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Reflections on the ozone hole

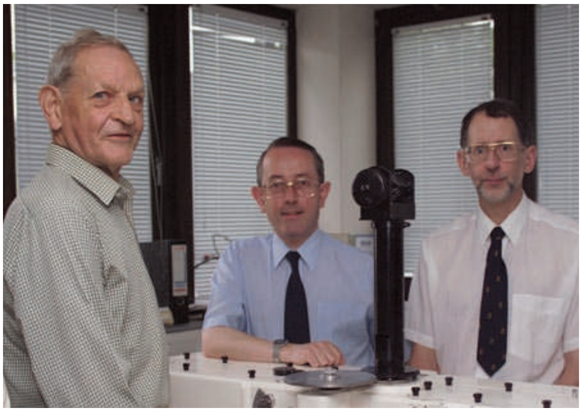
Jonathan Shanklin, one of the team who discovered the thinning ozone layer over the Antarctic 25 years ago, reflects on lessons learned from a tale of luck, public perception and fast environmental change.

Twenty-five years ago, Joseph Farman, Brian Gardiner and I discovered that Earth's protective layer of ozone was thinning dramatically above the Halley Research Station in Antarctica. We reported in *Nature*[1] that the minimum amount of ozone seen each spring in the Southern Hemisphere had declined sharply since the late 1970s, and that this was linked to a corresponding rise in the amount of chlorofluorocarbons (CFCs) in the atmosphere — which were commonly used as refrigerants and propellants at the time. The next year, NASA scientists published a reanalysis of their satellite data[2], confirming that a continent-wide 'ozone hole' formed above Antarctica each year. The study found that the lowest values of ozone, seen in mid-October, had fallen 40% from 1975 to 1984.

There were already concerns that CFCs could be depleting the ozone layer, which lies 10–35 kilometres above the ground and protects humanity from more than 90% of the Sun's harmful ultraviolet rays. This was a worry, because it could increase the risk of health problems such as skin cancer and cataracts. The Antarctic 'hole' was a powerful illustration of the effect of CFCs on ozone.

Each of the three members of our team at the British Antarctic Survey (BAS), and others involved in the work, would undoubtedly describe the discovery story in a different way, coloured by personal backgrounds. My perspective is that luck played its part, as in many other scientific discoveries. The story provides an example of how to capitalize on good luck in science — researchers should be reminded to question their preconceptions, for example, to ensure that people don't see only what they are looking for — and we should invest in long-term monitoring, even when it seems to yield no immediate insights or benefits. It also shows how public perception governs the ease with which policy changes can be made. Unfortunately, the circumstances that contributed to a successful plan of attack against the hole in the ozone layer are quite different from those surrounding today's climate-change challenge.

In 1977, I joined the BAS in Cambridge, UK, as a recent graduate in natural sciences from the University of Cambridge, with a specialization in experimental physics at the Cavendish laboratory. I had no background in meteorology, and no preconceived ideas of how the atmosphere behaved. The prevailing expectation at the time was that chlorine from CFCs would affect the ozone layer by photocatalytic decomposition, and that these effects would be most marked high in the tropical stratosphere. This view was based on the work of scientists such as Paul Crutzen, Mario Molina and Frank Sherwood Rowland, who later shared the Nobel Prize in Chemistry for their work on ozone depletion. In addition, studies of BAS data by Farman and Richard Hamilton had shown that ozone measurements in the Antarctic were least variable from year to year around the end of January, so if there was any persistent drift in the values then this would be the best place to look. No one was searching for long-term patterns in springtime data for the Antarctic. But I did not know any of this.



Joseph Farman, Brian Gardiner and Jonathan Shanklin (left to right) were the first to report on the Antarctic ozone hole.

CHRIS GILBERT/BRITISH ANTARCTIC SURVEY

Data backlog

One of my tasks at the BAS was to write computer programs to process observations made with our manual Dobson ozone spectrophotometers (an instrument still in use today to measure atmospheric ozone). At that time, researchers had to use slide rules or log tables to convert Dobson measurements into the amount of ozone in the column of air above. Needless to say, a backlog was building up. I supervised staff as they digitized the handwritten data sheets, and wrote a suite of codes to compute instrument calibrations and then calculate ozone amounts. By chance, the backlog covered the crucial decade when ozone levels began to drop.

I was also asked to help out with an 'open day' planned for the BAS in 1983, in part because I have a physics-teaching qualification. The popular press was reporting at the time on studies suggesting that aerosol spray cans and exhaust gases from Concorde flights could destroy the ozone layer. Models showed, however, that the expected loss of ozone thus far was only a few per cent. I wanted to reassure the public by showing that our ozone data from that year were no different from 20 years earlier. The graph we presented to the public showed that no significant change in ozone had been detected over the years, which was true overall — but it seemed that the springtime values did look lower from one year to the next.

As I remember it, there was no real eureka moment in the discovery, more a combination of pieces falling into place. Comments from observers at our Antarctic stations suggested that on occasion they saw unusually low ozone values in the spring. The graphs compiled for the open day weren't in themselves convincing, because the prevailing theory suggested that springtime values were highly variable and dependent on short-term weather conditions. What convinced the team was a graph plotting the minimum 11-day mean, which clearly showed that the spring decline was systematic. Farman crucially developed a chemical theory to explain the observations, linking them to rises in CFCs, and Gardiner carried out the essential quality control on the data. I was a minor player in the end result; my persistence in looking at the data was my real contribution.

