Sulfur Dioxide Concentrations

Sulfur dioxide (SO$_2$) is one of the multiple gaseous oxidized sulfur species and is formed during the combustion of fuels containing sulfur, primarily coal and oil. The largest anthropogenic source of SO$_2$ emissions in the U.S. is fossil fuel combustion at electric utilities and other industrial facilities. SO$_2$ is also emitted from certain manufacturing processes and mobile sources, including locomotives, large ships, and construction equipment (see SO$_2$ Emissions indicator). The highest concentrations of SO$_2$ are typically recorded in the vicinity of large emissions sources.

Short-term exposure to ambient SO$_2$ has been associated with various adverse health effects (U.S. EPA, 1994; ATSDR, 1998). Multiple human clinical studies, epidemiological studies, and toxicological studies support a causal relationship between short-term exposure to ambient SO$_2$ and respiratory morbidity. The observed health effects include decreased lung function, respiratory symptoms, and increased emergency department visits and hospitalizations for all respiratory causes. These studies further suggest that people with asthma are potentially susceptible or vulnerable to these health effects (U.S. EPA, 2016). In addition, SO$_2$ reacts with other air pollutants to form sulfate particles, which are constituents of fine particulate matter (PM$_{2.5}$). Inhalation exposure to PM$_{2.5}$ has been associated with various cardiovascular and respiratory health effects (see PM Concentrations indicator).

Ambient SO$_2$ also causes or contributes to numerous environmental impacts. For instance, ambient SO$_2$ along with ambient nitrogen oxides contribute to acidic deposition, and this deposition can harm susceptible aquatic and terrestrial ecosystems, including injury to forests and changes in the composition of fish and other aquatic species (see Acid Deposition indicator). In some watersheds, sulfate deposition increases mercury methylation rates, which leads to formation of methylmercury—the chemical form of mercury that accumulates in the aquatic food chain (U.S. EPA, 2008). In addition, SO$_2$ contributes to the formation of fine airborne particles that can impair visibility—an issue of particular concern in National Parks and Wilderness Areas (see Regional Haze indicator).

This indicator presents ambient SO$_2$ concentrations in parts per billion (ppb) from 1978 to 2016 using two averaging times: 1-hour averaging times to be consistent with the current primary National Ambient Air Quality Standard (NAAQS) and annual averaging times to present trends in long-term exposure levels. Trend data are based on measurements from the State and Local Air Monitoring Stations network and from other special purpose monitors. The number and spatial coverage of monitoring sites depend on the time horizon for the trends: for 1980 through 2016, 78 monitoring sites in 69 counties nationwide have sufficient data to characterize annual average trends; and for 1998 through 2016, 193 monitoring sites in 139 counties nationwide have sufficient data to characterize 1-hour trends. Trends are displayed for the entire nation and for each EPA Region. Refer to the technical documentation for the selection criteria that were applied to identify the sites with sufficient data to characterize air quality trends.

Trends in 1-hour SO$_2$ concentrations are presented for the annual 99th percentile 1-hour daily maximum, averaged over 3 consecutive years. This averaging time and statistic is consistent with the primary NAAQS, which was derived to protect public health, including the health of sensitive populations such as people with asthma. All exhibits in this indicator present the SO$_2$ NAAQS as a point of reference. The exhibits showing trends in 1-hour concentrations display the current NAAQS. The fact that the national or regional concentrations fall below the standards does not mean that all monitoring sites nationally or in any EPA Region also are below the standards. The indicator
also displays the number of trend sites nationwide at which SO$_2$ concentrations exceeded the level of the standards, but these statistics are not displayed for each EPA Region.

**What the Data Show**

Annual average SO$_2$ concentrations at 78 monitoring sites decreased by 91 percent between 1980 and 2016, and the 2016 levels are the lowest over the 37-year period of record (Exhibit 1). Annual average SO$_2$ levels have also steadily decreased in every EPA Region, with the greatest reduction (97 percent) observed in Region 2 (Exhibit 2). This downward trend in annual SO$_2$ concentrations parallels the downward trend observed in SO$_2$ emissions, which has been attributed largely to decreased emissions from electric utilities (the SO$_2$ Emissions indicator). Decreased emissions from mobile sources due to use of low-sulfur fuels has also contributed to the ambient concentration trend.

