Q13

How large is the depletion of the global ozone layer?

Depletion of the global ozone layer increased gradually in the 1980s and reached a maximum of about 5% in the early 1990s. The depletion has lessened since then and now is about 3% averaged over the globe. The average depletion exceeds the natural year-to-year variations of global total ozone. The ozone loss is very small near the equator and increases with latitude toward the poles. The larger polar depletion is attributed to the late winter/early spring ozone destruction that occurs there each year.

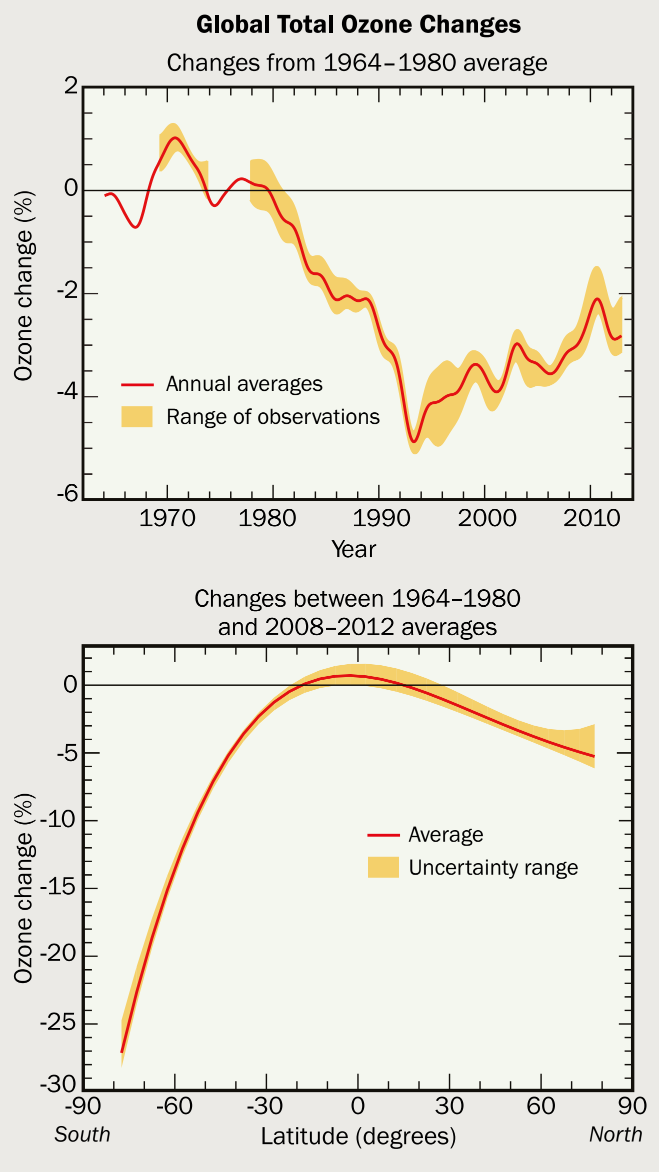
Global total ozone has decreased beginning in the 1980s (see Figure Q13-1). The decreases have occurred in the stratospheric ozone layer where most ozone resides (see Figure Q1-2). In the early 1990s, the depletion of global total ozone reached a maximum of about 5% below the 1964–1980 average. The depletion has lessened since then and during the early 2010s has averaged to about 3% below the 1964–1980 average. The observations shown in Figure Q13-1 have been smoothed to remove regular ozone changes that are due to natural seasonal and solar effects (see Q14). The depleted amounts are larger than the remaining natural variations in global total ozone amounts.

The observed global ozone depletion in the last three decades is attributable to increases in reactive halogen gases in the stratosphere. The lowest global total ozone values since 1980 have occurred in the years following the eruption of Mt. 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 Q14) and, thereby, increased global ozone depletion by 1–2% for several years following the eruption.

Polar regions. Observed total ozone depletion varies significantly with latitude on the globe (see Figure Q13-1). The largest reductions occur at high southern latitudes as a result of the severe ozone loss over Antarctica each late winter/early spring period. The next largest losses are observed in the high latitudes of the Northern Hemisphere, caused in part by winter losses over the Arctic. Although the depletion in polar regions is larger than at lower latitudes, the influence of polar regions on global ozone is limited by their small geographical area. Latitudes poleward of 60° account for only about 13% of Earth's surface.

