

Overview of Sulfur Dioxide (SO₂) Air Quality in the United States

Updated: July 11, 2025

1. Introduction

The 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 oxides of sulfur, hereafter referred to as the sulfur dioxide (SO₂) NAAQS. In previous reviews of the SO₂ NAAQS, this type of information has generally been included in atmospheric sections of the Integrated Science Assessment (ISA) and Policy Assessment (PA) for Sulfur Oxides. This document provides summaries of the air quality emissions and monitoring data to be included in future SO₂ NAAQS review supporting documents and will be updated at regular intervals as new data becomes available.

This document follows an organizational structure similar to that of the atmospheric sections of past SO₂ NAAQS review supporting documents. The subsequent sections are as follows: 2. Atmospheric Chemistry; 3. Sources and Emissions of SO₂; 4. Ambient Air Monitoring Requirements and Monitoring Networks; 5. Data Handling Conventions and Computations for Determining Whether the Standards are Met; and 6. SO₂ Concentrations Measured at Ambient Air Monitoring Sites Across the U.S.

2. Atmospheric Chemistry

Sulfur oxides are a group of closely related sulfur-containing gas-phase compounds [e.g., sulfur dioxide (SO₂), sulfur monoxide (SO), disulfur monoxide (S₂O), and sulfur trioxide (SO₃)]. Sulfur oxides also appear in the particle phase, as components of particulate matter (PM). The current indicator for the sulfur oxides NAAQS is SO₂, because, of the sulfur oxides, SO₂ is the most abundant in the atmosphere, the most important in atmospheric chemistry, and the one most clearly linked to human health effects. Sulfur dioxide is both a primary gas-phase pollutant (when formed during fuel combustion) and a secondary pollutant (when formed as the product of atmospheric gas- or aqueous-phase oxidation of reduced sulfur compounds, called sulfides).

The important gas-phase sulfur oxides in the troposphere are SO₂ and sulfuric acid (H₂SO₄). SO₃ is known to be present in the emissions of coal-fired power plants, factories, and refineries, but it reacts with water vapor in the stacks or immediately after release into the atmosphere within seconds to form H₂SO₄, which makes it difficult to detect in the ambient atmosphere. Gas-phase H₂SO₄, the product of both SO₂ and SO₃ oxidation, quickly condenses onto existing atmospheric particles or participates in new particle formation. Of these species, only SO₂ is present at concentrations in the gas phase that are relevant for chemistry in the atmospheric boundary layer and troposphere, and for human exposures. Other sulfur oxides, including both S(IV) and S(VI) compounds, appear in the atmosphere due to direct emissions and as the products of the oxidation of more reduced forms of sulfur. Gas-phase precursors to SO₂ include sulfides and partially oxidized sulfur-containing organic compounds.

The global atmospheric lifetime of SO₂ with respect to reactions with the OH radical in the troposphere is 7.2 days. The rate constant for the reaction between SO₂ and NO₃ radical is too small to be important in lowering SO₂ concentrations at urban or regional scales. The same is true for the reaction between SO₂ and the hydroperoxyl (HO₂) radical. In the stepwise oxidation of SO₂ by OH, SO₂ is oxidized to form SO₃, taking the sulfur atom from the S(IV) to S(VI) oxidation state, producing the bisulfite radical (HSO₃): SO₂ + OH + M → HSO₃ + M, where M is an unreactive gas molecule that absorbs excess destabilizing energy from the SO₂-OH transition state. This reaction is followed by HSO₃ + O₂ → SO₃ + HO₂. An alternative route involves a stabilized Criegee intermediate (sCI): SO₂ + sCI → SO₃ + products. The SO₃ that is generated by either oxidation mechanism (i.e., reaction with OH or via the Criegee reaction) is highly reactive. Water vapor is sufficiently abundant in the troposphere to ensure that SO₃ is quickly converted to gas-phase sulfuric acid: SO₃ + H₂O + M → H₂SO₄ + M. Because H₂SO₄ is extremely water soluble, gaseous H₂SO₄ will rapidly dissolve into the aqueous phase of aerosol particles and cloud droplets. Conversion from SO₂ to H₂SO₄ increases with increasing relative humidity and O₃ levels.

The basic mechanism of the aqueous-phase oxidation of SO₂ involves dissolution of SO₂ followed by the formation and dissociation of sulfurous acid (H₂SO₃). Additionally, in environments where ambient ammonia (NH₃) is abundant, SO₂ is subject to fast removal by cloud and fog droplets and ultimately forms ammonium sulfate [(NH₄)₂SO₄]. In the same way

that it is removed from the gas phase by dissolving into cloud droplets, SO₂ can be removed by dry deposition onto wet surfaces. Scavenging by rain (wet deposition) serves as another removal route. Modeling studies have shown that slightly more than half of SO₂ is lost by gas- and aqueous-phase oxidation, with the remainder of SO₂ loss accounted for by wet and dry deposition.

Sulfur dioxide is also known to adhere to and then react on dust particles. For some mineral compositions, SO₂ uptake on dust particles is sensitive to relative humidity, the mineral composition of the particle, and the availability of H₂O₂, the relevant oxidant. Once SO₂ is oxidized to H₂SO₄ on the particle surface, glyoxal, one of the most prevalent organic compounds in the atmosphere, will adhere to the surface and react to form oligomers and organosulfate compounds. This process is enhanced under high humidity conditions.

3. Sources and Emissions of SO₂

Sulfur is present to some degree in all fossil fuels, especially coal, and occurs as reduced organosulfur compounds. Coal also contains sulfur in mineral form (pyrite or other metallo-sulfur minerals) and in elemental form. Of the most common types of coal (anthracite, bituminous, subbituminous, and lignite), sulfur content varies between 0.4 and 4% by mass. Sulfur in fossil fuels is almost entirely converted to SO₂ during combustion, making accurate estimates of SO₂ combustion emissions possible based on fuel composition and combustion rates.

Fossil fuel combustion is the main anthropogenic source of primary SO₂, while volcanoes and wildfires are the main natural sources of primary SO₂. Anthropogenic SO₂ emissions originate primarily from point sources, including coal-fired electricity generating units (EGUs) and other industrial facilities. Industrial chemical and pulp and paper production, smelter and steel mill operations, natural biological activity (plants, fungi, and prokaryotes), and volcanoes are among many sources of reduced sulfur compounds that contribute, through various oxidation reactions in the atmosphere, to the formation of secondary SO₂. In addition to volcanic and other geologic SO₂ emissions, naturally occurring SO₂ is derived from the oxidation of sulfides emitted by low flux “area” sources, such as the oceans and moist soils. The mass of sulfur released into the environment by anthropogenic sources is comparable to natural sources.

Other anthropogenic sources of SO₂ emissions include industrial fuel combustion, other industrial processes, commercial marine vessels, and agricultural and prescribed fires. While electricity generation is the dominant industry sector contributing to SO₂ emissions on a national scale, other sectors can also have a significant influence on local air quality. Large emissions facilities other than EGUs that may substantially impact local air quality include copper smelters, pulp and paper mills, cement plants, iron and steel mills, petroleum refineries, and chemical processing plants.

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 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 vary 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 1 shows the main sources contributing to total SO₂ emissions in the U.S. in 2020. Coal combustion contributed 48% to total SO₂ emissions while combustion of other fossil fuels contributed only 9%. Industrial processes contributed 27% to total SO₂ emissions, while the remaining emissions came from fires and other sources.

Figure 2 shows the SO₂ emissions density in tons/mi²/year for each U.S. county based on the 2020 NEI. The majority of SO₂ emissions tend to be located near large point sources such as coal-fired EGUs or large industrial facilities. Counties near urban areas also tend to have higher SO₂ emissions due to the higher concentration of industrial facilities. Counties in rural areas may also have higher emissions due to oil and gas extraction or fires.

