Greenhouse Gas Concentrations

Energy from the sun drives the Earth's weather and climate. The Earth absorbs some of the energy it receives from the sun and radiates the rest back toward space. However, certain gases in the atmosphere, called greenhouse gases (GHGs), absorb some of the energy radiated from the Earth and trap it in the atmosphere. These gases essentially act as a blanket, making the Earth's surface warmer than it otherwise would be. This "greenhouse effect" occurs naturally, making life as we know it possible. Since the Industrial Revolution began in the late 1700s, however, people have added a substantial amount of GHGs into the atmosphere by burning fossil fuels, cutting down forests, and conducting other activities (see the U.S. Greenhouse Gas Emissions indicator). When GHGs are emitted into the atmosphere, many remain there for long time periods ranging from a decade to many millennia. Over time, these gases are removed from the atmosphere by chemical reactions or by emissions sinks, such as the oceans and vegetation, which absorb GHGs from the atmosphere. However, as a result of human activities, these gases are entering the atmosphere more quickly than they are being removed, and thus their concentrations are increasing.

Carbon dioxide, methane, nitrous oxide, and certain manufactured gases called halogenated gases (gases that contain chlorine, fluorine, or bromine) become well mixed throughout the global atmosphere because of their relatively long lifetimes and because of transport by winds. Concentrations of these GHGs are measured in parts per million (ppm), parts per billion (ppb), or parts per trillion (ppt) by volume. In other words, a concentration of 1 ppb for a given gas means there is one molecule of that gas in every 1 billion molecules of air. Some halogenated gases are considered major GHGs due to their very high global warming potentials and long atmospheric lifetimes even if they only exist at a few ppt. (Learn more about major GHGs, their atmospheric lifetimes, and their global warming potentials.)

Ozone is also a GHG, but it differs from other GHGs in several ways. The effects of ozone depend on its altitude, or where the gas is located vertically in the atmosphere. Most ozone naturally exists in the layer of the atmosphere called the stratosphere, which ranges from approximately 6 to 30 miles above the Earth's surface. Ozone in the stratosphere has a slight net warming effect on the planet, but it is good for life on Earth because it absorbs harmful ultraviolet radiation from the sun, preventing it from reaching the Earth's surface. In the troposphere—the layer of the atmosphere near ground level—ozone is an air pollutant that is harmful to breathe, a main ingredient of urban smog, and an important GHG that contributes to climate change. Unlike the other major GHGs, tropospheric ozone only lasts for days to weeks, so levels often vary by location and by season. For more information about stratospheric and tropospheric ozone, respectively, see the Stratospheric Ozone Levels Over North America and Ambient Concentrations of Ozone indicators.

This indicator describes concentrations of GHGs in the atmosphere. It focuses on the major GHGs that result from human activities.

For carbon dioxide, methane, nitrous oxide, and halogenated gases, recent measurements come from monitoring stations around the world, while measurements of older air come from air bubbles trapped in layers of ice from Antarctica and Greenland. By determining the age of the ice layers and the concentrations of gases trapped inside, scientists can learn what the atmosphere was like thousands of years ago.

This indicator also shows data from satellite instruments that measure ozone density in the troposphere, the stratosphere, and the "total column," or all layers of the atmosphere. These satellite data are routinely compared with ground-based instruments to confirm their accuracy. Ozone data have been averaged worldwide for each year to smooth out the regional and seasonal variations.

What the Data Show

Global atmospheric concentrations of carbon dioxide, methane, nitrous oxide, and certain manufactured GHGs have all risen significantly over the last few hundred years (Exhibits 1, 2, 3, and 4). Historical measurements show cyclical glacial-interglacial patterns over geological time scales, and they show that the current global atmospheric concentrations of carbon dioxide, methane, and nitrous oxide are unprecedented compared with the past 800,000 years (see Exhibits 1, 2, and 3).

Carbon dioxide concentrations have increased steadily since the beginning of the industrial era, rising from an annual average of 280 ppm in the late 1700s to 416 ppm in 2021 (average of five sites in Exhibit 1)—a 48 percent increase. Almost all of this increase is due to human activities (USGCRP, 2017).

