

## Report on the Environment <https://www.epa.gov/report-environment>

### Stratospheric Ozone Levels

Ozone is a gas present throughout Earth's atmosphere; 90 percent resides in the stratosphere, the layer of the atmosphere that starts about 6 to 9 miles above the Earth's surface at mid-latitudes, and the rest is located in the troposphere, the atmospheric layer that lies between the stratosphere and the Earth's surface. The environmental and human health implications of ground-level ozone are very different from those of ozone higher in the atmosphere, leading to the maxim: "Good up high, bad nearby" (U.S. EPA, 2003). In the troposphere, ozone poses both health and ecological risks, but the natural layer of ozone in the stratosphere shields and protects the Earth's surface from the sun's harmful ultraviolet (UV) rays—radiation that can lead to more cases of skin cancer, cataracts, and other health problems (U.S. EPA, 2006).

Increases in surface UV radiation have been associated with reductions in total ozone levels based on spectral measurements at a number of sites in Europe, North America, South America, Antarctica, and New Zealand (Kerr and McElroy, 1993; Booth and Madronich, 1994; WMO, 2014). For example, measurements between 1989 and 1993 over Toronto indicated that for every 1 percent decrease in total column ozone, after accounting for seasonal and daily variables not related to ozone, there was a corresponding increase—between 1.1 percent and 1.3 percent—in erythemally active UVB radiation reaching the surface (Kerr and McElroy, 1993).

Ozone in the stratosphere is constantly being produced naturally from dissociation of oxygen molecules by highly energetic, solar UV radiation. While this ozone is being transported poleward and downward through the natural motions of air in the stratosphere, it is also being naturally destroyed through catalytic reactions primarily involving nitrogen and hydrogen oxides.

Releases of various human-produced chemicals, such as the long-lived chlorofluorocarbons, hydrochlorofluorocarbons, bromine-containing halons, and methyl bromide (see the [Concentrations of Ozone-Depleting Substances indicator](#)), provide catalysts to accelerate ozone destruction. First observed in the late 1970s, this has depleted the levels of protective stratospheric ozone, particularly at medium to high latitudes. The U.S. has been a major contributor to the global emissions of these halocarbons, accounting for about a quarter of total worldwide emissions before most ozone-depleting substances (ODS) were banned in the 1990s. It takes about 3 years for emissions of ODS at the Earth's surface to migrate to the stratosphere and cause stratospheric ozone depletion (WMO, 2014).

This indicator tracks trends in the deviation from pre-1980 levels of total annually averaged ozone values integrated over the 35 to 60 degrees north latitude belt (the latitudes roughly corresponding to North America) from 1964 to 2016. The estimates are based on data from several different sources including ground-based and satellite measurements. The data on total ozone from ground-based measurements are from a network of surface stations, which are equipped with spectrophotometers. These instruments measure how thick the ozone layer would be if compressed in the Earth's atmosphere (at sea level and at 0°C), where one Dobson Unit (DU) is defined to be 0.01 mm thickness at standard temperature and pressure. Reliable data from regular measurements at these ground-based stations are available extending back to the 1960s, although geographical coverage is limited before the 1970s (Fioletov et al., 2002; WMO, 2014).

Near-continuous, global, total ozone data are available from satellite measurements beginning in 1979. These satellite data come from four sources: (1) The Global Ozone Monitoring Experiment (GOME) refers to data collected from instruments on board the European Space Agency's ERS-2 satellite, for which validated data are available dating back to 1995; (2) The Solar Backscatter Ultraviolet (SBUV) instruments have been collecting data since 1979, with one instrument (SBUV) on board the Nimbus 7 satellite and the other instruments (SBUV/2) on board a sequence of NOAA satellites; (3) The "merged satellite data" refer to total ozone data dating back to 1970 (not all years inclusive) constructed by merging observations from the SBUV/2 data and data collected by Total Ozone Mapping Spectrometer (TOMS) instruments on board the Nimbus 7 satellite; and (4) The National Institute of Water and Atmospheric Research (NIWA) assimilated data set is a merged data set constructed from observations dating back to 1979 collected by the TOMS, GOME, and SBUV instruments. Other publications provide further documentation on the four satellite data sets used in this indicator (WMO, 2014).

