Q12 How large is the depletion of the global ozone layer?

The abundance of globally averaged total ozone is now about 2–3% below the amount present during 1964–1980. The abundance of global total ozone declined steadily throughout the 1980s due to the increases in reactive halogen gases in the stratosphere resulting from human activities. In the early 1990s, global total ozone was depleted by 5% relative to the 1964–1980 average, the maximum depletion observed during the modern instrument era. In both hemispheres, total ozone depletion is small near the equator and increases toward the poles. The larger depletion at higher latitudes is due, in part, to the late winter/early spring destruction of ozone that occurs in polar regions, particularly in Antarctica.

Global total ozone started decreasing 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). By the early 1990s, total ozone was 5% lower than the 1964–1980 average. Ozone depletion subsequently diminished, so that by 2010 globally averaged ozone was 2-3% less than the 1964–1980 average. The observations shown in Figure Q12-1 have been smoothed to remove regular variations in ozone due to natural seasonal effects and year-to-year changes in atmospheric circulation (see Q13). Over the past few years, observed global ozone has been about 2.2% lower than the 1964-1980 average.

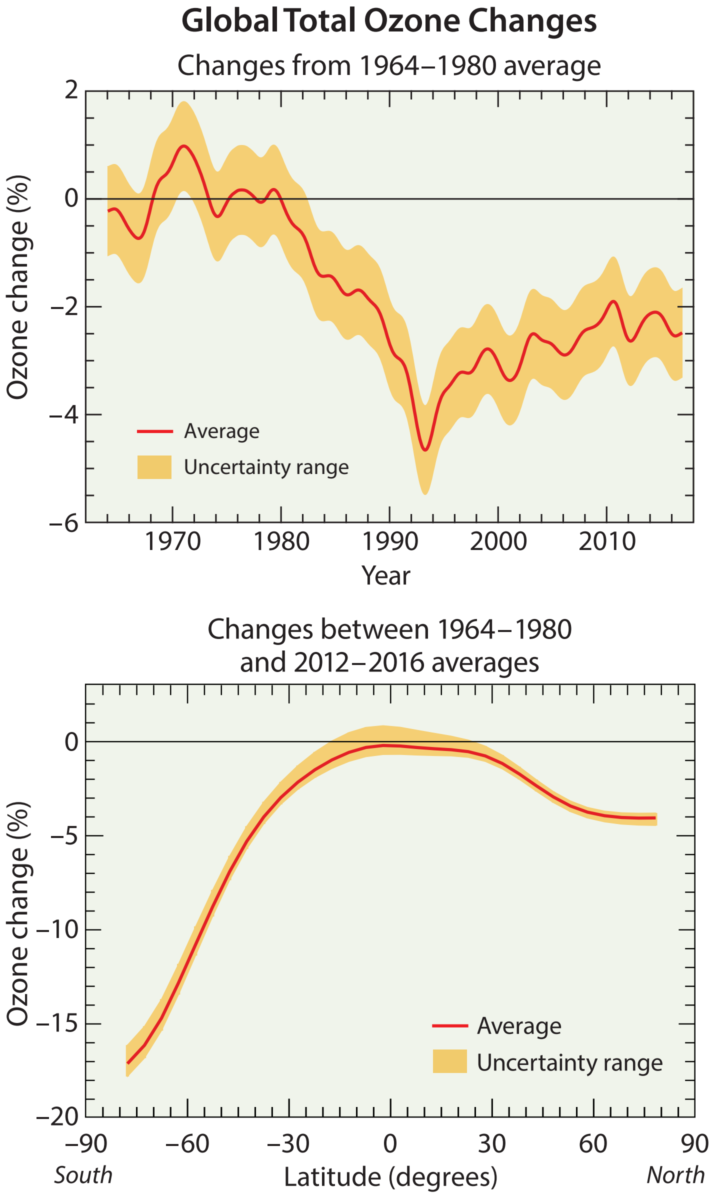
The observed global ozone depletion in the past four decades is attributable to increases in reactive halogen gases in the stratosphere (see Q13). The lowest global total ozone values since 1980 have occurred in the years following the volcanic eruption of Mount Pinatubo in 1991, which temporarily increased 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, increased global ozone depletion by about 2% for several years following the eruption.

Polar regions. Observed total ozone depletion varies significantly with latitude across the globe (see Figure Q12-1). The largest reductions occur at high southern latitudes as a result of the severe ozone loss over Antarctica each late winter/early spring period (see Q9 and Q10). The next largest losses are observed in the high latitudes of the Northern Hemisphere, caused in part by winter losses over the Arctic in some years (see Q11). Although the depletion of ozone in polar regions is larger than at lower latitudes, the contribution of polar ozone loss to globally averaged depletion is limited by the smaller geographical area of high-latitude regions. Latitudes poleward of 60° account for only about 13% of Earth's surface.