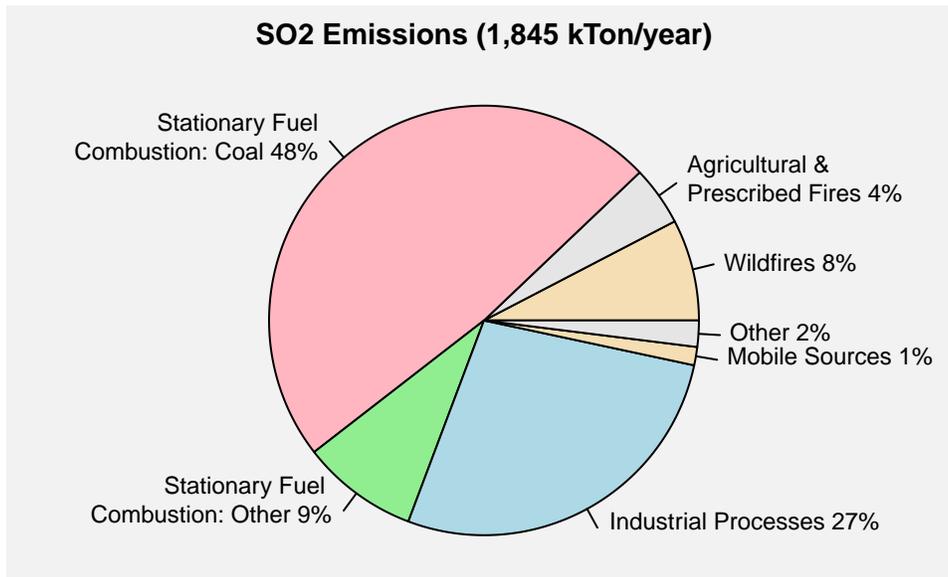


Figure 1. U.S. SO₂ emissions by sector. **Source:** 2020 NEI.

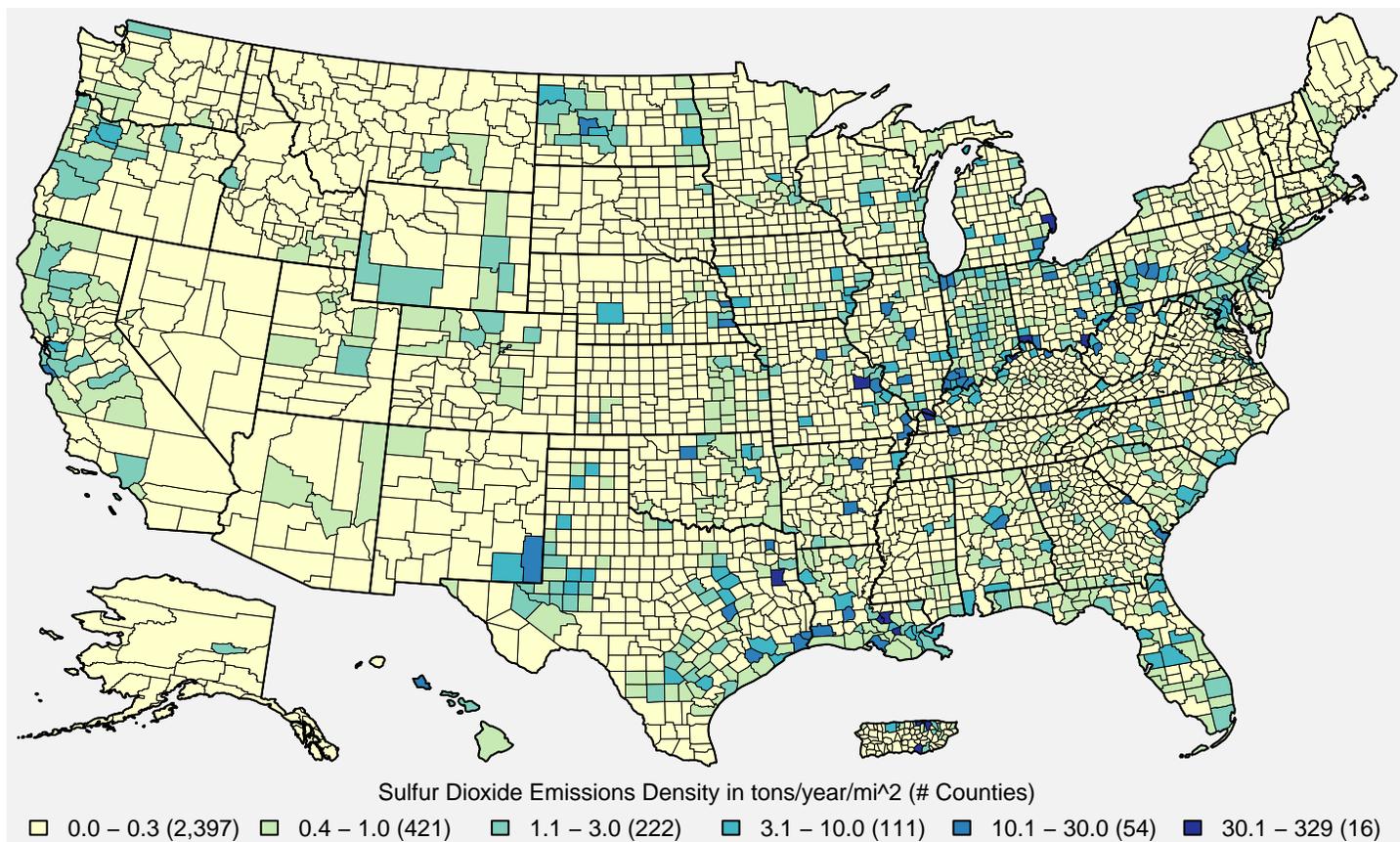


Figure 2. U.S. county-level SO₂ emissions density estimates in tons/year/mi². **Source:** 2020 NEI

Figure 3 shows the national SO₂ emissions trends from 2002 to 2024¹. Declines in SO₂ emissions are likely related to the implementation of national control programs developed under the Clean Air Act Amendments of 1990, including Phase I and II of the Acid Rain Program, the Clean Air Interstate Rule, the Cross-State Air Pollution Rule, and the adoption of low sulfur diesel fuel standards. An additional factor is changes in market conditions, such as the reduction of the use of coal in energy generation. These changes have resulted in a 89% decrease in SO₂ emissions from 2002 to 2024, including reductions of 94% in emissions from EGUs and 97% in emissions from mobile sources.

¹Data for Figure 3 come from the EPA's [Air Pollutant Emissions Trends Data](#). Note that emissions for some sectors are interpolated between inventory years, and the emissions for some sectors are held constant beyond the most recent inventory year (for details, see the "Development of Data" table in the [national emissions trends data file](#). For the purposes of this document, wildfires are considered to be natural emissions and thus are not included in Figure 3.

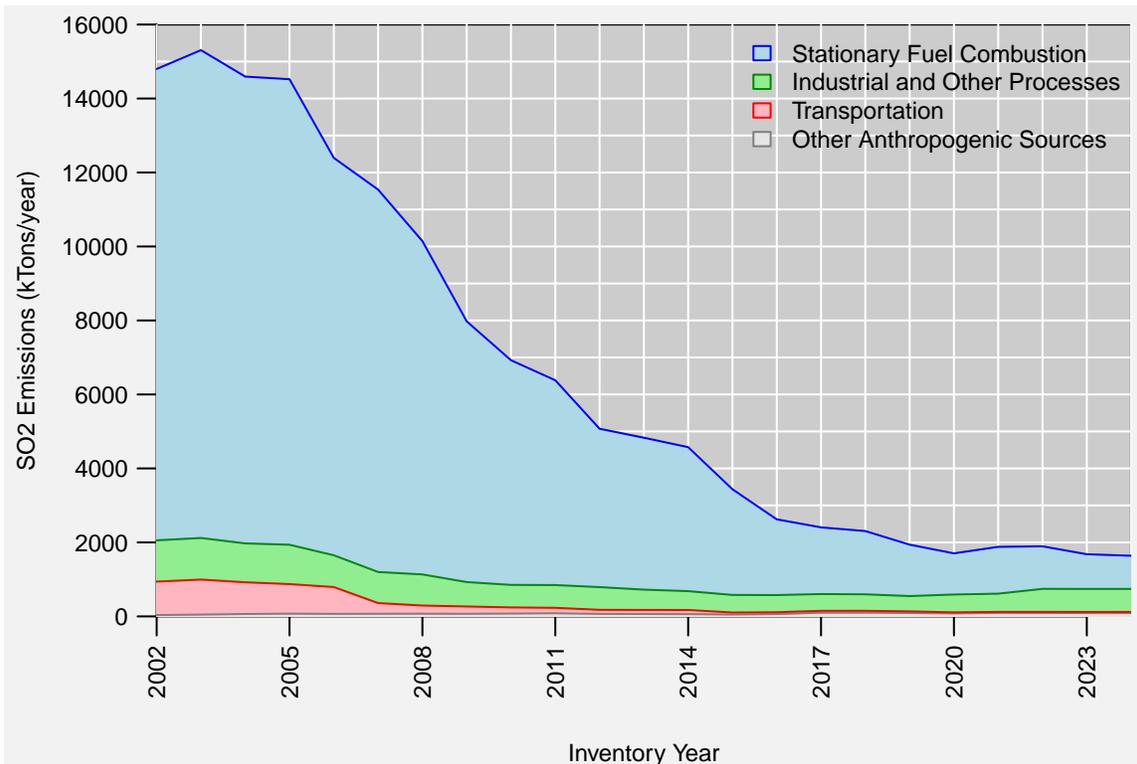


Figure 3. U.S. anthropogenic SO₂ emissions trend, 2002-2024. **Source:** EPA’s Air Pollutant Emissions Trends Data

4. Ambient Air Monitoring Requirements and Monitoring Networks

Ambient SO₂ concentrations are measured by monitoring networks operated by State, Local, and Tribal air agencies, which are typically funded in part by the EPA. Measurements are made using ultraviolet fluorescence (UVF) instruments, which are designated as Federal Reference Methods (FRMs) or Federal Equivalent Methods (FEMs) and the data are reported to EPA as hourly concentrations and either the maximum 5-minute concentration for each hour or twelve 5-minute average concentrations for each hour. There were 442 monitoring sites reporting hourly SO₂ concentration data to the EPA during the 2022-2024 period. The locations of these monitoring sites are shown in Figure 4.

