

Overview of Particulate Matter (PM) Air Quality in the United States

Updated: July 20, 2022

1. Introduction

The overall purpose of this document is to maintain an up-to-date graphical summary of air quality information that supports the review of the National Ambient Air Quality Standards (NAAQS) for particulate matter (PM). In previous reviews of the PM NAAQS, this type of information has generally been included in atmospheric sections of the Integrated Science Assessment (ISA) and Policy Assessment (PA) for PM. This stand-alone document will either replace or complement the air quality emissions and monitoring data in the atmospheric sections of future PM NAAQS documents, and will be updated at regular intervals as new data becomes available.

The content of past NAAQS documents' atmospheric sections has included major sections on emissions and concentration trends utilizing maps and data from the EPA's National Emissions Inventory (NEI) and the EPA's Air Quality System (AQS) database. In past NAAQS reviews, this often involved adaptation of figures and tables prepared for other reports, or development of new figures and tables using data analysis and mapping software. Additionally, the release of updated emission inventories and ambient monitoring data may not coincide with the schedule for the development of NAAQS documents. As a result, data access and resources can limit the availability of the most recent information for inclusion in NAAQS documents.

This stand-alone document allows the content to be updated as soon as new data becomes available, rather than pulling from whatever is available at the time of publication. It also ensures that the public will have access to a consistent set of maps and figures for each NAAQS pollutant that are updated on a routine basis, rather than separated by several years following the disparate schedules of the various NAAQS reviews for each pollutant. Moreover, a stand-alone document can be expanded to include new air quality analyses as they are completed, rather than following the timeline for the public release of the NAAQS documents. Finally, this document takes advantage of a more flexible digital format for the routinely prepared maps and trends figures, with an end product that more strongly emphasizes visual presentation of data and reduces the amount text, while also creating a more interactive presentation of the information through the use of external links.

This document follows an organization similar to the structure of the atmospheric sections of past PM NAAQS documents. The subsequent sections are as follows: 2. Atmospheric Chemistry; 3. Sources and Emissions of PM in Ambient Air; 4. Ambient Air Monitoring Requirements and Monitoring Networks; 5. Data Handling Conventions and Computations for Determining Whether the Standards are Met; and 6. PM Concentrations Measured at Ambient Air Monitoring Sites Across the U.S. These sections are broad enough in scope to handle changes in what is known about PM atmospheric science as it advances but specific enough that NAAQS-relevant information will be able to be quickly retrieved by users of the document.

2. Atmospheric Chemistry

In ambient air, PM is a mixture of substances suspended as small liquid and/or solid particles. Particle size is an important consideration for PM, as distinct health and welfare effects have been linked with exposures to particles of different sizes. Particles in the atmosphere range in size from less than 0.01 to more than 10 micrometers (μm) in diameter. When describing PM, subscripts are used to denote the aerodynamic diameter¹ of the particle size range in micrometers (μm) of 50% cut points of sampling devices. The EPA defines PM_{2.5}, also referred to as fine particles, as particles with aerodynamic diameters generally less than or equal to 2.5 μm . The size range for PM_{10-2.5}, also referred to as coarse particles, includes those particles with aerodynamic diameters generally greater than 2.5 μm and less than or equal to 10 μm . PM₁₀, which is comprised of both fine and coarse fractions, includes those particles with aerodynamic diameters generally less than or equal to 10 μm . Figure 1 provides perspective on these particle size fractions. In addition, ultrafine particles (UFP) are often defined as particles with a diameter of less than 0.1 μm .

¹Aerodynamic diameter is the size of a sphere of unit density (i.e., 1 g/cm³) that has the same terminal settling velocity as the particle of interest.

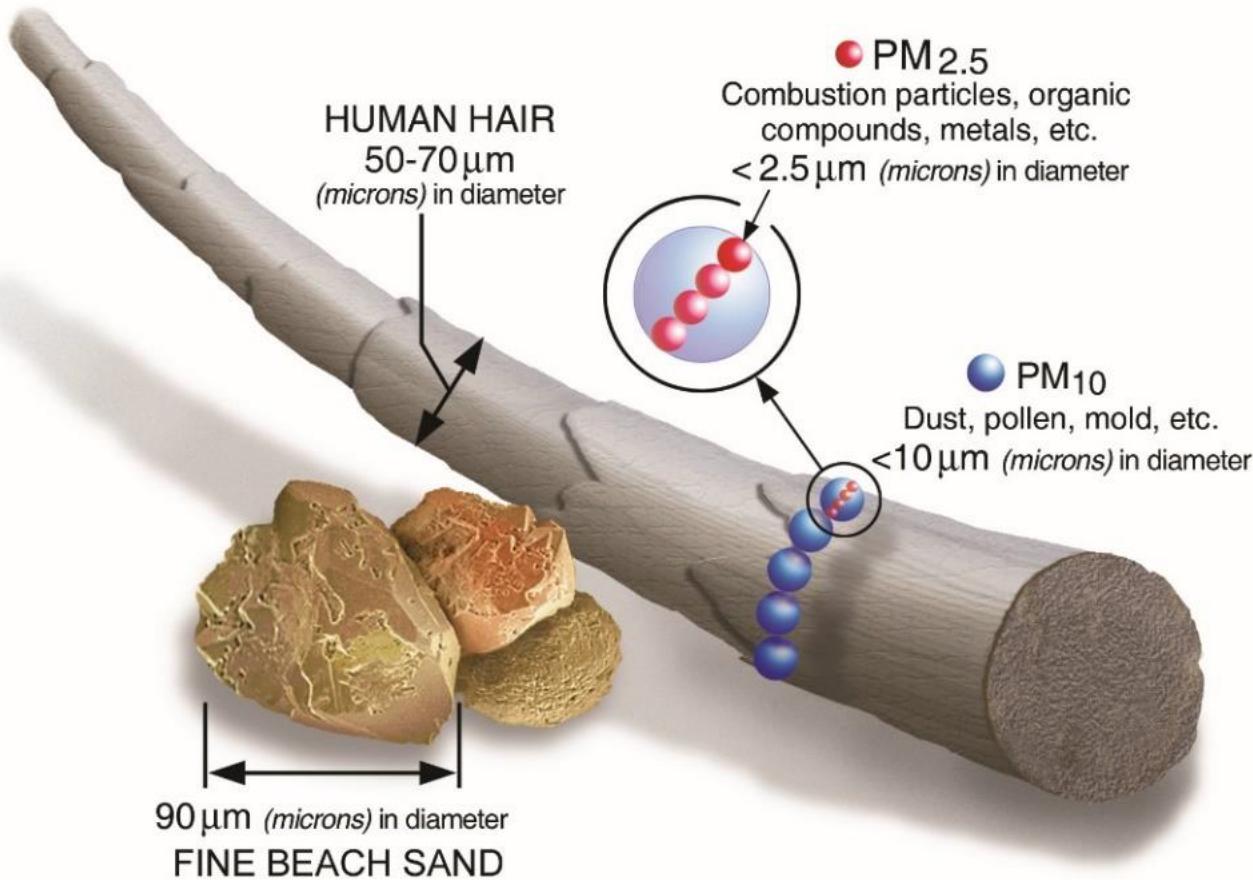


Figure 1. Comparisons of PM_{2.5} and PM₁₀ diameters to human hair and beach sand. Reproduced from Figure 2-1 of the 2020 PM PA.

Atmospheric distributions of particle size generally exhibit three distinct modes (“nucleation mode”, “accumulation mode”, and “coarse mode”) that roughly align with the PM size fractions defined above. Figure 2 below shows an example of the particle size distribution for each of these three modes. The nucleation mode is made up of freshly generated particles, formed either during combustion or by atmospheric reactions of precursor gases. The nucleation mode is especially prominent near sources like heavy traffic, industrial emissions, biomass burning, or cooking. While nucleation mode particles are only a minor contributor to overall ambient PM mass and surface area, they are the main contributors to ambient particle number. By number, most nucleation mode particles fall into the UFP size range, though some fraction of the nucleation mode number distribution can extend above 0.1 μm in diameter. Nucleation mode particles can grow rapidly through coagulation or uptake of gases by particle surfaces, giving rise to the accumulation mode. The accumulation mode is typically the predominant contributor to PM_{2.5} mass and surface area, though only a minor contributor to particle number. PM_{2.5} sampling methods measure most of the accumulation mode mass, although a small fraction of particles that make up the accumulation mode are greater than 2.5 μm in diameter. Coarse mode particles are formed by mechanical generation, and through processes like dust resuspension and sea spray formation. Most coarse mode mass is captured by PM_{10-2.5} sampling, but small fractions of coarse mode mass can be smaller than 2.5 μm or greater than 10 μm in diameter.

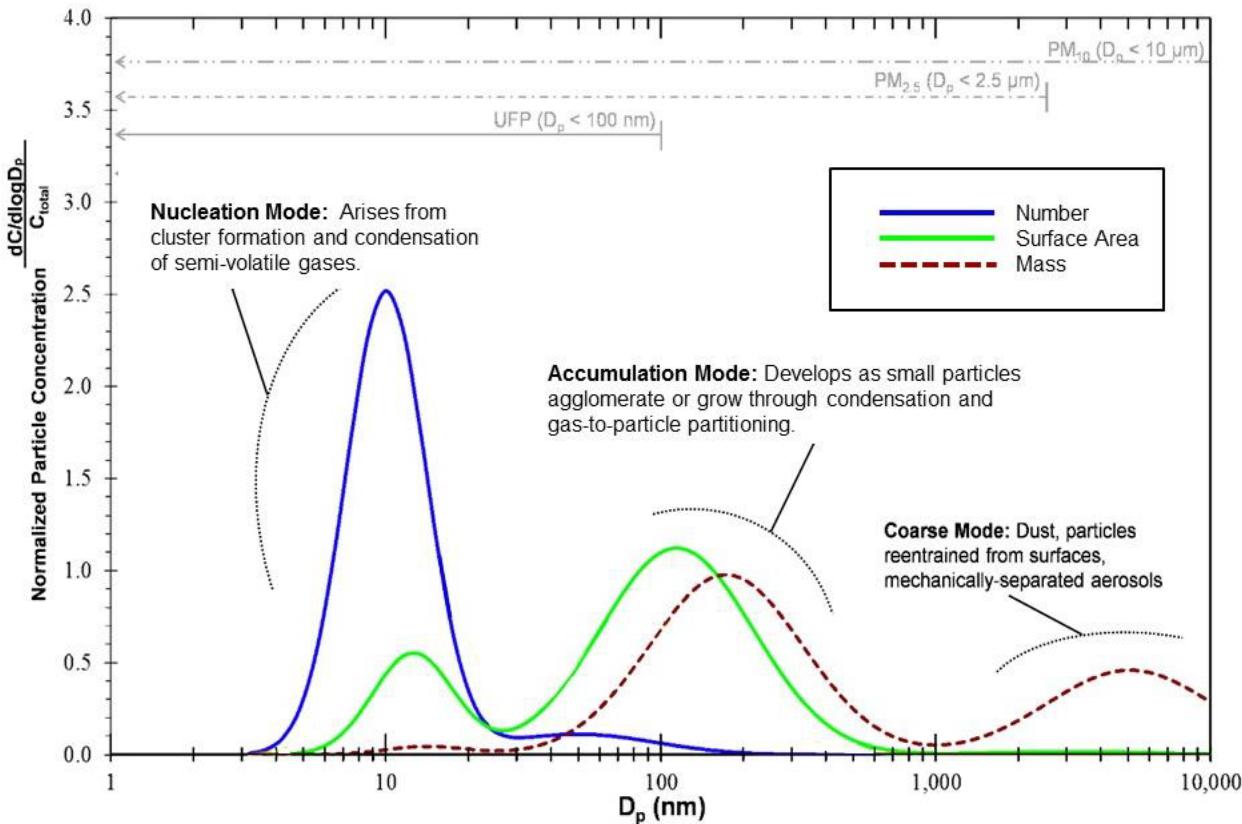


Figure 2. Comparison of particle size distribution by particle number, surface area, and mass. C_{total} = total particle concentration; D_p = particle diameter. Reproduced from Figure 2-1 of the [2019 PM ISA](#).

Most particles are found in the lower troposphere, where they can have residence times ranging from a few hours to weeks. Particles are removed from the atmosphere by wet deposition, such as when they are carried by rain or snow, or by dry deposition, such as gravitational settling or surface collision. Atmospheric lifetimes are generally longest for $\text{PM}_{2.5}$, which often remains in the atmosphere for days to weeks before being removed by wet or dry deposition. In contrast, atmospheric lifetimes for UFP and $\text{PM}_{10-2.5}$ are shorter. Within hours, UFP can undergo coagulation and condensation that lead to formation of larger particles in the accumulation mode, or can be removed from the atmosphere by evaporation, deposition, or reactions with other atmospheric components. $\text{PM}_{10-2.5}$ are also generally removed from the atmosphere within hours, through wet or dry deposition.

Secondary $\text{PM}_{2.5}$, which is derived from both natural and anthropogenic sources, accounts for a substantial fraction of the $\text{PM}_{2.5}$ mass. Secondary $\text{PM}_{2.5}$ forms through atmospheric photochemical oxidation reactions of both inorganic and organic gas-phase precursors, primarily sulfur dioxide (SO_2), nitrogen oxides (NO_x), and ammonia (NH_3). Reactions leading to sulfate (SO_4^{2-}) production from SO_2 , nitrate (NO_3^-) production from NO_x , and the gas-to-particle equilibrium between ammonia (NH_3) and ammonium (NH_4^+) are relatively well understood, while formation of secondary organic PM, often referred to as secondary organic aerosols (SOA), is less well resolved. In contrast, $\text{PM}_{10-2.5}$ is mainly primary in origin, as it is produced by the abrasion of surfaces or by the suspension of biological material.

Sources: [Integrated Science Assessment for Particulate Matter, May 2019](#)

[Policy Assessment for the Review of the PM NAAQS, January 2020](#)

3. Sources and Emissions of PM

PM is composed of both primary (directly emitted particles) and secondary chemical components. Primary PM is derived from direct particle emissions from specific PM sources while secondary PM originates from gas-phase chemical compounds present in the atmosphere that have participated in new particle formation or condensed onto existing particles. Primary particles, and gas-phase compounds contributing to secondary formation PM, are emitted from both anthropogenic and natural sources.

Anthropogenic sources of PM include both stationary and mobile sources. Stationary sources include fuel combustion for electricity production and other purposes, industrial processes, agricultural activities, and road and building construction and demolition. Mobile sources of PM include diesel- and gasoline-powered highway vehicles and other engine-driven sources (e.g., ships, aircraft, and construction and agricultural equipment). Both stationary and mobile sources directly emit primary PM to ambient air, along with secondary PM precursors (e.g., SO₂, NO_x) that contribute to the secondary formation of PM in the atmosphere.

Natural sources of PM include dust from the wind erosion of natural surfaces, sea salt, wildfires, primary biological aerosol particles (PBAP) such as bacteria and pollen, oxidation of biogenic hydrocarbons such as isoprene and terpenes to produce SOA, and geogenic sources such as sulfate formed from volcanic production of SO₂. Contributions of natural emission sources to PM_{2.5} concentrations can be interconnected with anthropogenic emissions through atmospheric chemistry, such as the modulation of biogenic SOA production by anthropogenic NO_x and SO₂ emissions.

Generally, the sources of PM for different size fractions vary. While PM_{2.5} in ambient air is largely emitted directly by sources such as those described above or through secondary PM formation in the atmosphere, PM_{10-2.5} is almost entirely from primary sources (i.e., directly emitted) and is produced by surface abrasion or by suspension of sea spray or biological materials such as microorganisms, pollen, and plant and insect debris.

The major components of PM_{2.5} mass include sulfate, nitrate, elemental or black carbon (EC or BC), organic carbon (OC), crustal materials, and sea salt. Some of these PM components are emitted directly to the air (e.g., EC/BC) while others are formed secondarily through reactions by gaseous precursors (e.g., sulfate, nitrate). Anthropogenic SO₂ and NO_x are the predominant precursor gases in the formation of secondary PM_{2.5} sulfate and nitrate, and ammonia is the gas-phase precursor for PM_{2.5} ammonium. Atmospheric oxidation of volatile organic compounds (VOCs), both anthropogenic and biogenic, is an important source of SOA, particularly in summer.

The [National Emissions Inventory \(NEI\)](#) is a comprehensive and detailed estimate of air emissions of criteria pollutants, precursors to criteria pollutants, and hazardous air pollutants from air emissions sources. The NEI is released every three years based primarily upon data provided by State, Local, and Tribal air agencies for sources in their jurisdictions and supplemented by data developed by the US EPA. The NEI is built using the EPA's Emissions Inventory System (EIS) first to collect the data from State, Local, and Tribal air agencies and then to blend that data with other data sources.

Accuracy in an emissions inventory reflects the extent to which the inventory represents the actual emissions that occurred. Anthropogenic emissions of air pollutants result from a variety of sources such as power plants, industrial sources, motor vehicles and agriculture. The emissions from any individual source typically varies in both time and space. For the thousands of sources that make up the NEI, there is uncertainty in one or both of these factors. For some sources, such as power plants, direct emission measurements enable the emission factors derived from them to be more certain than sources without such direct measurements. However, it is not practically possible to directly monitor each of the emission sources individually and, therefore, emission inventories necessarily contain assumptions, interpolation and extrapolation from a limited set of sample data.

Figure 3 shows the main sources contributing to primary PM_{2.5}, primary PM₁₀, SO₂, and NO_x emissions in the U.S. Fires, which include wildfires, prescribed fires, and agricultural fires, contributed about 44% of primary PM_{2.5} emissions and 17% of primary PM₁₀ emissions in 2017. Dust particles from roads, agriculture, and construction contributed 30% of primary PM_{2.5} emissions and 69% of primary PM₁₀ emissions, while most of the remaining primary PM emissions came from stationary fuel combustion (e.g., coal combustion for electricity), industrial and mobile sources. Regarding precursors to secondary PM formation, the main sources of SO₂ and NO_x are stationary fuel combustion (64% of total SO₂ emissions; 22% of total NO_x emissions), industrial processes (19% of total SO₂ emissions; 10% of total NO_x emissions) and mobile sources (8% of total SO₂ emissions; 52% of total NO_x emissions).

