

Q11

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 and early spring period (January–March). However, Arctic ozone depletion is less severe than that observed in the Antarctic and exhibits larger year-to-year differences as a consequence of the more 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 larger than those in the Antarctic. Consequently, an extensive 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 (see Q8), which increased in the stratosphere in the latter half of the 20th century (see Q15). Arctic depletion also occurs in the late winter/early spring period (January–March), however over a somewhat shorter period than in the Antarctic (July–October). Similar to the Antarctic (see Q10), Arctic ozone depletion occurs because of (1) periods of very low temperatures, which lead to the formation of polar stratospheric clouds (PSCs); (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 after the return of sunlight. However, these conditions occur less often in the Arctic than in the Antarctic.

Total ozone observed in the Arctic during spring (see **Figure Q11-1**), even for years with significant ozone depletion, is higher than is commonly observed in the Antarctic during spring. Exten-

sive 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. Furthermore, ozone depletion is limited because, in comparison to Antarctic conditions, average temperatures in the Arctic stratosphere are always significantly higher (see Figure Q9-1) and the isolation of polar stratospheric air is less effective (see Q9). These differences occur because northern latitudes have a greater prevalence of mountainous regions and contrasting areas of ocean and land than southern latitudes (compare Figures Q10-3 and Q11-2), which creates more meteorological disturbances that warm the Arctic stratosphere (see box in Q10). Consequently, the extent and timing of Arctic ozone depletion varies considerably from year to year.