## What the Data Show

There was little ozone change (beyond natural variations such as those resulting from the 11-year solar sunspot cycle) between 1964 and the late 1970s, but decreases in stratospheric ozone began to occur after 1979 (Exhibit 1). The ground-based data and four satellite data sets have similar ozone variations, with differences among the data sets typically less than 0.5 percent in reported total ozone levels. The mid-latitude decline of approximately 6 percent between 1979 and 1995 is in general agreement with previous profile trend estimates from satellite and ground-based records.

However, total ozone levels have begun to recover since 1995. For the mid-latitudes of the Northern Hemisphere, the average of the total ozone levels for the 4-year period from 2002 to 2005 was about 3 percent lower than the pre-1980 levels in the Northern Hemisphere (WMO, 2007). Similarly, the Northern Hemisphere mid-latitude annual total ozone levels between 2008 and 2013 were approximately 3.5 percent lower than the 1964-1980 average (WMO, 2014). While this indicator covers the entire 35 to 60 degrees north latitude belt, ozone varies little by longitude and the estimated 3 percent change in total ozone levels from pre-1980 to 2002-2005 can be taken to apply to North America. Annual total ozone levels over North America have remained relatively unchanged between 2000 and 2016. Although worldwide ODS emissions and atmospheric concentrations have decreased in recent decades, stratospheric ozone levels are only recently beginning to recover due to the long lifetimes of many ODS.

The 3 percent decrease over North America cited in the previous paragraph is very similar to the statistically significant globally averaged 2.0 decrease in total ozone between pre-1980 levels and levels between 2008 and 2013 (WMO, 2014). The decrease in the mid-latitudes of the Southern Hemisphere, by contrast, has been nearly twice as high as observed in the Northern Hemisphere, due largely to the springtime "ozone hole" over Antarctica. The trends in this indicator are consistent with well understood seasonal variations in ozone, and with natural variations such as those due to the 11-year solar cycle and the effects of volcanic eruptions.

## Limitations

- Fioletov et al. (2002) used estimates of ozone changes from several different, independent sources to derive some data used for this indicator. Differences in the calibration of instruments used to obtain the ground-based and satellite datasets together with interruptions in the observational records produce datasets with measurement errors typically around a few percent (WMO, 2010). The figure presented does, however, show good overall agreement

among the different data sources for changes in total ozone.