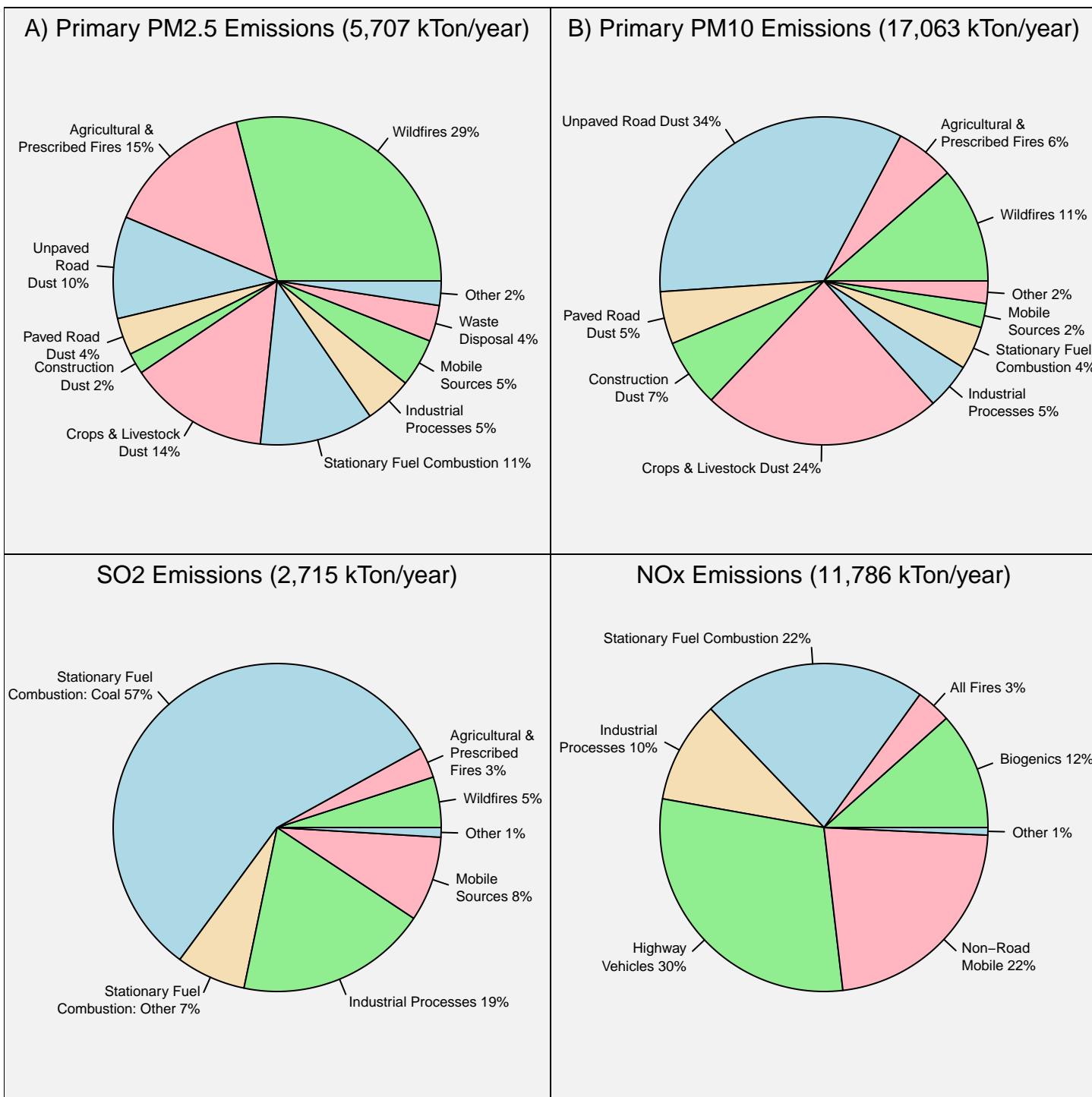


Figure 3: U.S. emissions for A) Primary PM_{2.5}; B) Primary PM₁₀; C) SO₂; and D) NO_x by sector. **Source:** 2017 NEI.

Figure 4 shows the national trends in U.S. anthropogenic primary PM_{2.5}, primary PM₁₀, SO₂, and NO_x emissions from 2002 to 2021.² Primary PM_{2.5} emissions reached a maximum of 5.2 million tons per year in 2007 and have decreased by 24% to 3.9 million tons per year in 2021. Similarly, direct PM₁₀ emissions reached a maximum of 20.7 million tons per year in 2007 and have decreased by 322% to approximately 14.4 million tons per year in 2021. SO₂ emissions have decreased by 88% since 2002, while NO_x emissions have decreased by 68% since 2002. The large reductions in NO_x and SO₂ emissions are largely due to reductions in the electricity generation and transportation sectors resulting from EPA programs such as the Clean Air Interstate Rule and the Cross-State Air Pollution Rule for electric generating units, as well as the adoption of more stringent fuel economy standards and low sulfur diesel fuel standards for mobile sources.

²For the purposes of this document, wildfires are considered to be natural emissions and thus are not included in Figure 4.

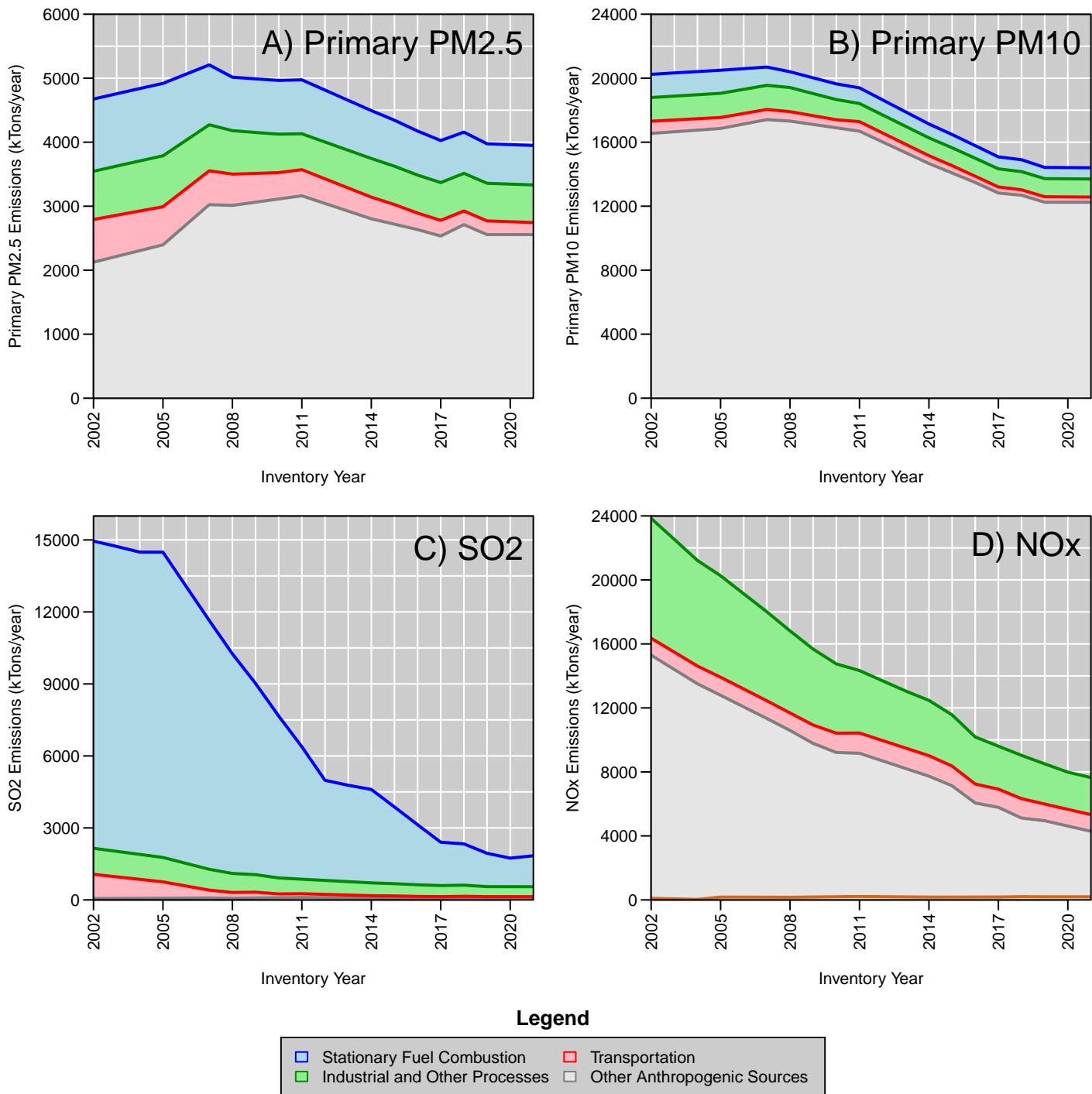


Figure 4. U.S. anthropogenic emissions trends for: A) Primary PM_{2.5}; B) Primary PM₁₀; C) SO₂; and D) NO_x. **Source:** EPA's Air Pollutant Emissions Trends Data

Figure 5 through Figure 8 show county-level estimates of U.S. emissions densities (in tons/year/mi²) for primary PM_{2.5}, primary PM₁₀, SO₂, and NO_x emissions, respectively based on the 2017 NEI. Primary PM emissions tended to be highest near urban areas due to the larger number of industrial sources and vehicles, and near the center of the country due to dust from roads and agricultural sources. Parts of the northwest U.S. and California also experienced higher emissions due to wildfires in 2017. The highest SO₂ emissions tend to be located near large point sources such as coal-fired power plants or large industrial facilities, while the highest NO_x emissions tend to be located near urban areas and large point sources.

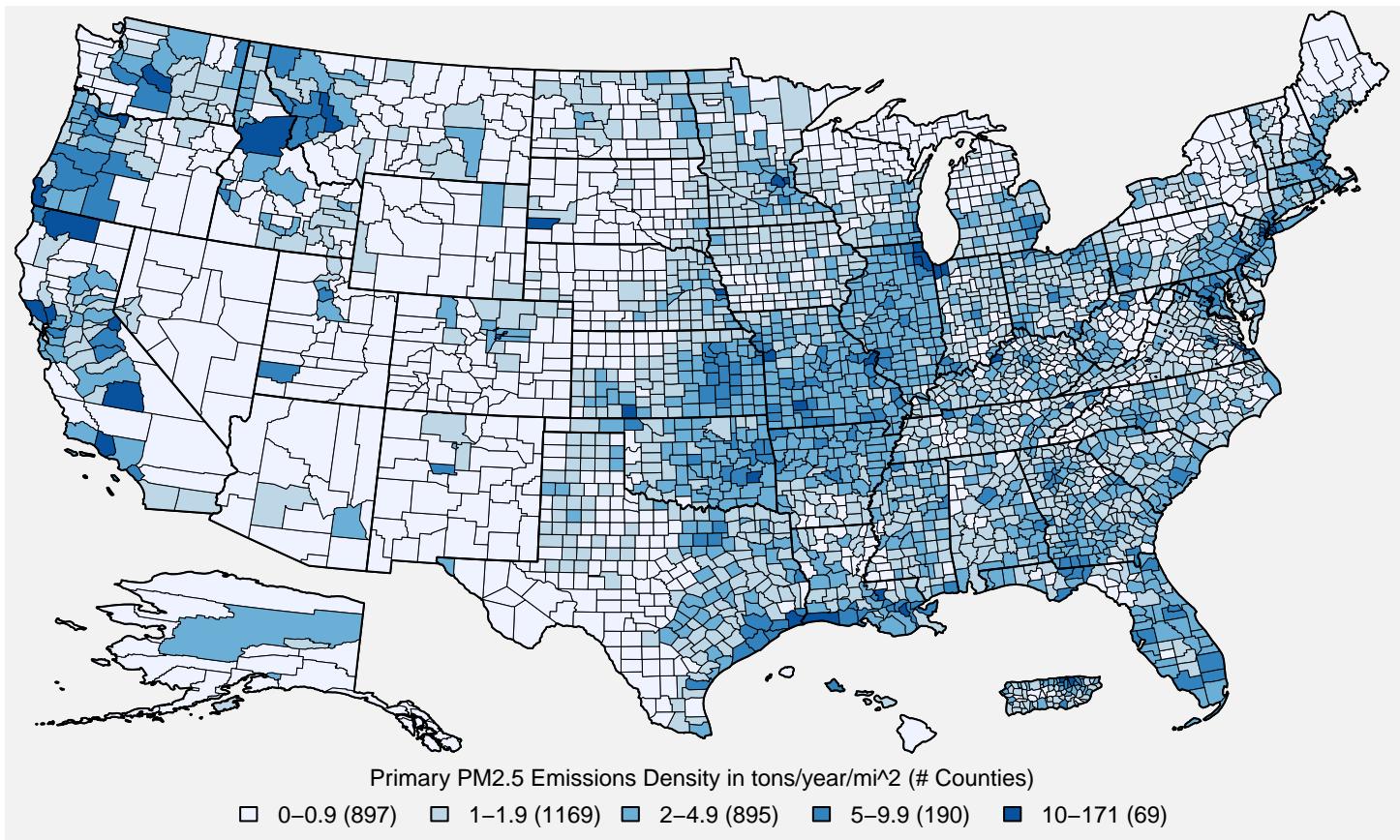


Figure 5. U.S. county-level primary PM_{2.5} emissions density estimates in tons/year/mi². **Source:** [2017 NEI](#)

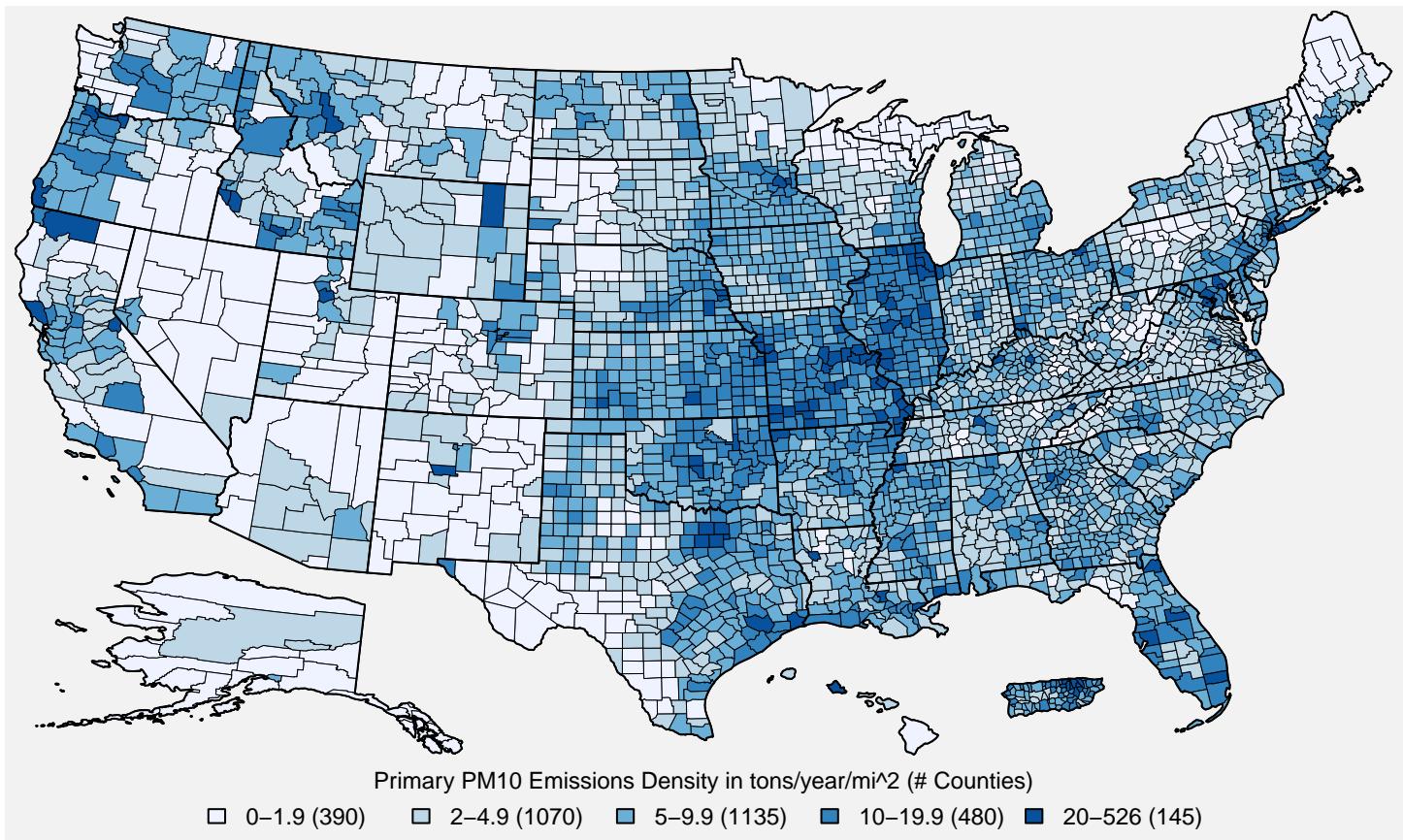


Figure 6. U.S. county-level primary PM₁₀ emissions density estimates in tons/year/mi². **Source:** [2017 NEI](#)