The annual 99$^{th}$ percentile of daily maximum 1-hour SO$_2$ concentrations, averaged over 3 consecutive years, also exhibited a downward trend. These data were displayed for two different time horizons to account for as many monitoring sites as possible, because more sites meet the site selection criteria when considering more recent, shorter time frames:

- For 1978 to 2016, the 3-year average of the 99$^{th}$ percentile of daily maximum 1-hour SO$_2$ concentrations decreased by 82 percent across the 24 sites with sufficient data (Exhibit 3). Among these sites, the number reporting concentrations above the level of the 1-hour NAAQS decreased by 85 percent (Exhibit 4).
- For 1998 to 2016, the 3-year average of the 99$^{th}$ percentile of daily maximum 1-hour SO$_2$ concentrations decreased by 69 percent across the 193 sites with sufficient data (Exhibit 5). Among these sites, the number reporting concentrations above the level of the 1-hour NAAQS decreased by 86 percent (Exhibit 6). Consistent with the nationwide trend, the 99$^{th}$ percentile of daily maximum 1-hour SO$_2$ concentrations averaged over 3 consecutive years also steadily decreased between 1998 and 2016 in the EPA Regions, with the greatest percent reduction observed in Region 1 and Region 2 (Exhibit 7).

Also shown in Exhibit 1, 3, and 5 are the 90$^{th}$ and 10$^{th}$ percentiles based on the annual measurements at the monitoring sites. This provides additional graphical representation of the variability of measured concentrations across the monitoring sites for a given year. The shaded areas in these exhibits display the concentration range where 80 percent of measured values occurred for that year.

**Limitations**

- While many SO$_2$ monitoring sites are located near dense population centers, other sites are located near emissions sources and the trends might not accurately reflect conditions outside the immediate monitoring areas.
- Because of the relatively small number of trend sites in some EPA Regions, the regional trends are subject to greater uncertainty than the national trends. Some EPA Regions with low average concentrations may include areas with high local concentrations, and vice versa. In addition, the trend sites in this indicator are not dispersed uniformly across all states in the
EPA Regions. The 193 sites for the 1998-2016 trends are located in 35 states. In the remaining 15 states, there currently are insufficient long-term data from the existing monitoring sites to include in this indicator.

- To ensure that long-term trends are based on a consistent set of monitoring sites, selection criteria were applied to identify the subset of SO\textsubscript{2} monitoring sites with sufficient data to assess trends since 1978. Monitoring sites without sufficient data are not included in the trend analysis. Some excluded monitoring sites reported SO\textsubscript{2} concentrations above the level of the NAAQS over the time frame covered by this indicator. In 2016, 12 sites in the U.S. measured SO\textsubscript{2} concentrations above the level of the 1-hour NAAQS. This is consistent with the data in Exhibit 6, but the numbers are not identical because Exhibit 6 is based on a 3-year time horizon and not a single calendar year.

- Because of the relatively small number of trend sites for the long-term period 1980-2016, the national trends in Exhibits 1 to 4 may not necessarily be representative of the entire U.S.

**Data Sources**

Summary data in this indicator were provided by EPA’s Office of Air Quality Planning and Standards, based on SO\textsubscript{2} ambient air monitoring data in EPA’s Air Quality System (U.S. EPA, 2017a) (https://www.epa.gov/aqs). National and regional trends in this indicator are based on the subset of SO\textsubscript{2} monitoring stations that have sufficient data to assess trends.

**References**


Exhibit 1. Ambient annual SO\textsubscript{2} concentrations in the U.S., 1980–2016

Coverage: 78 monitoring sites in 69 counties nationwide (out of a total of 421 sites measuring SO\textsubscript{2} in 2016) that have sufficient data to assess SO\textsubscript{2} trends since 1980.

In 2010, the annual average SO\textsubscript{2} NAAQS (30 ppb) was revoked (U.S. EPA, 2017b).

Information on the statistical significance of the trends in this exhibit is not currently available. For more information about uncertainty, variability, and statistical analysis, view the technical documentation for this indicator.

Data source: U.S. EPA, 2017a

Coverage: 78 monitoring sites in 69 counties nationwide (out of a total of 421 sites measuring SO$_2$ in 2016) that have sufficient data to assess SO$_2$ trends since 1980.

