

Q12

Is there depletion of the Arctic ozone layer?

Yes, significant depletion of the Arctic ozone layer now occurs in most years in the late winter/early spring period (January–March). However, the maximum depletion is less severe than that observed in the Antarctic and with large year-to-year differences as a consequence of the highly variable meteorological conditions found in the Arctic polar stratosphere. Even the most severe Arctic ozone depletion does not lead to total ozone amounts as low as those seen in the Antarctic, because Arctic ozone abundances during early winter before the onset of ozone depletion are much higher than those in the Antarctic. A large and recurrent “ozone hole,” as found in the Antarctic stratosphere, does not occur in the Arctic.

Significant depletion of ozone has been observed in the Arctic stratosphere in recent decades. The depletion is attributable to chemical destruction by reactive halogen gases, which increased in the stratosphere in the latter half of the 20th century (see Q16). Arctic depletion also occurs in the late winter/early spring period (January–March), but over a somewhat shorter period than in the Antarctic (July–October). Similar to the Antarctic (see Q11), Arctic depletion occurs because of (1) the periods of extremely low temperatures, which cause polar stratospheric clouds (PSCs) to form; (2) the large abundance of reactive halogen gases produced in reactions on PSCs; and (3) the isolation of polar stratospheric air, which allows time for chemical destruction processes to occur.

Arctic ozone depletion is much less than that observed each Antarctic winter/spring season. Large and recurrent ozone holes as found in the Antarctic stratosphere do not occur in the Arctic. Stratospheric ozone abundances during early winter, before the onset of ozone depletion, are naturally higher in the Arctic than in the Antarctic because transport of ozone from its source region in the tropics to higher latitudes is more vigorous in the Northern Hemisphere. Depletion is limited because, in comparison to Antarctic conditions, Arctic average temperatures are always significantly higher (see Figure Q10-1) and the isolation of polar stratospheric air is less effective. Temperature and other meteorological differences occur because northern polar latitudes have more land and mountainous regions than southern polar latitudes (compare Figures Q11-3 and Q12-2). In a few Arctic winters, for example, PSCs did not form because temperatures never reached low enough values. These differences cause the extent and timing of Arctic ozone depletion to vary considerably from year to year. Depletion in some winter/spring seasons occurs over many weeks, in others only for brief early or late periods, and in some not at all.

Long-term total ozone changes. Satellite observations can be used in two important ways to examine the average total ozone abundances in the Arctic region for the last 30–40 years and to contrast these values with Antarctic abundances:

- First, *total ozone poleward of 63°N* averaged for each March shows quantitatively how total ozone has changed in the Arctic (see Figure Q12-1). The seasonal poleward and downward transport of ozone-rich air is naturally stronger in the Northern Hemisphere. As a result, total ozone values at the *beginning* of each winter season in the Arctic are considerably higher than those in the Antarctic. Before depletion sets in, normal Arctic values are close to 450 DU and Antarctic values close to 330 DU. Decreases from pre-ozone-hole average values (1970–1982) were observed in the Arctic by the mid-1980s, when larger changes were already occurring in the Antarctic. The decreases in total ozone are generally much smaller than those found in the Antarctic and lead to total ozone values that are