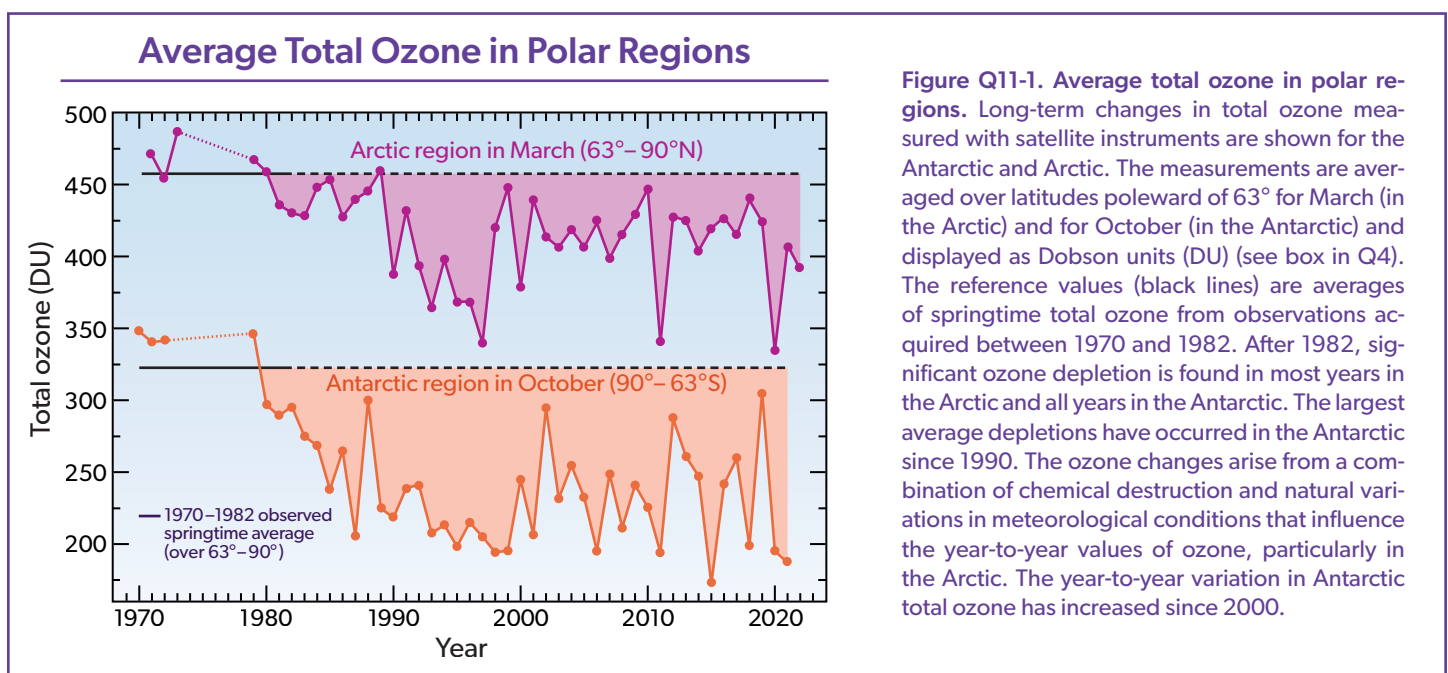


Figure Q11-1. Average total ozone in polar regions. Long-term changes in total ozone measured with satellite instruments are shown for the Antarctic and Arctic. The measurements are averaged over latitudes poleward of 63° for March (in the Arctic) and for October (in the Antarctic) and displayed as Dobson units (DU) (see box in Q4). The reference values (black lines) are averages of springtime total ozone from observations acquired between 1970 and 1982. 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 arise from a combination of chemical destruction and natural variations in meteorological conditions that influence the year-to-year values of ozone, particularly in the Arctic. The year-to-year variation in Antarctic total ozone has increased since 2000.

