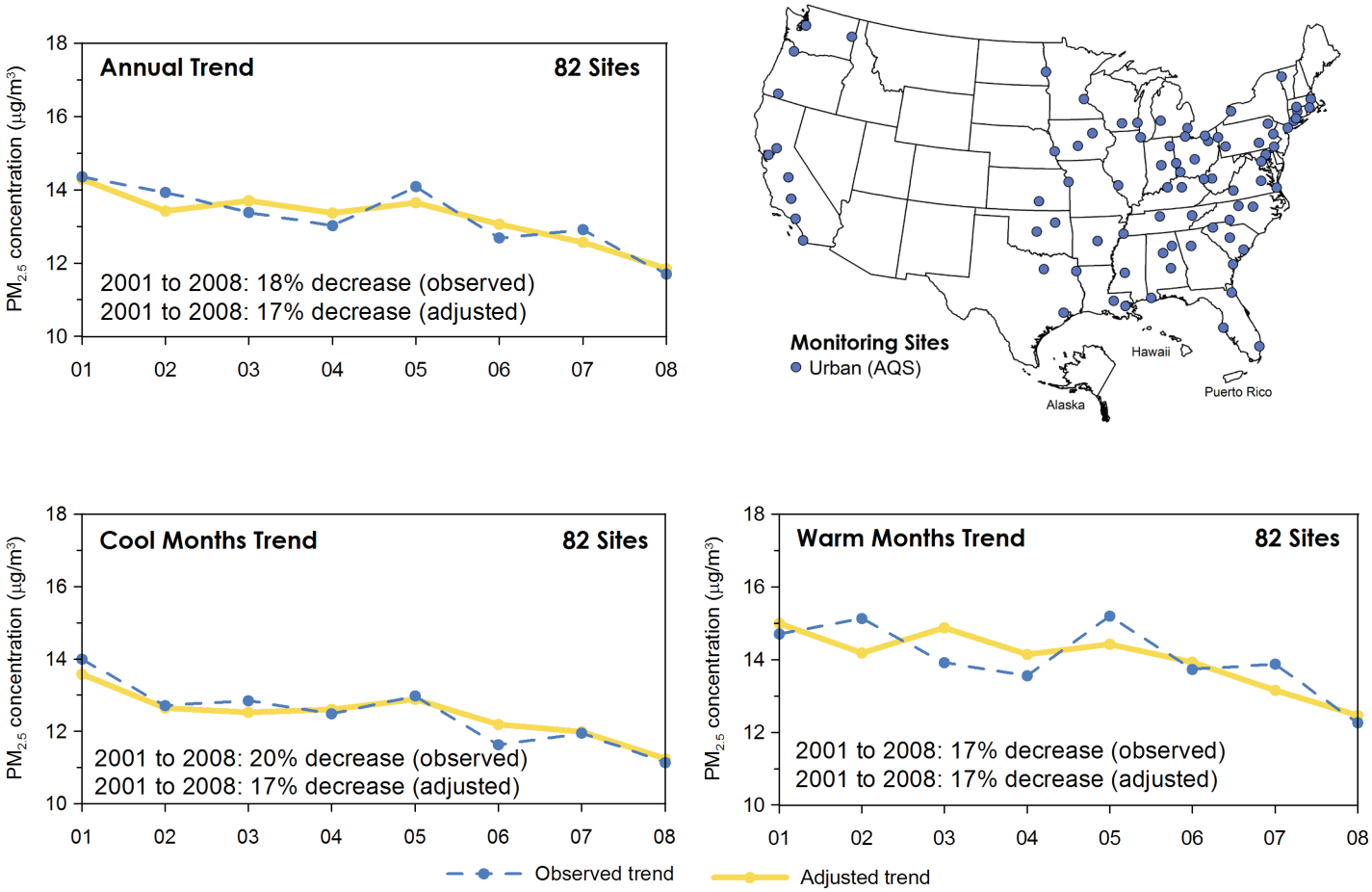


Figure 16. Trends in annual, cool-month (October–April) and warm-month (May–September) average $PM_{2.5}$ concentrations in µg/m³ (before and after adjusting for weather), and the location of urban monitoring sites used in the average.