The concentration of methane in the atmosphere has more than doubled since preindustrial times, reaching over 1,800 ppb in recent years (see the range of measurements for 2020 and 2021 in Exhibit 2). This increase is predominantly due to agriculture and fossil fuel use (IPCC, 2022). Methane concentration measurements since 1950 demonstrate a pattern of higher values from research sites located in northern latitudes—a result of the higher number of methane sources in the northern hemisphere and methane's relatively short lifetime compared with other long-lived GHGs. Despite the latitudinal differences, however, the pattern over the past two centuries shows a common trend in all locations.

Over the past 800,000 years, concentrations of nitrous oxide in the atmosphere rarely exceeded 280 ppb. Levels have risen since the 1920s, however, reaching a new high of 334 ppb in 2021 (average of four sites in Exhibit 3). This increase is primarily due to agriculture (USGCRP, 2017).

Concentrations of many of the halogenated gases shown in Exhibit 4 were essentially zero a few decades ago but have increased rapidly as they have been incorporated into industrial products and processes. Some of these chemicals have been or are currently being phased out of use because they are ozone-depleting substances, meaning they also cause harm to the Earth's protective ozone layer. As a result, concentrations of many major ozone-depleting gases have begun to stabilize or decline. Concentrations of other halogenated gases have continued to rise, however, especially where the gases have emerged as substitutes for ozone-depleting chemicals.

Overall, the total amount of ozone in the atmosphere decreased by more than 4 percent between 1979 and 2020 (Exhibit 5). All of the decrease happened in the stratosphere, with most of the decrease occurring between 1979 and 1994. Changes in stratospheric ozone reflect the effect of ozone-depleting substances. These chemicals have been released into the air for many years, but recently, international efforts have reduced emissions and phased out their use. Globally, the amount of ozone in the troposphere increased by about 12 percent between 1979 and 2020 (Exhibit 5).

Limitations

- This indicator includes several of the most important halogenated gases, but some others are not shown. Many other halogenated gases are also GHGs but Exhibit 4 is limited to a set of common examples that represent most of the major types of these gases.

- The indicator does not address certain other pollutants that can affect climate by either reflecting or absorbing energy. For example, sulfate particles can reflect sunlight away from the Earth, while black carbon aerosols (soot) absorb energy.
- Data for nitrogen trifluoride (Exhibit 4) reflect modeled averages based on measurements made in the Northern Hemisphere and some locations in the Southern Hemisphere, to represent global average concentrations over time. The global averages for ozone cover only the area between 50°N and 50°S latitude (77 percent of the Earth's surface), because at higher latitudes the lack of sunlight in winter creates data gaps and the angle of incoming sunlight during the rest of the year reduces the accuracy of the satellite measuring technique.
- This indicator does not include concentrations of water vapor. Although water vapor is the most abundant GHG in the atmosphere, human activities have only a small direct influence on it, primarily through irrigation and deforestation (USGCRP, 2017). The surface warming caused by human production of other GHGs, however, leads to an increase in atmospheric water vapor, because warmer temperatures make it easier for water to evaporate and stay in the air in vapor form. This creates a "feedback loop" in which warming leads to more warming.

Data Sources

Global atmospheric concentration measurements for carbon dioxide (Exhibit 1), methane (Exhibit 2), and nitrous oxide (Exhibit 3) come from a variety of monitoring programs and studies published in peer-reviewed literature. References for the underlying data are noted below the corresponding exhibits. Global atmospheric concentration data for selected halogenated gases (Exhibit 4) were compiled by the the Advanced Global Atmospheric Gases Experiment (AGAGE, 2022), and the National Oceanic and Atmospheric Administration (NOAA, 2019). A similar figure with many of these gases appears in the Intergovernmental Panel on Climate Change's Fifth Assessment Report (IPCC, 2013). Satellite measurements of ozone were processed by the National Aeronautics and Space Administration and validated using ground-based measurements collected by the National Oceanic and Atmospheric Administration (NASA, 2013, 2021, 2022).