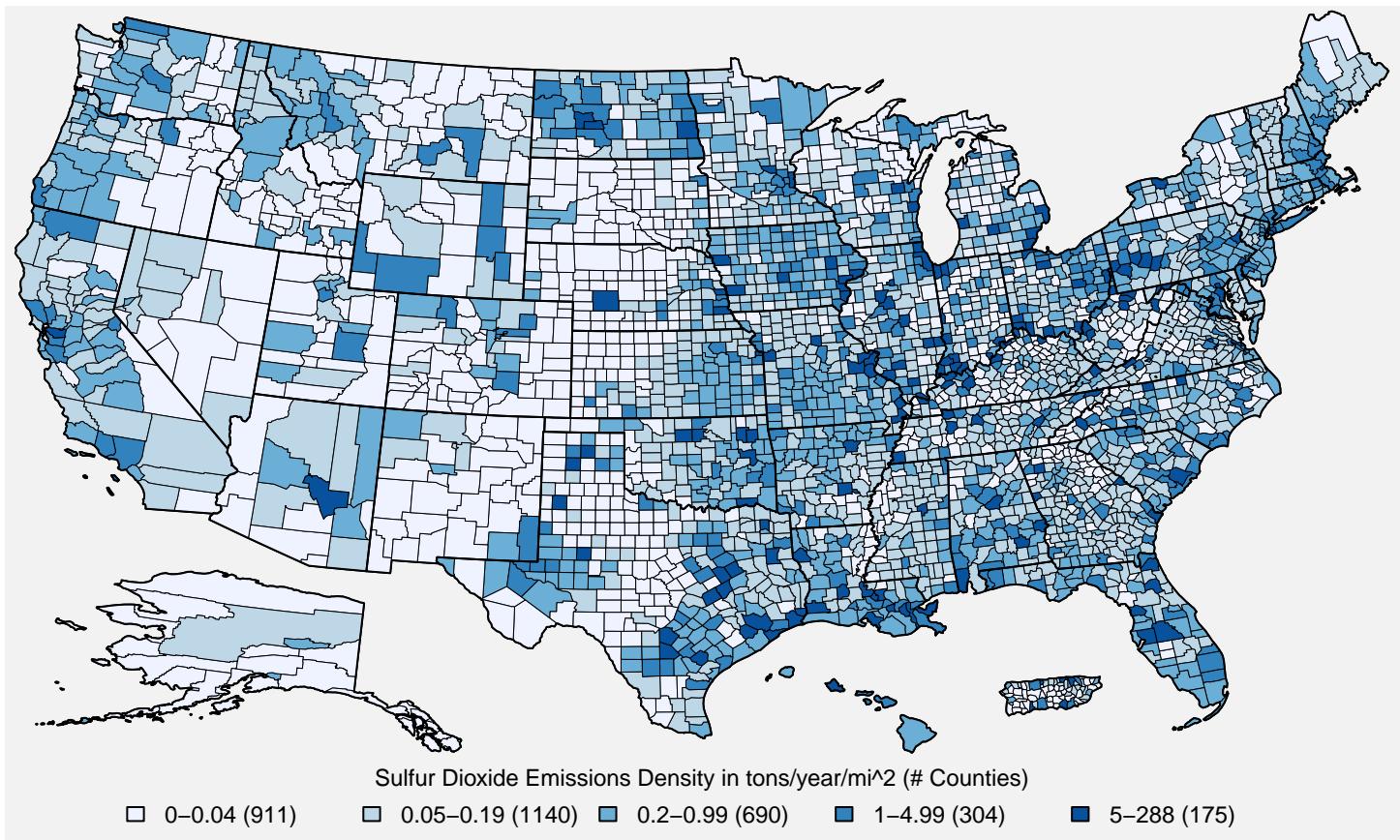


Figure 7. U.S. county-level SO₂ emissions density estimates in tons/year/mi². **Source:** [2017 NEI](#)

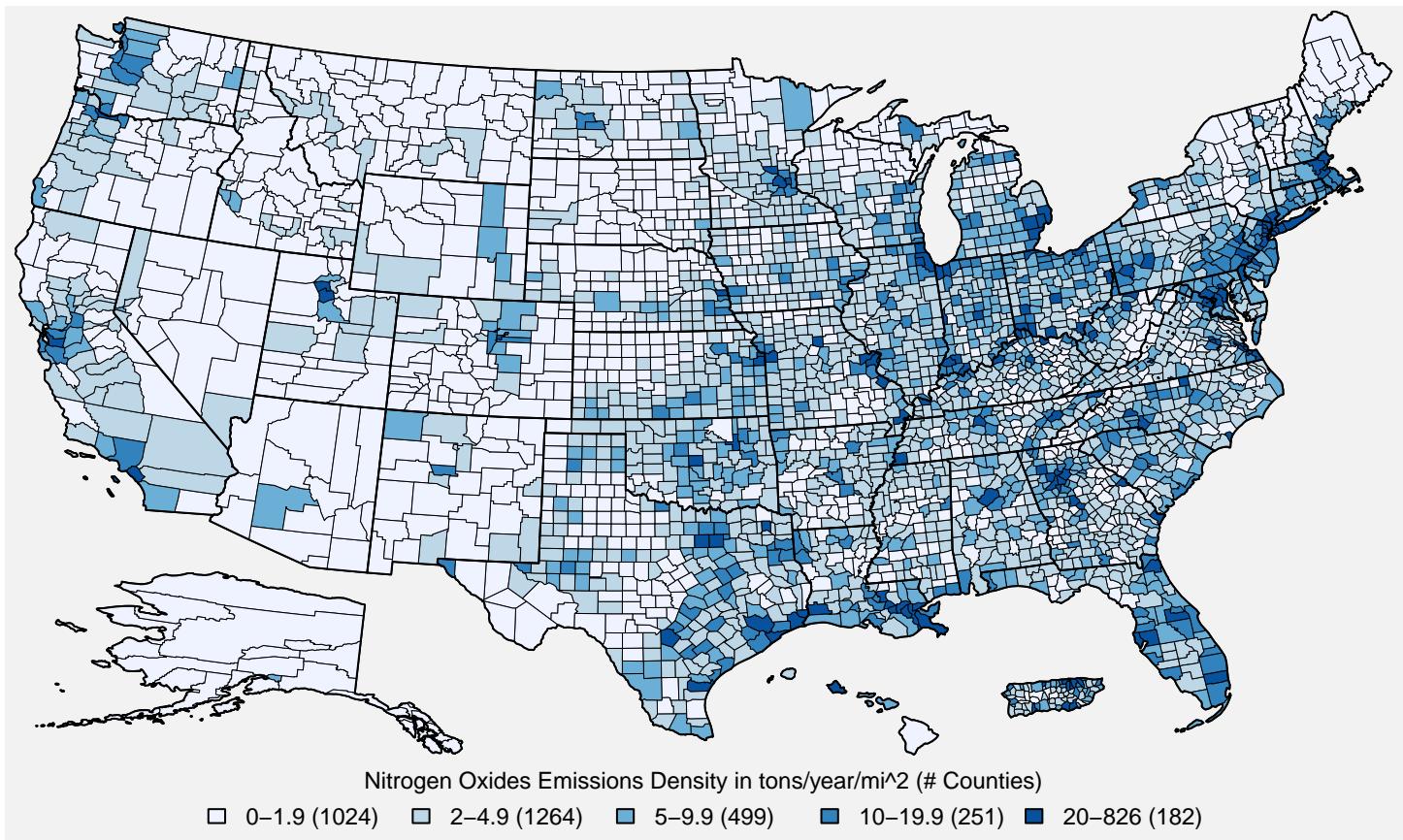


Figure 8. U.S. county-level NO_x emissions density estimates in tons/year/mi². **Source:** [2017 NEI](#)

4. Ambient Air Monitoring Requirements and Monitoring Networks

The EPA and its partners at state, local, and tribal monitoring agencies manage and operate the nation's ambient air monitoring networks. The EPA provides minimum monitoring requirements for PM and other pollutants in 40 CFR Part 58. Monitoring agencies carry out and perform ambient air monitoring in accordance with the EPA's requirements and guidance. Federal Reference Methods (FRMs) and Federal Equivalence Methods (FEMs) are monitoring methods that have been approved for use by states and other monitoring organizations to assess NAAQS compliance and implementation. The FRMs for measuring PM₁₀, PM_{2.5}, and PM_{10-2.5} are specified in CFR 40 Part 50, Appendices J, L, and O, respectively, while performance requirements for the approval of FRM and FEMs are in 40 CFR Part 53.

The EPA and monitoring agencies manage and operate robust national monitoring networks for both PM₁₀ and PM_{2.5}, as these are the two measurement programs directly supporting the PM NAAQS. PM₁₀ measurements are based on gravimetric mass, while PM_{2.5} measurements include gravimetric mass and chemical speciation. A smaller network of stations is operating and reporting data for PM_{10-2.5} gravimetric mass and a few monitors are operated to support special projects, including pilot studies, for continuous speciation and particle count data.

The EPA first established NAAQS for PM in 1971 based on total suspended particulates, or TSP. The TSP NAAQS was replaced by the PM₁₀ NAAQS in 1987. TSP sampling remains in operation at a limited number of locations primarily to provide measurements for the Lead (Pb) NAAQS as well as for instances where a state may continue to have state standards for TSP. The size of the TSP network peaked in the mid-1970s when over 4,300 TSP samplers were in operation. There were 133 monitoring sites reporting Pb TSP data to EPA during the 2019-2021 period.

To support the 1987 PM₁₀ NAAQS, the EPA and its state and local partners implemented the first size-selective PM monitoring network in 1990 with the establishment of a PM₁₀ network consisting of mainly high-volume samplers. The PM₁₀ monitoring network peaked in size in 1995 with 1,665 stations reporting data. There were 725 monitoring sites reporting PM₁₀ data to EPA during the 2019-2021 period. Figure 9 shows the locations of these monitoring sites. Approximately 61% of these monitoring sites operate FEMs which report continuous PM₁₀ data while the remaining sites operate FRMs which typically collect samples every day, every 3rd day, or every 6th day.

To support the 1997 PM NAAQS, the first PM NAAQS with PM_{2.5} as an indicator, the EPA and states implemented a PM_{2.5} monitoring network consisting of ambient air monitoring sites with PM_{2.5} mass and/or chemical speciation measurements. Network operation began in 1999 with nearly 1,000 monitoring stations operating FRMs to measure fine particle mass. The PM_{2.5} monitoring program remains one of the largest ambient air monitoring programs in the U.S. There were 1069 monitoring sites reporting PM_{2.5} data to EPA during the 2019-2021 period. Figure 10 shows the locations of these monitoring sites. Approximately 50% of these monitoring sites operate FEMs which report continuous PM_{2.5} data while the remaining sites operate FRMs which typically collect samples every day, every 3rd day, or every 6th day.

The main network of monitors providing ambient data for use in implementation activities related to the NAAQS is the State and Local Air Monitoring Stations (SLAMS) network, which comprises about 86% of PM_{2.5} and 75% of PM₁₀ monitoring sites. Two important subset of SLAMS sites are the [National Core \(NCore\) multipollutant monitoring network](#) and the [near-road monitoring network](#). The NCores network was designed to collect consistent measurements of criteria pollutants for trends and NAAQS compliance purposes. NCores was fully operational as of 2011 and consists of approximately 60 urban monitoring stations and 20 rural monitoring stations. Each state is required to have at least one NCores station. PM_{2.5} monitoring was required for near-road network sites as part of the 2012 PM_{2.5} NAAQS review and these sites monitors were phased into the network between 2015 and 2017. Near-road sites are required in each metropolitan statistical area (MSA) with a population of 1,000,000 or greater. There were 54 sites reporting PM_{2.5} data to EPA during the 2019-2021 period.

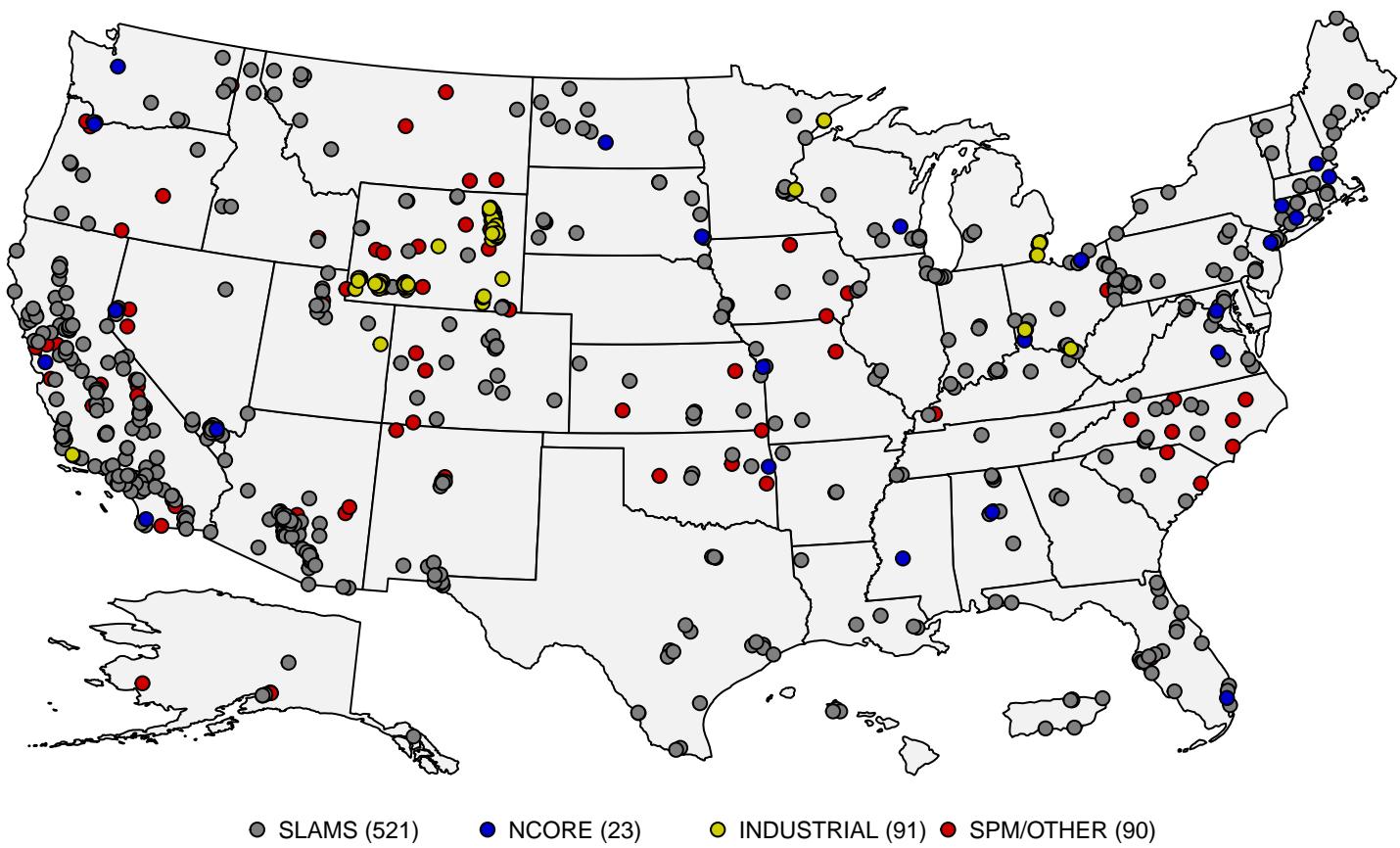


Figure 9: Map of U.S. PM₁₀ monitoring sites reporting data to the EPA during the 2019-2021 period. **Source:** [AQS](#).

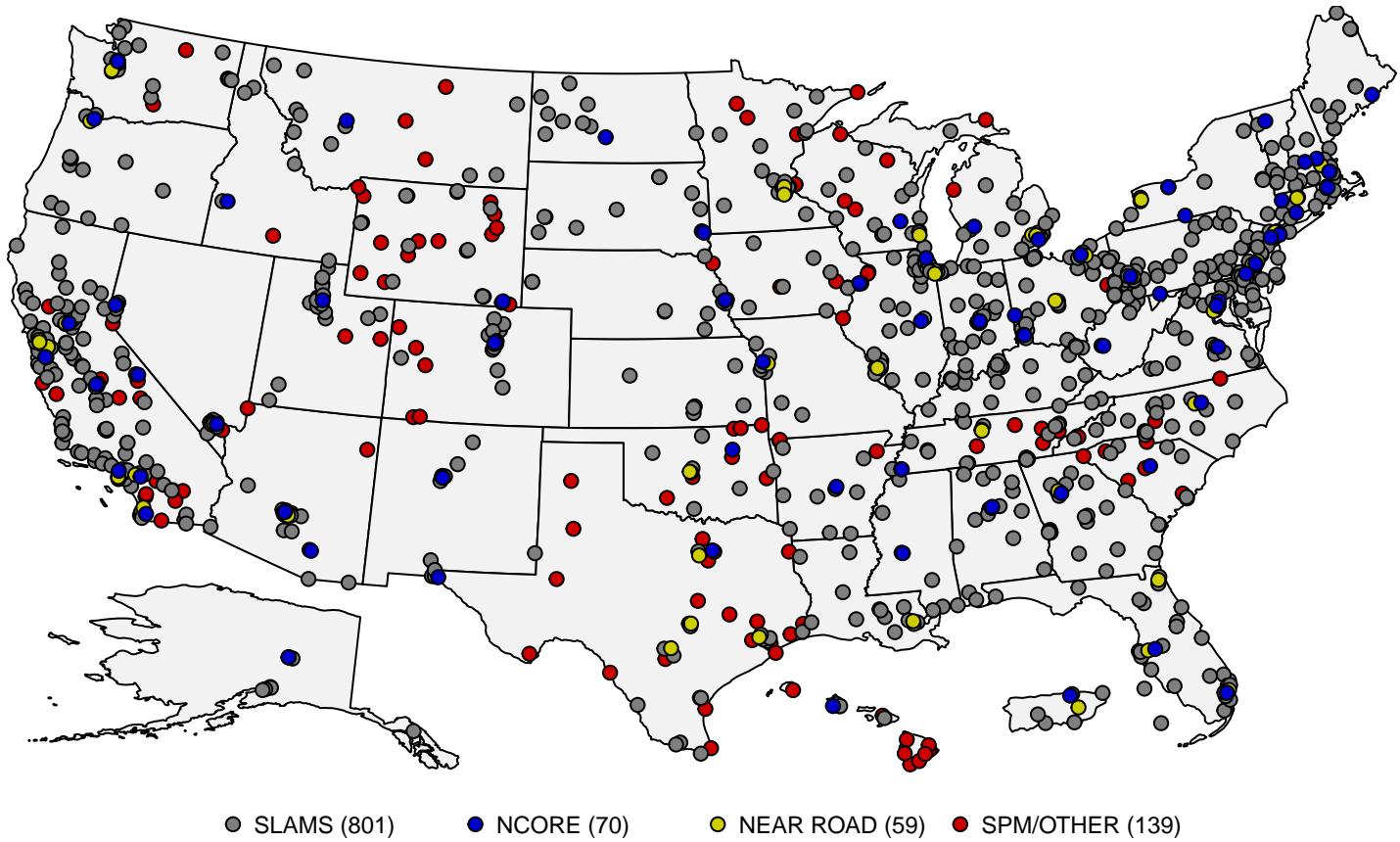


Figure 10: Map of U.S. PM_{2.5} monitoring sites reporting data to the EPA during the 2019-2021 period. **Source:** [AQS](#).