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 over 75% of all SO₂ monitoring sites. An important subset of SLAMS sites is the [NCore multipollutant monitoring network](#), which was designed to collect consistent measurements of criteria pollutants for trends and NAAQS compliance purposes. The NCore 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 NCore station.

In 2015, the EPA finalized the [Data Requirements Rule \(DRR\)](#), which required States to monitor or model ambient SO₂ levels in areas with stationary sources of SO₂ emissions of over 2,000 tons per year. The EPA identified over 300 sources meeting these criteria, and the States chose to set up ambient monitoring sites to assess compliance with the SO₂ NAAQS near 71 of these sources. These monitors were required to begin operating by January 1, 2017 and collect data through the end of 2019 to show compliance with the SO₂ NAAQS. Some of these monitors are operated by the States as SLAMS monitors, while others are operated by the industrial sources, which are shown as yellow dots on the map in Figure 4.

Finally, there are also a number of Special Purpose Monitoring Stations (SPMs), which are not required but are often operated by air agencies for short periods of time (i.e., less than 3 years) to collect data for human health and welfare studies, as well as other types of monitoring sites, including monitors operated by federal agencies and tribal governments. The SPMs are typically not used to assess compliance with the NAAQS.

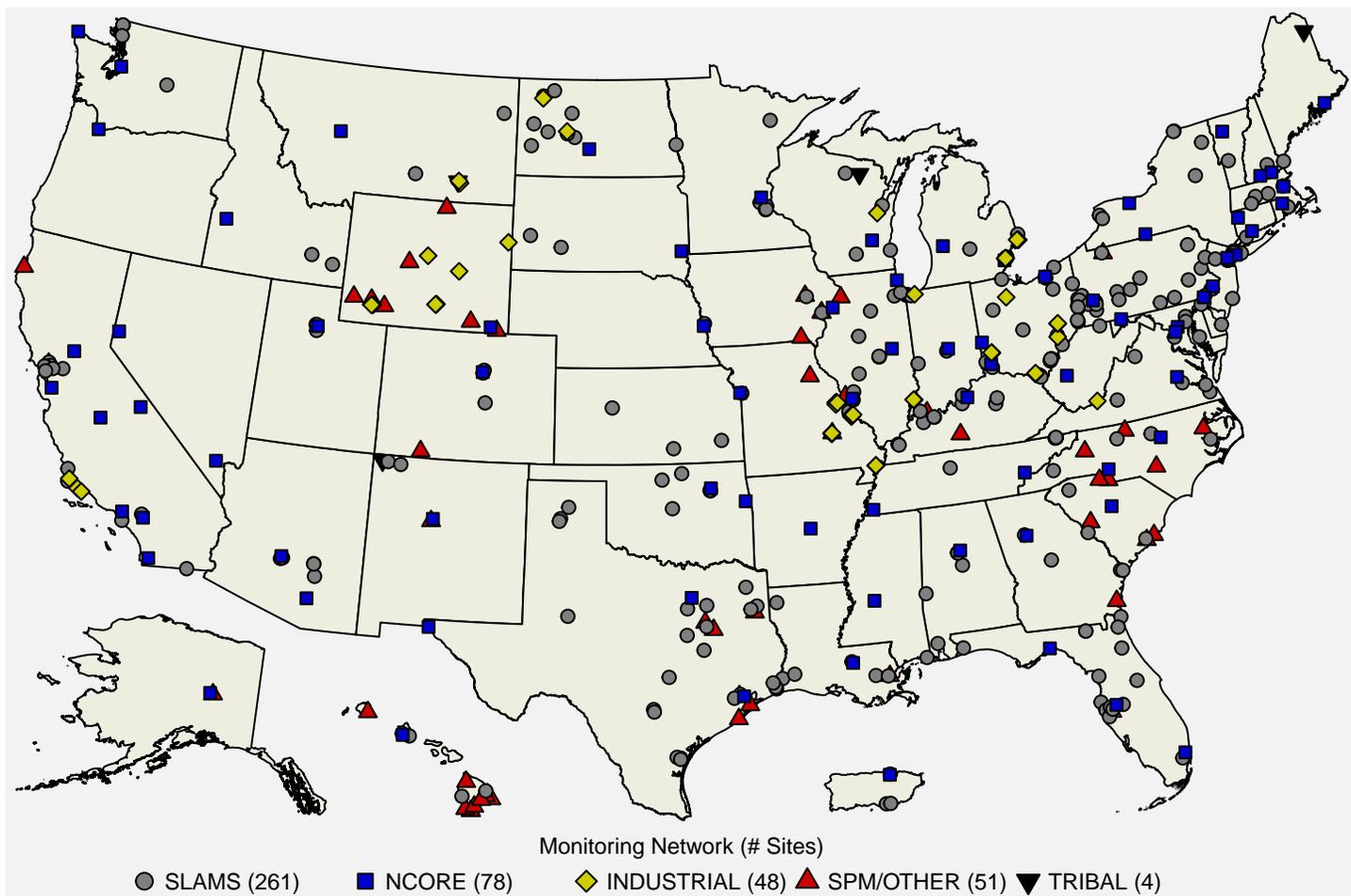


Figure 4: Map of U.S. SO₂ monitoring sites reporting data to the EPA during the 2022-2024 period. **Source:** AQS.

To provide an assessment of data quality, monitoring agencies must perform quality assurance (QA) checks at least once every two weeks to derive estimates of precision and bias for SO₂ and the other gaseous criteria pollutant measurements using calibration gas. For SO₂ monitors, the data quality goal for precision and bias is 10 percent. Ambient air quality data and associated QA data are reported to the EPA via the [Air Quality System \(AQS\)](#).² Data are reported quarterly and must be submitted to AQS within 90 days after the end of each calendar quarter (i.e. Jan/Feb/Mar, Apr/May/Jun, Jul/Aug/Sep, Oct/Nov/Dec). Additionally, each monitoring agency is required to certify all FRM/FEM data that is submitted to AQS annually, taking into consideration any QA findings, and a data certification letter must be sent to the EPA Regional Administrator by May 1st of the following year.

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 primary SO₂ NAAQS, established in 2010, has a 1-hour averaging time, and the secondary SO₂ NAAQS, established in 2024, has an annual averaging time. The procedures for calculating design values for the primary and secondary SO₂ NAAQS are detailed in [Appendix T to 40 CFR Part 50](#) and are summarized below.

Hourly SO₂ measurement data collected at an ambient air monitoring site using FRMs or FEMs, meeting all applicable requirements in 40 CFR Part 58, and reported to AQS in parts per billion (ppb) with decimal digits after the first decimal place truncated are used in design value calculations. If multiple monitors collect measurements at the same site, one monitor is designated as the primary monitor. Measurement data collected with the primary monitor are used to calculate the design value, and may be supplemented with data from collocated monitors whenever data is not available for the primary monitor.

²Quality assurance requirements for monitors used in evaluations of the NAAQS are provided in [Appendix A to 40 CFR Part 58](#). Annual summary reports of precision and bias can be obtained for each monitoring site at the EPA's [Air Data website](#).

For the primary SO₂ NAAQS, the maximum hourly concentration is determined for each day (i.e., the “daily maximum value”) in a given 3-year period. For each year, the 99th percentile of the daily maximum values is determined, and the design value is the average of the three annual 99th percentile values, rounded to the nearest integer in ppb. The primary SO₂ NAAQS is met when the design value is less than or equal to 75 ppb, the level of the NAAQS.

For the secondary SO₂ NAAQS, daily mean concentration values are calculated from the hourly measurements for each day in a given 3-year period. For each year, the annual mean of the daily mean values is determined, and the design value is the average of the three annual mean values, rounded to the nearest integer in ppb. The secondary SO₂ NAAQS is met when the design value is less than or equal to 10 ppb, the level of the NAAQS.