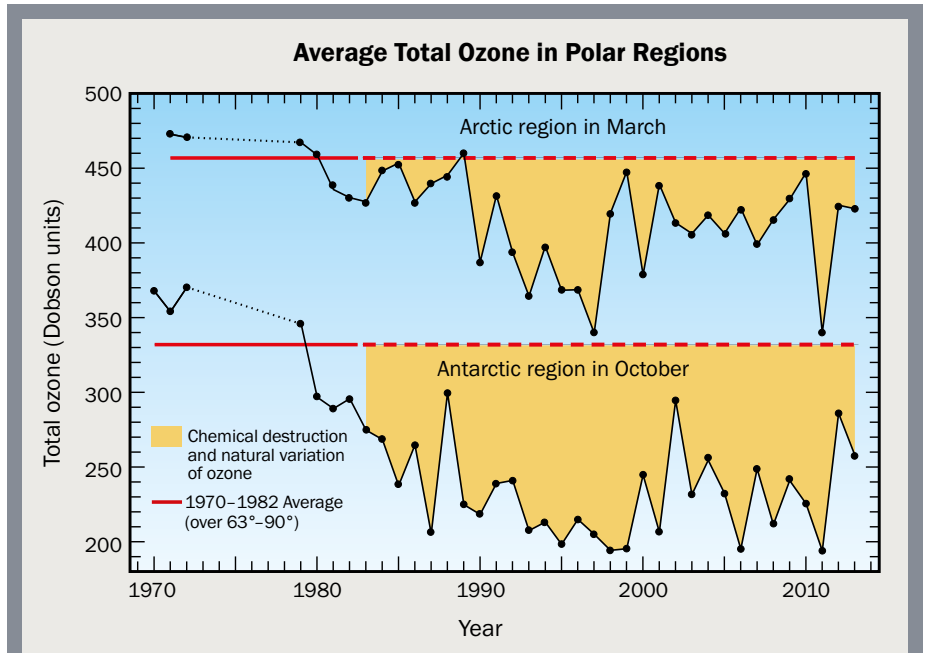


Figure Q12-1. Average total ozone in polar regions.

Long-term changes in average total ozone are shown for the Antarctic and Arctic, defined by latitudes between 63° and 90°. Total ozone is measured with satellite instruments. The reference values (red lines) are averages of springtime total ozone values available from observations between 1970 and 1982. Each point represents a monthly average for October in the Antarctic or March in the Arctic. After 1982, significant ozone depletion is found in most years in the Arctic and all years in the Antarctic. The largest average depletions have occurred in the Antarctic since 1990. The ozone changes are the combination of chemical destruction and natural variations. Variations in meteorological conditions influence the year-to-year changes in ozone, particularly in the Arctic. Natural variations have also increased in the Antarctic since 2000. Essentially all of the decrease in the Antarctic and usually about 50% of the decrease in the Arctic each year are attributable to chemical destruction by reactive halogen gases. In the Arctic, the other 50% is attributable to natural variations in the amounts of ozone transported to polar regions before and during winter. Average total ozone values over the Arctic are naturally larger at the beginning of each winter season because, in the preceding months, more ozone is transported poleward in the Northern Hemisphere than in the Southern Hemisphere.

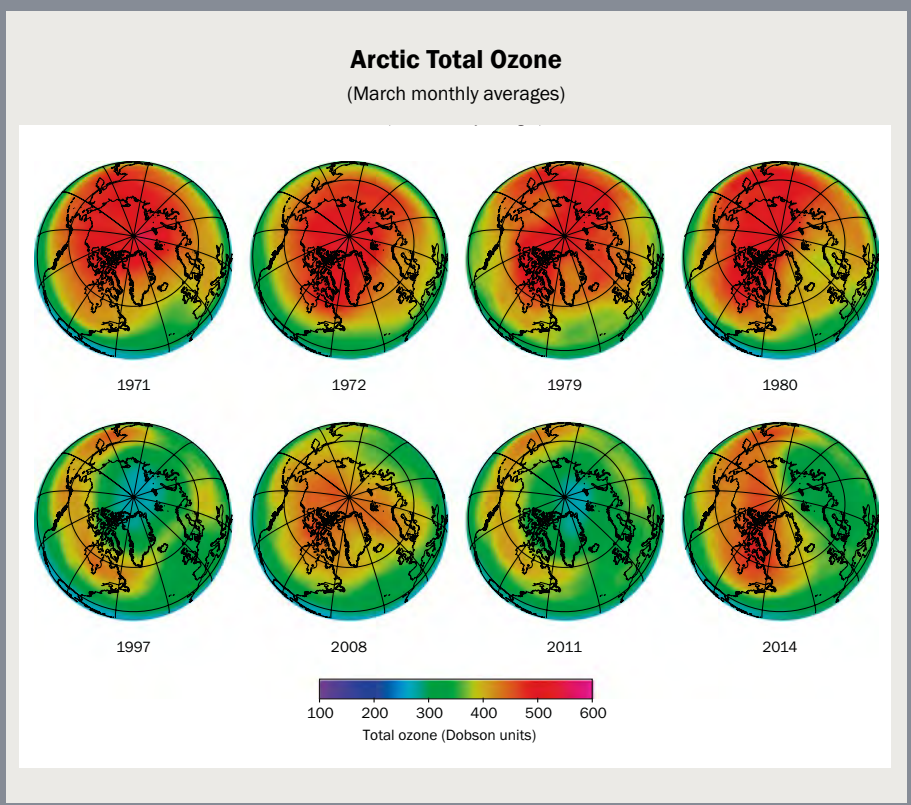
on average around 10–15% below pre-ozone-hole values. Maximum decreases in Arctic total ozone of about 30% observed in March 1997 and 2011 are the most comparable to Antarctic depletion. In both these Arctic winters, meteorological conditions kept ozone transport to high latitudes below average values, and in 2011 persistently low temperatures facilitated severe chemical ozone depletion by ODSs.

