The 1996 Antarctic ozone hole

SIR — Springtime Antarctic ozone depletion has been particularly severe since about 1992, with a loss of about two-thirds of the ozone column at the South Pole during September and near-total destruction of ozone in the 14–19-km region[1]. The 1995 ozone hole was one of the longer-lasting events; however, total column ozone measurements at the South Pole for the September 19 to October 13 minimum-ozone period gave average values of 129 Dobson units (DU) compared with 109 DU in 1993 and 119 DU in 1994. The average values are precise to within a few units, so that interannual differences of 10 DU are significant. In particular, the rate at which ozone was destroyed at the South Pole in September 1995 was considerably less than in 1993 or 1994. Analysis of the trend suggests that this rate will again be high in 1996.

The rate of halogen-catalysed ozone destruction depends not only on how much halogen has been transported to the polar stratosphere, but also on the winter and spring temperatures, which can affect the amount of stratospheric cloud particle surface area available and the heterogeneous reaction rates[2]. Interannual temperature variations, probably associated with the quasi-biennial oscillation (QBO) in air transport from the tropics[3], appear to have been present in the late 1980s and affected Antarctic minimum ozone in alternate years[4,5] with less ozone depletion in 1986 and 1988 than in 1987 and 1989. Beginning in 1990, the QBO-related oscillation ceased, resulting in smaller variations in the amount of ozone lost from year to year in the 1990s (*a* in the figure).

There has been a general increase in the September ozone loss rate since 1986 (*b* in the figure), with periodic maxima in the 18–22-km region in 1987, 1989, 1991 and 1994. At 16–18 km, the periodicity was similar except that it was interrupted in 1992 by the enhanced depletion associated with the Pinatubo volcanic aerosol[6], which is clearly evident below 16 km. By 1994 these aerosol effects had largely subsided.

Integrated over the 12–20-km region, the September ozone loss rate increased from about 2 to 3.5 DU per day over the past 10 years. This 75% increase in loss rate would require about a 30% increase in halogen levels if the chlorine dimer cycle[2] were dominant, in agreement with estimates of the stratospheric halogen increase (about 2.4 to 3.2 parts per billion from 1986 to 1995[7]). The interannual variability in the 12–20-km ozone loss rate is typically of the order of 20%, suggesting a variability in halogen levels of about 10%. The periodicity observed in the 18–22-km ozone depletion rate is matched in the QBO as indicated by tropical winds at 10, 30 and 50 hPa in the figure (*c*). No similar variations in stratospheric temperature can be detected, so the effect does not appear to be related to a modulation in polar stratospheric clouds or heterogeneous reaction rates. The high depletion rates occur during the spring following the transition of tropical winds from westerly to easterly (descending easterlies). In particular, ozone loss rates have been greater in years where the 10 hPa winds have been easterly for several months early in the calendar year preceding the ozone-hole period. Understanding the cause of this variability in ozone loss rate will be important for the detection of the expected recovery of the ozone hole early in the next century.

During the descending easterly QBO phase, transport from the tropics to the poles is enhanced[8], and may result in the transport of more ozone-depleting halogens before formation of the winter vortex, with enhanced ozone depletion in the following spring. Enhanced winter transport at higher altitude with subsidence into the ozone-depletion region could also account for elevated ozone-depleting chemicals at this time. This might account for the more rapid September ozone decline immediately following the descending easterly QBO phase. If this hypothesis is correct, the September ozone depletion rate in 1996 should again be high because the west to east wind transition was completed in May 1996 (*c* in the figure). A steeper loss rate in September will drive ozone to lower values going into October, when the total-ozone minimum is observed. Combined with higher levels of halogens in the global stratosphere, this should result in a deeper South Pole ozone hole in 1996 than appeared in 1995, by as much as 10 DU in the late September–early October average total column ozone value.

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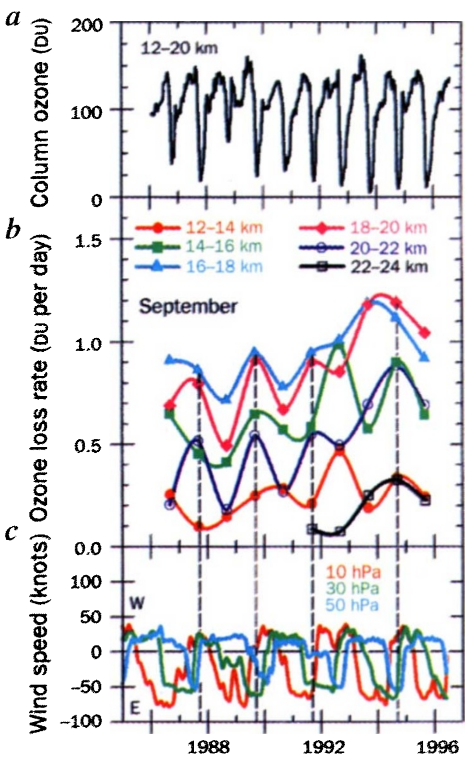

a, Amount of ozone in the 12–20-km column in DU obtained from 613 balloon soundings from the Amundsen–Scott Station at the South Pole between January 1986 and June 1996. A three-point running mean was used to smooth the data. The 12–20-km altitude range is the region of maximum polar stratospheric cloud formation and where 80–90% of the depletion in the total ozone column occurs. Note the biennial oscillation in amount of austral springtime (September–October) ozone lost before 1990 and the lack of this periodicity thereafter. Maximum springtime ozone loss occurred in 1993 with nearly a total loss of ozone between 12 and 20 km, with a slight recovery in 1994 and 1995. *b*, The average ozone loss rate for 2-km layers from 12 to 24 km determined from a linear fit to the balloon-borne ozone versus time data for September. The r^2 for the linear fit was generally > 0.9. Ozone loss above 22 km was not evident before 1991. Note the enhanced loss rates in the lower stratosphere in 1992, which are believed to be the result of Pinatubo volcanic aerosol augmenting polar stratospheric cloud effects on hetero— geneous chemistry. *c*, Singapore (1.3° N) winds at 10, 30 and 50 hPa (approximately 28, 21 and 18.5 km, respectively, in the winter/spring Antarctic stratosphere). Tropical stratospheric winds switch from easterly (E) to westerly (W) with an approximately 2-year period, thus the origin of the QBO. Dashed vertical lines mark the September ozone-depletion periods which displayed maxima in ozone loss rate above 18 km.

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