As a result of the 2006 PM NAAQS review, the EPA promulgated a new FRM for the measurement of PM_{10-2.5} mass in ambient air. Although the standard for coarse particles uses a PM₁₀ indicator, a new FRM for PM_{10-2.5} mass was developed to provide a basis for approving FEMs and to promote the gathering of scientific data to support future reviews of the PM NAAQS. PM_{10-2.5} measurements are currently reported at NCORE stations, IMPROVE monitoring stations, and at a few additional locations where state or local agencies choose to operate a PM_{10-2.5} method. There were 286 monitoring sites reporting PM_{10-2.5} data to EPA during the 2019-2021 period. Figure 11 shows the locations of these monitoring sites. Additionally, some sites that operate both PM₁₀ and PM_{2.5} monitors also report PM_{10-2.5} concentrations by taking the difference of the two measurements.

Due to the complex nature of fine particles, the EPA and states implemented the [Chemical Speciation Network \(CSN\)](#) to better understand the components of fine particle mass at selected locations across the country. The CSN was first piloted at 13 sites in 2000, and after the pilot phase, the program continued with deployment of the Speciation Trends Network (STN) later that year. The CSN ultimately grew to 54 trends sites and peaked in operation in 2005 with 252 stations: the 54 trends stations and nearly 200 supplemental stations. There were 105 CSN sites reporting data to EPA during the 2019-2021 period. The locations of these sites are shown in Figure 12. Additionally, PM_{2.5} speciation measurements are collected at NCORE stations, which are also shown in Figure 12.

Specific components of fine particles are also measured through the [Interagency Monitoring of Protected Visual Environments \(IMPROVE\)](#) monitoring program, which supports the regional haze program and tracks changes in visibility in Class I areas as well as many other rural and some urban areas. CSN and IMPROVE data can also be used to better understand visibility through calculation of light extinction using the IMPROVE algorithm³ to support reviews of the secondary PM NAAQS. There were 152 IMPROVE sites reporting data to EPA during the 2019-2021 period. The locations of these sites are shown in Figure 12.

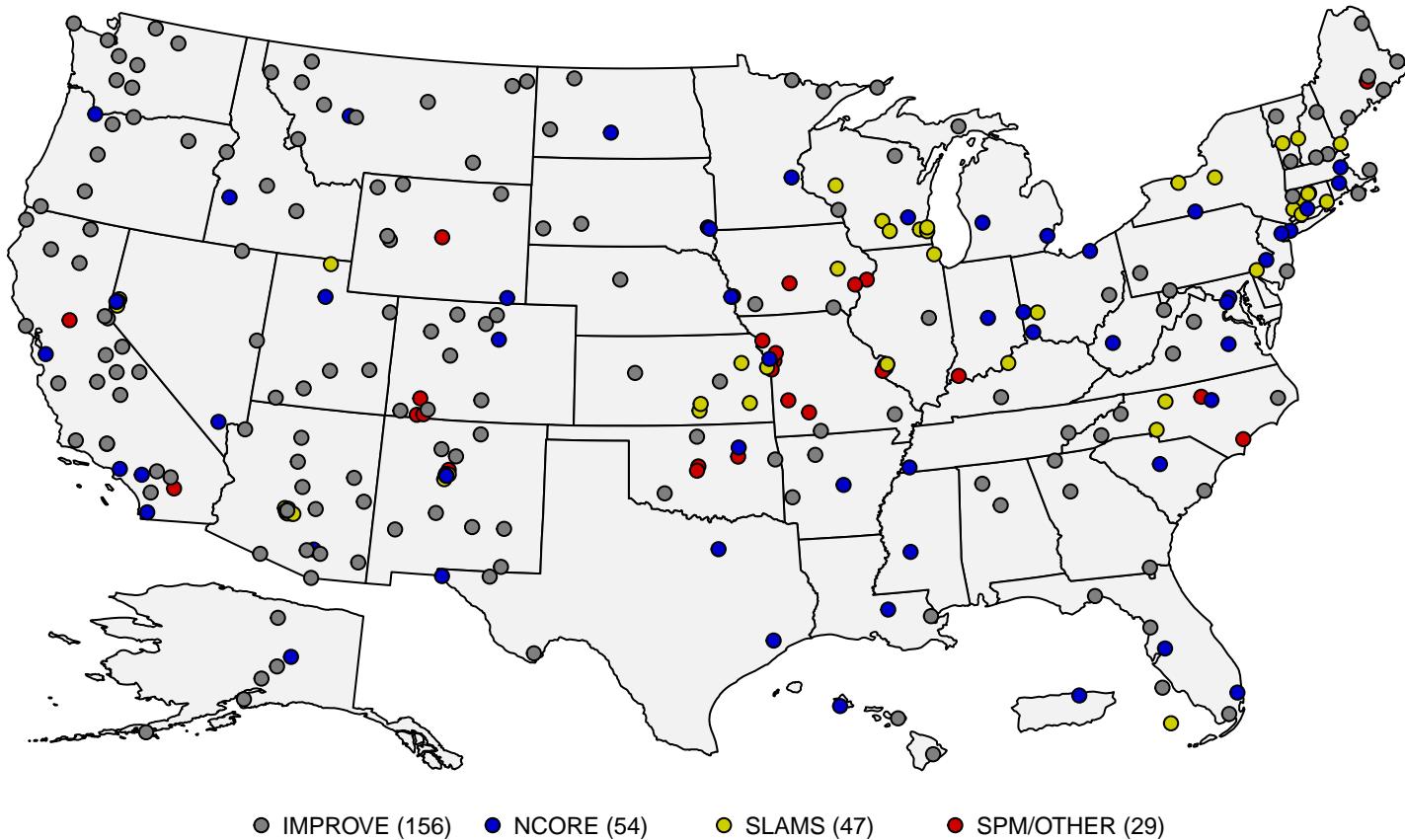


Figure 11: Map of U.S. PM_{10-2.5} monitoring sites reporting data to the EPA during the 2019-2021 period. **Source:** [AQS](#).

³The IMPROVE algorithm is an equation to estimate light extinction based on the measured concentration of several PM components and is used to track visibility progress in the Regional Haze Rule. More information about the IMPROVE algorithm is available at the [IMPROVE website](#).

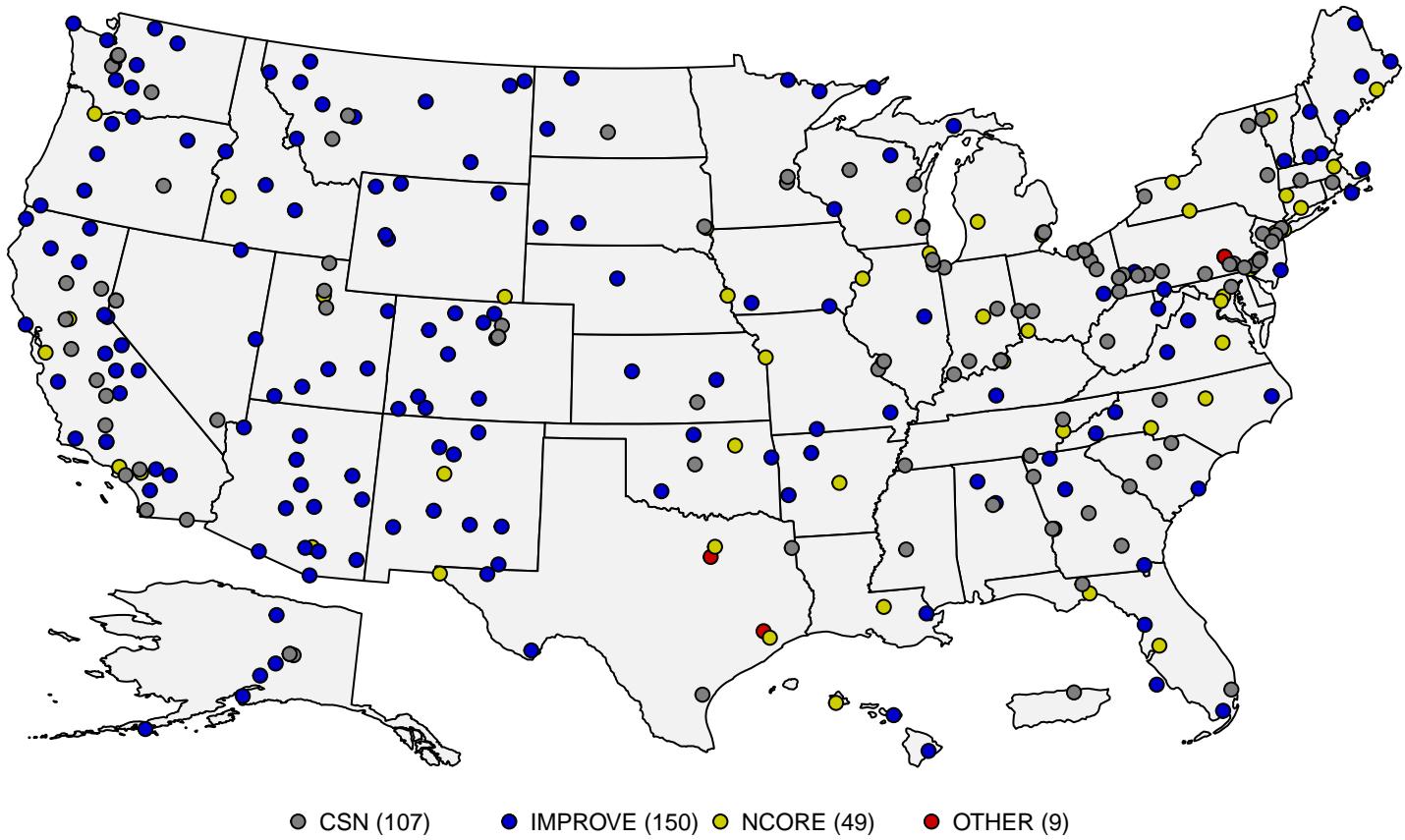


Figure 12: Map of U.S. PM_{2.5} speciation monitoring sites reporting data to the EPA during the 2019-2021 period. Source: AQS.

5. Data Handling Conventions and Computations for Determining Whether the Standards are Met

To assess whether a monitoring site or geographic area (usually a county or urban area) meets or exceeds a NAAQS, the monitoring data are analyzed consistent with the established regulatory requirements for the handling of monitoring data for the purposes of deriving a design value. A design value summarizes ambient air concentrations for an area in terms of the indicator, averaging time and form for a given standard such that its comparison to the level of the standard indicates whether the area meets or exceeds the standard. The procedures for calculating design values for the current PM NAAQS (established in 2012) are detailed in [Appendix K to 40 CFR Part 50](#) for PM₁₀ and in [Appendix N to 40 CFR Part 50](#) for PM_{2.5}.

Daily 24-hour PM₁₀ samples collected at an ambient air monitoring site using Federal Reference or Equivalent Methods, meeting all applicable requirements in 40 CFR Part 58, and reported to AQS in micrograms per meter cubed ($\mu\text{g}/\text{m}^3$) with decimal digits truncated are used in design value calculations. If there are multiple monitors at a site, a separate design value is calculated for each monitor. First, the number of exceedances of the NAAQS is determined for each calendar quarter (i.e., Jan/Feb/Mar, Apr/May/Jun, Jul/Aug/Sep, Oct/Nov/Dec) over a 3-year period. The level of the PM₁₀ NAAQS is 150 $\mu\text{g}/\text{m}^3$, but monitored concentrations are rounded to the nearest 10 $\mu\text{g}/\text{m}^3$ when compared to the NAAQS, so an exceedance occurs when measured concentrations are 155 $\mu\text{g}/\text{m}^3$ or greater.

To correct for missing data, the observed number of exceedances in each calendar quarter is adjusted by dividing it by the data completeness rate during that quarter and rounded to the nearest hundredth, which is the expected number of exceedances for that quarter. This adjustment is performed regardless of sampling schedule, for example, a monitoring site that has an every 3rd day sampling schedule will have a minimum of 3 expected exceedances for each observed exceedance even if the data completeness rate is 100%. The annual number of expected exceedances is the sum of the expected exceedances over the four calendar quarters, and the design value is the average of the annual expected exceedances over three consecutive years, rounded to the nearest tenth. The PM₁₀ NAAQS are met when the design value is less or equal to 1.0.

A PM₁₀ design value meeting the NAAQS must meet minimum data completeness requirements in order to be considered valid. Specifically, a monitor must have reported concentrations for a minimum of 75% of the scheduled sampled days in

each calendar quarter of the 3-year period in order to be considered valid. A PM₁₀ design value greater than the NAAQS is always considered valid. Appendix K to 40 CFR Part 50 has additional language describing situations where a valid design value may be derived for a monitor which does not meet these minimum data completeness criteria.

Daily 24-hour PM_{2.5} samples collected at an ambient air monitoring site using Federal Reference or Equivalent Methods, meeting all applicable requirements in 40 CFR Part 58, and reported to AQS in ($\mu\text{g}/\text{m}^3$) with decimal digits after the first decimal place truncated are used in design value calculations. If hourly samples are reported from a continuous PM_{2.5} monitor, 24-hour average concentrations will be calculated from the hourly data. A calculated 24-hour average concentration is considered valid if hourly concentrations are available for at least 18 of the 24 hours in a given calendar day, or, if after substituting zero for the missing hourly concentrations, the resulting average is greater than the level of the 24-hour PM_{2.5} NAAQS. If multiple monitors are operating at a site, one monitor is designated as the primary monitor. Daily values from collocated monitors are substituted on days where data is missing for the primary monitor to create a site-level data record.

For the annual PM_{2.5} NAAQS, the 24-hour concentrations from the site-level data record are averaged over each calendar quarter for a consecutive 3-year period. The four quarterly averages are then averaged over each year to calculate an annual average, and finally the annual PM_{2.5} design value is the average of the three annual average values, rounded to the nearest tenth. The annual PM_{2.5} NAAQS are met when the design value is less than or equal to 12.0 $\mu\text{g}/\text{m}^3$. Annual PM_{2.5} design values must have a minimum of 75% data completeness in each calendar quarter (according to the sampling schedule for the site) in order to be considered valid. In addition, for sites which fail to meet the 75% quarterly minimum data completeness, there are two data substitution tests in Appendix N to 40 CFR Part 50 by which an annual design value above or below the NAAQS, respectively, may be considered valid.

For the 24-hour PM_{2.5} NAAQS, the 98th percentile of the 24-hour concentrations from the site-level data record is calculated for each of the three years. The 24-hour PM_{2.5} design value is the average of the three 98th percentile values, rounded to the nearest integer. The 24-hour PM_{2.5} NAAQS are met when the design value is less than or equal to 35 $\mu\text{g}/\text{m}^3$. Similar to the annual design values, 24-hour design values must have a minimum of 75% data completeness in each calendar quarter to be considered valid. In addition, a site with a design value meeting the NAAQS may also be considered valid if it is able to pass the 24-hour NAAQS data substitution test in Appendix N to 40 CFR Part 50.

6. PM Concentrations Measured at Ambient Air Monitoring Sites Across the U.S.

Table 1 below presents summary statistics based on daily PM₁₀, PM_{2.5}, and PM_{10-2.5} monitoring data reported to AQS for 2019 to 2021 for the full year and for each calendar quarter. There are two daily metrics for PM₁₀ and PM_{2.5}: the daily 24-hour average (DA24) metric, which is available for both filter-based and continuous monitoring instruments, and the maximum daily 1-hour average (MDA1) metric, which is available only for continuous monitoring instruments. For PM_{10-2.5}, only filter-based measurements are available, thus only the DA24 metric is shown. Table 2 presents summary statistics for the same daily metrics based on 2019-2021 PM₁₀, PM_{2.5}, and PM_{10-2.5} monitoring data for each [NOAA Climate Region](#)⁴.

Figure 13 and Figure 14 show maps of the annual and 24-hour PM_{2.5} design values, respectively, at U.S. ambient air monitoring sites based on monitoring data from the 2019-2021 period. All sites in the eastern U.S. were meeting both the 2012 Annual PM_{2.5} NAAQS of 12 $\mu\text{g}/\text{m}^3$ and the 2006 24-hour PM_{2.5} NAAQS of 35 $\mu\text{g}/\text{m}^3$ during this period. Many sites in the western U.S. were still violating the 24-hour NAAQS in 2019-2021, while a smaller number of sites were also violating the annual NAAQS. Large areas of the Western U.S. were impacted by smoke from wildfires in 2020 and 2021. The highest annual design values are located in the San Joaquin Valley of California, while the highest 24-hour design values are located in Mono County, California, which was heavily impacted by wildfire smoke in 2020.

The PM₁₀ NAAQS is unique in that the form of the standard is expressed in terms of expected exceedances rather than a concentration-based value. Alternatively, a “design concentration” can be used to show PM₁₀ concentrations that would be expected at each site based on the averaging time and form of the NAAQS. The design concentration for PM₁₀ is determined using a table lookup procedure⁵. For example, for a PM₁₀ monitor with 3 years of complete daily sampling data, the design concentration is the 4th highest 24-hour average concentration measured during the 3-year period. Figure 15 shows a map of the PM₁₀ design concentrations based on monitoring data from the 2019-2021 period. The overall pattern appears similar to Figure 14, with generally low design concentrations in the eastern U.S. and higher concentrations in parts of the western U.S. One notable difference is the presence of several sites with high design concentrations in the central U.S., which is likely due to higher emissions of coarse particulates in those regions. This is corroborated by Figure 16, which shows the average of the PM_{10-2.5} concentrations measured at U.S. monitoring sites during the 2019-2021 period.

⁴For Table 2, monitoring sites in Alaska were assigned to the Northwest Region and monitoring sites in Hawaii were assigned to the West region.

⁵The table lookup procedure is documented in Section 6.3 of the 1987 EPA guidance document [PM₁₀ SIP Development Guideline](#).