$PM_{2.5}$ COMPOSITION

The chemical composition of $PM_{2.5}$ is characterized in terms of five major components that generally comprise the mass of $PM_{2.5}$: sulfate, nitrate, organic carbon (OC), elemental carbon (also called black carbon, BC), and crustal material.

Figure 17 shows regional differences in the composition of $PM_{2.5}$ nationwide. On average, sulfate is the largest component by mass in the eastern U.S. Generally, the largest sources of sulfate in the eastern U.S. are electric utilities and industrial boilers. OC is the next largest component in the East. The primary sources of OC are highway vehicles, non-road mobile, waste burning, wildfires, and vegetation. Next is nitrate; the largest sources of nitrate originate from highway vehicles, non-road mobile, electric utilities, and industrial boilers. Elemental carbon is a small component of the overall $PM_{2.5}$ composition (typically 5-10 percent in U.S. cities). Elemental carbon is directly emitted from incomplete combustion processes such as fossil fuel and biomass burning. Crustal material is typically a small fraction of $PM_{2.5}$ mass, although two cities show higher than average values (Birmingham, AL and Detroit, MI). Crustal material comes from suspended soil and metallurgical operations.

In the West, OC is generally the largest estimated component of $PM_{2.5}$ by mass. Fireplaces and woodstoves are important contributors to OC in the West. On an annual average basis, nitrate, sulfate, or crustal material can also represent substantial components of $PM_{2.5}$ for the western U.S. The composition varies from city to city and may vary by geography. For example, in southern California and port cities in the Northwest, emissions from marine vessels also likely contribute a significant portion of $PM_{2.5}$ sulfate.

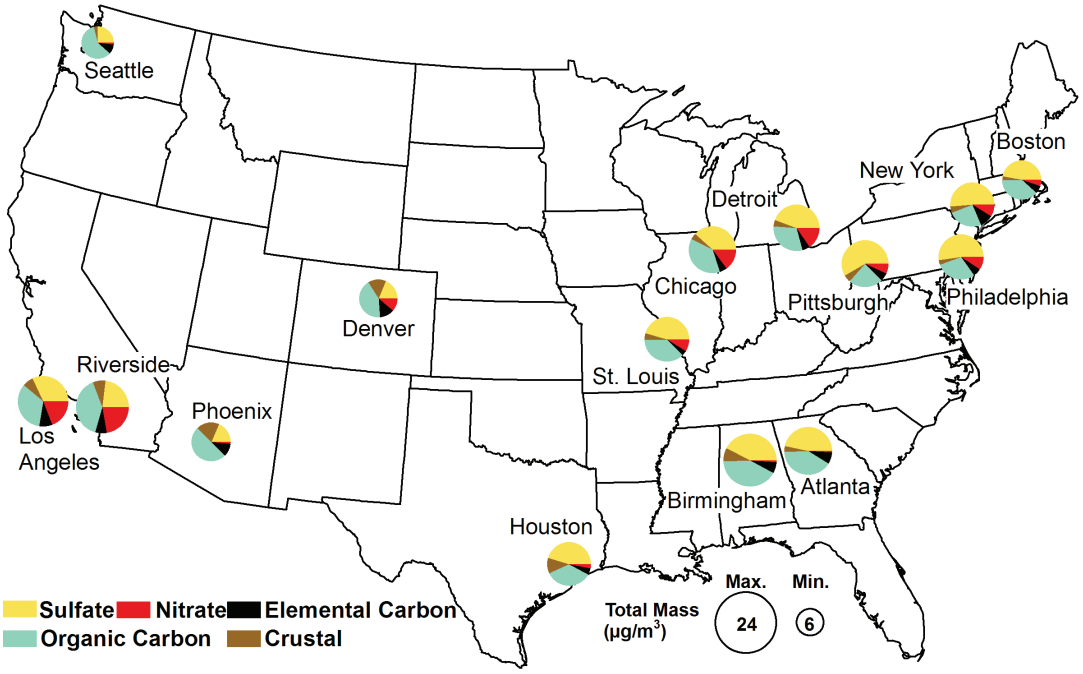


Figure 17. Four-season average of $PM_{2.5}$ composition for 15 U.S. cities.

