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 is more variable from year to year. A large and recurrent "ozone hole," as found in the Antarctic stratosphere, does not occur in the Arctic.

Significant depletion of total 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 20^{th} century (see Q16). Arctic depletion also occurs in the late winter/early spring period (January–March) 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 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. Depletion is limited because, in comparison to Antarctic conditions, Arctic average temperatures are always significantly higher (see Figure Q10-1) and the isolation of 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 in the Antarctic. Before depletion sets in, normal Arctic values are close to 450 DU and Antarctic values near 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 have reached a maximum of about 30% and generally remain smaller than those found in the Antarctic. The low value of Arctic total ozone in March 1997 relative to 1970–1982 observations is the most comparable to Antarctic depletion. In the 1996/1997 Arctic winter, low temperatures facilitated large amounts of chemical depletion, while meteorological conditions kept ozone transport to high latitudes below average values.

  Overall, the Arctic values tend to show larger year-to-year variability than in the Antarctic. Ozone differences from the 1970-to-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.
- 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 late 2000s, values above 450 DU were increasingly absent from the March average maps. A comparison of the 1971 and 2009 maps, for example, shows a striking reduction of total ozone throughout the Arctic region. The large geographical extent of low total ozone in the map of March 1997 is rare in

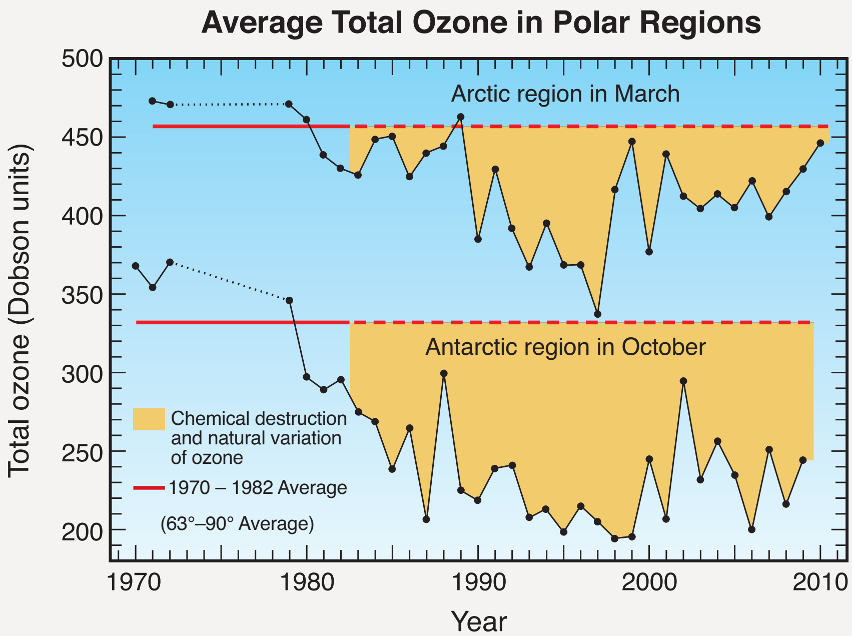

Figure Q12-1. Average total ozone in polar regions. Long-term changes in average total ozone are shown for the Antarctic and Arctic for the respective regions defined by latitudes between 63° and 90°. Total ozone is measured with satellite instruments. The reference values (red lines) are averages of 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. 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.

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 using Arctic profiles from the Ny-Ålesund research station at 79°N. For 1991–2009, the March average reveals a substantial ozone layer and total ozone of 382 DU, contrasting sharply with the severely depleted Antarctic ozone layer in the October average for these years. 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 profile shown for 29 March 1996 is one of the most severely depleted in the two-decade record from Ny-Ålesund. Although significant, this depletion is modest 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, 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), ending PSC formation and reactions on aerosols, as well as the most effective chemical cycles that destroy ozone. Wintertime isolation of high-latitude air ends during this time with 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 this large-scale transport and mixing processes, any ozone depletion disappears by April or earlier.