In addition, the design value must meet data completeness requirements in order to be considered valid. Specifically, a sample day is considered complete when at least 18 hourly measurements are reported. For each calendar quarter, the quarter is considered complete if at least 75% of the days in the quarter have complete data. The primary and secondary SO₂ design values are considered complete when all 12 calendar quarters in the 3-year period have complete data. In addition, there are data substitution tests specified in Appendix T to 40 CFR Part 50 which may be used to yield a valid design value above or below the NAAQS, in the event that a site falls short of the minimum data completeness requirements.

6. SO₂ Concentrations Measured at Ambient Air Monitoring Sites Across the U.S.

Table 1 below presents summary statistics based on two daily SO₂ metrics, the daily maximum 1-hour (MDA1) metric, and the daily 24-hour average (DA24) metric. These statistics are presented for year-round and each season (winter=Dec/Jan/Feb, spring=Mar/Apr/May, summer=Jun/Jul/Aug, autumn=Sep/Oct/Nov) based on data reported to AQS for 2022-2024. Table 2 presents the same set of summary statistics for the two daily SO₂ metrics based on four types of sites: source-oriented sites, urban non-source sites, rural non-source sites, and sites in Hawaii County, HI which are regularly impacted by natural SO₂ emissions from volcanic eruptions.

Table 1 shows that SO₂ concentrations are generally similar throughout the year, and that the vast majority of concentrations measured in recent years are well below the NAAQS. The distribution of measured SO₂ concentrations is very skewed, with a mean MDA1 concentration that is approximately three times higher than the median MDA1 concentration and a mean DA24 concentration that is over twice as high as the median DA24 concentration. Table 2 shows that while median SO₂ concentrations at source-oriented sites are only slightly higher than at non-source sites in urban areas, the mean and peak concentrations measured at source-oriented sites are several times higher than those measured at non-source sites in urban areas. Rural non-source sites typically measure slightly lower concentrations than urban non-source sites, while the Hawaii sites affected by volcanic eruptions usually measure higher concentrations than a typical source-oriented site.

Table 1. National distribution of SO₂ concentrations in ppb by season for 2022-2024.³ **Source:** AQS.

metric	season	N.sites	N.obs	mean	SD	min	p1	p5	p10	p25	p50	p75	p90	p95	p98	p99	max	max.site
MDA1	all	359	376,917	2.9	12.8	-3.0	-0.3	0.0	0.0	0.3	0.9	1.9	4.5	9.9	22.5	37.3	1083.4	150012020
MDA1	winter	350	91,412	3.1	14.8	-3.0	-0.3	0.0	0.0	0.3	1.0	2.0	4.4	9.8	23.0	40.3	499.3	291439001
MDA1	spring	353	94,501	3.0	13.5	-3.0	-0.3	0.0	0.0	0.3	0.8	1.8	4.9	10.9	24.4	40.1	481.4	291439001
MDA1	summer	351	93,108	2.7	10.4	-2.4	-0.3	0.0	0.0	0.3	0.9	1.9	4.8	9.7	20.8	33.2	427.8	150012020
MDA1	autumn	347	91,438	2.8	12.7	-2.4	-0.2	0.0	0.0	0.3	0.9	1.9	4.3	9.8	22.5	37.4	1083.4	150012020
DA24	all	359	376,917	0.9	4.1	-3.9	-0.6	-0.1	0.0	0.1	0.4	0.9	1.6	2.4	4.3	7.0	387.6	291439001
DA24	winter	350	91,412	1.0	4.9	-3.1	-0.5	-0.1	0.0	0.1	0.4	1.0	1.7	2.5	4.9	8.7	387.6	291439001
DA24	spring	353	94,501	0.9	4.5	-3.9	-0.6	-0.1	0.0	0.1	0.4	0.9	1.7	2.5	4.6	7.5	329.1	291439001
DA24	summer	351	93,108	0.8	2.9	-2.7	-0.6	-0.1	0.0	0.1	0.4	0.9	1.6	2.3	3.8	6.0	183.1	291439001
DA24	autumn	347	91,438	0.9	4.1	-3.3	-0.5	-0.0	0.0	0.1	0.4	1.0	1.6	2.3	4.2	6.9	296.1	291439001

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. winter = December/January/February; spring = March/April/May; summer = June/July/August; autumn = September/October/November.

³Negative concentration values may appear in AQS datasets down to the negative of the lower detection limit (LDL) to allow for normal instrument variability at very low concentrations. Data that exceed the negative of the LDL is typically indicative of a malfunction or another issue that affects the data defensibility.

Table 2. Distribution of SO₂ concentrations in ppb by site type for 2022-2024.³ **Source:** AQS.

metric	site.type	N.sites	N.obs	mean	SD	min	p1	p5	p10	p25	p50	p75	p90	p95	p98	p99	max	max.site
MDA1	All	359	376,917	2.9	12.8	-3.0	-0.3	0.0	0.0	0.3	0.9	1.9	4.5	9.9	22.5	37.3	1083.4	150012020
MDA1	Source Oriented	141	148,655	5.0	19.0	-3.0	-0.3	0.0	0.0	0.4	1.0	2.9	10.0	20.0	39.8	62.7	499.3	291439001
MDA1	Urban Non-Source	183	191,921	1.3	2.8	-3.0	-0.2	0.0	0.0	0.3	0.7	1.5	2.8	4.4	8.0	12.0	268.0	270530954
MDA1	Rural Non-Source	26	26,896	0.9	1.4	-1.6	-0.1	0.0	0.0	0.2	0.5	1.2	2.2	3.2	4.4	5.9	53.8	191770006
MDA1	Hawaii Volcanic	9	9,445	6.3	24.1	-1.1	-0.5	0.0	0.2	0.7	1.4	2.9	9.6	28.6	66.6	98.2	1083.4	150012020
DA24	All	359	376,917	0.9	4.1	-3.9	-0.6	-0.1	0.0	0.1	0.4	0.9	1.6	2.4	4.3	7.0	387.6	291439001
DA24	Source Oriented	141	148,655	1.3	6.4	-3.2	-0.6	-0.1	0.0	0.1	0.5	1.1	2.2	3.6	7.4	12.7	387.6	291439001
DA24	Urban Non-Source	183	191,921	0.5	0.9	-3.9	-0.5	-0.1	0.0	0.1	0.3	0.8	1.3	1.7	2.4	3.1	150.2	270530954
DA24	Rural Non-Source	26	26,896	0.5	0.7	-2.5	-0.4	0.0	0.0	0.1	0.3	0.7	1.4	1.8	2.6	3.0	6.8	380130004
DA24	Hawaii Volcanic	9	9,445	1.8	3.9	-1.6	-0.7	-0.3	0.0	0.4	1.0	1.7	3.2	5.9	13.0	18.7	90.2	150010005

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.

Figure 5 shows a map of the primary SO₂ design values at U.S. ambient air monitoring sites based on data the 2022-2024 period and Figure 6 shows a map of the secondary SO₂ design values based on data from the 2022-2024 period. There were 11 sites with design values exceeding the primary SO₂ NAAQS and 2 sites with design values exceeding the secondary SO₂ NAAQS. The maximum primary SO₂ design value was 396 ppb and the maximum secondary SO₂ design value was 32 ppb, both recorded at a monitoring site near an industrial park in Missouri. The sites with design values exceeding the primary NAAQS in Hawaii are due to natural SO₂ emissions from recurring volcanic eruptions.