Arctic Total Ozone

March monthly averages

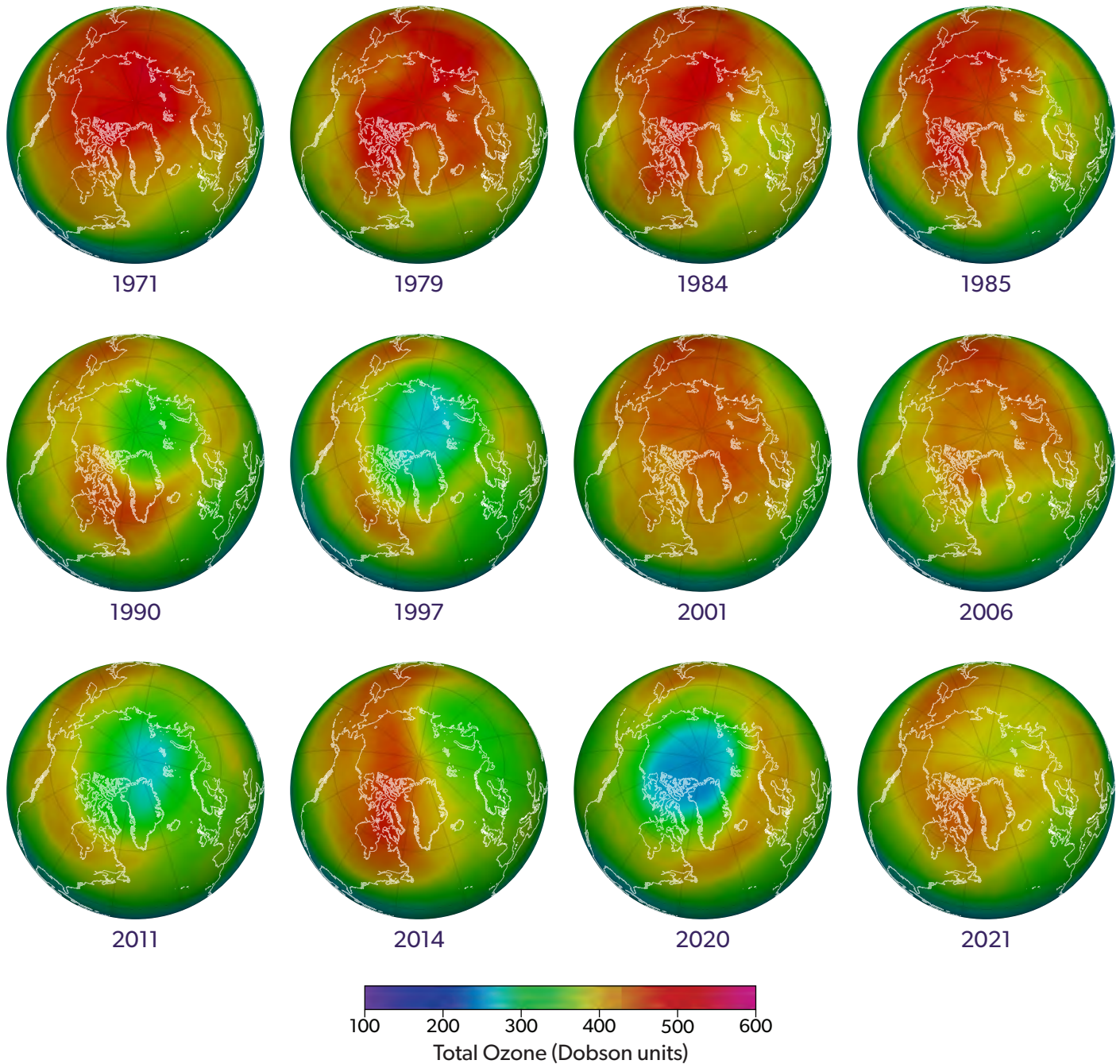
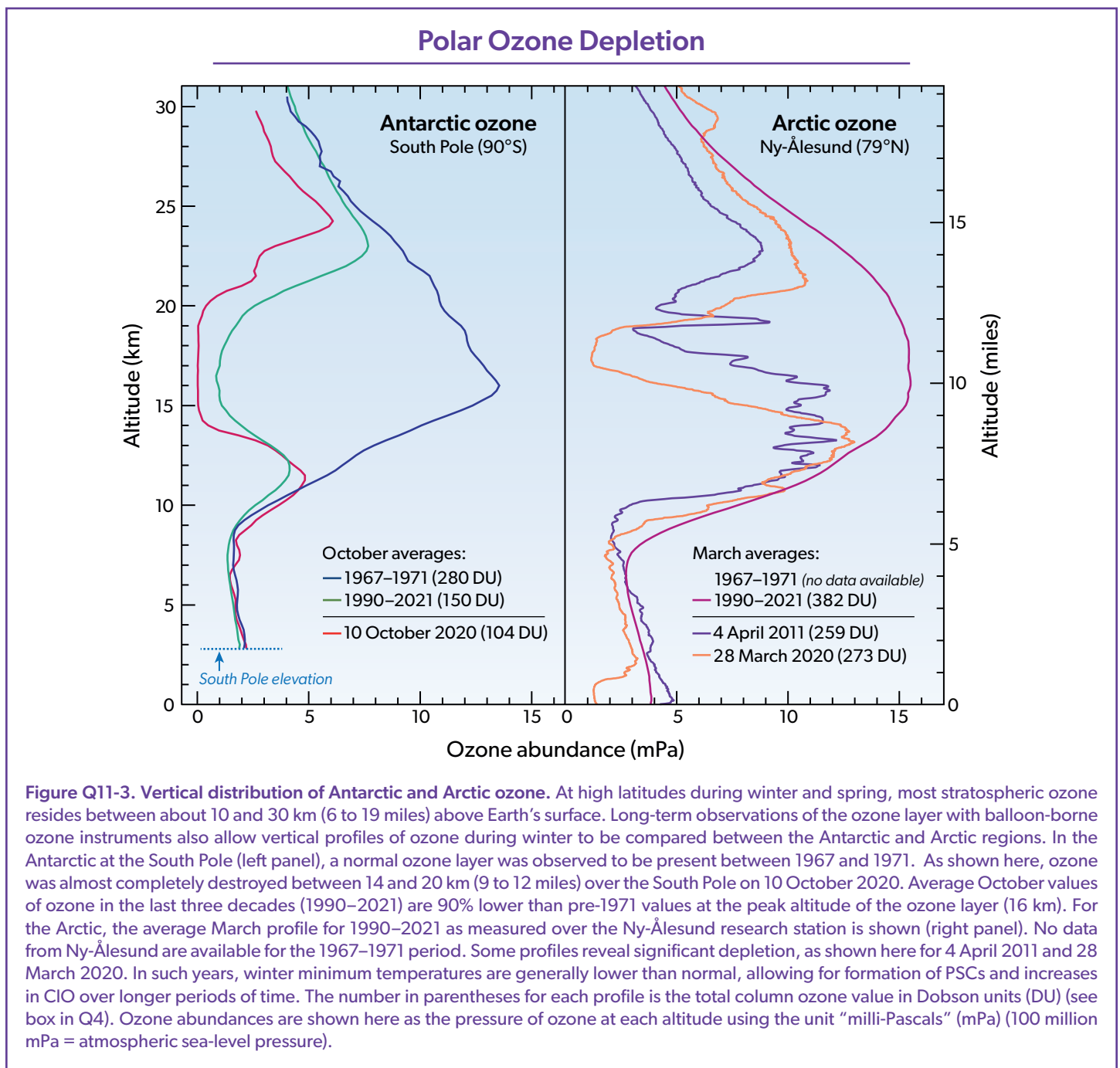