Midlatitude regions. Ozone depletion is also observed at midlatitudes. In comparison with the 1964–1980 average amounts, total ozone averaged for 2012–2016 is about 3% lower in northern midlatitudes (35°N–60°N) and about 5.5% lower at southern midlatitudes (35°S–60°S). Midlatitude 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 average ozone at midlatitudes. Second, chemical destruction occurring at midlatitudes contributes to observed depletion in these regions. Ozone depletion at midlatitudes is much smaller than in polar regions (see Q20) because the amount of reactive halogen gases is lower and the seasonal increase of ClO, the most reactive halogen gas, does not occur.

Tropical region. Total ozone in the tropics (20°N–20°S latitude) has been only weakly affected by chemical depletion. 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) converted to reactive halogen gases is still very small. With little reactive halogen available, total ozone depletion in this region is also very 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 an average of 4 to 7 years, allowing time for significant conversion of ODSs to reactive halogen gases (see Figure Q5-1). These systematic differences in 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.

Figure Q12-1. Global total ozone changes. Ground-based and satellite observations show depletion of global total ozone beginning in the 1980s. The top panel compares the difference between annual averages of total ozone averaged over 60°S to 60°N latitude, relative to the amount of ozone that was present 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 (see Figure Q10-3). On average, global ozone decreased each year between 1980 and 1990. The depletion worsened for a few years after 1991 due to the effect of volcanic aerosol from the eruption of Mount Pinatubo (see Q13). Since 2010, global ozone has been about 2-3% less than the 1964–1980 average. The bottom panel shows how the 2012–2016 depletion varies with latitude over the globe. The largest decreases have occurred at high latitudes in both hemispheres because of the large winter/spring depletion in polar regions. The losses in the Southern Hemisphere are greater than those in the Northern Hemisphere because of the Antarctic ozone hole. Long-term changes in the tropics are much smaller because reactive halogen gases are less abundant in the tropical lower stratosphere than at mid or high latitudes, and ozone production rates are greater.



Initial Signs of Ozone Recovery

The Montreal Protocol, strengthened by its Amendments and Adjustments, has successfully controlled the production and consumption of ozone-depleting substances (ODSs), which act to destroy the ozone layer (see Q14). As a result, atmospheric abundances of ODSs have peaked and are now decreasing (see Q6 and Q15). By 2018, equivalent effective stratospheric chlorine (EESC; the total chlorine and bromine abundances in the stratosphere) had declined by 18% at midlatitudes from peak values that occurred in 1997. This raises the question, is global ozone increasing in response to the observed decrease in EESC?

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. For example, the global ozone minimum was observed half a decade before the EESC maximum was reached. This difference in timing resulted from the strong global ozone response to enhanced amounts of stratospheric aerosol after the volcanic eruption of Mount Pinatubo in 1991, 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, 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 variations of the stratospheric circulation. These variations lead to ozone variability in most regions of the atmosphere 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 (CO_2), which warm the lower atmosphere, affect ozone by decreasing stratospheric temperatures and by strengthening the stratospheric circulation. A warmer atmosphere slows down the rate of ozone loss reactions and a stronger circulation enhances the transport of ozone from the tropics to middle and high latitudes.

Midlatitude observations show an ozone increase of about 2% per decade in the upper stratosphere (between 35 and 45 km altitude) over the period 2000–2016. Model simulations that allow for separation of the various factors that affect ozone suggest that about half of this increase results from a cooling in this region due to rising amounts of atmospheric CO_2, while the other half results from decreases in EESC. Variations in upper stratospheric ozone are mainly controlled by changes in chemistry and temperature in this region of the atmosphere, rather than stratospheric circulation. The increase in upper stratospheric ozone coincident with the decline in EESC constitutes an initial sign of ozone recovery. However, ozone in the upper stratosphere makes only a small contribution to total 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 (see Figure Q12-1). The value of EESC peaked in the midlatitude stratosphere in 1997 (see Figure Q13-1). Since 1997, total ozone has increased in the range of 0.3-1.2% per decade. A significant component of the year-to-year fluctuations in total ozone is caused by natural variation in the stratospheric circulation. Consequently, attribution of the observed increase in global total ozone since 1997 to declining levels of EESC is not yet definitive. The decline in EESC since 1997 is expected to have caused an increase in total ozone of about 1% per decade, which is small compared to the natural year-to-year variability in total ozone that has been observed (see Figure Q13-1).

There are emerging indications that the size and maximum ozone depletion (depth) of the Antarctic ozone hole has diminished since 2000 (see Figure Q10-2). This recovery is clearest during September, which is early spring in the Southern Hemisphere. Although accounting for the effect of natural variability on the size and depth of the ozone hole is challenging, the weight of evidence suggests that the decline in EESC made a substantial contribution to these observed trends.

The impact on stratospheric ozone from accumulated emissions of the most prominent ODSs, CFC-11 and CFC-12, will continue for several decades because of the long atmospheric lifetime of these ODSs. Assuming compliance with the Montreal Protocol, EESC will continue to decline over the coming decades and will return to pre-1980 levels around midcentury (see Figures Q15-1 and Q20-2). Increases in GHG abundances are expected to accelerate the return of the global ozone layer to pre-1980 levels (see Q20). However, 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.