The maps in Figure 18 reveal somewhat different patterns between seasons. While sulfate is a major component in the eastern U.S. in the spring, fall, and (particularly) summer, the sulfate contribution during winter is offset by larger amounts of nitrate in the Midwest and OC in the Southeast. Nitrate is lower in the spring and fall, particularly in the southeastern cities and is essentially zero during the summer in the eastern U.S. Crustal material is a substantial summertime component in Houston, TX, and is generally low elsewhere in the East during all seasons. In the West, wintertime OC and elemental carbon are generally the largest components of $PM_{2.5}$, followed by nitrate. Nitrate can represent a larger percentage in the spring and fall. Crustal material represents a relatively high percentage year-round in arid Phoenix, AZ and Denver, CO.

It is important to note that although studies have begun to focus on how different constituents of particulate matter (PM) may affect health outcomes, at this point there is no conclusive evidence that any component is "harmless"—studies continue to link numerous components to health effects and the evidence does not support excluding any PM component or source from regulation. Thus, though different ambient mixtures of PM may be observed in different geographical areas and during different seasons, EPA continues to regulate $PM_{2.5}$ and PM_{10} by mass and most control strategies are designed to reduce mass rather than individual components from particular sources.

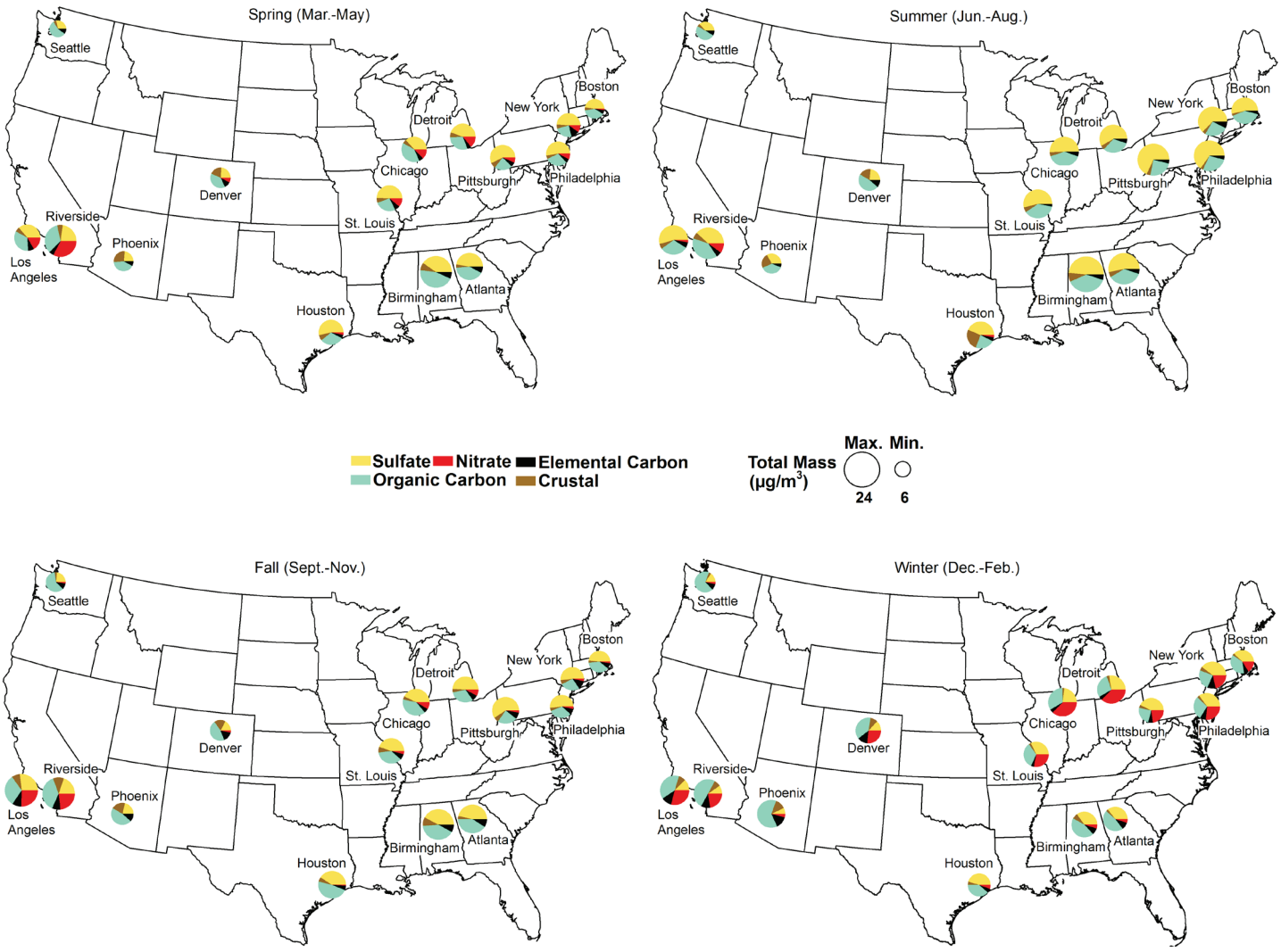


Figure 18. $PM_{2.5}$ composition by season for 15 U.S. cities.

PARTICLES' EFFECTS ON CLIMATE

Particles have both direct and indirect effects on climate. The direct effects come from particles' ability to absorb and scatter light. The different types of particles have different impacts on climate: some warm (positive forcing); others cool (negative forcing). The net effect for all particles in the atmosphere is cooling, as scattering generally dominates (National Academy of Sciences, 2005), though effects can vary dramatically by region.