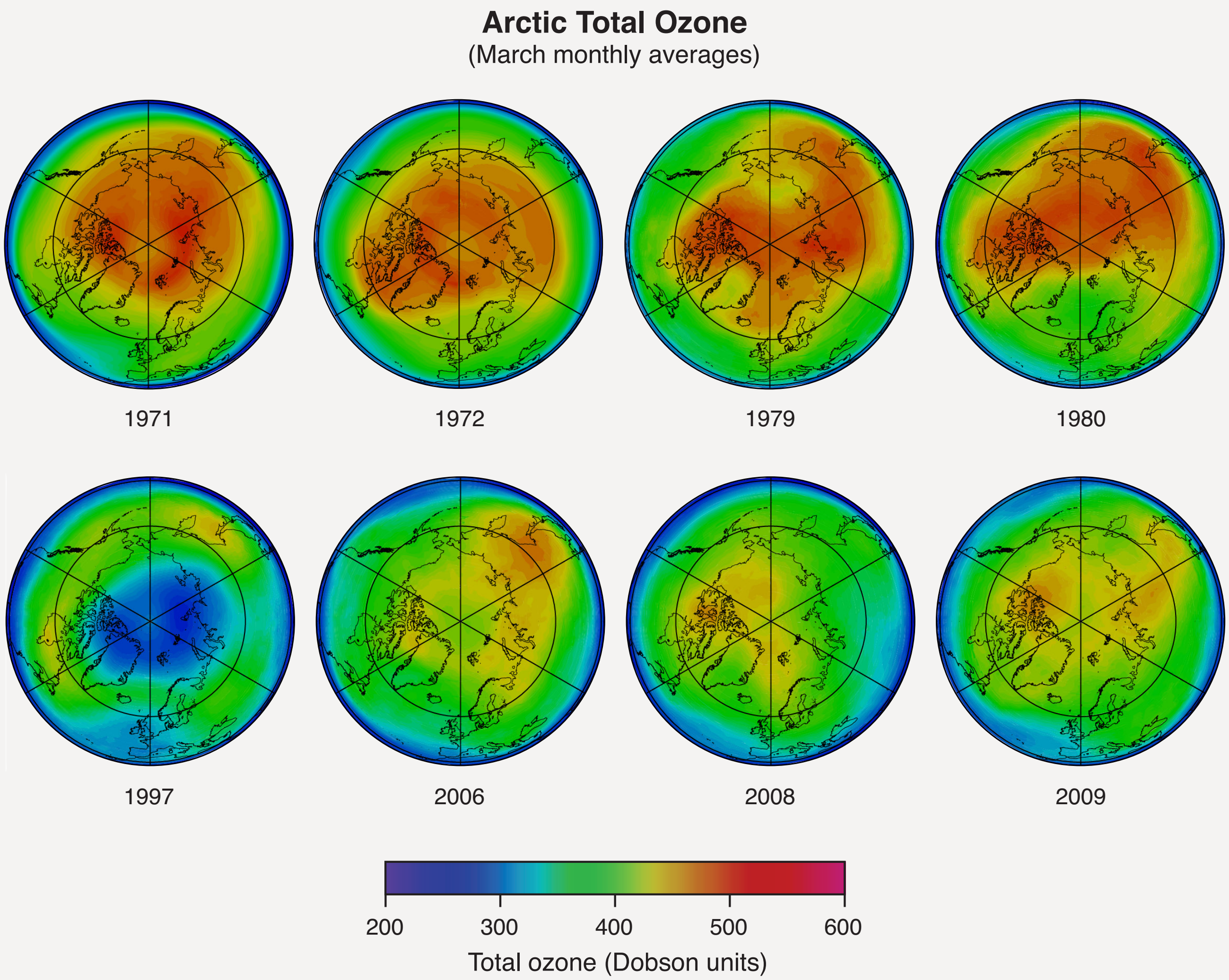

Figure Q12-2. Arctic total ozone. Long-term changes in Arctic total ozone are evident in this series of total ozone maps derived from satellite observations. Each map is an average during March, the month when some ozone depletion is usually observed in the Arctic. In the 1970s, the Arctic region had normal ozone values in March, with values of 450 DU and above (orange and 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, the extent of values of 450 DU and above is greatly reduced in comparison with the 1970s maps. The large region of low total ozone in 1997 is unusual in the Arctic record and is attributable to meteorological conditions that led to below-average stratospheric temperatures and a strong polar vortex that winter. (Note the difference in color scale with Figure Q11-3.)

