

Q12

How large is the depletion of the ozone layer outside of polar regions?

The abundance of total ozone between 60°S and 60°N is now about 2–3% below the amount present during 1964–1980. The abundance of total ozone in this region declined steadily throughout the 1980s due to the increases in reactive halogen gases in the stratosphere resulting from human activities. In the early 1990s, due to additional ozone loss that followed the 1991 eruption of Mount Pinatubo, total ozone between 60°S to 60°N was depleted by 5% relative to the 1964–1980 average, the maximum depletion observed over the past six decades. In both hemispheres, total ozone depletion is small near the equator and increases toward the poles. The larger depletion at higher latitudes, particularly in the Southern Hemisphere, is driven in part by the late winter/early spring destruction of polar ozone, which influences ozone at lower latitudes following the breakdown of the polar vortex in each hemisphere.

Decreases in total ozone averaged over 60°S to 60°N, termed here *global ozone*, first became apparent in the 1980s (see **Figure Q12-1**) due to the rise in stratospheric halogens that result from human activities (see **Figure Q15-1**). Most of the depletion has occurred in the stratospheric ozone layer, where most ozone resides (see **Figure Q1-2**). Following the eruption of Mount Pinatubo in June 1991, global ozone in the early 1990s reached a minimum value that was 5% lower than the 1964–1980 average. This massive volcanic eruption dramatically increased the number of sulfuric acid-containing particles throughout the stratosphere. These particles significantly increased the effectiveness of reactive halogen gases in destroying ozone (see **Q13**) and, thereby, decreased global ozone by an additional 2% relative to its long-term trend for several years following the eruption. Since the mid-1990s, global ozone has gradually increased, due to the recovery of the ozone layer from this volcanically-induced perturbation as well as the slow, steady decline in stratospheric halogens driven by the Montreal Protocol (see **Q14**). Since 2010, global ozone has been about 2 to 3% below the 1964–1980 average.

Polar regions. Observed total ozone depletion varies significantly with latitude across the globe. The largest reductions occur at high southern latitudes as a result of the severe ozone loss over Antarctica each year during winter/spring (see **Q9** and **Q10**). The next largest depletion is observed in the high latitudes of the Northern Hemisphere, caused in part by winter losses over the Arctic in some years (see **Q11**). Since ozone loss in polar regions is described extensively in the answers to other questions, the focus below is on the 60°S–60°N region, where the vast majority of the world's population resides.

Midlatitude regions. Ozone depletion is also observed at midlatitudes. Present-day (2017–2020 average) total ozone at midlatitudes of the Southern Hemisphere (SH) (35°S–60°S) is about 5% below the 1964–1980 average, whereas total ozone at midlatitudes of the Northern Hemisphere (NH) (35°N–60°N) is about 4% below the 1964–1980 average (see **Figure Q12-1**). Midlatitude ozone depletion has two contributing factors. First, ozone-depleted air over both polar regions is dispersed away from the

poles during and after each winter/spring period, thereby reducing ozone at midlatitudes. Second, chemical destruction of ozone occurs at midlatitudes, contributing to the observed reductions in these regions. Ozone depletion at midlatitudes is much smaller than in polar regions (see **Figure Q20-1**) because the amount of reactive and reservoir halogen gases is lower and the dramatic seasonal increase of ClO, the most important reactive halogen gas (see **Figure Q7-3**), does not occur at midlatitudes. The slightly larger depletion of ozone at SH midlatitudes, compared to NH midlatitudes, is caused by the dispersion of air from the Antarctic ozone hole.

Tropical region. Total ozone in the tropics (20°S–20°N latitude) has been only weakly affected by chemical depletion. Present-day total ozone in the tropics is about 1% below the 1964–1980 average. In the tropical lower stratosphere, air is transported from the lower atmosphere (troposphere) over about an 18-month period. As a result, the fraction of ozone-depleting substances (ODSs) (halogen source gases) that is converted to reactive and reservoir halogen gases (see **Figure Q7-1**) is small. With little reactive and reservoir halogen gases available, total ozone depletion in this region is also small. In addition, net ozone production occurs in the tropics because of high average amounts of solar ultraviolet radiation. In contrast, stratospheric air in polar regions has been in the stratosphere for about 4 to 7 years, allowing time for significant conversion of ODSs to reactive and reservoir halogen gases (see **Figure Q5-1**). These systematic differences in the composition of stratospheric air are a consequence of large-scale atmospheric transport: air enters the stratosphere in the tropics, moves poleward in both hemispheres, and then descends and ultimately returns to the troposphere in the middle to high latitudes.

