Winds, Pollutants Drive Ozone Hole

Man-made chlorofluorocarbons are destroying ozone over Antarctica each spring, but the weather there allows it to happen and could be making it worse from year to year

SCIENTISTS returning from instrument-laden flights into the thinning ozone layer over Antarctica, the worst thinning seen so far, say they have support for both sides of the debate over the hole's cause. For atmospheric chemists who argued that chlorofluorocarbons form the hole, the chemistry encountered in the Antarctic lower stratosphere was wildly perturbed, much as predicted. Man-made pollutants would appear to be destroying ozone every austral spring.

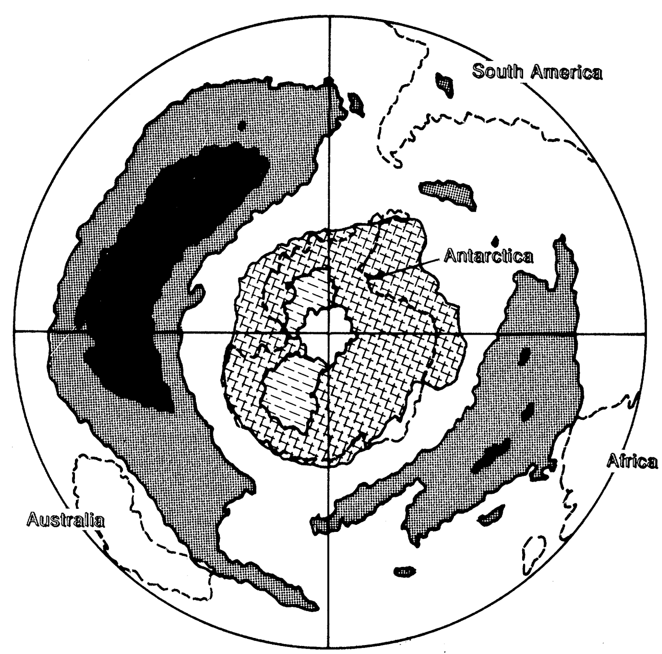
For meteorologists who suggested that the hole could merely reflect the unique weather of the Antarctic stratosphere, the hole-penetrating flights showed that the extreme cold there plays an essential role in driving ozone destruction by forming ice particles that help accelerate the chemical reactions. Because such conditions are rare or intermittent at lower latitudes, it could be argued that the chemical destruction of ozone outside the springtime Antarctic is not likely to be proceeding faster than conventional theory predicts.

However, chemistry still cannot explain completely the sudden deepening of the hole since about 1976 or springtime ozone decreases that extend halfway to the equator. Those ozone losses probably involve changes in the winds that carry ozone toward the pole. Thus, purely meteorological influences are also thinning the ozone layer.

The new observations come from the Airborne Antarctic Ozone Experiment. Coordinated by the National Aeronautics and Space Administration (NASA) and sponsored by U.S. and international agencies, the $10-million experiment involved flying two instrument-laden planes, a DC-8 and a modified U-2 called ER-2, from Punta Arenas, Chile, the world's southernmost city, into the hole over Antarctica. Ground and satellite observations were made as well. The effort involved 150 scientists and support personnel from 19 organizations representing four countries, all linked by satellite to colleagues, computers, and nearly real-time satellite observations. The resulting overnight analyses allowed day-by-day revision of flight plans during the 6 weeks of flying more than 175,000 kilometers.

At a 30 September press conference at the end of the experiment, Robert Watson of NASA headquarters in Washington, D.C., told how nearly every chemical species theorized to be involved in the destruction of ozone within the hole was present in anomalous concentrations.

- Chlorine monoxide, the pivotal agent of destruction in all proposed theories, was present in abundances 100 to 500 times those predicted or observed at mid-latitudes. This confirmed the earlier report made by Philip Solomon and his colleagues at the State University of New York at Stony Brook of up to 1 part per billion chlorine monoxide in last year's hole (*Science*, 5 June, p. 1182). These ground-based analyses, regarded by some as marginal, had not been widely accepted. That much chlorine monoxide is sufficient to destroy ozone, according to Watson, "with one big caveat—*if* our current understanding of the chlorine-ozone catalytic cycle is correct." Chlorine dioxide, which can also be directly involved in ozone destruction, was detected at "highly elevated concentrations compared to those at mid-latitude."
- Hydrochloric acid, an innocuous form of chlorine, was "very low" within the hole. At mid-latitudes this compound ties up most of the chlorine present, forming an inactive reservoir of chlorine and preventing it from rapidly destroying ozone. In the hole much of this harmless chlorine has apparently been converted to the active form, chlorine monoxide.
- Nitrogen compounds were also very low within the hole. Outside the hole, this so-called odd nitrogen was present at 8 to 12 parts per billion while inside the abundance was only 0.5 to 4 parts per billion. Odd nitrogen also forms reservoir compounds with chlorine.
- Abundances of nitric oxide, nitrogen dioxide, and nitric acid decrease toward the center of the hole. Consequently, said Wat-



The ozone hole. *The central hatchured area represents the Antarctic ozone hole, as mapped by the Total Ozone Mapping Spectrometer aboard the Nimbus-7 satellite. The lowest ozone concentration in this 15 September map is about 150 Dobson units. Typical values outside the hole are about 300 Dobson units. The dark arcs outside the hole are part of a ring of high ozone (up to 400 Dobson units) created by stratospheric circulation patterns. The springtime ring has been thinning, too.*

son, "All theories that need to propose high levels of nitrogen are incorrect. We believe they're wrong." That eliminates the theory that ultraviolet radiation or cosmic rays varying in step with the sunspot cycle have been raining ozone-destroying nitrogen compounds down from the upper atmosphere.