Table 1. National distribution of PM concentrations in $\mu\text{g}/\text{m}^3$ by quarter based on monitoring data from 2019 to 2021. Source: [AQS](#).

pollutant	metric	quarter	N.sites	N.obs	mean	SD	min	p1	p5	p10	p25	p50	p75	p90	p95	p98	p99	max	max.site
PM10	DA24	all	725	488,628	21.0	25.0	-48.0	2.0	4.0	6.0	10.0	16.0	26.0	41.0	54.0	75.0	97.0	3,956.0	060510011
PM10	DA24	1st quarter	706	121,978	16.0	21.0	-3.0	1.0	3.0	4.0	7.0	12.0	20.0	30.0	39.0	54.0	66.0	3,427.0	060510011
PM10	DA24	2nd quarter	699	120,695	20.0	24.0	-48.0	2.0	5.0	6.0	10.0	16.0	25.0	38.0	47.0	63.0	79.0	3,956.0	060510011
PM10	DA24	3rd quarter	693	123,021	27.0	29.0	-1.0	4.0	7.0	10.0	14.0	20.0	32.0	49.0	64.0	92.0	120.0	2,310.0	060510011
PM10	DA24	4th quarter	697	122,934	22.0	24.0	-3.0	1.0	4.0	5.0	9.0	15.0	26.0	44.0	60.0	85.0	111.0	1,343.0	060510011
PM10	MDA1	all	440	396,413	59.0	161.0	-6.0	6.0	10.0	14.0	21.0	34.0	61.0	111.0	166.0	280.0	417.0	35,585.0	060510011
PM10	MDA1	1st quarter	422	98,667	45.0	158.0	-1.0	5.0	8.0	11.0	17.0	28.0	48.0	83.0	120.0	200.0	292.0	26,803.0	060510011
PM10	MDA1	2nd quarter	424	98,220	58.0	185.0	1.0	7.0	11.0	15.0	22.0	35.0	60.0	105.0	154.0	269.0	402.0	35,585.0	060510011
PM10	MDA1	3rd quarter	422	99,620	71.0	171.0	0.0	10.0	15.0	18.0	26.0	42.0	73.0	133.0	200.0	344.0	511.0	28,161.0	040213014
PM10	MDA1	4th quarter	424	99,906	61.0	121.0	-6.0	6.0	9.0	13.0	20.0	34.0	66.0	120.0	179.0	295.0	440.0	11,508.0	060510011
PM2.5	DA24	all	1,067	801,756	8.1	8.1	-6.7	0.5	2.0	2.8	4.5	6.7	9.9	14.1	17.8	24.1	31.0	824.1	060510005
PM2.5	DA24	1st quarter	1,034	197,097	7.7	5.4	-6.7	0.4	1.8	2.6	4.2	6.5	9.8	14.0	17.5	22.4	26.4	222.4	040130019
PM2.5	DA24	2nd quarter	1,037	198,683	6.8	4.1	-4.8	0.5	1.8	2.6	4.1	6.0	8.6	11.7	13.9	17.2	20.1	134.2	350130022
PM2.5	DA24	3rd quarter	1,027	202,940	9.7	12.8	-5.1	1.0	2.6	3.5	5.2	7.6	10.9	15.7	21.0	33.7	49.3	824.1	060510005
PM2.5	DA24	4th quarter	1,033	203,036	8.2	6.8	-4.0	0.5	1.9	2.7	4.4	6.8	10.3	15.0	19.0	25.2	30.9	487.4	060510001
PM2.5	MDA1	all	781	695,394	16.3	18.6	-6.4	3.0	5.0	6.1	9.0	13.0	18.9	27.4	36.0	53.0	72.8	1,467.2	060510001
PM2.5	MDA1	1st quarter	737	169,510	16.0	13.1	-3.0	3.0	5.0	6.0	9.0	13.1	19.5	27.9	35.0	46.4	57.9	726.1	040130019
PM2.5	MDA1	2nd quarter	750	172,135	13.8	11.7	-5.0	3.0	5.0	6.0	8.0	11.5	16.3	22.9	28.9	39.6	51.0	896.0	230030014
PM2.5	MDA1	3rd quarter	750	176,262	18.6	27.8	-5.0	4.0	6.0	7.0	9.3	13.2	19.0	29.0	43.0	78.0	122.1	1,467.2	060510001
PM2.5	MDA1	4th quarter	761	177,487	16.9	16.8	-6.4	3.0	5.0	6.1	9.0	13.5	20.0	29.9	38.7	54.0	69.0	1,464.4	060510001
PM10-2.5	DA24	all	202	54,632	5.3	6.2	-3.8	0.0	0.2	0.5	1.4	3.4	6.9	12.2	16.7	22.9	28.9	162.0	060190011
PM10-2.5	DA24	1st quarter	202	15,377	3.5	4.8	-3.0	-0.1	0.1	0.2	0.7	1.8	4.3	8.6	12.4	17.8	22.5	108.1	230190002
PM10-2.5	DA24	2nd quarter	202	15,553	5.7	5.6	-2.6	0.1	0.5	0.9	2.0	4.1	7.4	12.3	16.3	21.3	25.8	96.0	530390003
PM10-2.5	DA24	3rd quarter	199	12,081	7.1	6.8	-3.8	0.4	1.1	1.6	2.9	5.2	9.0	15.0	19.3	25.8	31.3	162.0	060190011
PM10-2.5	DA24	4th quarter	198	11,621	5.2	7.4	-2.6	0.0	0.1	0.3	1.0	2.7	6.4	12.8	19.0	27.3	33.9	106.9	060190011

N.sites = number of sites; N.obs = number of observations; SD = standard deviation; min = minimum; p1, p5, p10, p25, p50, p90, p95, p98, p99 = 1st, 5th, 10th, 25th, 50th, 90th, 95th, 98th, 99th percentiles; max = maximum; max.site = AQS ID number for the monitoring site corresponding to the observation in the max column. 1st quarter = January/February/March; 2nd quarter = April/May/June; 3rd quarter = July/August/September; 4th quarter = October/November/December.

Table 2. National distribution of PM concentrations in $\mu\text{g}/\text{m}^3$ by climate region based on monitoring data from 2019 to 2021. Source: [AQS](#). N.sites = number of sites; N.obs = number of observations; SD = standard deviation; min = minimum; p1, p5, p10, p25, p50, p90, p95, p98, p99 = 1st, 5th, 10th, 25th, 50th, 90th, 95th, 98th, 99th percentiles; max = maximum; max.site = AQS ID number for the monitoring site corresponding to the observation in the max column. Central = Illinois, Indiana, Kentucky, Missouri, Ohio, Tennessee, West Virginia; East North Central = Iowa, Minnesota, Michigan, Wisconsin; Northeast = Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont; Northwest = Alaska, Idaho, Oregon, Washington; South = Arkansas, Kansas, Louisiana, Mississippi, Oklahoma, Texas; Southeast = Alabama, Florida, Georgia, North Carolina, South Carolina, Virginia; Southwest = Arizona, Colorado, New Mexico, Utah; West = California, Hawaii, Nevada; West North Central = Montana, Nebraska, North Dakota, South Dakota, Wyoming.

pollutant	metric	region	N.sites	N.obs	mean	SD	min	p1	p5	p10	p25	p50	p75	p90	p95	p98	p99	max	max.site	
PM10	DA24	all	725	488,628	21.0	25.0	-48.0	2.0	4.0	6.0	10.0	16.0	26.0	41.0	54.0	75.0	97.0	3,956.0	060510011	
PM10	DA24	Central	66	33,203	20.0	13.0	0.0	3.0	6.0	7.0	11.0	16.0	24.0	35.0	44.0	58.0	68.0	205.0	295100093	
PM10	DA24	East North Central	41	22,683	19.0	13.0	0.0	3.0	6.0	8.0	11.0	16.0	24.0	34.0	43.0	56.0	68.0	169.0	191630017	
PM10	DA24	Northeast	57	30,335	14.0	9.0	0.0	2.0	4.0	6.0	8.0	12.0	18.0	24.0	30.0	38.0	45.0	161.0	230031011	
PM10	DA24	Northwest	35	22,647	18.0	27.0	-1.0	1.0	3.0	4.0	8.0	13.0	21.0	34.0	46.0	68.0	94.0	1,012.0	530050002	
PM10	DA24	South	51	23,779	20.0	15.0	0.0	3.0	6.0	8.0	12.0	17.0	24.0	35.0	44.0	57.0	71.0	440.0	201950001	
PM10	DA24	Southeast	75	49,264	17.0	9.0	0.0	3.0	6.0	8.0	11.0	15.0	20.0	26.0	32.0	42.0	51.0	453.0	720330004	
PM10	DA24	Southwest	97	85,641	28.0	26.0	-2.0	3.0	5.0	8.0	13.0	22.0	35.0	51.0	65.0	88.0	110.0	1,228.0	040213014	
PM10	DA24	West	167	120,598	26.0	38.0	-48.0	2.0	4.0	6.0	11.0	19.0	32.0	50.0	68.0	102.0	133.0	3,956.0	060510011	
PM10	DA24	West North Central	136	100,478	16.0	17.0	-3.0	1.0	3.0	4.0	6.0	11.0	20.0	33.0	45.0	62.0	76.0	1,354.0	560370013	
PM10	MDA1	all	440	396,413	59.0	161.0	-6.0	6.0	10.0	14.0	21.0	34.0	61.0	111.0	166.0	280.0	417.0	35,585.0	060510011	
PM10	MDA1	Central	30	27,088	47.0	60.0	2.0	8.0	12.0	15.0	21.0	31.0	51.0	87.0	124.0	196.0	272.0	2,000.0	390170020	
PM10	MDA1	East North Central	24	18,655	44.0	49.0	2.0	8.0	12.0	14.0	20.0	30.0	49.0	84.0	119.0	181.0	234.0	985.0	270531909	
PM10	MDA1	Northeast	27	25,438	31.0	30.0	1.0	6.0	10.0	12.0	16.0	24.0	36.0	57.0	79.0	108.0	139.0	1,278.0	090092123	
PM10	MDA1	Northwest	26	21,924	50.0	82.0	0.0	5.0	8.0	11.0	18.0	31.0	53.0	95.0	139.0	244.0	365.0	4,366.0	530050002	
PM10	MDA1	South	24	19,706	42.0	66.0	1.0	8.0	12.0	15.0	22.0	31.0	47.0	72.0	98.0	154.0	217.0	4,205.0	201950001	
PM10	MDA1	Southeast	56	46,479	34.0	28.0	-6.0	9.0	13.0	15.0	20.0	27.0	38.0	57.0	76.0	108.0	137.0	1,140.0	120952002	
PM10	MDA1	Southwest	70	72,099	94.0	198.0	0.0	8.0	14.0	19.0	32.0	55.0	97.0	173.0	271.0	495.0	766.0	28,161.0	040213014	
PM10	MDA1	West	125	114,882	70.0	240.0	-1.0	7.0	11.0	15.0	24.0	41.0	72.0	127.0	191.0	314.0	475.0	35,585.0	060510011	
PM10	MDA1	West North Central	58	50,142	44.0	65.0	0.0	4.0	6.0	8.0	14.0	26.0	49.0	93.0	141.0	229.0	313.0	1,719.0	560010800	
15	PM2.5	DA24	all	1,067	801,756	8.1	8.1	-6.7	0.5	2.0	2.8	4.5	6.7	9.9	14.1	17.8	24.1	31.0	824.1	060510005
	PM2.5	DA24	Central	164	110,189	8.9	4.7	-4.9	1.9	3.3	4.1	5.7	8.0	11.1	14.8	17.7	21.6	24.8	89.5	180890022
	PM2.5	DA24	East North Central	92	71,955	7.7	5.6	-5.1	0.2	1.8	2.7	4.2	6.5	9.7	13.9	17.3	22.0	25.8	208.7	270072304
	PM2.5	DA24	Northeast	171	141,143	7.5	4.6	-4.0	1.0	2.3	3.1	4.6	6.6	9.3	12.7	15.5	19.8	24.0	129.2	230030014
	PM2.5	DA24	Northwest	51	37,484	8.6	17.3	-3.0	0.4	1.5	2.1	3.4	5.4	9.0	15.5	21.9	34.1	55.4	593.0	410130100
	PM2.5	DA24	South	107	76,755	8.8	5.0	-1.0	1.8	3.2	4.0	5.6	7.8	10.9	14.6	17.6	21.8	25.5	110.6	482010024
PM2.5	DA24	Southeast	163	109,669	7.9	4.1	-4.5	1.5	3.0	3.8	5.2	7.1	9.7	12.9	15.3	18.8	21.7	60.7	132150012	
PM2.5	DA24	Southwest	77	66,204	7.6	6.2	-3.6	1.0	2.0	2.7	4.0	6.0	9.0	14.0	18.6	25.5	32.3	222.4	040130019	
PM2.5	DA24	West	165	134,561	9.1	13.4	-6.7	0.3	1.5	2.2	3.8	6.4	10.4	16.6	23.7	38.3	55.0	824.1	060510005	
PM2.5	DA24	West North Central	75	53,294	5.8	7.2	-4.8	-0.7	0.5	1.1	2.4	4.2	6.9	11.5	16.5	24.9	34.4	276.5	300530018	
PM2.5	MDA1	all	781	695,394	16.3	18.6	-6.4	3.0	5.0	6.1	9.0	13.0	18.9	27.4	36.0	53.0	72.8	1,467.2	060510001	
PM2.5	MDA1	Central	93	87,972	17.4	13.0	-0.4	4.8	6.8	8.1	10.9	15.0	20.7	28.1	34.5	45.2	55.9	622.4	180890022	
PM2.5	MDA1	East North Central	71	61,418	14.9	15.2	-2.0	3.0	4.4	5.7	8.0	12.0	18.0	26.1	33.0	44.0	56.3	876.0	191530030	
PM2.5	MDA1	Northeast	134	132,871	13.9	10.7	-1.8	3.4	5.0	6.0	8.3	12.0	16.9	23.0	28.1	37.0	46.0	916.0	230030014	
PM2.5	MDA1	Northwest	33	27,264	19.1	29.2	-1.0	3.0	5.0	6.0	8.0	12.0	20.0	35.0	51.0	83.9	128.3	943.0	530330080	
PM2.5	MDA1	South	72	65,132	17.3	14.1	-1.0	4.7	6.8	8.0	10.7	14.4	20.0	28.0	35.0	48.9	64.5	621.4	482011039	
PM2.5	MDA1	Southeast	104	86,880	15.1	10.9	-5.0	4.7	6.2	7.2	9.4	13.0	17.7	24.0	29.9	40.7	52.2	727.0	371230001	
PM2.5	MDA1	Southwest	68	63,106	17.1	19.6	-1.1	2.7	4.7	6.0	8.3	12.5	19.5	31.0	41.9	63.0	86.4	836.0	350130022	
PM2.5	MDA1	West	140	120,137	19.3	30.2	-5.0	3.0	5.0	6.0	9.0	13.0	20.7	34.0	48.5	80.0	124.0	1,467.2	060510001	
PM2.5	MDA1	West North Central	65	50,265	14.4	16.3	-6.4	2.0	3.9	4.8	6.7	10.1	17.0	27.0	36.9	55.1	73.0	673.5	301110087	
PM10-2.5	DA24	all	202	54,632	5.3	6.2	-3.8	0.0	0.2	0.5	1.4	3.4	6.9	12.2	16.7	22.9	28.9	162.0	060190011	
PM10-2.5	DA24	Central	13	3,437	5.4	4.7	-0.5	0.2	0.9	1.3	2.3	4.3	6.9	10.8	14.0	19.5	23.3	42.9	390350060	
PM10-2.5	DA24	East North Central	15	4,547	7.4	7.5	-2.0	0.0	0.3	0.6	1.9	5.0	10.3	17.7	22.3	27.9	31.6	74.4	191550009	
PM10-2.5	DA24	Northeast	26	6,624	3.9	3.8	-1.0	0.1	0.4	0.8	1.5	3.1	5.3	7.9	10.0	13.2	16.0	108.1	230190002	
PM10-2.5	DA24	Northwest	25	7,103	3.2	5.4	-3.8	-0.1	0.0	0.2	0.6	1.6	3.7	7.2	11.1	19.3	28.4	96.0	530390003	
PM10-2.5	DA24	South	14	3,420	6.7	5.8	-2.0	0.2	0.8	1.4	2.8	5.3	8.8	13.5	16.9	22.3	27.4	69.8	481090101	
PM10-2.5	DA24	Southeast	21	5,435	5.4	5.0	-3.0	0.1	0.6	1.1	2.3	4.3	6.9	10.6	13.6	19.6	24.2	56.8	130499000	
PM10-2.5	DA24	Southwest	38	10,863	5.8	6.7	-2.6	0.0	0.2	0.5	1.5	3.5	7.8	14.3	18.6	24.9	30.7	100.3	040139997	
PM10-2.5	DA24	West	29	7,746	6.7	8.3	-0.3	0.0	0.3	0.6	1.5	4.2	9.2	15.6	20.2	28.8	36.5	162.0	060190011	
PM10-2.5	DA24	West North Central	20	5,201	3.0	3.8	-0.9	0.0	0.1	0.2	0.6	1.7	3.9	7.5	10.2	15.0	18.2	48.0	300779000	

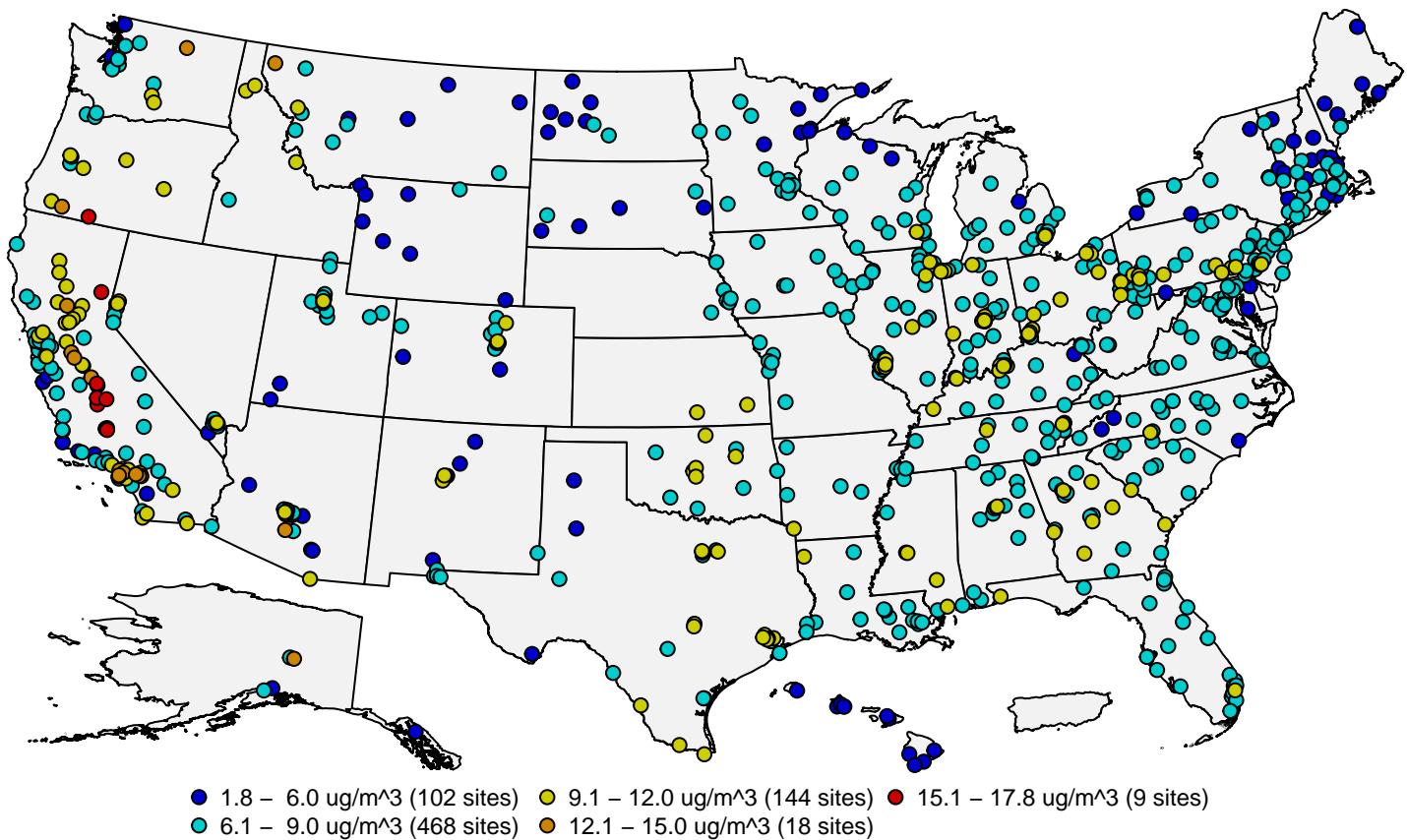


Figure 13: Annual PM_{2.5} design values in $\mu\text{g}/\text{m}^3$ for the 2019-2021 period. Source: [AQS](#).