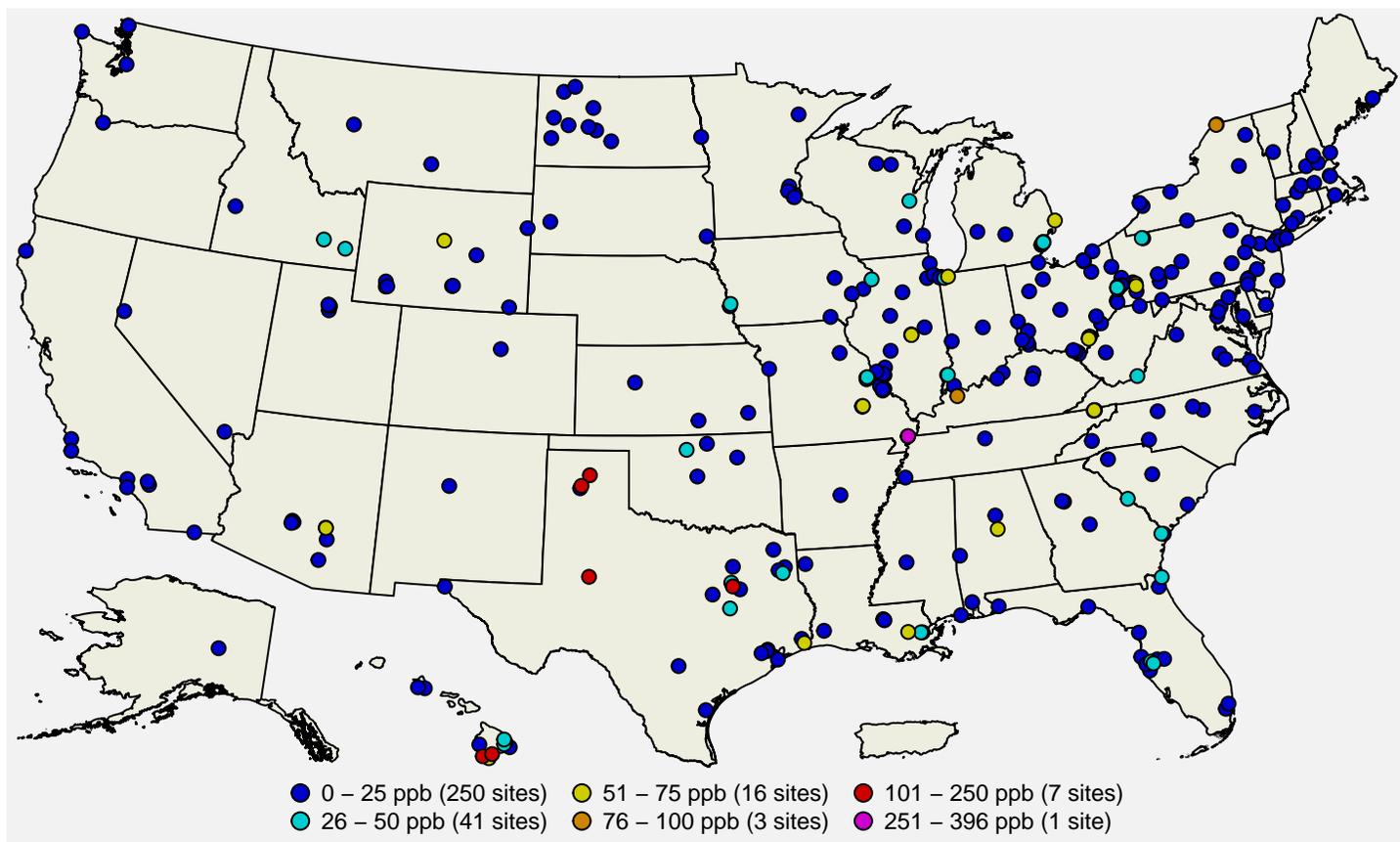


Figure 5: Primary SO₂ design values in ppb for the 2022-2024 period. **Source:** AQS.

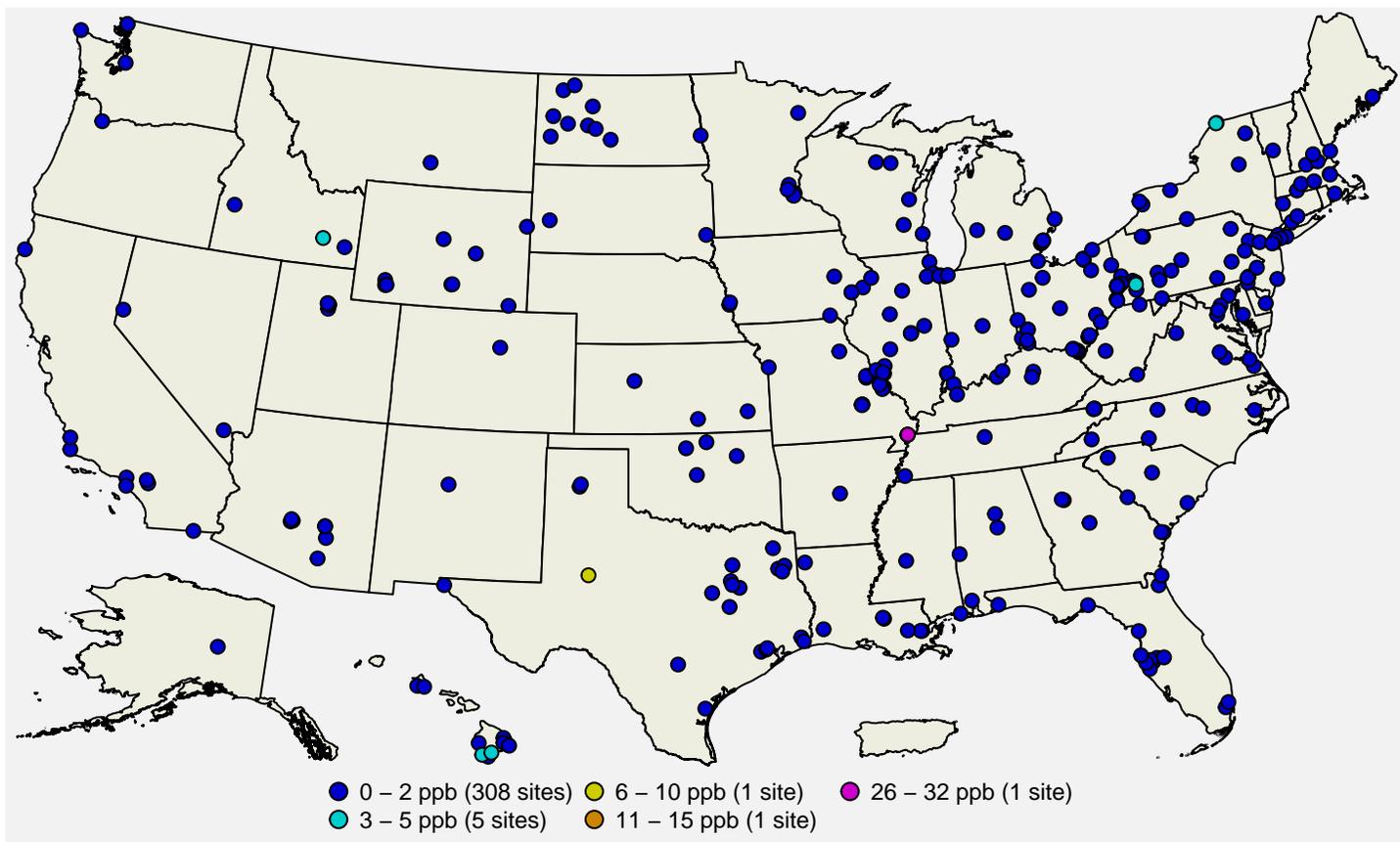


Figure 6: Secondary SO₂ design values in ppb for the 2022-2024 period. **Source:** AQS.

Figure 7 shows a map of the site-level trends in the primary SO₂ design values at U.S. monitoring sites having valid a design value in at least 19 of the 25 3-year periods from 1998-2000 through 2022-2024, while Figure 8 shows a similar map based on site-level trends in the secondary SO₂ design values. The trends were computed using the Thiel-Sen estimator, and tests for significance (p -value < 0.05) were computed using the Mann-Kendall test. From these figures it is apparent that SO₂ concentrations have been decreasing at nearly all sites in the U.S. There were no sites with significant increasing trends in the primary SO₂ design values. There was one site with a significant increasing trend in the secondary SO₂ design values, but the maximum design value at this site was only 2 ppb, well below the secondary SO₂ NAAQS of 10 ppb.

Figure 9 shows the national trends in the primary SO₂ design values based on the 161 sites shown in Figure 7, while Figure 10 shows the national trends in the secondary SO₂ design values based on the 158 sites shown in Figure 8. The national median of the primary SO₂ design values has decreased by about 92% from 71 ppb in 2000 to 6 ppb in 2024, while the national median of the secondary SO₂ design values has decreased by about 80% from 5 ppb in 2000 to 1 ppb in 2024.

Figure 11 shows the national distribution of the annual 99th percentile MDA1 SO₂ concentrations reported in each year from 1980 to 2024, while Figure 12 shows the national distribution of the annual mean SO₂ concentrations reported in each year from 1980 to 2024.⁴ The red line shows the number of sites included in the boxplot for each year, and the high concentrations originating from the sites in Hawaii influenced by volcanic eruptions are marked with orange dots. The median annual 99th percentile MDA1 SO₂ concentration decreased by about 96%, from 131 ppb in 1980 to 5.5 ppb in 2024. Similarly, the national median of the annual mean SO₂ concentrations decreased by about 94%, from 8.3 ppb in 1980 to 0.5 ppb in 2024.