■ Bromine monoxide, which is derived from industrial uses of bromine, is one compound whose abundance in the hole, a few parts per trillion, seems to argue against its proposed role in accelerating ozone destruction. "Theory requires a level of bromine significantly larger than this," said Watson. "Unless something is wrong with the laboratory data, bromine chemistry cannot be the dominant factor."

With these preliminary analyses in hand, the picture of the chemistry within the hole is generally consistent with the theoretical predictions made since the 1985 recognition of the hole's rapid deepening. There are some discrepancies. The variations of chlorine dioxide from day to night are difficult to explain with known mechanisms, and chlorine monoxide decreases too precipitously at lower altitudes. These irregularities aside, the abundance of chlorine monoxide during the formation of the hole varied inversely with that of ozone on both large and small scales. That is "very strong evidence that chlorine monoxide has a mechanism by which it destroys ozone," according to Watson.

Given the low bromine concentrations, the destruction mechanism presumably involves the combination of two chlorine monoxide molecules to form a dimer which in turn can decompose to produce free chlorine that continues the destruction process. The problem, Watson pointed out, is that the dimer can also decompose in a way that leads to no destruction of ozone. Current understanding of which way this reaction tends to go "is in poor shape," says Watson, but it should be improved during the next few months as a result of laboratory experiments.

The airborne experiments also pointed to a reason for the low abundances of chlorine reservoir compounds. As predicted by a number of groups, at least some of the missing nitrogen was found tied up in ice particles. The extreme cold of the Antarctic stratosphere in winter (-80°C and colder) seems to have wrung water vapor from the air to form ice particles and left it unusually dry. Nitric acid might also freeze out at similar temperatures. In addition to locking up nitrogen that slows ozone destruction, the resulting ice particles might provide a surface that accelerates reactions releasing active chlorine from the inactive reservoirs.

There is every indication that chlorine is destroying ozone in the hole, but meteorology must also have a role, according to Watson. "Meteorology is critical," he said. "It is not simply chemistry. The strong weight of evidence suggests that both participate." After all, it is the extreme durability of the swirling wintertime vortex over Antarctica that fends off intrusions of warmer air and leads to the exceptional cold that freezes out polar stratospheric clouds. Smaller, more intermittent areas of cloud form in the Arctic. Without these wispy, cirrus-like clouds, the surface-catalyzed chemistry of the hole presumably could not proceed.

Meterology must have been more directly involved in some ozone changes recorded by satellite sensors. On 5 September the ozone over 3 million square kilometers near the Palmer Peninsula decreased by 10% during 24 hours. That seemed too rapid to be explained by chemistry. Most likely, ozone-poor air moved into the region from lower altitudes or from a site of chemical ozone depletion. However, researchers found no support for one of the first purely dynamical theories of hole formation. There was no sign that low-level, ozone-poor air was rising into the stratosphere to decrease ozone concentrations over all of Antarctica.

Other kinds of ozone decreases are also difficult to explain by purely chemical means. The rate of change of ozone with altitude over the Palmer station at 64°S, outside the chemically perturbed region, is about the same as the rate over the Halley Bay site at 78°S, where the chemistry is clearly perturbed. "It's a puzzler," said Watson. For that matter, in past years ozone has decreased each spring as much as 20% below pre-1979 values as far north as 45°S, the latitude of New Zealand. With the obviously perturbed chemistry pinned down to a region south of 68°S, dynamics would seem to be the only possible explanation. The abrupt initiation in about 1976 of the hole's progressive deepening must also be explained. The gradual increase of chlorofluorocarbons began decades earlier.

The favored mechanism among meteorologists for the wide-ranging ozone depletion as well as the year-to-year deepening of the hole is a stratospheric climate change that seems to be gripping the Southern Hemisphere. According to James Angell of the National Oceanic and Atmospheric Agency (NOAA) in Silver Spring, Maryland, the Southern Hemisphere stratosphere cooled by more than 2°C between 1980 and 1985 so that it is "much colder than ever before." Over Antarctica the stratosphere cooled by 2 to 4 degrees since 1980.