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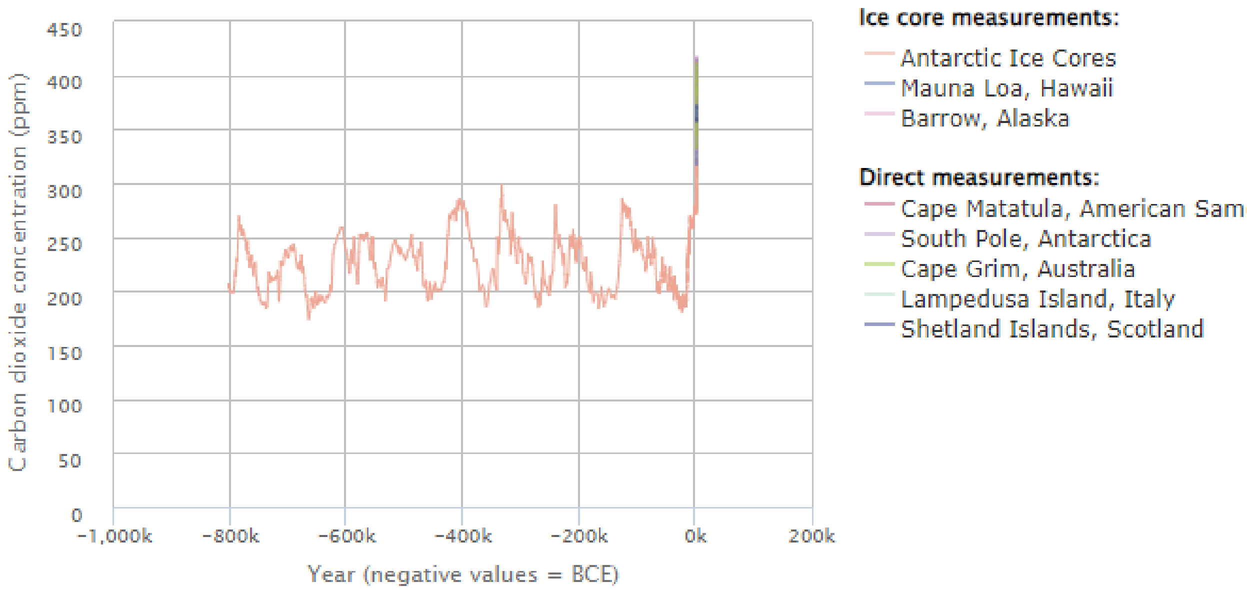
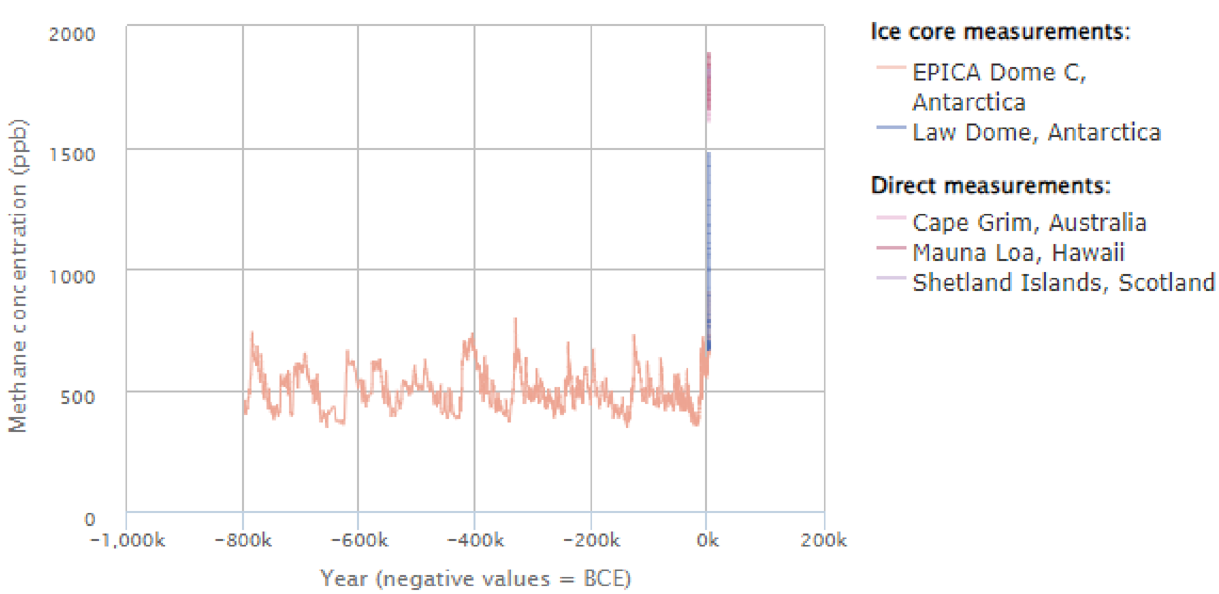
Exhibit 1. Global atmospheric concentrations of carbon dioxide over time



Authoritative scientific assessments have concluded that concentrations of carbon dioxide now substantially exceed the highest concentrations recorded in ice cores during the past 800,000 years. For more information about uncertainty, variability, and statistical analysis, view the technical documentation for this indicator.