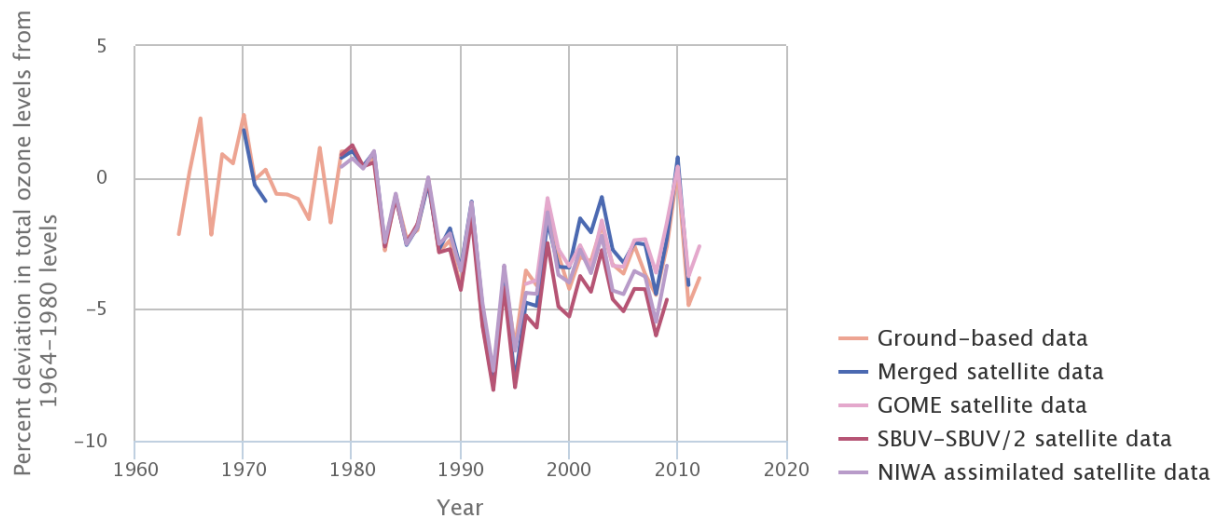
## Data Sources

Summary data for this indicator were provided by the World Meteorological Organization. The 1964-2013 data in this indicator are taken from the Organization's 2014 Scientific Assessment of Ozone Depletion (WMO, 2014), which presents ozone data based on multiple sets of measurements (e.g., Fioletov et al., 2002). The 2014 to 2016 data were provided by the parties who post total ozone data to the World Ozone and UV Data Centre (Fioletov, 2017).

## References

- Booth, R.C., and S. Madronich. 1994. Radiation amplification factors—improved formulation accounts for large increases in ultraviolet radiation associated with Antarctic ozone depletion. In: Weiler, C.S., and P.A. Penhale, eds. Ultraviolet radiation and biological research in Antarctica. Antarctic Research Series. Washington, DC: American Geophysical Union. pp. 39-42.
- Fioletov, V. 2017. Unpublished total ozone data. Raw data posted to the World Ozone and Ultraviolet Radiation Data Centre (WOUDC) website. <https://woudc.org/data/explore.php>.
- Fioletov, V.E., G.E. Bodeker, J.B. Kerr, A.J. Miller, R.D. McPeters, and R. Stolarski. 2002. The global ozone and zonal total ozone variations estimated from ground-based and satellite measurements: 1978-2000. *J. Geophys. Res.* 107(D22).
- Kerr, J.B., and C.T. McElroy. 1993. Evidence for large upward trends of ultraviolet-B radiation linked to ozone depletion. *Science* 262:1032-1034.
- U.S. EPA (United States Environmental Protection Agency). 2006. Air quality criteria for ozone and related photochemical oxidants. EPA/600/R-05/004aF-cF. Research Triangle Park, NC. <https://cfpub.epa.gov/ncea/risk/recordisplay.cfm?deid=149923>.
- U.S. EPA. 2003. Ozone: good up high, bad nearby. EPA/451/K-03/001. Washington, DC. <https://www.epa.gov/sites/production/files/documents/gooduphigh.pdf> (PDF) (4 pp, 1.2MB).
- WMO (World Meteorological Organization). 2014. Scientific assessment of ozone depletion: 2014. Geneva, Switzerland. <https://www.esrl.noaa.gov/csd/assessments/ozone/2014/>.
- WMO. 2010. Scientific assessment of ozone depletion: 2010. Geneva, Switzerland. <https://www.esrl.noaa.gov/csd/assessments/ozone/2010/>.
- WMO. 2007. Scientific assessment of ozone depletion: 2006. Geneva, Switzerland. <https://www.esrl.noaa.gov/csd/assessments/ozone/2006/>.

### Exhibit 1. Total ozone levels over North America, 1964–2012



Total ozone refers to the sum of all the ozone in a column of air from Earth's surface to the top of the atmosphere. Although not quite all of this ozone is in the stratosphere, on average only a minimal fraction is not, and therefore total ozone is the standard measurement used to describe levels of stratospheric ozone.

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:** WMO et al., 2007; Fioletov, 2014

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