Figure Q11-2. Arctic total ozone. Long-term changes in Arctic total ozone are evident in this series of total ozone maps derived from satellite observations. Each map is an average during March, the month when some ozone depletion is usually observed in the Arctic. The years chosen are shown to highlight the strong year-to-year variability of Arctic ozone as well as the tendency towards lower values over time, during the half-century long record of satellite data. In the 1970s and 1980s, the Arctic region had normal ozone values in March, with values of 450 DU and above (red colors). Low values of total ozone on the scale of the Antarctic ozone hole do not occur in the Arctic. Instead, in late winter and early spring ozone depletion has eroded the normal high values of total ozone. For most years starting in the 1990s, the geographic extent of ozone values of 450 DU and above is reduced in comparison with the 1970s. The large regions of low total ozone in March of 1997, 2011, and 2020 (blue colors) are unusual in the Arctic record (see Figure Q11-1). Meteorological conditions during these three winters led to below-average stratospheric temperatures and strong polar vortices, conditions favorable to strong ozone depletion by reactive halogen gases.

Arctic ozone depletion in some winter/spring seasons occurs over many weeks, in others only for brief periods. These differences are controlled by the stability of and temperature within the Arctic vortex circulation system. Meteorological conditions affect the strength of the circulation of air in the Arctic stratosphere and the amount of ozone transported to the polar region. When the Arctic vortex is weak and disrupted, the polar region has larger amounts of ozone since temperatures are higher than normal and more ozone is transported by the winds to high latitudes. In contrast, a strong and stable vortex leads to lower-than-normal amounts of total ozone in the Arctic due to both more severe chemical loss and weaker poleward transport of ozone.

Long-term total ozone changes. Two important ways in which satellite observations can be used are to examine the average total ozone abundances in the Arctic region for the last half century and to contrast these values with Antarctic abundances.

- First, *total ozone averaged poleward of 63°N* for each March shows how total ozone has changed in the Arctic (see Figure Q11-1). The seasonal poleward and downward transport of ozone-rich air is naturally stronger in the Northern Hemisphere. As a result, before ozone depletion begins normal Arctic values are close to 450 DU while Antarctic values are close to 330 DU. Changes in total ozone from the 1970–1982 average value



(horizontal line in Figure Q11-1) are due to a combination of chemical destruction by halogens and meteorological (natural) variations. In the last quarter century, these two aspects have contributed about equally to the observed year-to-year variations of ozone in the Arctic. 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 in the Arctic are generally much smaller than those found in the Antarctic and lead to total ozone values that are typically about 10 to 20% below normal. Maximum decreases in total ozone of about 30% observed in March 1997, 2011, and 2020 for considerable regions of the Arctic (see **Figure Q11-2**) are the most comparable to Antarctic depletion. In all three Arctic winters, meteorological conditions inhibited transport of ozone-rich air to high latitudes, and in 2011 and 2020 persistently low temperatures facilitated severe chemical depletion of ozone by reactive halogens (see Q8).