While annual 99th percentile values as high as 2,000 ppb (2 ppm) were measured near some industrial sources in the 1980s, all of the 99th percentile concentration values above 500 ppb that have been reported since 2010 have come from sites in Hawaii that are influenced by volcanic eruptions, except for one site where the data quality in 2023 is still being assessed. The SO₂ monitoring network grew quickly in the early 1980s, reaching a peak size of over 800 sites in 1984. Since then, the monitoring network has slowly decreased in size as many sites measuring low concentrations have been discontinued. There was a brief increase in the number of sites in 2017, as SO₂ monitors required through the DRR (see section 4 above for more information) came online. These additional sites were all located near major industrial sources of SO₂ and likely caused the slight increase in the median concentration observed in 2017.

⁴For this analysis, the annual 99th percentile MDA1 SO₂ concentrations and annual mean SO₂ concentrations were retrieved from AQS for all U.S. sites for years that had at least 50% annual data completeness.

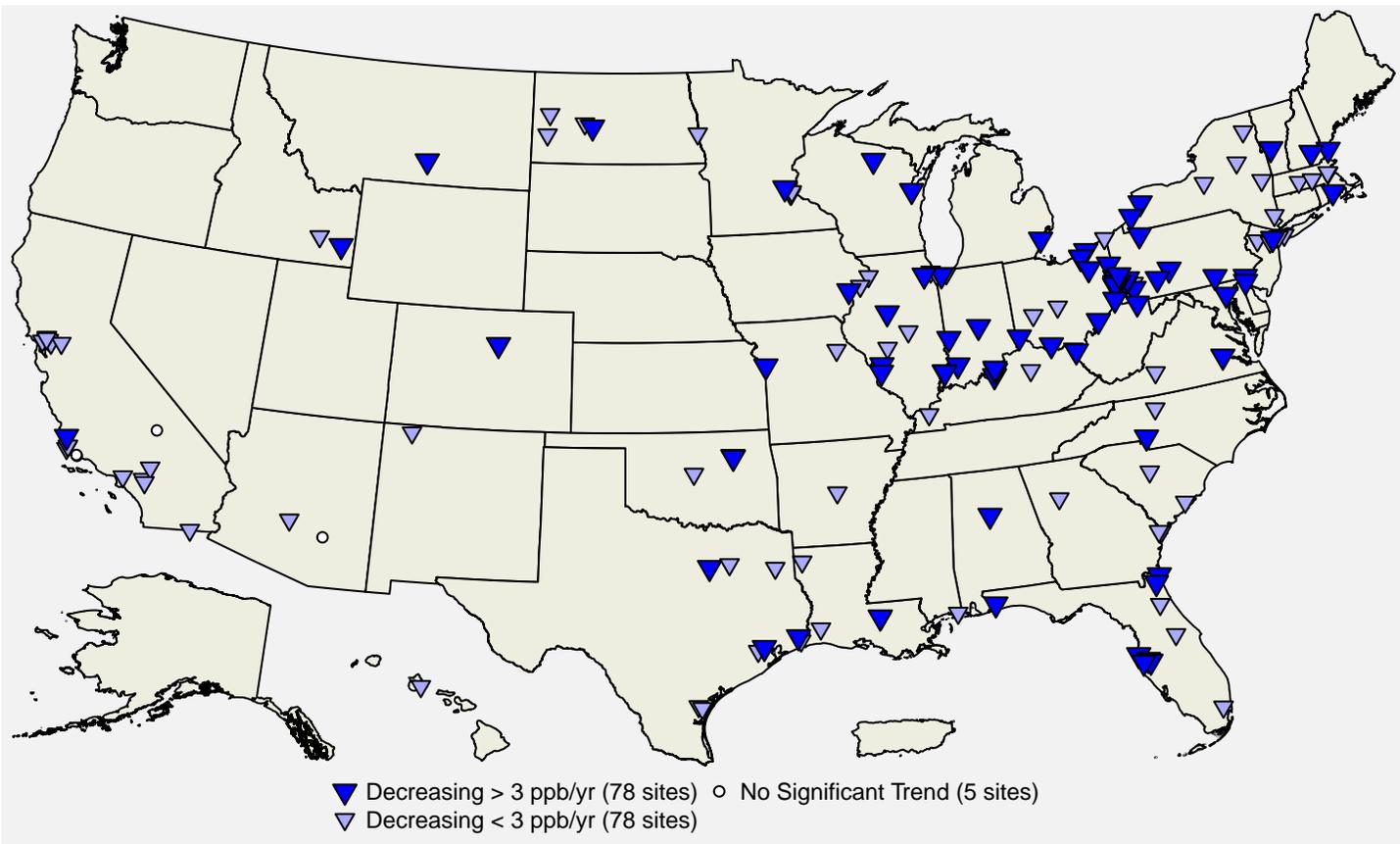


Figure 7: Site-level trends in primary SO₂ design values based on data from 2000 through 2024. **Source:** AQS, trends computed using R statistical software.

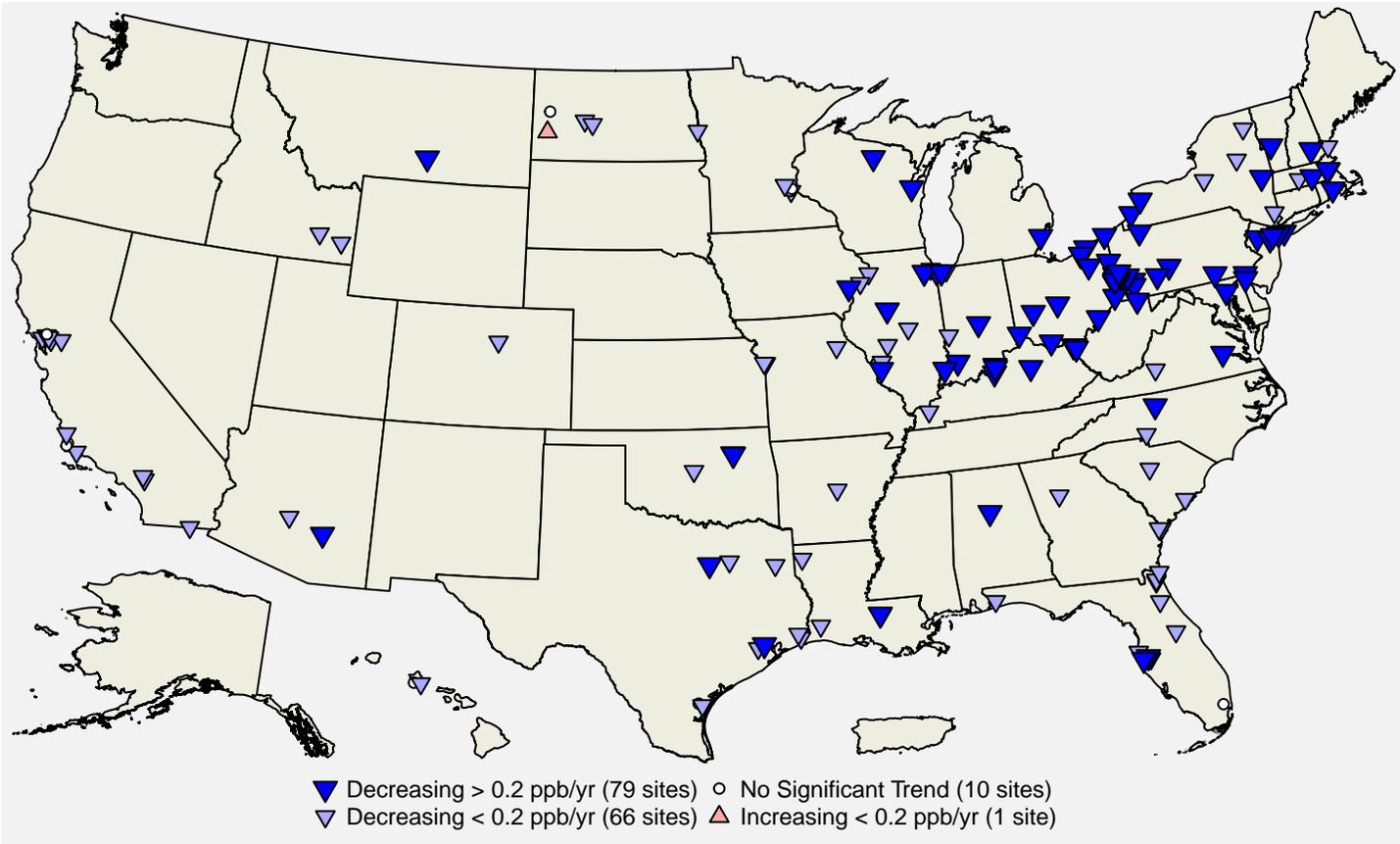


Figure 8: Site-level trends in secondary SO₂ design values based on data from 2000 through 2024. **Source:** AQS, trends computed using R statistical software.