Ozone recovery. The Montreal Protocol, strengthened by its amendments and adjustments, has successfully controlled the production and consumption of ODSs, which act to destroy the ozone layer (see **Q14**). As a result, a quantity termed equivalent effective stratospheric chlorine (EESC; the total chlorine and bromine abundances in the stratosphere) peaked in the late 1990s and is now decreasing (see **Q6** and **Q15**). An increase in upper stratospheric

Global and Regional Total Ozone Changes

Observed changes relative to the 1964–1980 average

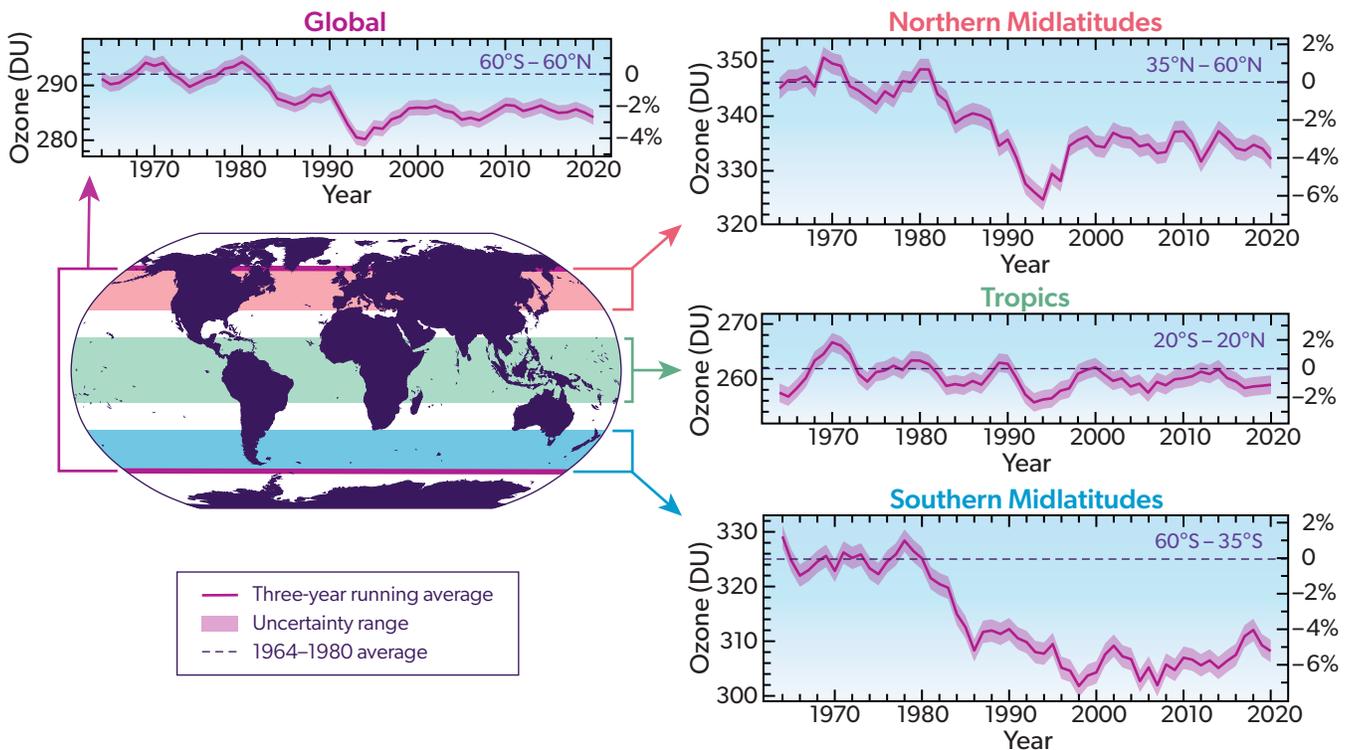


Figure Q12-1. Global total ozone changes. Ground-based and satellite observations show depletion of global total ozone beginning in the 1980s. The various panels compare the difference between annual averages of total ozone averaged over 60°S–60°N (“Global”), 35°N–60°N (“Northern Midlatitudes”), 20°S–20°N (“Tropics”), and 35°S–60°S (“Southern Midlatitudes”) to the amount of ozone that was present in these regions during the period 1964–1980. Seasonal effects have been removed from the observational data set. A 1964–1980 baseline is used because large amounts of ozone depletion had not occurred during these years, as evident in the data record. Global ozone decreased between 1980 and 1990. The depletion worsened for a few years after 1991 due to the effect of volcanic aerosols from the eruption of Mount Pinatubo (see Q13). Since 2010, global ozone has been about 2 to 3% below the 1964–1980 average, ozone in the northern and southern midlatitudes has been about 2 to 5% and 4 to 7% below the 1964–1980 average, respectively, and ozone in the Tropics is about 0 to 2% below the 1964–1980 average.

ozone coincident with the decline in EESC is well documented, constituting an important initial sign of the recovery of the ozone layer. However, ozone in the upper stratosphere makes only a small contribution to total ozone.

The depletion of total ozone over 1979 to 1995 varies as a function of latitude, with the largest losses occurring at the highest latitudes in both hemispheres (see **Figure Q12-2**). Over this time period EESC nearly doubled. The pattern of ozone loss as a function of latitude is caused by two factors: 1) the tendency for larger levels of reactive and reservoir halogen gases to be present at higher latitudes due to the pattern of large-scale atmospheric transport along with the time required for significant conversion of ODSs to reactive and reservoir halogen gases as described above (see Q5 and Q7) and 2) greater influence of the dispersal of severely ozone-depleted air from the Antarctic (Q10) and Arctic (Q11) vortices at the end of their respective winters at the higher latitudes.