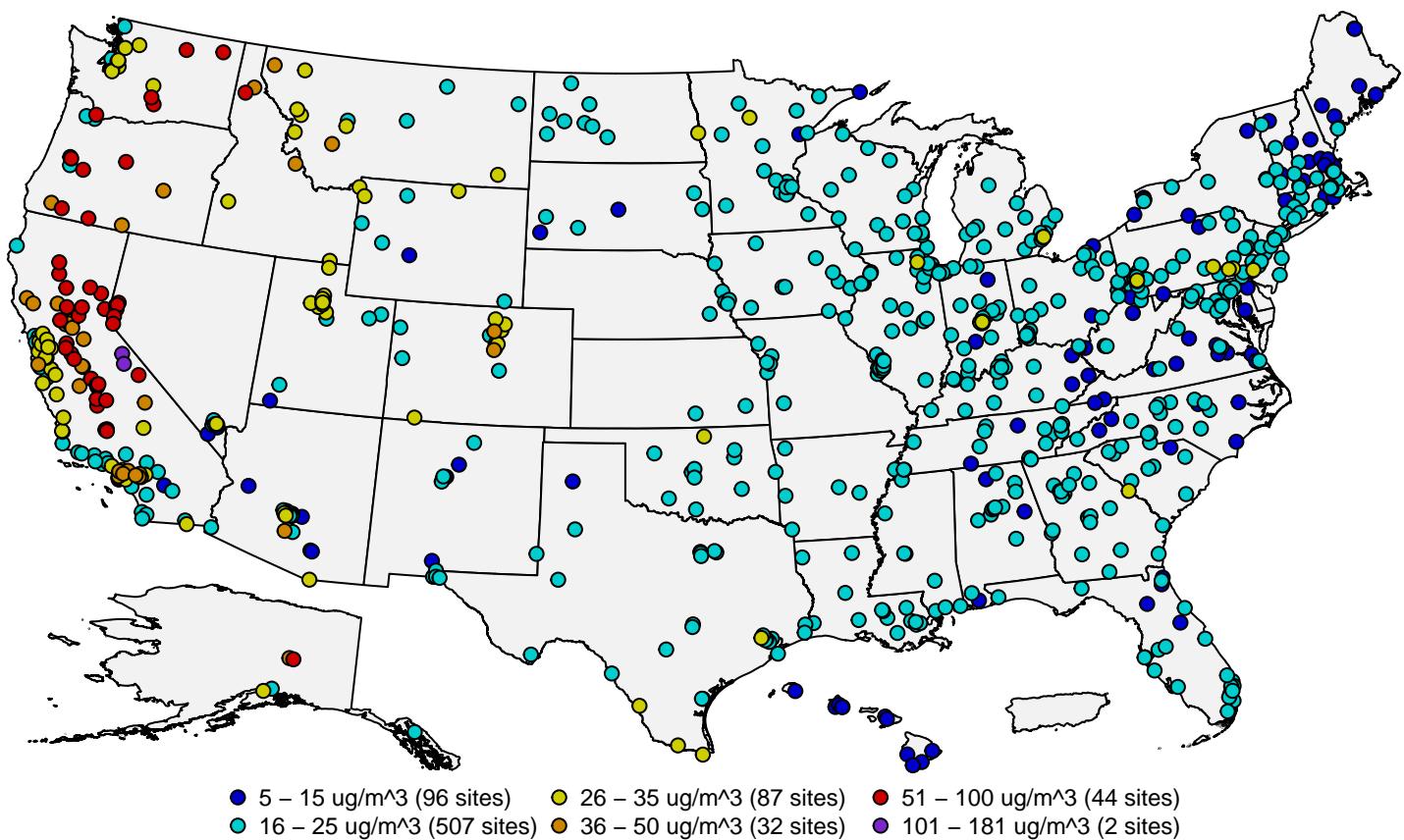


Figure 14: 24-hour PM_{2.5} design values in $\mu\text{g}/\text{m}^3$ for the 2019-2021 period. Source: [AQS](#).

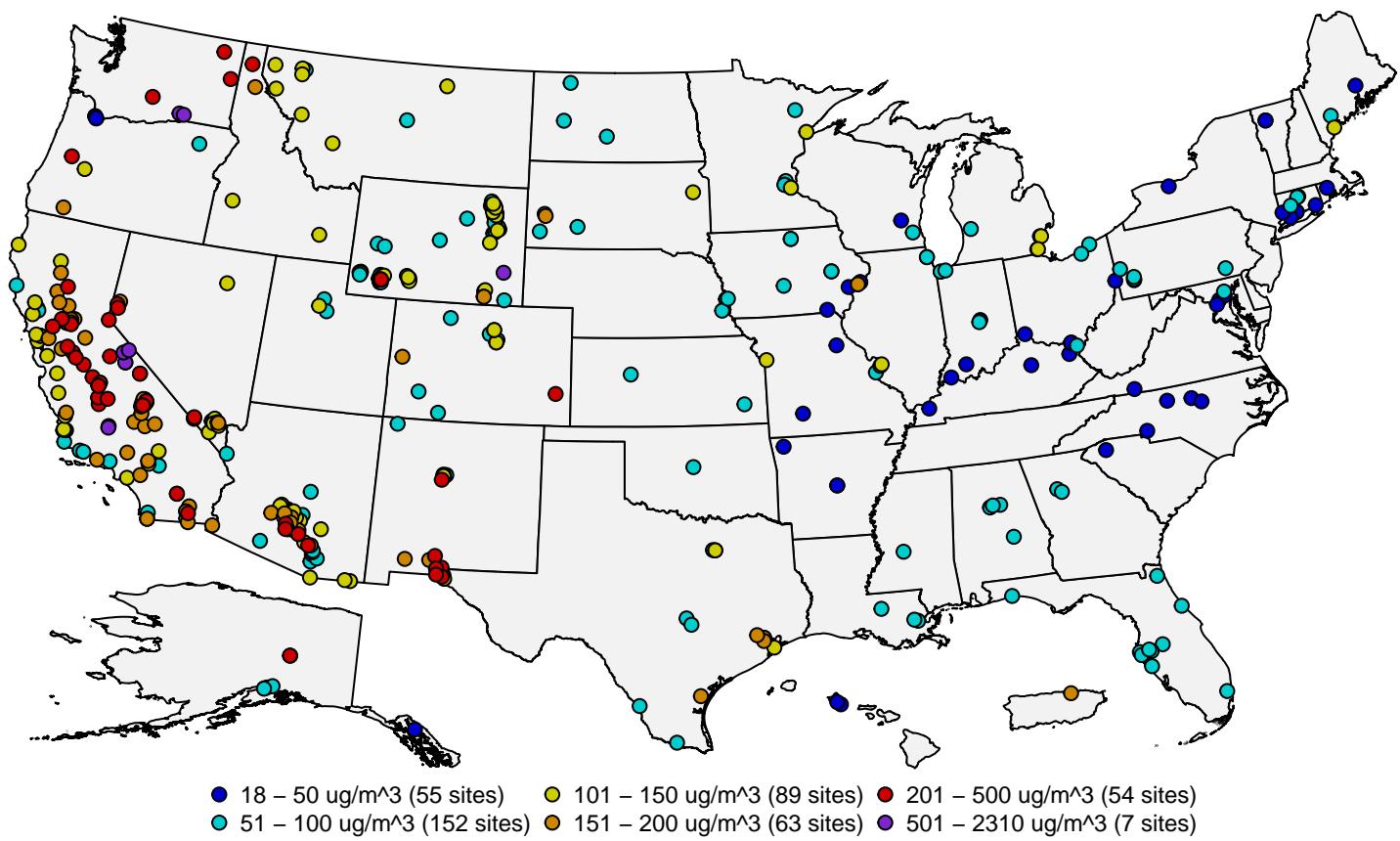


Figure 15: PM₁₀ design concentrations in $\mu\text{g}/\text{m}^3$ for the 2019-2021 period. Source: [AQS](#).

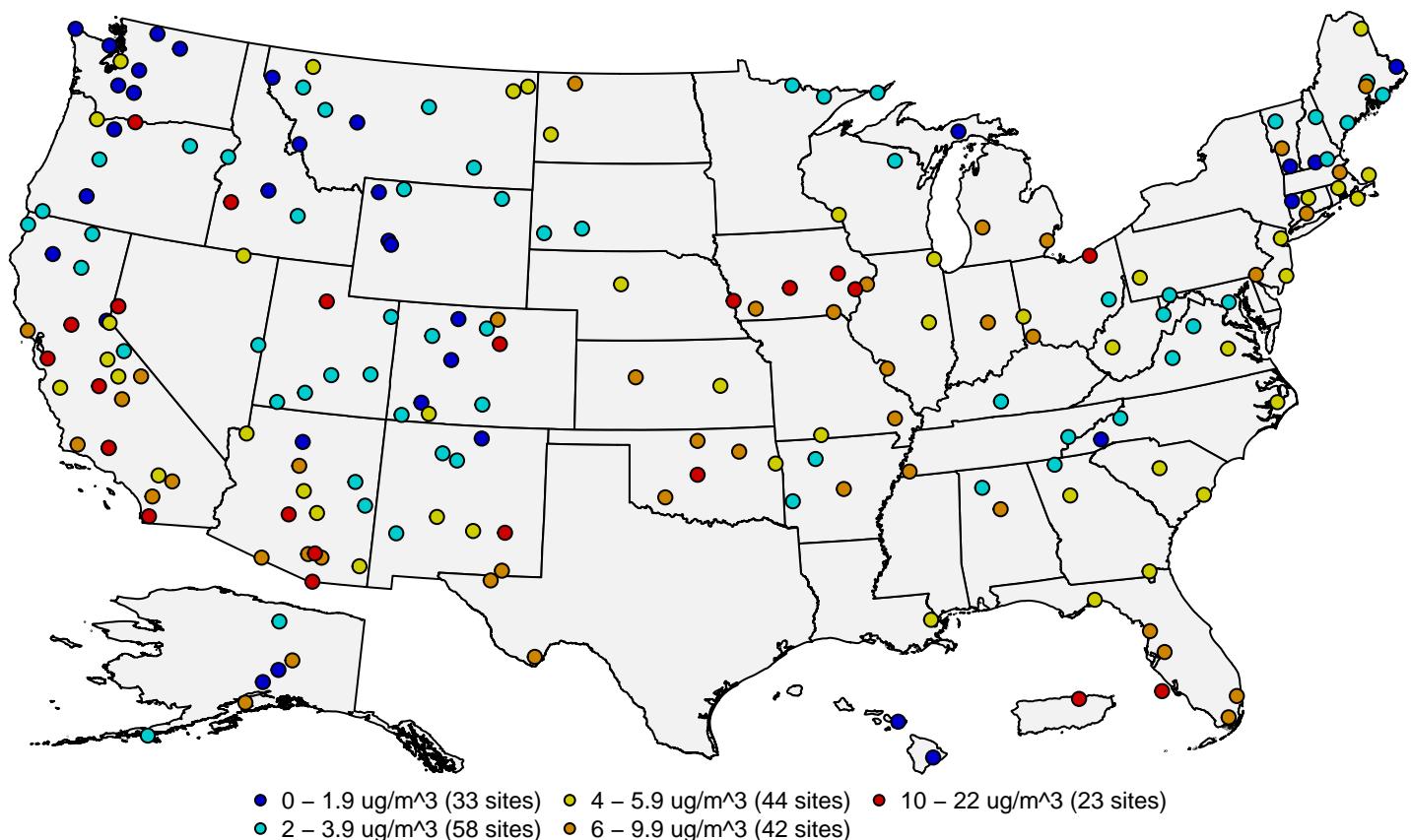


Figure 16: Average PM_{10-2.5} concentrations in $\mu\text{g}/\text{m}^3$ for the 2019-2021 period. Source: [AQS](#).

Figure 17 and Figure 18 show site-level trends in the annual and 24-hour PM_{2.5} design values, respectively, for sites having valid design values in at least 15 of the 20 3-year periods from 2000-2002 through 2019- 2021. The trends were computed using the Thiel-Sen estimator, and tests for significance were computed using the Mann-Kendall test. From this figure it is apparent that most of the U.S. has experienced significant decreasing trends in both the annual and 24-hour PM_{2.5} design values over the past two decades, especially in the eastern U.S., where regional control programs such as the Clean Air Interstate Rule (CAIR) and the Cross-State Air Pollution Rule (CSAPR) have enabled large reductions in NO_x and SO₂ emissions, which led to long-term reductions in secondary PM_{2.5} components. There has been less progress in the western U.S., where most controls to-date have focused on local reductions, and emissions from wildfires in recent years have caused increases in PM_{2.5} concentrations in some areas.

Figure 19 shows site-level trends in PM₁₀ design concentrations for sites having valid design values in at least 17 of the 22 3-year periods from 1998-2000 through 2019-2021, while Figure 20 shows site-level trends in annual average PM_{10-2.5} concentrations for sites having data for at least 13 of the 17 years from 2005 to 2021. The trends in PM₁₀ design concentrations are much more variable than those for PM_{2.5}. While trends in the eastern U.S. are decreasing in most locations, there is no clear pattern in the western U.S., with sites even in close proximity sometimes having trends in opposite directions. Nationally, over half of the sites had no significant trend. The reason for this is apparent from Figure 20, which shows no clear trend in coarse particulate concentrations at the vast majority of U.S. monitoring sites.

Figure 21 shows the national trends in the annual and 24-hour PM_{2.5} design values based on the 381 sites in Figure 17 and the 419 sites in Figure 18. Both the annual and 24-hour design values exhibited steady decreases from 2002 to 2016. In recent years, the median annual design value has remained relatively constant at about 8 $\mu\text{g}/\text{m}^3$ while the 10th and 90th percentile trends have also remained relatively flat at about 6 $\mu\text{g}/\text{m}^3$ and 10 $\mu\text{g}/\text{m}^3$, respectively. The 10th percentile and median of the 24-hour design values, which are based on the annual 98th percentile, have also remained relatively constant at about 15 $\mu\text{g}/\text{m}^3$ and 20 $\mu\text{g}/\text{m}^3$, respectively, since 2016. However, the 90th percentile of the 24-hour design values has increased substantially in the past 5 years largely as a result of increased wildfire activity in the western U.S.

Figure 22 shows the national trend in the PM₁₀ design concentration based on the 438 sites in Figure 19. The national median of the design concentrations has remained flat over the past two decades, though there has been an increase of about 20 $\mu\text{g}/\text{m}^3$ since 2016. The 10th percentile design concentration has decreased slowly over the full trends period, while the 90th percentile has been highly variable, most likely as a result of year-to-year fluctuations in weather conditions and wildfire emissions.