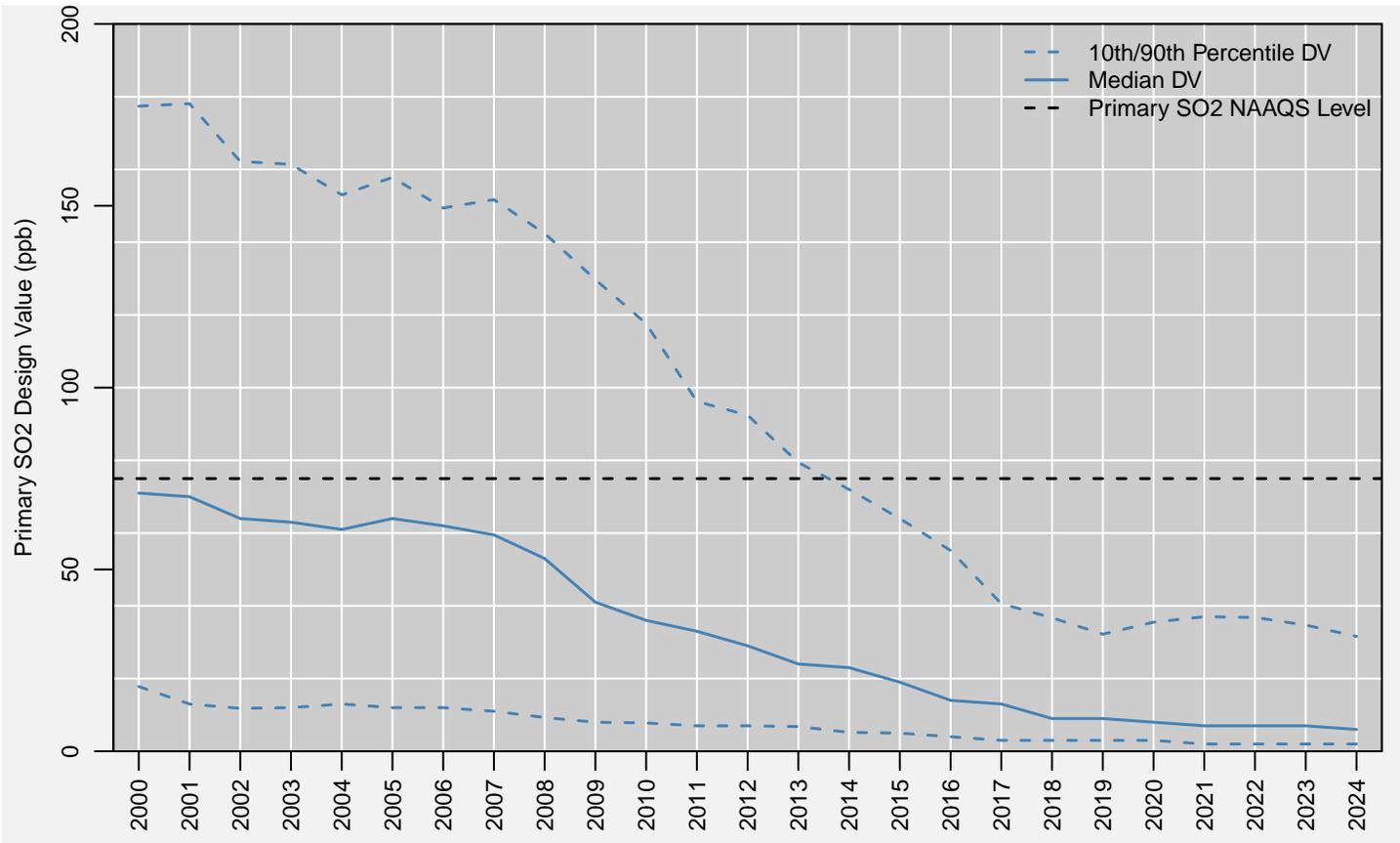


Figure 9: National trends in primary SO₂ design values in ppb, 2000 to 2024. **Source:** AQS.

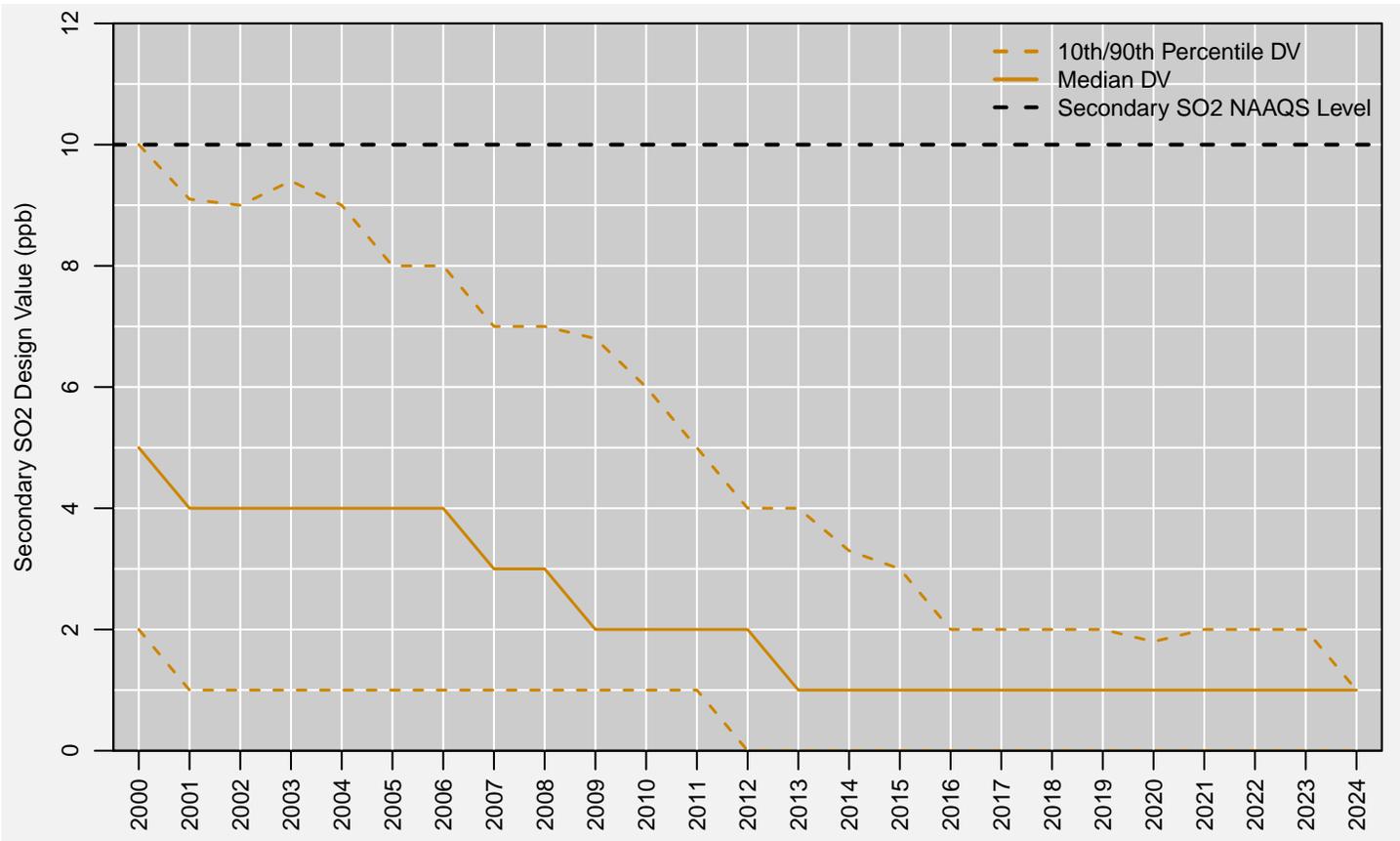


Figure 10: National trends in secondary SO₂ design values in ppb, 2000 to 2024. **Source:** AQS.