Over the time period 1996 to 2020, there has been a rise in total ozone of 0.4 % per decade averaged over 60°S–60°N (see Figures Q12-1 and Q12-2) that is consistent with the decline in the abundance of ODSs (see Q14 and Q15). The data indicate most of this increase in total ozone occurs between 35°–60° of the Southern Hemisphere. For the tropics (20°S–20°N), trends in total ozone over 1996 to 2020 are small and not statistically significant. The abundance of EESC at midlatitudes declined by about 15% from 1996 to 2020. The smaller decline of EESC over this 24-year time period compared to the doubling of EESC over the shorter 1979 to 1995 time period is due to the long lifetime for atmospheric removal of ODSs (see Table Q6-1), combined with the rapid growth in the emissions of ODSs in the 1970s and 1980s (see Figure Q0-1). The small increase in ozone shown in Figure Q12-2 for 1996 to 2020 is consistent with the scientific community’s current understanding of the processes that control the abundance of atmospheric ozone.

Total Ozone Trends

Trend in total column ozone due to halogen chemistry

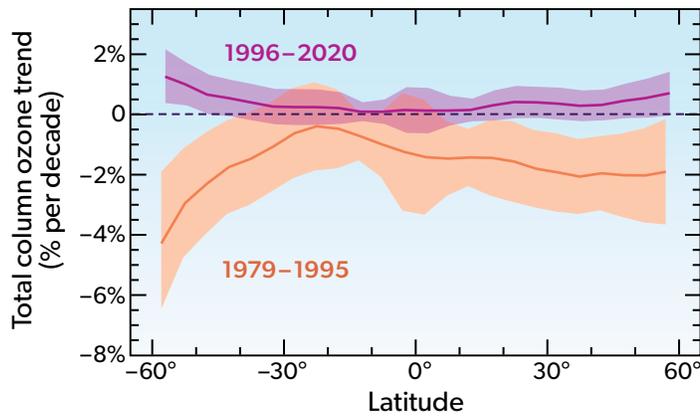


Figure Q12-2. The change in total ozone due to ODSs as a function of latitude, from 60°S to 60°N, for two time periods, 1979–1995 and 1996–2020, expressed as percent change per decade. The trends are based on a statistical model analysis of measurements of total ozone from numerous ground-based and satellite instruments. The model analysis includes the effects on total ozone from ozone-depleting substances (ODSs), stratospheric aerosols, solar ultraviolet (UV) radiation emitted by the Sun, and stratospheric air motions. The figure isolates the resulting chemically-driven change in total ozone due to trends in ODSs only for two time periods (solid lines), along with the total uncertainty (shaded regions).

Identifying an ozone increase that is attributable to the observed decrease in the amount of ODSs is challenging because halogen levels are not the only factor that determines the abundance of stratospheric ozone. Total ozone declined over most of the globe (60°S–60°N) during the 1980s and early 1990s, reaching a minimum in 1993 due to the combined effects of ODSs and the eruption of Mount Pinatubo in 1991 (see Figures Q12-1 and Q13-1). This global ozone minimum was observed half a decade before the EESC maximum was reached due to the strong global ozone response to enhanced amounts of stratospheric sulfate aerosol after the volcanic eruption of Mount Pinatubo, which led to increased ozone depletion for several years. Observed global ozone increases in the mid-1990s were caused by the steady removal of volcanic aerosol from the stratosphere by natural processes, which occurred at the time EESC was approaching its maximum (see Q13).

Another factor complicating the identification of ozone recovery in different regions of the atmosphere is the year-to-year variation of the stratospheric circulation. In most regions of the atmosphere, these variations lead to ozone variability that is currently still larger than the increases in ozone expected from the observed decrease in EESC. Finally, increases in greenhouse gases (GHGs) such as

carbon dioxide (CO₂), which warm the lower atmosphere, affect ozone by decreasing stratospheric temperatures and by strengthening the stratospheric circulation. A colder stratosphere slows down the rate of ozone loss reactions (outside of polar regions), while a stronger circulation enhances the transport of ozone from the tropics to middle and high latitudes.

The impact on stratospheric ozone from accumulated emissions of most ODSs will continue for several decades because of the long atmospheric lifetime of these gases. Assuming compliance with the Montreal Protocol, EESC will continue to decline over the coming decades and will return to pre-1980 levels around 2066 (see Figure Q15-1). Increases in the abundance of most GHGs are expected to accelerate this EESC-driven return of the global ozone layer to pre-1980 levels. However, not all ozone-depleting gases are halogen compounds. Nitrous oxide (N₂O), a GHG with sources attributed to natural processes and various human activities, is projected to increase in the future, which will result in additional ozone depletion (see Q20). Finally, as long as atmospheric abundances of ODSs remain elevated, the possibility of substantial reductions in total ozone following major volcanic eruptions (see Q13) will persist.