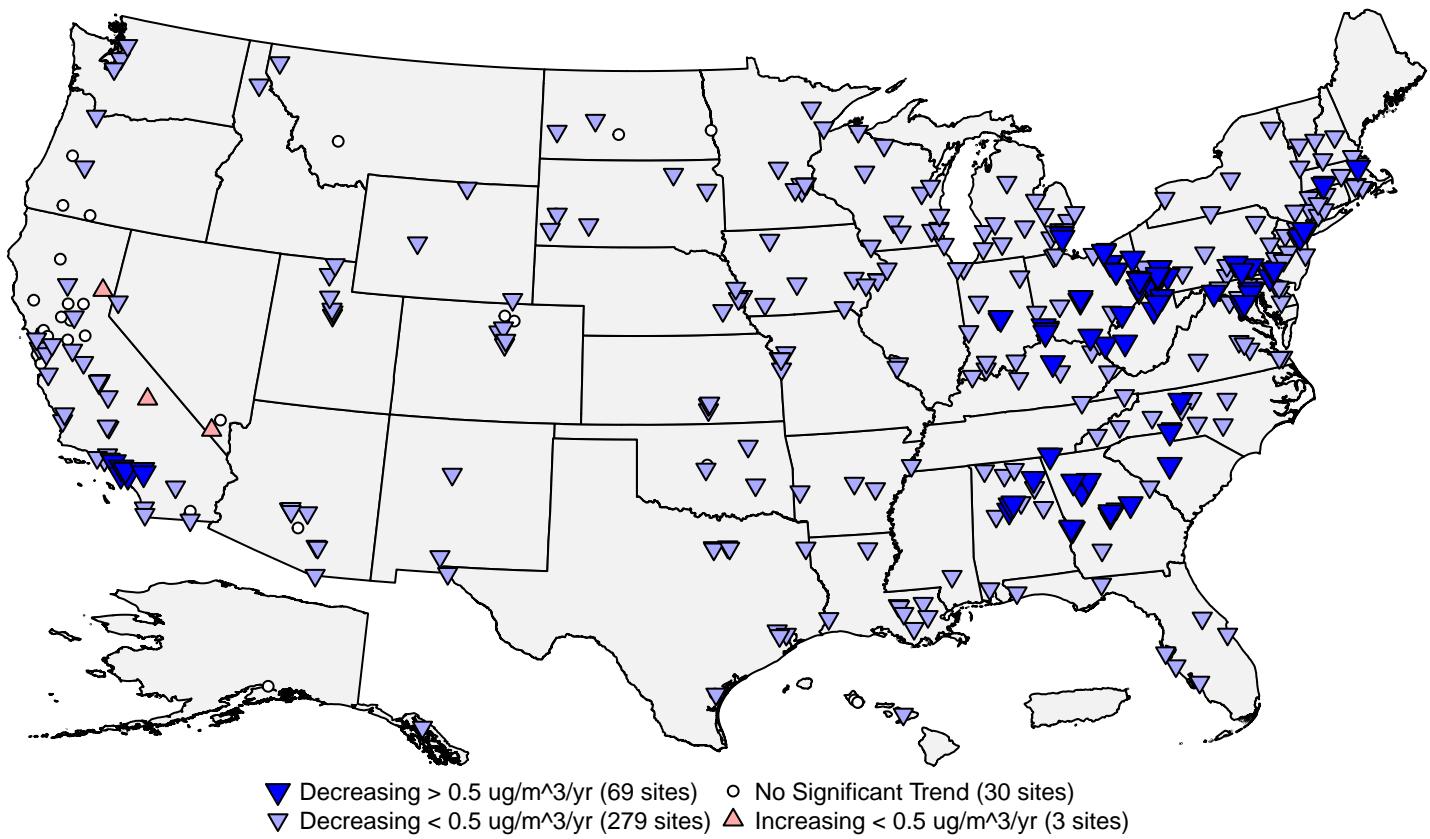


Figure 17: Site-level trends in annual PM_{2.5} design values based on data from 2002 through 2021. **Source:** AQS, trends computed using R statistical software.

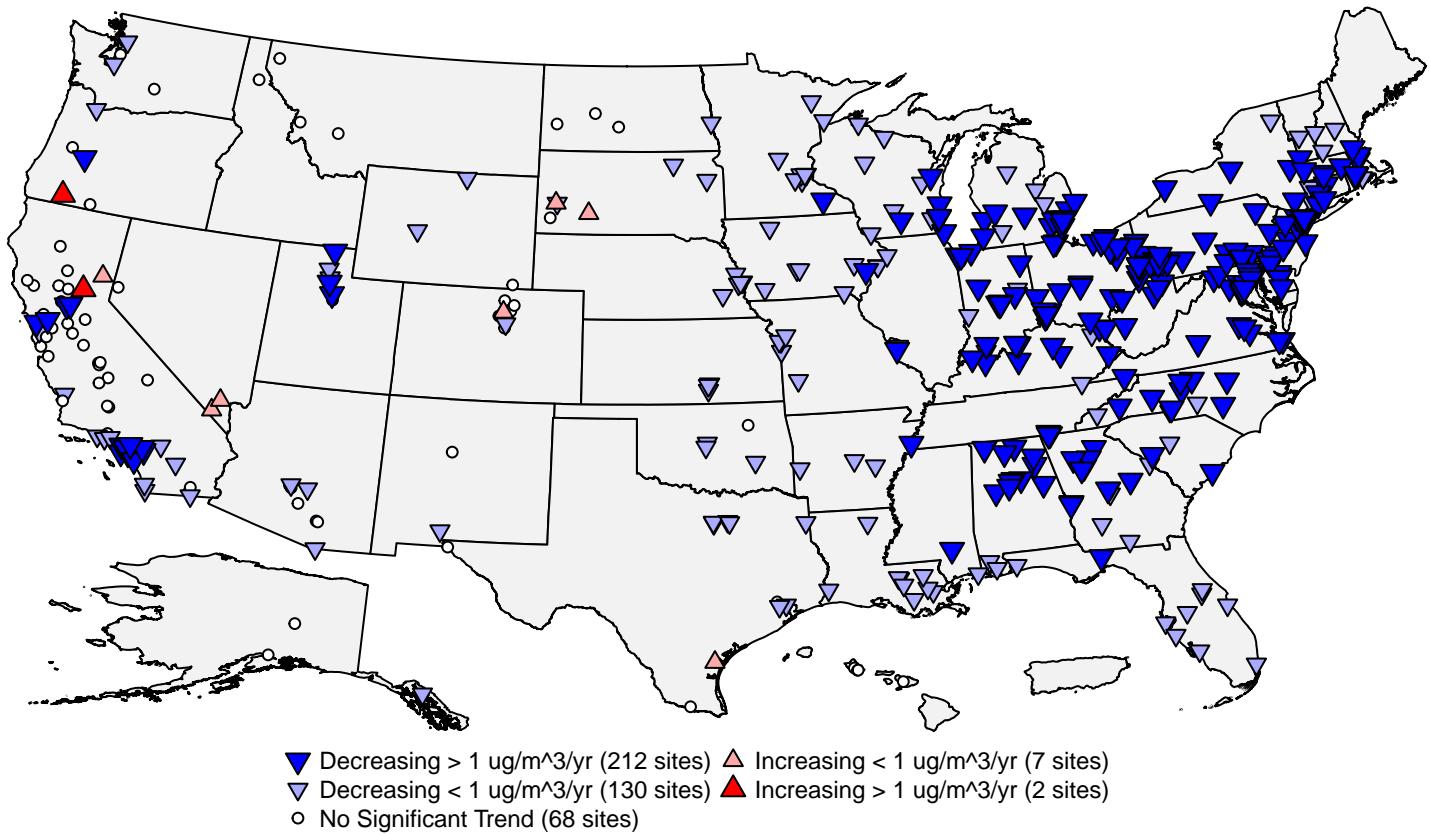


Figure 18: Site-level trends in 24-hour PM_{2.5} design values based on data from 2002 through 2021. **Source:** AQS, trends computed using R statistical software.

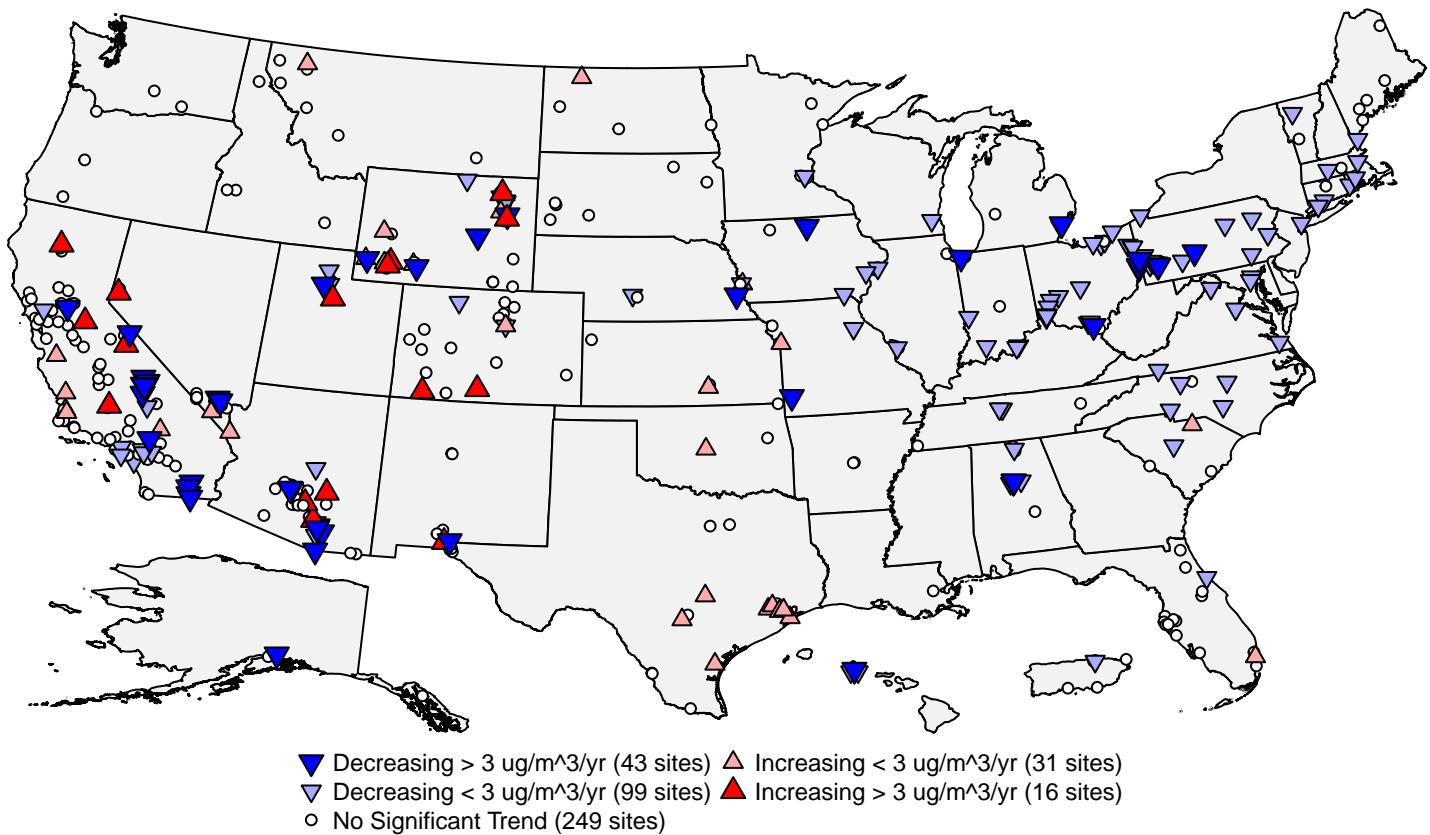


Figure 19: Site-level trends in PM₁₀ design concentrations based on data from 2000 through 2021. **Source:** AQS, trends computed using R statistical software.

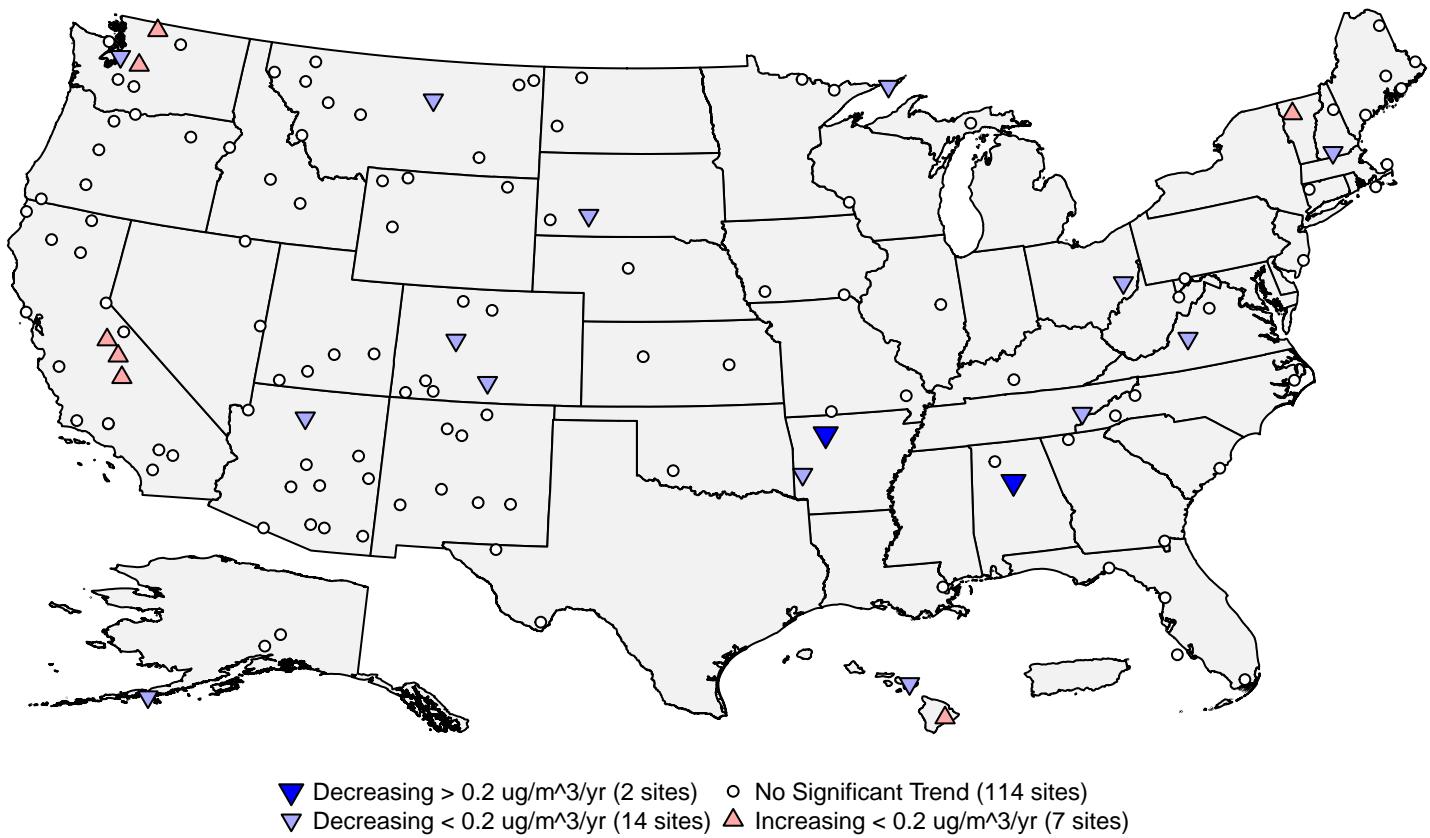


Figure 20: Site-level trends in annual average PM_{10-2.5} concentrations based on data from 2005 through 2021. **Source:** AQS, trends computed using R statistical software.

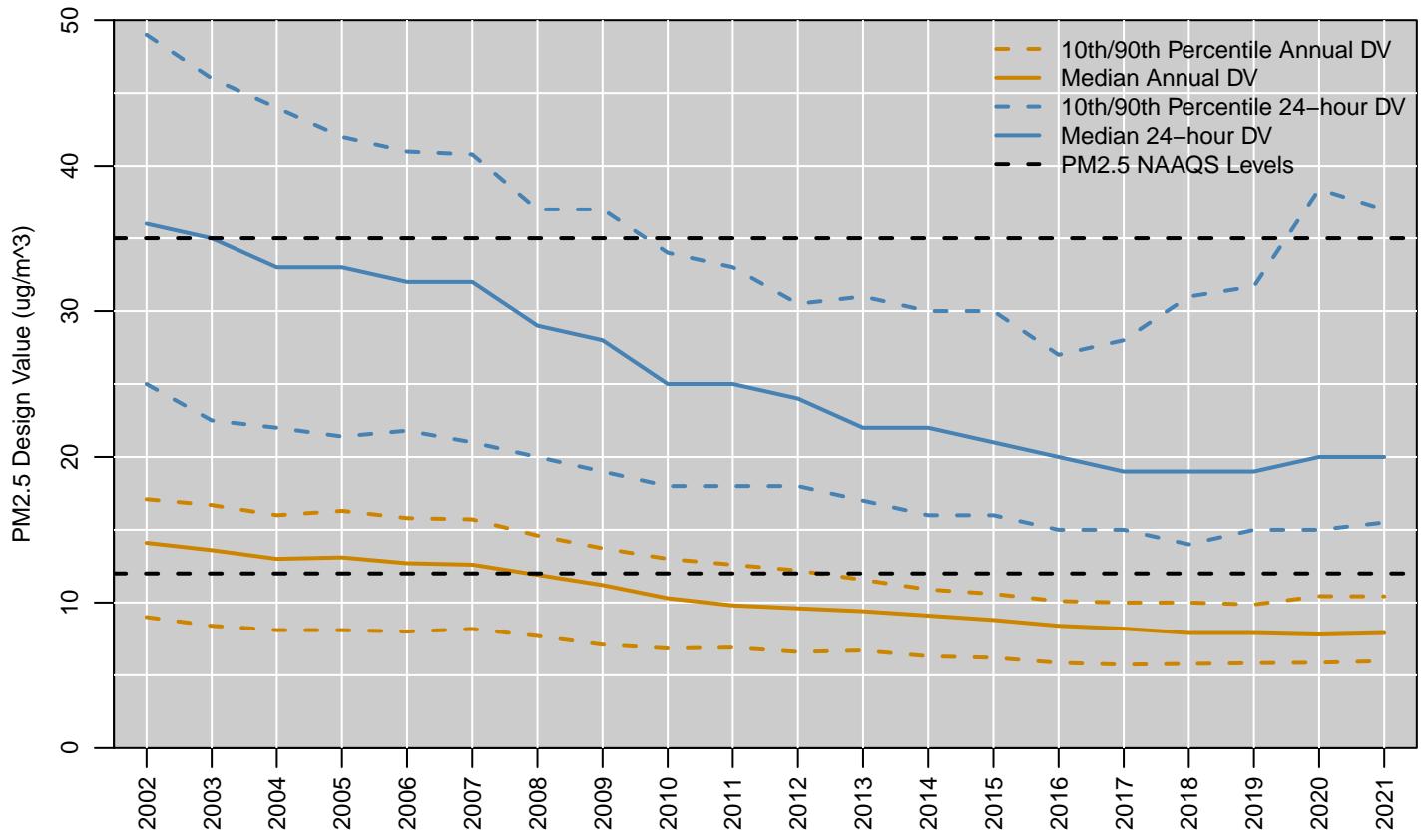


Figure 21: National trend in PM_{2.5} design values in $\mu\text{g}/\text{m}^3$, 2002 to 2021. **Source:** [AQS](#).

