Q12: Is there depletion of the Arctic ozone layer?

Yes, significant depletion of the Arctic ozone layer now occurs in some years in the late winter/spring period (January-April). However, the maximum depletion is generally 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 ozone depletion in the Arctic stratosphere occurs in cold winters because of reactive halogen gases. The depletion, however, is much less than occurs in every Antarctic winter and spring. Although Arctic depletion does not generally create persistent "ozone hole"-like features in Arctic total ozone maps, depletion is observed in altitude profiles of ozone and in long-term average values of polar ozone.

Altitude profiles of Arctic ozone. Arctic ozone is measured using balloonborne instruments (see *Q5*), as in the Antarctic (see *Q11*). Balloon measurements show changes within the ozone layer, the vertical region that contains the highest ozone abundances in the stratosphere. ***Figure Q11-2*** shows an example of a depleted ozone profile in the Arctic region on 30 March 1996, and contrasts the depletion with that found in the Antarctic. The 30 March spring profile shows much less depletion than the 2 October spring profile in the Antarctic. In general, some reduction in the Arctic ozone layer occurs each winter/spring season. However, complete depletion each year over a broad vertical layer, as is now common in the Antarctic stratosphere, is not found in the Arctic.

Long-term total ozone changes. Satellite observations can be used to examine the average total ozone abundances in the Arctic region for the last three decades and to contrast them with results from the Antarctic (see ***Figure Q12-1***). Decreases from the pre-ozone-hole average values (1970-1982) were observed in the Arctic beginning in the 1980s, when similar changes were occurring in the Antarctic. The decreases have reached a maximum of 22%, but have remained smaller than those found in the Antarctic since the mid-1980s. The year-to-year changes in the average Arctic and Antarctic average ozone values reflect annual variations in meteorological conditions that affect the extent of low polar temperatures and the transport of air into and out of the polar stratosphere. The effect of these variations is generally greater for the Arctic than the Antarctic. In almost all years, most of the Arctic ozone decrease (about 75%) is attributable to chemical destruction by reactive halogen gases.

Arctic vs. Antarctic. The Arctic winter stratosphere is generally warmer than its Antarctic counterpart (see ***Figure Q10-1***). Higher temperatures reduce polar stratospheric cloud (PSC) formation, the conversion of reac-

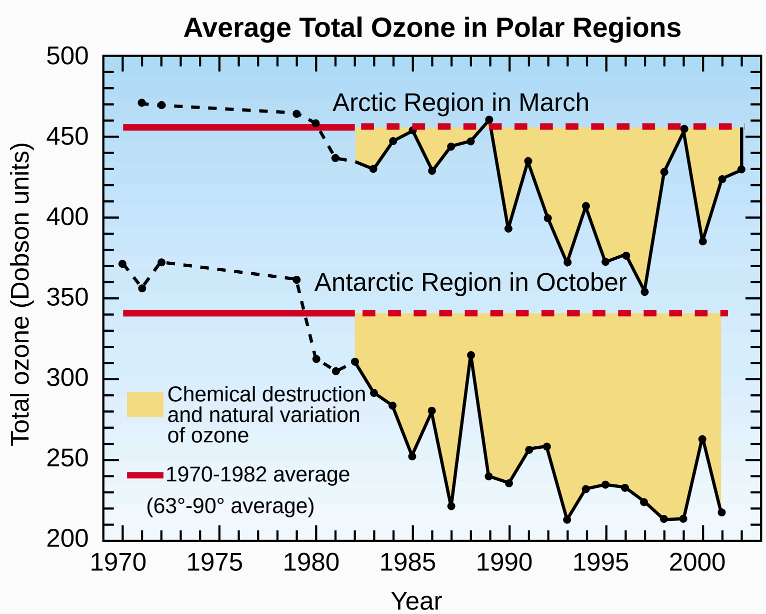

Figure Q12-1. Average polar ozone. Total ozone in polar regions is measured by well-calibrated satellite instruments. Shown here is a comparison of average springtime total-ozone values found between 1970 and 1982 (solid red line) with those in later years. Each point represents a monthly average in October in the Antarctic or in 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 in the last decade. Natural variations in meteorological conditions influence the year-to-year changes in depletion, particularly in the Arctic. Essentially all of the decrease in the Antarctic and usually most of the decrease in the Arctic each year are attributable to chemical destruction by reactive halogen gases. Average total ozone values over the Arctic are initially larger each winter/spring season because more ozone is transported poleward in the Northern Hemisphere each season than in the Southern Hemisphere.

tive chlorine gases to form ClO, and, as a consequence, the amount of ozone depletion (see *Q10*). Furthermore, the temperature and wind conditions are much more variable in the Arctic from winter to winter and within a winter season than in the Antarctic. Large year-to-year differences occur in Arctic minimum temperatures and the duration of PSC-forming temperatures into early spring. In a few Arctic winters, minimum temperatures are not low enough for PSCs to form. These factors combine to cause ozone depletion to be variable in the Arctic from year to year, with some years having little to no ozone depletion.

As in the Antarctic, depletion of ozone in the Arctic is confined to the late winter/spring season. In spring, temperatures in the lower stratosphere eventually warm, thereby ending PSC formation and the most effective chemical cycles that destroy ozone. The subsequent transport of ozone-rich air into the Arctic stratosphere displaces ozone-depleted air. As a result, ozone layer abundances are restored to near-normal values until the following winter.

High Arctic total ozone. A significant difference exists between the Northern and Southern Hemispheres in how ozone-rich stratospheric air is transported into the polar regions from lower latitudes during fall and winter. In the northern stratosphere, the poleward and downward transport of ozone-rich air is stronger. As a result, before the onset of ozone depletion in the 1980s, total ozone values in the Arctic were considerably higher than in the Antarctic in winter and spring (see ***Figure Q12-1***). The Arctic values have remained higher to the present day because of the greater depletion of Antarctic ozone.

Replacing the Loss of “Good” Ozone in the Stratosphere

The idea is sometimes put forth that humans could replace the loss of global stratospheric ozone, called “good” ozone, by making ozone and transporting it to the stratosphere. Ozone amounts reflect a balance in the stratosphere between continual production and destruction by mostly naturally occurring reactions (see *Q2*). The addition of chlorine and bromine to the stratosphere from human activities has increased ozone destruction and lowered “good” ozone amounts. Adding manufactured ozone to the stratosphere would upset the existing balance. As a consequence, most added ozone would be destroyed in chemical reactions within weeks to months as the balance was restored. So, it is not practical to consider replacing the loss of global stratospheric ozone because the replacement effort would need to continue indefinitely, or as long as increased chlorine and bromine amounts remained.

Other practical difficulties in replacing stratospheric ozone are the large amounts of ozone required and the delivery method. The total amount of atmospheric ozone is approximately *3000 megatons* (1 megaton = 1 billion kilograms) with most residing in the stratosphere. The replacement of the average global ozone loss of 3% would require 90 megatons of stratospheric ozone to be distributed throughout the layer located many kilometers above Earth’s surface. The energy required to produce this amount of ozone would be a significant fraction of the electrical power generated in the United States, which is now approximately 5 trillion kilowatt hours. Processing and storing requirements for ozone, which is explosive and toxic in large quantities, would increase the energy requirement. In addition, methods suitable to deliver and distribute large amounts of ozone to the stratosphere have not been demonstrated yet. Concerns for a global delivery system would include further significant energy use and unforeseen environmental consequences.