Particles also have important indirect effects on climate. For example, different particles can increase or decrease the reflectivity of clouds, leading to cooling or warming effects. Particles also influence cloud lifetime and precipitation, and may affect droughts, rainfall, and stream flows. However, there remains relatively high scientific uncertainty about these indirect effects (National Academy of Sciences, 2005).

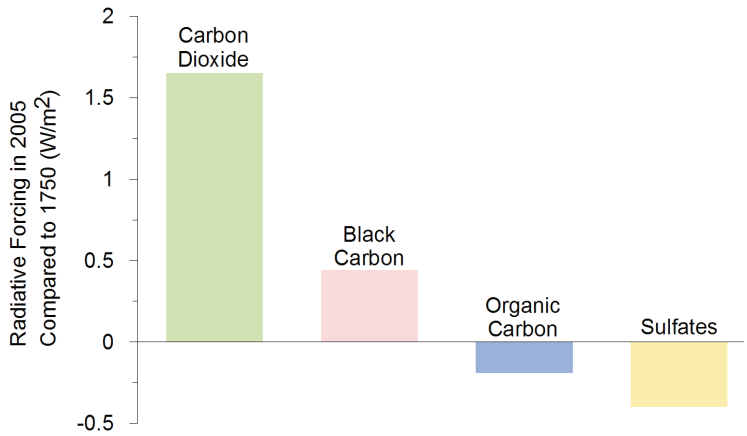


Figure 19. Net radiative forcing (Watts per m²) associated with the presence of different pollutants in the atmosphere, based on concentrations in 2005 compared to pre-industrial levels. (Source: Black carbon data [IPCC, 2007]. Carbon dioxide, organic carbon, sulfates data [National Academy of Sciences, 2005].)

As shown in Figure 19, the direct effects of particles on climate are significant even when compared to carbon dioxide (CO_2), the most important greenhouse gas. However, the direction of the climate impact from particles (warming vs. cooling) varies by particle type and location of emission, which makes designing control strategies more challenging. Sources emitting BC also emit OC and may emit NO_x and SO_2, all of which form particles that tend to have a cooling effect. Thus, while the health benefits of reducing all types of emissions

RETROFITTING DIESEL ENGINES

From the farm to the interstate highway to the neighborhood grocery store, diesel engines are found in every corner of society. Despite EPA's stringent diesel engine and fuel standards, which, for new engines, are being phased in over the next decade, 20 million engines already in use continue to emit relatively large amounts of oxides of nitrogen (NO_x) and fine particulate matter ($PM_{2.5}$). Both of these pollutants contribute to serious health conditions, such as asthma, and worsen heart and lung disease. In addition, diesel engines emit black carbon and carbon dioxide, which contribute to global climate change.

Fortunately, a variety of cost-effective technologies can dramatically reduce harmful emissions, save fuel, and help our nation meet its clean air and sustainability goals. In 2000, to address the concerns of both new and existing diesel engines, EPA created the National Clean Diesel Campaign (NCDC), a partnership program that incorporates traditional regulatory approaches and innovative non-regulatory approaches to achieve results.