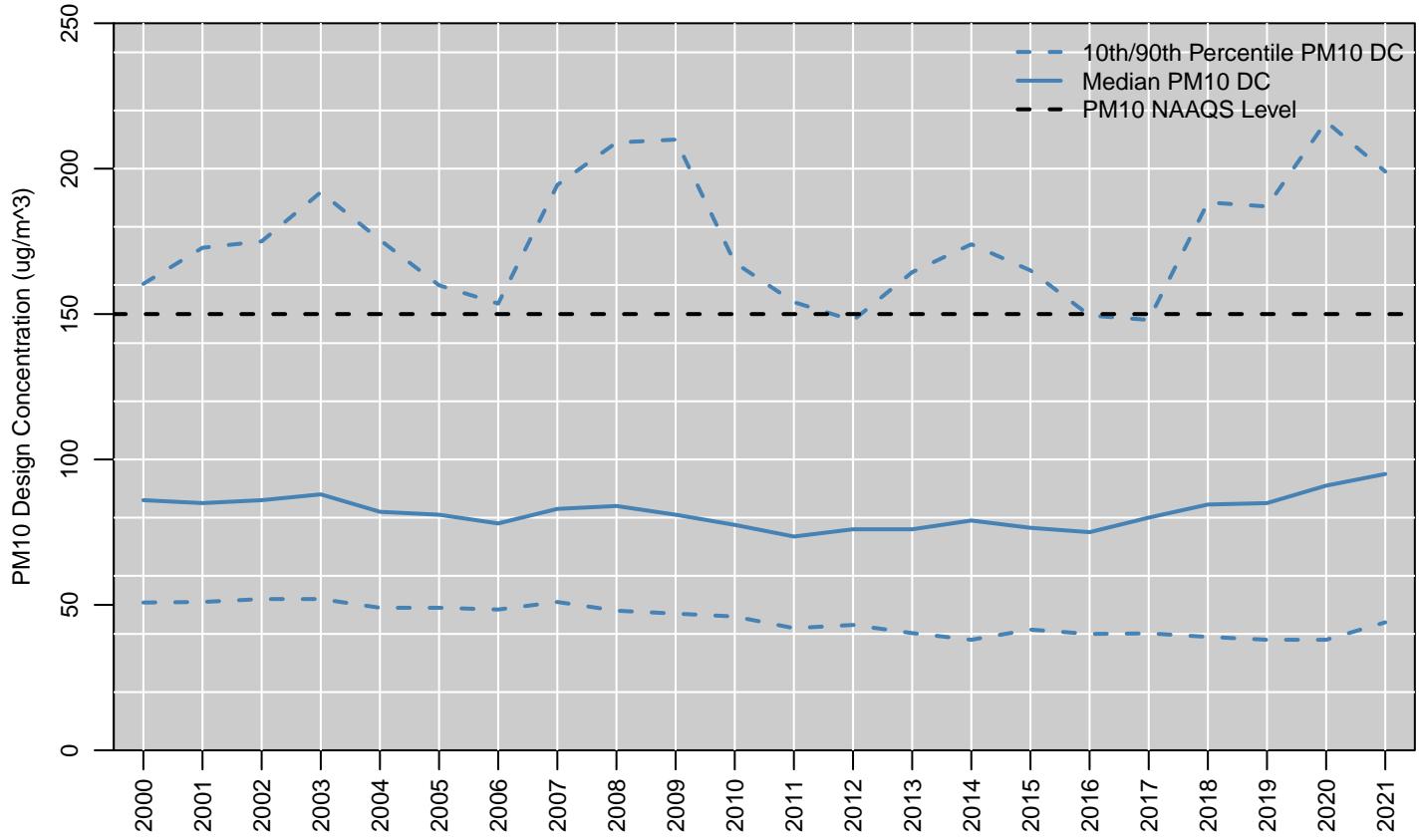


Figure 22: National trend in PM₁₀ design concentrations in $\mu\text{g}/\text{m}^3$, 2000 to 2021. **Source:** [AQS](#).

Figure 23 has a map with pie charts showing the major PM_{2.5} species as a fraction of total mass as measured by selected NCORE, CSN, and IMPROVE sites during the 2019 to 2021 period. The six species shown are sulfates (SO₄), nitrates (NO₃), elemental carbon (EC), organic carbon (OC), crustal material, and sea salt. The pie charts are located at each monitoring site on the map. This figure portrays several aspects of regional variability in PM_{2.5}, for example, large portions of total PM_{2.5} can be attributed to sulfates in the Appalachian region, nitrates in the upper Midwest, OC in the Pacific Northwest, crustal material in the southwest, and sea salt in coastal areas.

Figure 24 shows the average concentrations for four PM_{2.5} components (sulfates, nitrates, EC, and OC) based on data collected during the 2019 to 2021 period. From this figure it is apparent that sulfate concentrations are highest in the Ohio River valley and along the Gulf of Mexico, while nitrate concentrations are highest in the upper Midwest, along the mid-Atlantic urban corridor, and in parts of California. EC and OC are spatially more variable, with the highest sites scattered across the country. EC concentrations tend to be higher near urban areas, especially those with large industrial sources, while OC tends to be more concentrated in rural areas, with impacts from prescribed burns, wildfires, and residential wood smoke.

Figure 25 shows trends in annual average concentrations for sulfates, nitrates, EC, and OC based on sites that collected data for at least 12 out of 16 years from 2006 to 2021⁶. Broad national reductions in SO₂ emissions have resulted in significant reductions in sulfate concentrations nationally and especially in the eastern U.S. Similarly, reductions in NO_X emissions have resulted in significant decreasing trends in nitrates in most of the U.S., especially in areas where nitrate concentrations were historically highest. EC and OC concentrations were more variable, with some sites showing significant decreases and the remaining sites having no clear trend.

⁶Although PM_{2.5} speciation monitoring has been conducted since 2000, the trends in Figure 25 begin in 2006 to avoid losing CSN sites, which experienced a change in EC and OC sampling methods between 2007 and 2010.

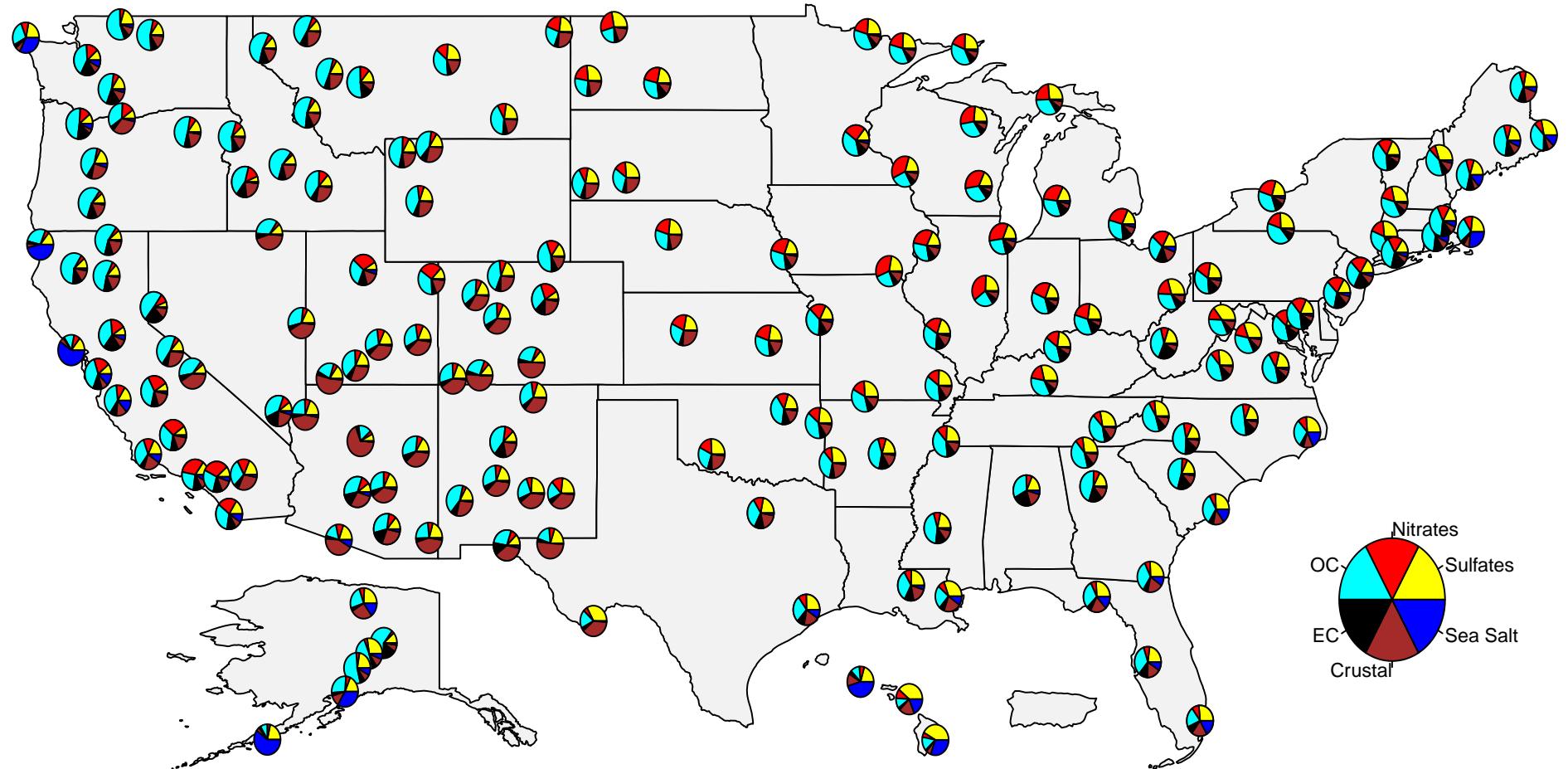


Figure 23: Map showing pie charts of PM_{2.5} component species at selected U.S. monitoring sites based on 2019-2021 data. Source: [AQS](#).

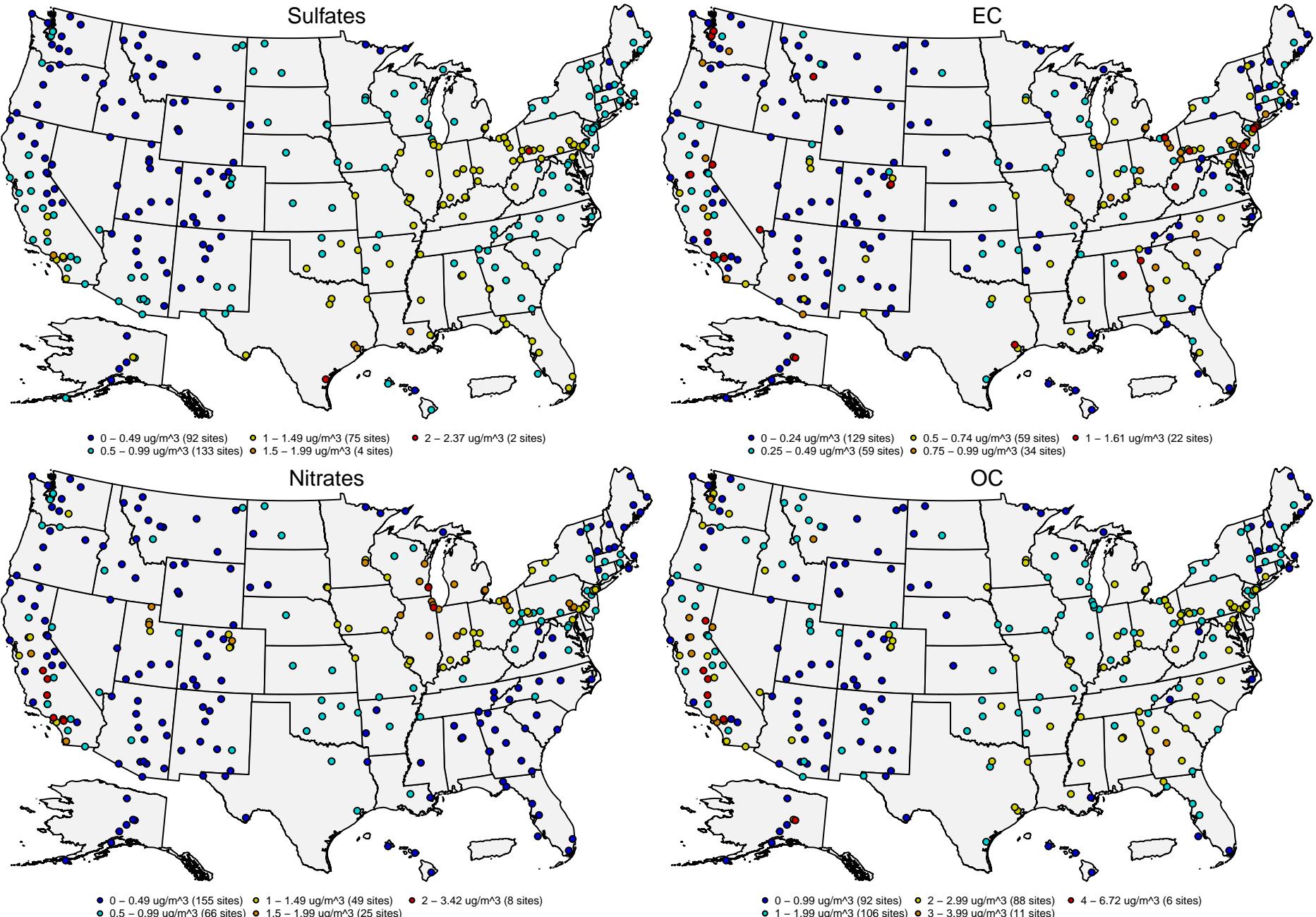


Figure 24: Average concentrations for sulfates (top left), nitrates (bottom left), elemental carbon (top right), and organic carbon (bottom right) at U.S. monitoring sites based on 2019-2021 data. **Source:** [AQS](#).

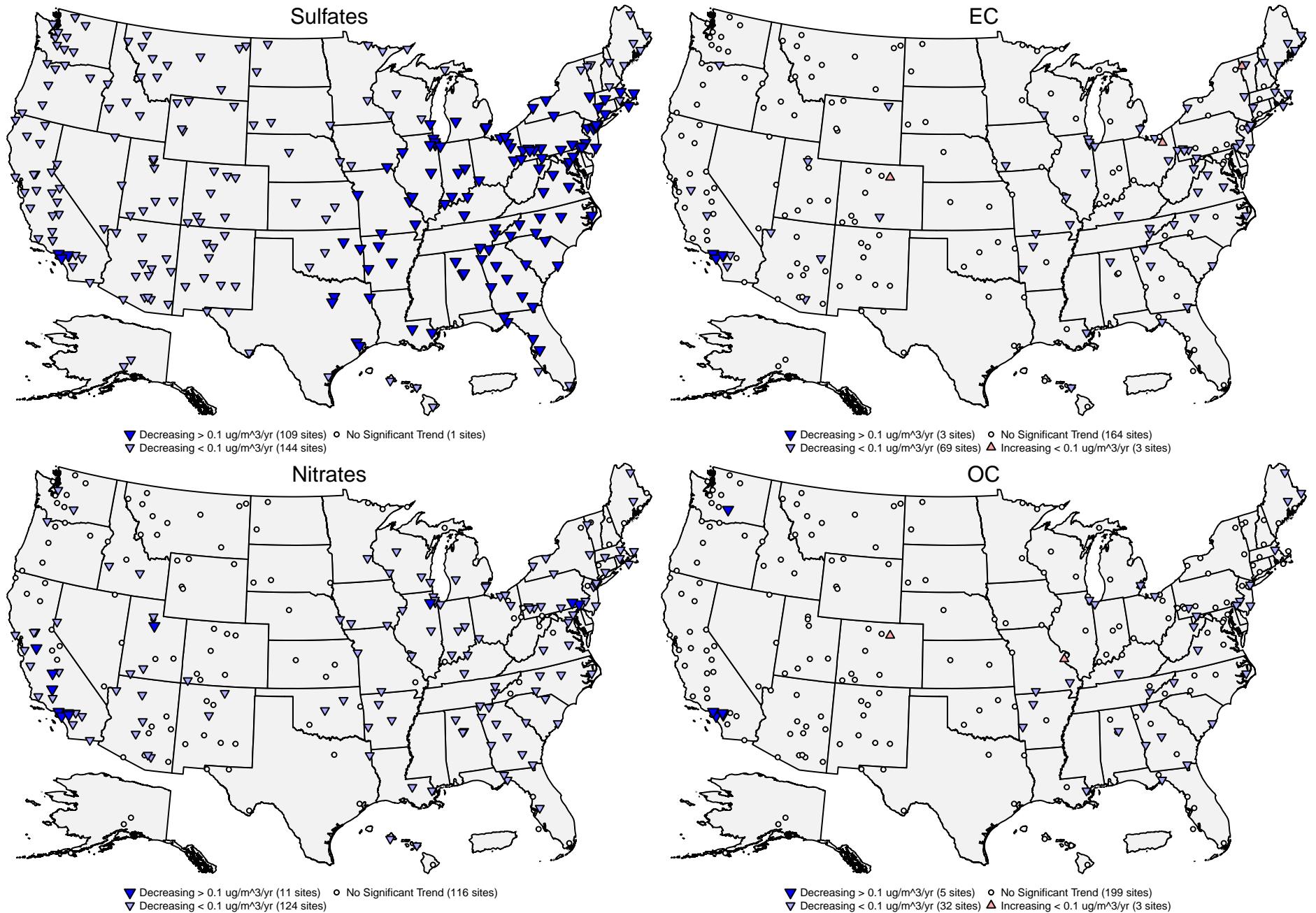


Figure 25: Site-level trends in annual average concentrations for sulfates (top left), nitrates (bottom left), elemental carbon (top right), and organic carbon (bottom right) based on data from 2006 through 2021. **Source:** [AQS](#), trends computed using R statistical software.

Additional Resources

- Particulate Matter (PM) Pollution
- Reviewing National Ambient Air Quality Standards (NAAQS): Scientific and Technical Information
- Air Emissions Inventories
- Ambient Monitoring Technology Information Center (AMTIC)
- Air Quality Design Values
- National Air Quality: Status and Trends of Key Air Pollutants
- Air Data: Air Quality Data Collected at Outdoor Monitors Across the U.S.