Data source: Bereiter et al., 2015; Chamard et al., 2001; CSIRO, 2022a; NOAA, 2022a,b; Steele et al., 2007

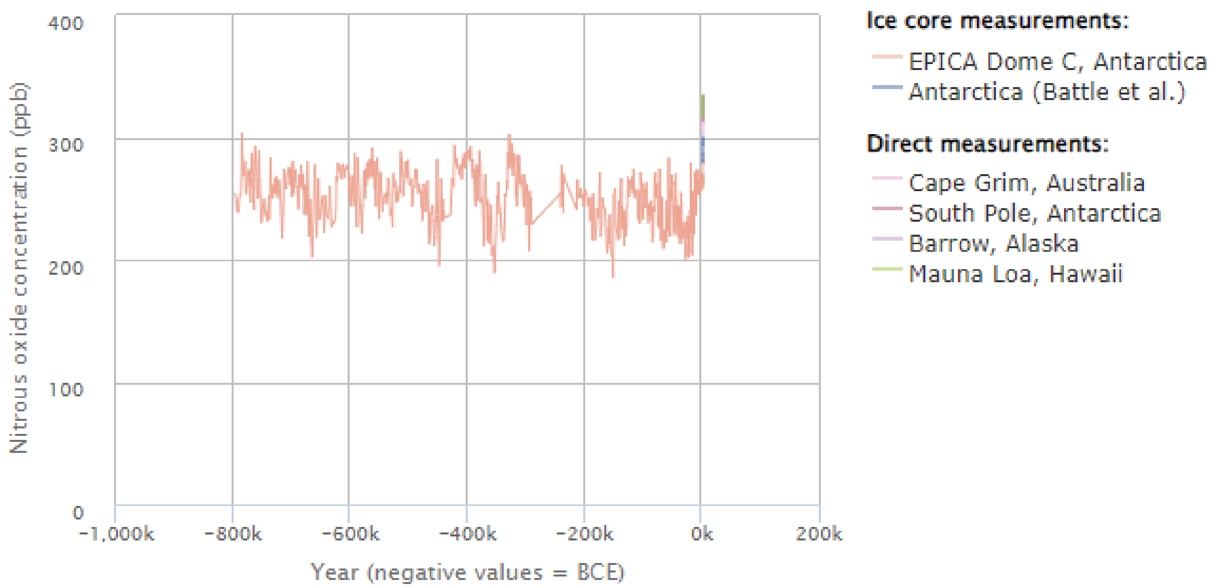
Exhibit 2. Global atmospheric concentrations of methane over time



Authoritative scientific assessments have concluded that concentrations of methane now substantially exceed the highest concentrations recorded in ice cores during the past 800,000 years. For more information about uncertainty, variability, and statistical analysis, view the technical documentation for this indicator.

Data source: CSIRO, 2022b; Etheridge et al., 2002; Loulergue et al., 2008; NOAA, 2021; Steele et al., 2002

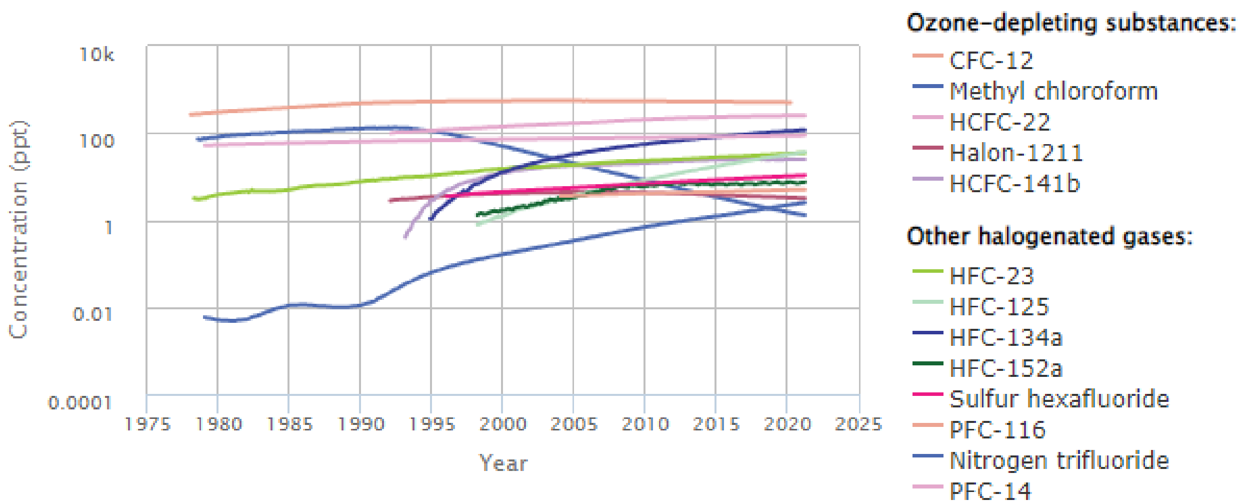
Exhibit 3. Global atmospheric concentrations of nitrous oxide over time