The connection between temperature and ozone is found in the winds that carry both

NASA

NASA

How to spy on the ozone hole. *This ER-2, a modified version of the U-2 spy plane, flew up to an altitude of 21 kilometers to probe the chemistry and weather of the Antarctic ozone hole. Described as a "rocket engine with glider wings," it carries instrumentation in two wing pods (above and left) and the fuselage. The wheels seen beneath the port wing drop off at take off. They are only used to keep the plane from tipping over while on the ground.*

heat and ozone from the tropical stratosphere, where abundant sunlight makes for high ozone production, toward the pole. Ronald Nagatani and Alvin Miller of NOAA's Climate Analysis Center in Camp Springs, Maryland, have compared a measure of the forces driving those winds in September with October temperatures and ozone concentrations at 70°S, near the edge of the chemically perturbed region. All three properties varied together between 1979 and 1985, the correlation coefficient for forcing and ozone being a high 0.91. The overall trend was downward as the amount of ozone left in the springtime hole decreased. The same relation held in 1986, when the hole's depletion was less than in 1985. The driving forces this past September were between those of the two previous years, Miller reports, suggesting that the hole would be deeper this year than last. As of mid-September, ozone within the hole had fallen to levels 15% lower than it had in 1985, heretofore the deepest hole seen. The final extent of the 1987 thinning will not be known until early or mid-October.

What all this means for the world outside the springtime Antarctic may be a bit clearer than it was before. Watson at first declined to speculate, but he eventually conceded that "I could speculate that it has been a change in both meteorology and chemistry." The future course of the climate change would be anybody's guess. Whether ozone and heat transport toward the South Pole will slow further, lowering springtime ozone outside the hole even more and freezing out more ice particles within the hole with their attendant ozone destruction, cannot be predicted.

As to the rest of the globe, "If this picture holds up—the mechanism of ice particle formation and surface reactions—then the question would be how frequently similar conditions occur elsewhere. We believe the required conditions are unique to the Antarctic. They are probably not extensive elsewhere." Stratospheric aerosols outside polar latitudes are far less abundant and consist of liquid sulfuric acid droplets, not frozen water. Their surfaces might not accelerate reactions involving chlorine. If freezing out of nitric acid is crucial to releasing large amounts of active chlorine, accelerated ozone destruction might not occur outside the Antarctic and parts of the Arctic, Watson noted.

Watson sees no reason at this point to reconsider the planned international reductions of chlorofluorocarbon production agreed to last month in Montreal. A review of the scientific basis for the Montreal Protocol is already scheduled for 1989. ■

RICHARD A. KERR

Why Do Women Live Longer Than Men?

Mortality is higher among males from conception to old age; but females suffer more from nonfatal illness and autoimmune disorders

WOMEN outlive men by a margin of 4 to 10 years throughout the industrialized world. The reasons are both behavioral and biological—in the first half of the life-span, masculine tendencies to violence, as measured in homicides, suicides, and accidents, take an excess toll. In the latter half, cardiovascular disease accounts for most of the gap.

The gender gap was the subject of a recent conference called by the National Institute on Aging (NIA), which attempted to integrate some of the findings from biology and behavior. Although epidemiological studies have provided a wealth of information on relative morbidity and mortality between the sexes, the causes of the differences are poorly understood. Yet unraveling this question would yield important information both on sex differences and on the causes of longevity.

Now that females are no longer being felled by childbirth, it has become clear that they enjoy an advantage in both psychological and biological robustness. Said James V. Neel of the University of Washington, "we really are the weaker sex, biologically less fit than females at every step of the way."

The differential starts at conception. The ratio of males to females conceived is believed to be about 115 to 100; yet this advantage is pared to about 105 by birth owing to the male excess in spontaneous abortions, miscarriages, and stillbirths. "In utero it's a jungle—prime time for natural selection," said Neel. Males also have a higher neonatal and infant death rate. The male preponderance continues to erode in adolescence and by age 30, the sex ratio is equal. By 65, said Kenneth Manton of Duke University, 84% of females and 70% of males are still alive.

According to Deborah Wingard of the University of California, San Diego, who reported on a longitudinal study of 5000 adults in Alameda County, the male-to-female death ratio is the highest for homicide, at 3.9 to 1, followed by lung cancer, suicide, pulmonary disease, accidents, cirrhosis, and heart disease (2 to 1).


UPI/Bettmann Newsphotos

Katherine Hepburn: *Golden years.*

The good news is that the gender gap has not gotten any worse in the past 4 years—primarily because of men's changing habits with regard to smoking, exercise, and cholesterol consumption, which has resulted in a significant drop in the death rate from heart disease.

Nonetheless, maleness seems to carry intrinsic risk. This was illustrated in a provocative if puzzling investigation carried out by Kirby Smith of Johns Hopkins University, who has been studying the little-understood Y chromosome. Smith has been looking at death rates in four generations of an Amish family. The males in this family are functionally normal but karyotyping has revealed that they are missing the long arm of their Y chromosomes. Smith compared the average life-spans of males and females with those of two nearby Amish families. He found that among the comparison families the women lived to their mid-70s and the men died 5 or 6 years earlier. In the family with the deletion in the arm of the Y, the women lived on average to age 77.4, while the 14 men substantially outlived them, to an average age of 82.3. Smith does not know what genes might have been in the missing arm—so far there is only one identified Y gene, a cell-surface antigen. Perhaps, he said, this