- Second, **total ozone maps** over the Arctic and surrounding regions (see Figure Q11-2) show year-to-year changes in total ozone during March. In the 1970s, total ozone values were near 450 DU when averaged over the Arctic region in March. Beginning in the 1990s and continuing until present, values above 450 DU have been increasingly absent from the March average maps. A comparison of the maps in the 1970s and 2020, for example, shows a striking reduction of total ozone throughout the Arctic region. The large geographical extent of low total ozone in the March maps for years 1997, 2011, and 2020 represent exceptional events in the Arctic observational record of the last five decades, as noted above in the discussion of Figure Q11-1. The large-scale differences between Arctic ozone distributions observed in March 2011, 2014, 2020, and 2021 are a prime example of the influence of meteorology in driving year-to-year variations in Arctic ozone depletion. Despite the decline in the concentration of reactive gases in the polar stratosphere beginning around year 2000, there is little evidence of recovery of Arctic ozone. Detection of ozone recovery for the Arctic is made difficult by the smaller amount of depletion compared to the Antarctic, combined with larger natural variability in the year-to-year changes in the amount of Arctic ozone.

Altitude profiles of Arctic ozone. As in the Antarctic, Arctic ozone is measured using a variety of instruments (see Q4). These measurements document daily to seasonal changes within the ozone layer. Spring Arctic and Antarctic balloon-borne ozone measurements are shown in **Figure Q11-3**. Arctic profiles were ob-

tained from the Ny-Ålesund research station at 79°N. For 1990–2021, the March average reveals the presence of a substantial ozone layer, contrasting sharply with the severely depleted Antarctic ozone layer in the October average over the same time period. This contrast further demonstrates how higher stratospheric temperatures, more variable meteorology, and larger amounts of ozone present in mid-winter have protected the Arctic ozone layer from having extended altitude regions of near-zero ozone as regularly occurs in the Antarctic, despite there being similar abundances of halogen gases (see Q7) in the two regions.

The Arctic ozone profiles shown in Figure Q11-3 for 4 April 2011 and 28 March 2020 are two of the most severely depleted in the 30-year record from Ny-Ålesund. Arctic ozone reached exceptionally low values in the spring of 2020 due to the presence of a very stable, cold, and long-lived polar vortex that led to lower-than-normal poleward transport of ozone and enabled extensive halogen-catalyzed chemical loss of ozone, which exceeded the previous record-breaking loss in spring 2011 (see Figure Q11-1). Chemical loss averaged over the Arctic vortex for March 2020 is estimated to be about 120 DU, nearly equal to the difference between the total ozone values associated with the 28 March 2020 profile and the 1991–2021 average profile shown in Figure Q11-3. Chemical loss of Arctic ozone in spring 2020 is similar in magnitude to the loss that regularly occurs over Antarctica.

Substantial chemical loss of Arctic ozone will continue to occur during cold winters and springs, as long as the concentrations of ODSs are well above natural levels. Although significant, the Arctic ozone depletion during both 2011 and 2020 resulted in amounts of ozone between 15 and 20 km altitude that are substantially larger than routinely observed in the Antarctic during October, such as in the profile from 10 October 2020 shown in Figure Q11-3. In the Antarctic stratosphere, near-complete depletion of ozone over many kilometers in altitude and over areas almost as large as North America is a common occurrence (see Figure Q10-2).

Restoring ozone in spring. As in the Antarctic, ozone depletion in the Arctic is largest in the late winter/early spring season. In spring, temperatures in the polar lower stratosphere increase (see Figure Q9-1), halting the formation of PSCs, the production of ClO, and the chemical cycles that destroy ozone. The breakdown of the polar vortex ends the isolation of air in the high-latitude region, allowing 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, the signature of large-scale and extensive ozone depletion at high northern latitudes typically disappears by April or earlier.