Midlatitude regions. Ozone depletion is also observed at the midlatitudes spanning the region between equatorial and polar latitudes. In comparison with the 1964–1980 averages, total ozone averaged for 2008–2012 is about 3.5% lower in northern midlatitudes (35°N–60°N) and about 6% 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 outside polar regions. Second, chemical destruction occurring at midlatitudes contributes to observed depletion in these regions. This contribution is much smaller than in polar regions because the amounts of reactive halogen gases are lower and a seasonal increase of the most reactive halogen gases, such as the increase in ClO in the polar winter lower stratosphere (see Figure Q8-3), does not occur in midlatitude regions.

Tropical region. Total ozone in the tropics (20°N–20°S latitude) has been only weakly affected by chemical ozone depletion. In the tropical lower stratosphere, air has been transported from the lower atmosphere (troposphere) within the previous 18 months. As a result, the conversion of ozone-depleting substances (ODSs) 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, ozone production is high because average solar ultraviolet radiation is highest in the tropics. 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. The systematic differences in the age of stratospheric air are well understood and are a consequence of the 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.



Global Total Ozone Changes

Changes from 1964–1980 average

Changes between 1964–1980 and 2008–2012 averages

Figure Q13-1. Global total ozone changes. Satellite observations show depletion of global total ozone beginning in the 1980s. The top panel compares annual averages of global ozone with the average from the period 1964 to 1980 before the ozone hole appeared. Seasonal and solar effects have been removed from the observational data set. 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 Mt. Pinatubo eruption (see Q14). Average global ozone for 2008–2012 is about 2.5% below the 1964–1980 average. The bottom panel shows how the 2008–2012 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 ODSs that act to destroy the ozone layer (Q15). As a result, atmospheric abundances of ODSs have peaked and are now decreasing (Q7 and Q16). By 2012, equivalent effective stratospheric chlorine (EESC; the total chlorine and bromine abundances in the stratosphere) had declined by 15% at midlatitudes from peak values of around 15 years ago. This raises the question, is global ozone increasing in response to the observed EESC decreases?

Identifying an ozone increase is not easy, because ODS levels are not the only factor that determines global ozone levels. For example, the global ozone minimum was observed half a decade before the EESC maximum was reached. The difference in the timing resulted from the strong global ozone response to enhanced stratospheric aerosol loading after the Mount Pinatubo eruption in 1991, which led to increased ozone depletion for several years. Observed global ozone increases through the 1990s were therefore a result of the steady removal of the aerosol from the stratosphere, and not a sign of decreasing ODSs (see Q14). 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 signal expected from the observed EESC decreases. Finally, greenhouse gas increases (such as carbon dioxide, CO_2) affect ozone by decreasing stratospheric temperatures (which slows down ozone depletion rates) and by strengthening the stratospheric circulation (which enhances the transport of ozone from the tropics to higher latitudes). It is therefore difficult to attribute observed ozone changes to these different factors.

Observations now show a clear 5% increase of ozone in the upper stratosphere (42 km) over the 2000-2013 period. Model simulations that allow for separation of the different factors suggest that about half of this increase results from a cooling in this region due to CO_2 increases, while the other half results from EESC decreases. Also, total column ozone declined over most of the globe during the 1980s and early 1990s (by about 2.5% averaged over 60°S to 60°N). It has remained relatively unchanged since 2000, with indications of a small increase in total column ozone in recent years. Models suggest that this small increase is likely due to EESC decreases. These findings based on both models and observations suggest that there are initial signs of ozone recovery.

Because of their long lifetime, the impact on stratospheric ozone of the most prominent ODSs (CFC-11 and CFC-12) will continue for many decades after emissions have ceased. Assuming continued compliance with the Montreal Protocol, EESC will continue to decline over the coming decades and will return to pre-1980 levels around midcentury. With the exception of the tropics (see Q20), climate change is expected to accelerate the return of the ozone layer to pre-1980 levels. However, as long as ODS levels remain elevated in the atmosphere, the possibility of extreme low-ozone events due to volcanic eruptions or cold winter conditions persists into the second half of the 21st century.