Overall, Arctic total ozone values tend to show larger year-to-year variability than those in the Antarctic. Ozone differences from the 1970–1982 average value are due to a combination of chemical destruction by ODSs and meteorological (natural) variations. In the last two decades, these two aspects have contributed about equally to observed ozone changes. The amount of chemical destruction depends in large part on stratospheric temperatures. Meteorological conditions determine how well Arctic stratospheric air is isolated from ozone-rich air at lower latitudes and influence the extent of low temperatures.

Q12

Figure Q12-2. Arctic total ozone.

Long-term changes in Arctic total ozone are evident in this series of total ozone maps derived from satellite observations. Each map is an average during March, the month when some ozone depletion is usually observed in the Arctic. In the 1970s, the Arctic region had normal ozone values in March, with values of 450 DU and above (red colors). Ozone depletion on the scale of the Antarctic ozone hole does not occur in the Arctic. Instead, late winter/early spring ozone depletion has eroded the normal high values of total ozone. On the maps from the late 2000s and early 2010s, the extent of values of 450 DU and above is greatly reduced in comparison with the 1970s maps. The large regions of low total ozone in 1997 and 2011 (blue colors) are unusual in the Arctic record, but not unexpected. The meteorological conditions led to below-average stratospheric temperatures and a strong polar vortex in these winters, conditions favorable to strong ozone depletion.



- Second, *total ozone maps* over the Arctic and surrounding regions (see Figure Q12-2) show year-to-year changes in March total ozone. In the 1970s, total ozone values were near 450 DU when averaged over the Arctic region in March. Beginning in the 1990s and continuing into the early 2010s, values above 450 DU were increasingly absent from the March average maps. A comparison of the maps in the 1970s and early 2010s, for example, shows a striking reduction of total ozone throughout the Arctic region. The large geographical extent of low total ozone in the maps of March 1997 and March 2011 represent exceptional events in the Arctic observational record of the last three decades as noted above in the discussion of Figure Q12-1.

Altitude profiles of Arctic ozone. Arctic ozone is measured using a variety of instruments (see Q5), as in the Antarctic, to document daily to seasonal changes within the ozone layer. Spring Arctic and Antarctic balloonborne measurements are contrasted in Figure Q12-3. Arctic profiles were obtained from the Ny-Ålesund research station at 79°N. For 1989–2014, the March average reveals a substantial ozone layer, contrasting sharply with the severely depleted Antarctic ozone layer in the October average over a similar time period. This further demonstrates how higher stratospheric temperatures and meteorological variability have protected the Arctic ozone layer from the greater ozone losses that occur in the Antarctic, despite similar reactive halogen abundances in the two regions.

The separate Arctic profiles shown for 29 March 1996 and 1 April 2011 are two of the most severely depleted in the 25-year long record from Ny-Ålesund. Although significant, the depletion during both events is smaller in comparison to that routinely observed in the Antarctic, such as in the profile from 9 October 2006. The near-complete depletion of ozone over many kilometers in altitude and over areas almost

as large as North America, as is now common in the Antarctic stratosphere, has never been observed in the Arctic.