In 2008, for the first time, Congress appropriated funding under the Energy Policy Act of 2005 to reduce emissions from diesel engines in the nation's existing fleet. In the first year of the program, the EPA's NCDC distributed $49.2 million to initiate diesel emission reduction projects and programs across the country. In addition, the American Recovery and Reinvestment Act of 2009 provided $300 million in new funding for national and state programs to support the implementation of verified and certified diesel emissions reduction technologies.

As a result of this funding and NCDC projects across the country, hundreds of thousands of tons of pollutants and air toxics will be reduced over the lifetime of the program.

contributing to ambient PM are relatively clear, the net climate impact of PM emissions reduction strategies will depend on the relative amounts of each of these components reduced from controlled sources.

TRENDS IN PM_{10} CONCENTRATIONS

Nationally, 24-hour PM_{10} concentrations declined by 19 percent between 2001 and 2008, as shown in Figure 20.

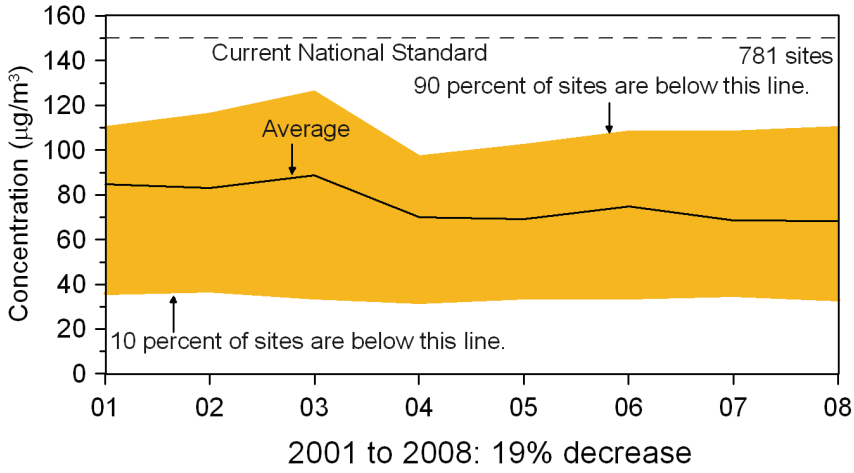


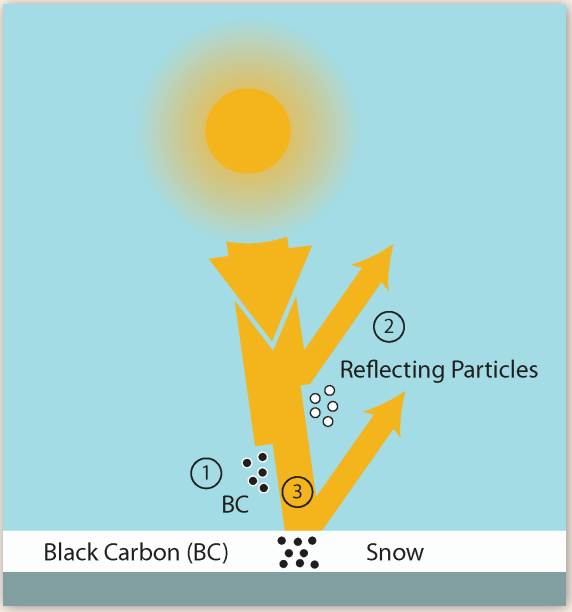
Figure 20. National PM_{10} air quality trend, 2001-2008 (second maximum 24-hour concentration in µg/m³).

UNDERSTANDING LINKAGES BETWEEN BLACK CARBON AND CLIMATE

Black carbon (BC) is emitted directly as a result of incomplete combustion of fuels, generally from man-made sources. Many BC particles are too small to be visible. One-half to two-thirds of BC emissions in the U.S. come from the burning of fossil fuels, while the remainder comes from biomass burning. Unless specifically controlled, diesel engines are major producers of BC.

BC emissions are a component of fine particle pollution, which causes adverse health effects. BC emissions also lead to climate warming by absorbing incoming and reflected sunlight in the atmosphere (direct effects) and by darkening clouds, snow, and ice, thereby reducing the reflection of light back into space (indirect effects). Other effects may include changes in precipitation and cloud patterns. The total climate impact of BC currently in the atmosphere has been estimated to be anywhere from 10 percent to more than 60 percent as large as the climate impact from carbon dioxide (CO_2). These effects may be concentrated in regions such as the Arctic and the Himalayas, where glaciers provide critical fresh water reservoirs for nearly 1.3 billion people.