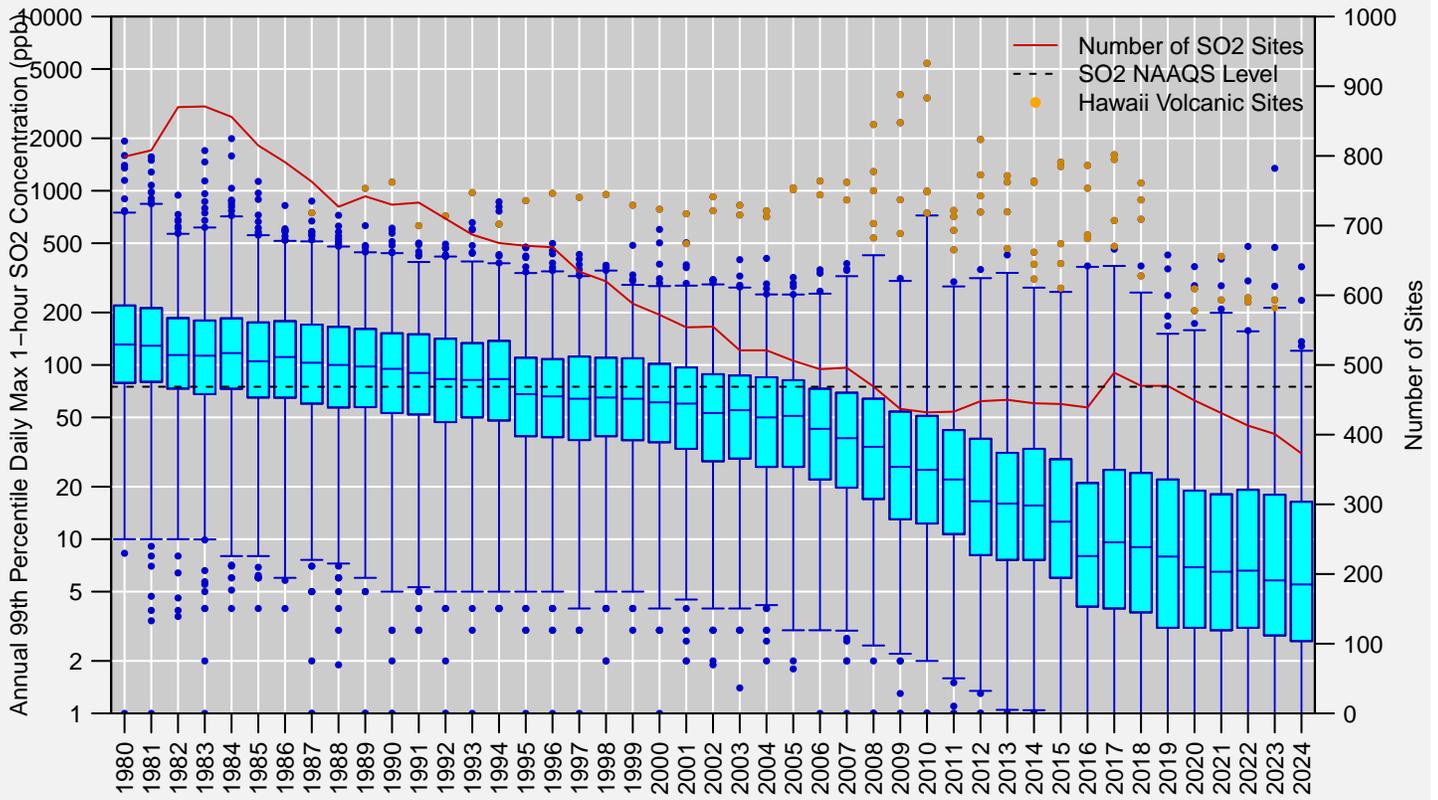


Figure 11: Distribution of annual 99th percentile MDA1 SO₂ concentrations measured at U.S. monitoring sites, 1980 to 2024. Boxes represent the median and interquartile range, whiskers extend to the 1st and 99th percentiles, and values outside this range are shown as circles.⁵ The red line shows the number of SO₂ monitoring sites reporting data to EPA in each year. **Source:** AQS.

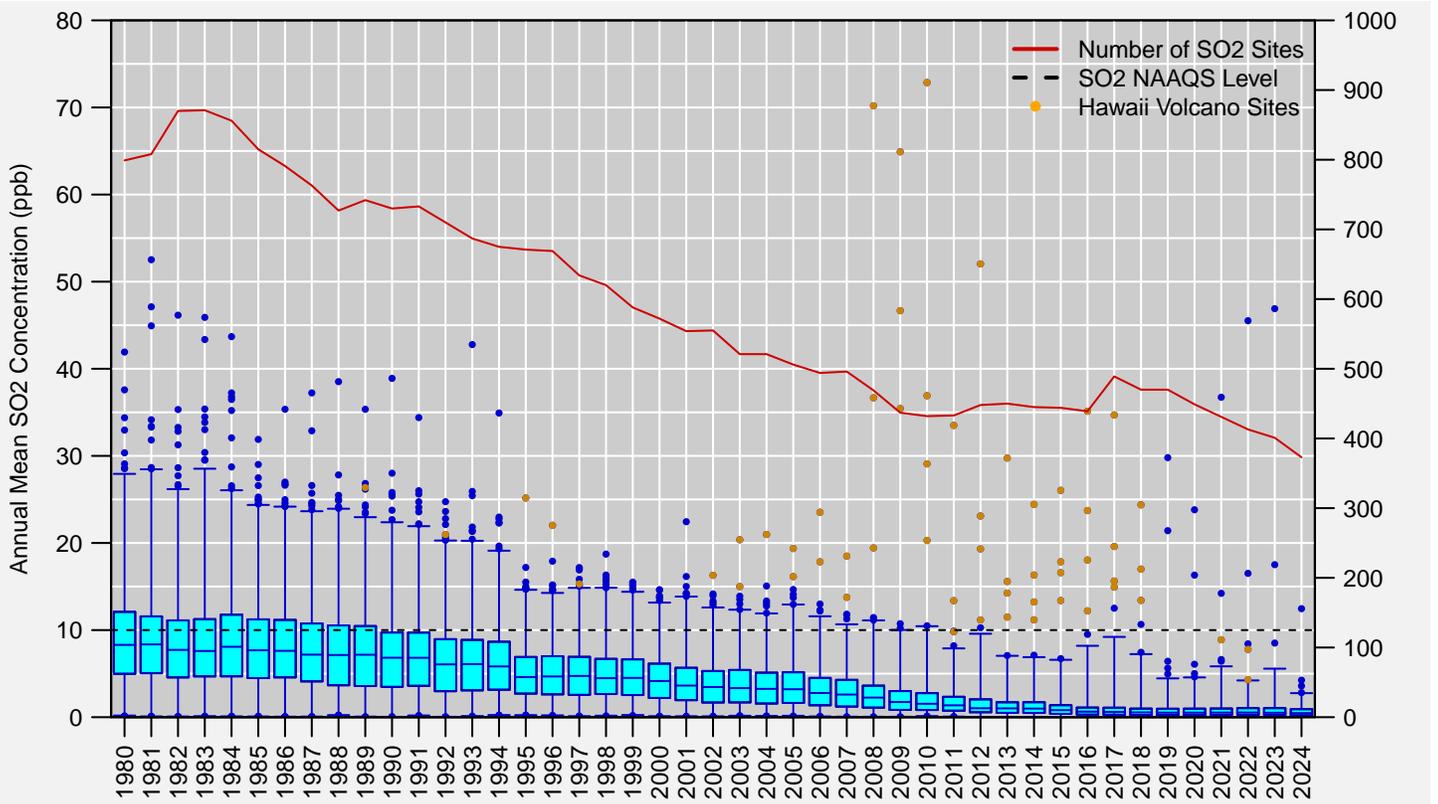


Figure 12: Distribution of annual mean SO₂ concentrations measured at U.S. monitoring sites, 1980 to 2024. Boxes represent the median and interquartile range, whiskers extend to the 1st and 99th percentiles, and values outside this range

⁵In Figures 11 and 12, orange circles are used to represent measurements from sites on the big island of Hawaii, while blue circles are used to represent measurements from all other sites.

are shown as circles.⁵ The red line shows the number of SO₂ monitoring sites reporting data to EPA in each year. **Source:** [AQS](#).

References

U.S. EPA. [Integrated Science Assessment for Sulfur Oxides - Health Criteria \(Final Report, December 2017\)](#). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-17/451, 2017.

U.S. EPA. [Policy Assessment for the Review of the Primary NAAQS for Sulfur Oxides \(Final Report, May 2018\)](#). U.S. Environmental Protection Agency, Research Triangle Park, NC, EPA-452/R-18-002, 2018.

U.S. EPA. [Integrated Science Assessment for Oxides of Nitrogen, Oxides of Sulfur and Particulate Matter - Ecological Criteria \(Final Report, October 2020\)](#). U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-20/278, 2020.

U.S. EPA. [Policy Assessment for the Review of the Secondary NAAQS for Oxides of Nitrogen, Oxides of Sulfur and Particulate Matter \(Final Report, January 2024\)](#). U.S. Environmental Protection Agency, Research Triangle Park, NC, EPA-452/R-24-003, 2024.

Additional Resources

- [Sulfur Dioxide \(SO₂\) Pollution](#)
- [Sulfur Dioxide \(SO₂\) Primary Air Quality Standards](#)
- [Nitrogen Dioxide \(NO₂\) and Sulfur Dioxide \(SO₂\) Secondary Air Quality Standards](#)
- [National Emissions Inventory \(NEI\)](#)
- [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.](#)