States in Regions 7 and 10 have removed SO$_2$ monitors in recent years because of low concentrations, and consequently none of these Regions' monitoring sites has a complete record dating back to 1980. Thus, no trend lines for Regions 7 and 10 are shown.

In 2010, the annual average SO$_2$ NAAQS (30 ppb) was revoked (U.S. EPA, 2017b).

Information on the statistical significance of the trends in this exhibit is not currently available. For more information about uncertainty, variability, and statistical analysis, view the technical documentation for this indicator.

Data source: U.S. EPA, 2017a

The current 1-hour SO\(_2\) NAAQS was established in 2010 and is shown to provide context for the magnitude of pollutant concentrations. No 1-hour SO\(_2\) NAAQS existed prior to 2010 (U.S. EPA, 2017b).

**Coverage:** 24 monitoring sites in 24 counties nationwide (out of a total of 385 sites measuring SO\(_2\) in 2016) that have sufficient data to assess SO\(_2\) trends since 1978.

Information on the statistical significance of the trends in this exhibit is not currently available. For more information about uncertainty, variability, and statistical analysis, view the technical documentation for this indicator.

**Data source:** U.S. EPA, 2017a
Exhibit 4. Ambient 1-hour SO\textsubscript{2} concentrations above the level of the current NAAQS in the U.S., 1978–2016

The current 1-hour SO\textsubscript{2} NAAQS was established in 2010 and is shown to provide context for the magnitude of pollutant concentrations. No 1-hour SO\textsubscript{2} NAAQS existed prior to 2010 (U.S. EPA, 2017b).

Coverage: 24 monitoring sites in 24 counties nationwide (out of a total of 385 sites measuring SO\textsubscript{2} in 2016) that have sufficient data to assess SO\textsubscript{2} trends since 1978.

Information on the statistical significance of the trends in this exhibit is not currently available. For more information about uncertainty, variability, and statistical analysis, view the technical documentation for this indicator.

Data source: U.S. EPA, 2017a

The current 1-hour SO$_2$ NAAQS was established in 2010 and is shown to provide context for the magnitude of pollutant concentrations. No 1-hour SO$_2$ NAAQS existed prior to 2010 (U.S. EPA, 2017b).

**Coverage:** 193 monitoring sites in 139 counties nationwide (out of a total of 385 sites measuring SO$_2$ in 2016) that have sufficient data to assess SO$_2$ trends since 1998.

Information on the statistical significance of the trends in this exhibit is not currently available. For more information about uncertainty, variability, and statistical analysis, view the technical documentation for this indicator.

**Data source:** U.S. EPA, 2017a
Exhibit 6. Ambient 1-hour SO₂ concentrations above the level of the current NAAQS in the U.S., 1998–2016

The current 1-hour SO₂ NAAQS was established in 2010 and is shown to provide context for the magnitude of pollutant concentrations. No 1-hour SO₂ NAAQS existed prior to 2010 (U.S. EPA, 2017b).

Coverage: 193 monitoring sites in 139 counties nationwide (out of a total of 385 sites measuring SO₂ in 2016) that have sufficient data to assess SO₂ trends since 1998.

Information on the statistical significance of the trends in this exhibit is not currently available. For more information about uncertainty, variability, and statistical analysis, view the technical documentation for this indicator.

Data source: U.S. EPA, 2017a
The current 1-hour \( \text{SO}_2 \) NAAQS was established in 2010 and is shown to provide context for the magnitude of pollutant concentrations. No 1-hour \( \text{SO}_2 \) NAAQS existed prior to 2010 (U.S. EPA, 2017b).

**Coverage:** 191 monitoring sites in 138 counties in the EPA Regions (out of a total of 385 sites measuring \( \text{SO}_2 \) in 2016) that have sufficient data to assess \( \text{SO}_2 \) trends since 1998.

States in Region 10 have removed \( \text{SO}_2 \) monitors in recent years because of low concentrations, and consequently none of this Region’s monitoring sites has a complete record dating back to 1980. Thus, no trend line for Region 10 is shown.

Information on the statistical significance of the trends in this exhibit is not currently available. For more information about uncertainty, variability, and statistical analysis, view the technical documentation for this indicator.

**Data source:** U.S. EPA, 2017a