Actions taken to reduce emissions of BC could produce almost immediate benefits for climate: while CO_2 remains in the atmosphere for decades to centuries, freshly emitted BC is in the atmosphere for a very short time. Reducing BC today may reduce climate forcing in the near term.



(1) Sunlight absorbed by BC particles warms the air.

(2) Other types of particles scatter or reflect light and cool the atmosphere.

(3) Sunlight absorbed by BC and some other particles on snow speeds up melting and results in less sunlight reflected.

Considerable uncertainty remains regarding the levels of BC emissions from various sources, the transport of these emissions around the globe, and the net impacts of BC and co-emitted pollutants such as organic carbon on the Earth's energy balance and global climate patterns.

When comparing two 3-year periods, 2001-2003 and 2006-2008, most sites showed a decline or little change in PM_{10} , as shown in Figure 21. Twenty-seven sites located in the Southwest, South Carolina, Missouri, Wyoming, and Montana showed a decline greater than 50 µg/m^3. Ninety-one sites showed an increase of greater than 10 µg/m^3 over the trend period. Five of these sites (Houston, TX; Albany, GA; Phoenix, AZ; Butte-Silver Bow, MT; and Trinity County, CA) showed large increases of 50 µg/m^3 or more.

Figure 22 shows that in 2008, the highest PM_{10} concentrations were located in California, Arizona, and New Mexico. Within these areas some sites showed a decline greater than 50 µg/m^3. Highest concentrations are largely located in dry and/or industrial areas with a high number of coarse particle sources.

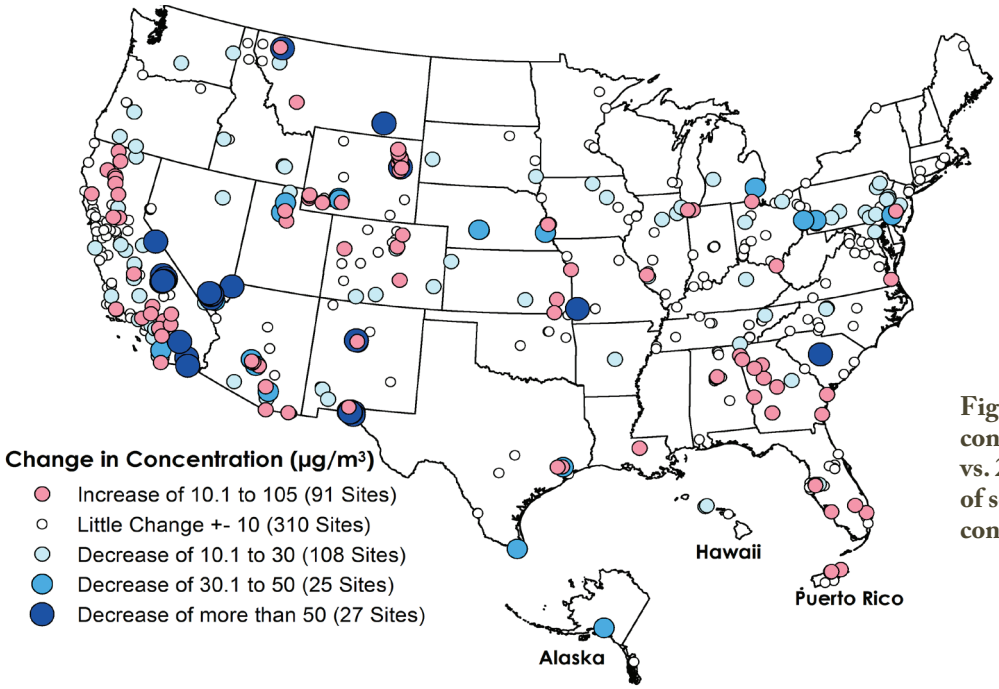


Figure 21. Change in PM_{10} concentrations in µg/m^3, 2001-2003 vs. 2006-2008 (3-year average of second maximum 24-hour concentrations).