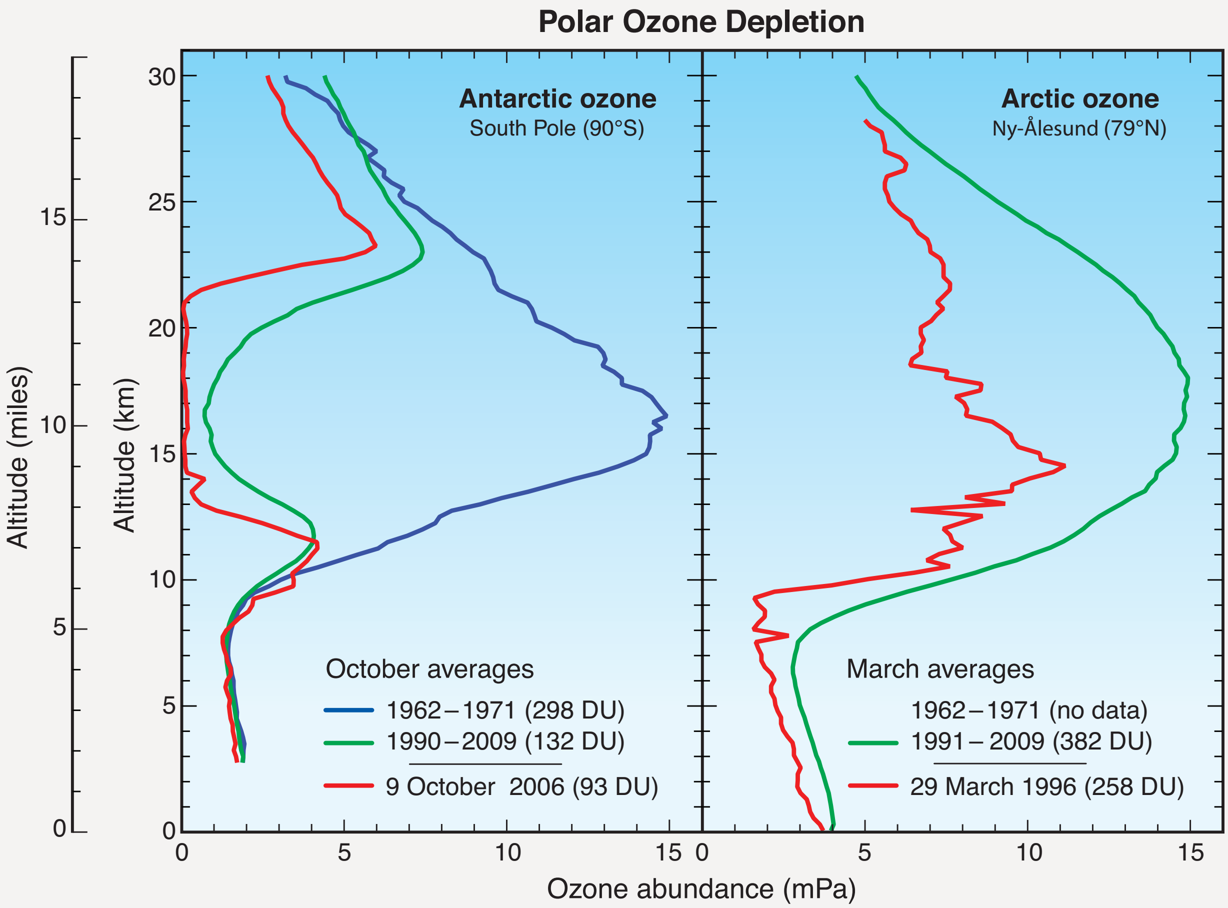

Figure Q12-3. Vertical distribution of Arctic and Antarctic ozone. Most stratospheric ozone resides between about 10 and 30 kilometers (6 to 19 miles) above Earth's surface. Long-term observations of the ozone layer with balloonborne instruments allow winter ozone altitude profiles to be compared between 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 more recent years, 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 (1990–2009) 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 1991–2009 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. In such years, winter minimum temperatures are generally lower than normal, allowing PSC formation for longer periods. Arctic profiles with depletion similar to that shown for 9 October 2006 at the South Pole have never been observed. 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).