Authoritative scientific assessments have concluded that concentrations of nitrous oxide now substantially exceed the highest concentrations recorded in ice cores during the past 800,000 years. For more information about uncertainty, variability, and statistical analysis, view the technical documentation for this indicator.

Data source: Battle et al., 1996; CSIRO, 2022c; NOAA, 2022c; Schilt et al., 2010

Exhibit 4. Global atmospheric concentrations of selected halogenated gases, 1978–2021

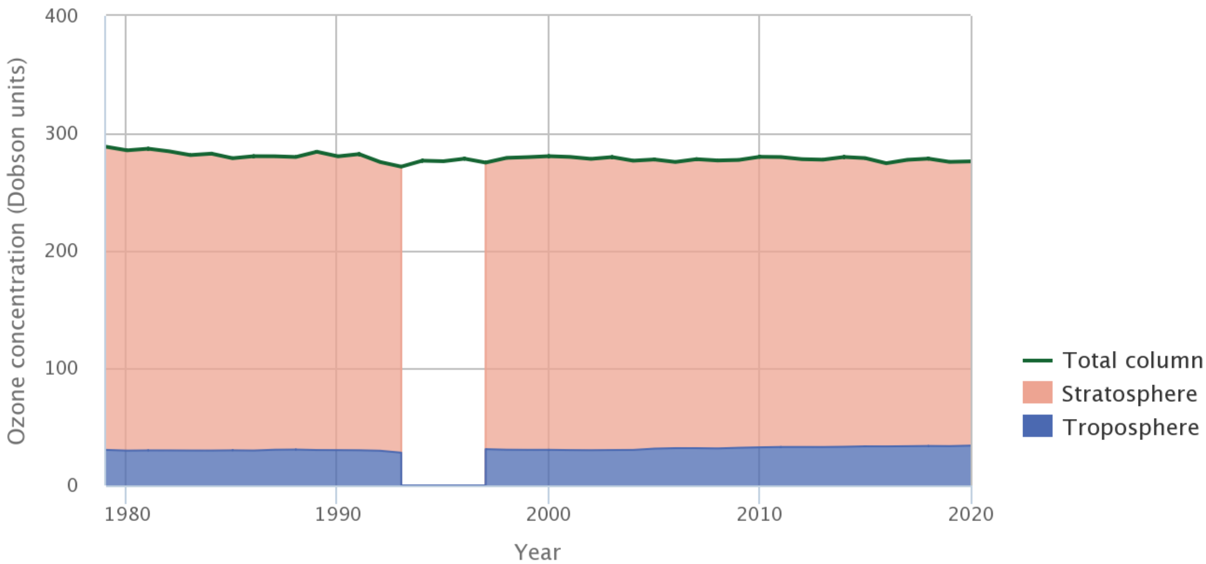


Trends are presented for selected halogenated gases with sufficient data to support long-term trend analysis.

Authoritative scientific assessments have concluded that concentrations of HCFCs, HFCs, PFCs, sulfur hexafluoride, and certain other halogenated gases are increasing, while concentrations of major chlorofluorocarbons (CFCs) increased over the last several decades but are now decreasing. For more information about uncertainty, variability, and statistical analysis, view the technical documentation for this indicator.

Data source: AGAGE, 2022; NOAA, 2019; Rigby, 2017

Exhibit 5. Global atmospheric concentrations of ozone, 1979–2020



These data show how ozone is divided between the troposphere and stratosphere, except from 1994 to 1996, when only the total is available, due to limited satellite coverage.

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

Data source: NASA, 2013, 2021, 2022