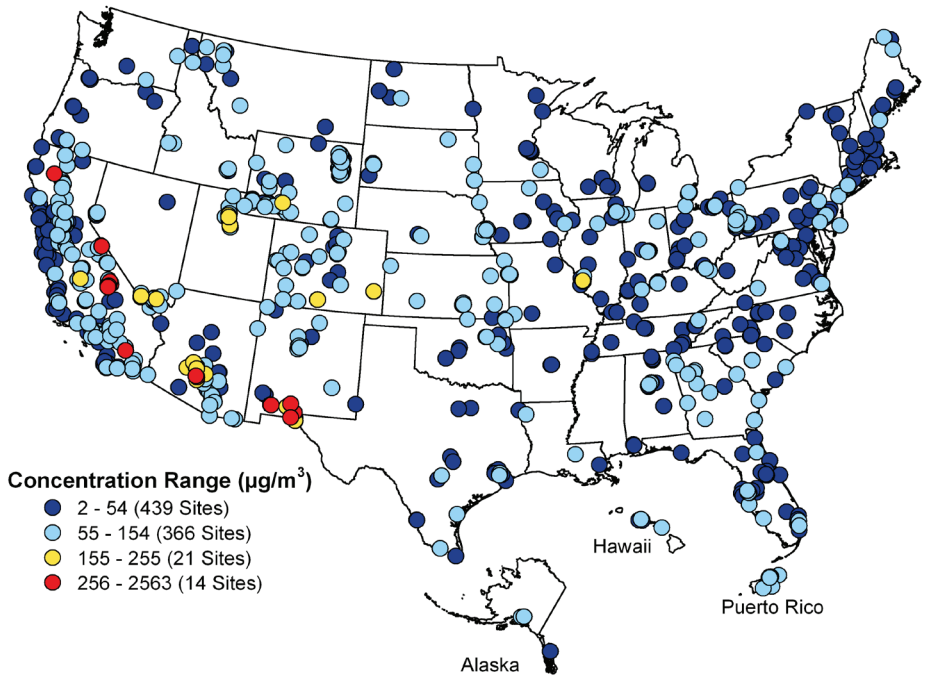


Figure 22. PM_{10} concentrations in µg/m^3, 2008 (second maximum 24-hour concentration).

Note: 2563 (µg/m^3) is from a site located in the Mono Basin nonattainment area where the major source of PM_{10} is from a dry lake bed (Mono Lake).

COOKSTOVE POLLUTION THREATENS PUBLIC HEALTH AND CLIMATE

Roughly half of the world's population—especially in Asia, Africa, and parts of Latin America—uses wood, dung, coal, or other solid fuels for cooking and heating. This leads to extraordinarily high indoor concentrations of fine particle pollution, carbon monoxide, and other toxic pollutants. The World Health Organization estimates that indoor stove use leads to an estimated 1.5 million premature deaths each year, mostly among women and young children, making it the fourth most serious health risk factor in poor developing countries after undernourishment, unsafe sex, and unsafe water, sanitation, and hygiene. Fuel wood collection also limits economic and educational opportunities for women and children and can put substantial pressure on local forests and ecosystems.

An unvented, traditional stove in Ethiopia produces high indoor smoke levels for a woman and young child. (Credit: John Mitchell, U.S. EPA)

Use of clean and efficient cookstoves and fuels would significantly improve public health and could also provide important climate benefits. It is estimated that an improved cookstove typically reduces carbon dioxide-equivalent emissions by 1 to 4 tons per year—almost as much as taking a typical U.S. car off the road. Crude, traditional cookstoves account for about a quarter of global black carbon emissions, which contribute to regional and global warming, though the net climate impact also depends on co-emissions of other (primarily reflecting) particles.

An improved plancha stove with a chimney in Guatemala significantly lowers indoor smoke levels. (Credit: Richard Grinnell, HELPS International, http://www.helpsintl.org)

In 2002, the EPA and 13 partners launched the Partnership for Clean Indoor Air (PCIA) to help households adopt clean cooking and heating practices to improve health, livelihood, and quality of life. Today, PCIA has over 310 active partner organizations working in over 115 countries around the world (http://www.PCIAonline.org). Already, key PCIA partners have reported helping 2.4 million households adopt clean cooking and heating practices, reducing harmful exposures for more than 18 million people.