Restoring ozone in spring. As in the Antarctic, ozone depletion in the Arctic is confined to the late winter/early spring season. In spring, temperatures in the polar lower stratosphere increase (see Figure Q10-1), halting PSC formation and production of ClO, and thus the most effective chemical cycles that destroy ozone. The breakdown of the polar vortex ends the wintertime isolation of high-latitude air, increasing exchange of air between the Arctic stratosphere and lower latitudes. This allows more ozone-rich air to be transported poleward, where it displaces or mixes with air in which ozone may have been depleted. As a result of these large-scale transport and mixing processes, any ozone depletion typically disappears by April or earlier.

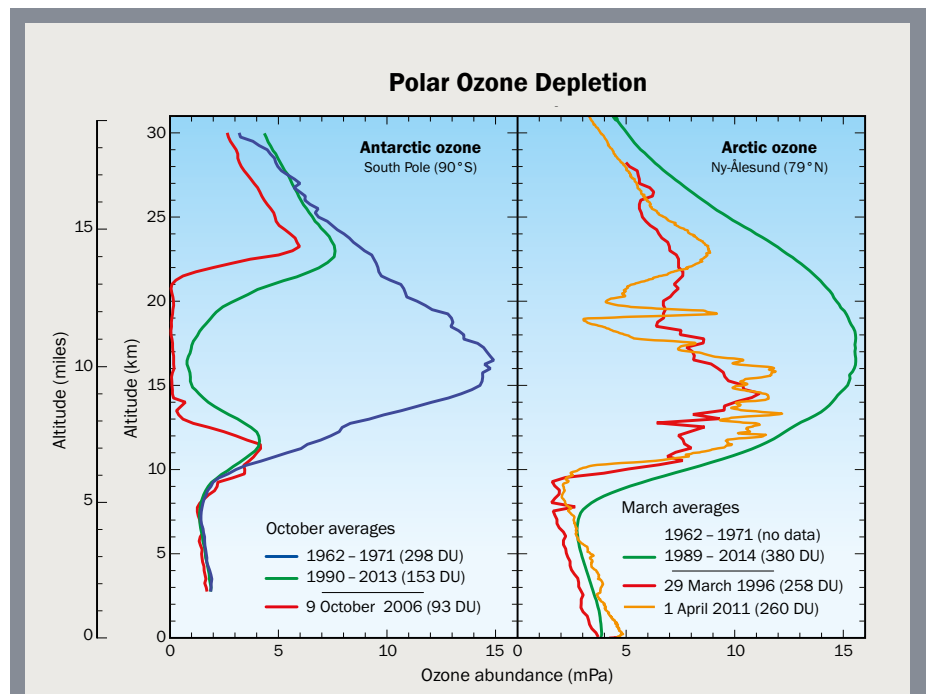


Figure Q12-3. Vertical distribution of Arctic and Antarctic ozone.

Most stratospheric ozone resides between about 10 and 30 kilometers (6 to 19 miles) above Earth's surface. Long-term observations of the ozone layer with balloonborne instruments allow winter ozone altitude profiles to be compared between the Antarctic and Arctic regions. In the Antarctic at the South Pole (left panel), a normal ozone layer was observed to be present between 1962 and 1971. In the past two decades, as shown here for 9 October 2006, ozone is almost completely destroyed between 14 and 21 kilometers (9 to 13 miles) in the Antarctic in spring. Average October values in the last decades (1990–2013) are 90% lower than pre-1980 values at the peak altitude of the ozone layer (16 kilometers). In contrast, the Arctic ozone layer is still present in spring as shown by the average March profile for 1989–2014 obtained over the Ny-Ålesund site (right panel). No Ny-Ålesund data are available for the 1962–1971 period before significant ODS destruction began. Some March profiles do reveal significant depletion, as shown here for 29 March 1996 and 1 April 2011. In such years, winter minimum temperatures are generally lower than normal, allowing PSC formation for longer periods. Depletion similar to that shown for 9 October 2006 at the South Pole has never been observed in the Arctic. The number in parentheses for each profile is the total ozone value in Dobson units (DU). Ozone abundances are shown here as the pressure of ozone at each altitude using the unit "milli-Pascals" (mPa) (100 million mPa = atmospheric sea-level pressure).