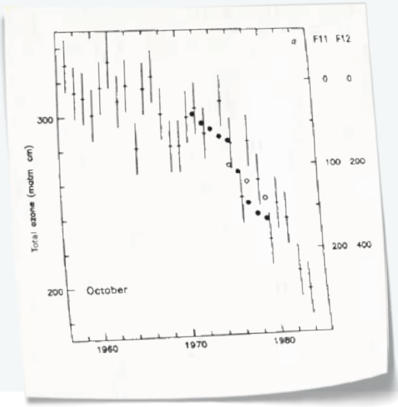
In our paper, we adjusted the graph to make the close relation between ozone decline and CFC concentrations clear: we flipped the axis for the CFCs (with high concentrations, unusually, at the bottom, and low concentrations at the top) and adjusted the scale. This resulted in a dramatic figure (see 'Going down'), although I was slightly surprised that we were allowed to present it this way.

Interestingly, the ozone monitoring at the BAS Halley station wasn't originally intended for monitoring long-term ozone changes: it was

NASA

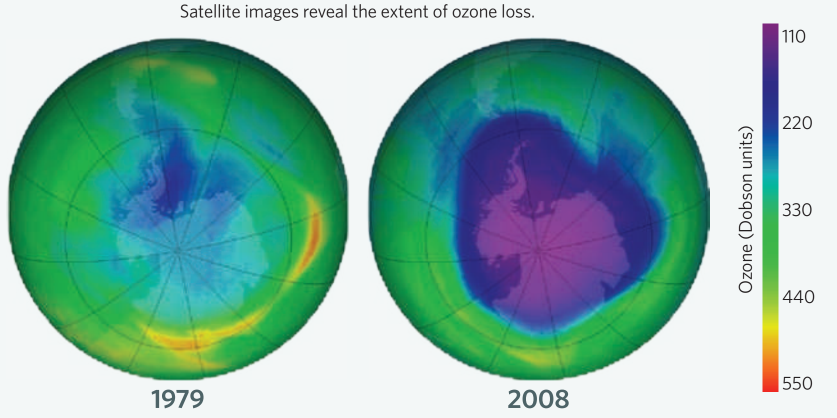
GOING DOWN

The 1985 paper showed ozone loss (bars, left *y* axis) against concentrations of two types of CFCs (circles, right *y* axis).



THE HOLE STORY

Satellite images reveal the extent of ozone loss.



set up to help improve weather forecasting and verify theories of atmospheric circulation. As it turned out, Halley had several advantages over other Antarctic stations for detecting the ozone loss. First, it had a continuous ozone record going back to the International Geophysical Year of 1957–58, whereas others, for example the Japanese Syowa station, had only patchy records. The relatively northern latitude of Halley meant that we could begin observations earlier in the spring than at the South Pole, and so see the lowest levels of ozone. In addition, the centre of the ozone hole is often offset towards the Atlantic Ocean, giving Halley lower ozone values than would be visible from stations on the Pacific side of the continent.

There has been much discussion about how we managed to report the hole before the researchers looking at satellite data. In the years running up to the discovery, we were making ground-based measurements to coincide with satellite overpasses, and communicating them to the Satellite Ozone Analysis Center at the University of California in Livermore. After the 1983 open day I wrote to the head of the centre, asking whether the satellites were confirming some low-ozone values. I never received a reply — perhaps another lucky break for our team. I don't know what happened behind the scenes with the satellite teams, but I do know that they were overwhelmed by large amounts of data. One of their goals was to look at latitudinal variation in ozone, which probably involved averaging ozone values around a latitude circle. This sort of analysis would have effectively hidden the ozone hole, because of its offset from the pole.

Although satellites can give global coverage, there are often differences between sensors in each new generation of satellites, and so there is still the need for ground-based results — even today for ozone. But in periods of economic decline there is always a temptation to suspend long-term monitoring programmes that don't have any obvious immediate utility. In the early 1980s, the BAS was looking at ways to economize, and the ozone monitoring at Halley was in the frame to be cut; nothing seemed to be changing, and there seemed little reason to keep it going. But it is programmes such as these that provide the crucial evidence for political decisions governing the future of our planet.

Public persuasion

Concerns about the ozone layer led to the 1987 Montreal Protocol to phase out CFCs. The discovery of the ozone hole undoubtedly helped to seal those negotiations, but there were several other important drivers to international accord. Chemical manufacturers were able and willing, after some initial resistance, to produce CFC substitutes. The public was keen to see action: the evidence was strong and clear; the hole sounded threatening; and there was a link between thinning ozone and cancer. And the public did not feel bullied or threatened — no one was telling them to radically change their way of life. There was a problem, and something could be done about it.

> "Perhaps the most startling lesson from the ozone hole is just how quickly our planet can change."

By contrast, the evidence for man-made climate change is less clear-cut to the average person. And people are given the impression that civilization will collapse unless they abandon cars and radically change their lives in other difficult ways. Not surprisingly, there is confusion and resistance. By a happy accident, the Montreal Protocol has done more to reduce greenhouse-gas emissions than the Kyoto treaty[3] — CFCs are potent greenhouse gases. Yet it is unclear how the success of the Montreal Protocol could be duplicated in bringing a climate treaty into force. We now face a problem that requires difficult change, and so requires a new approach to convince people to take action.

Today we have a good understanding of the physics and chemistry that govern the ozone layer. These are summarized in quadrennial assessments, the most recent being the World Meteorological Organization 2006 report[4], with another planned for this year. Minimum ozone levels have been roughly constant over the past 15 years, at about 70% below the late-1970s levels (see 'The hole story'). Some researchers have begun to say that they see a recovery, but I believe that this is premature, particularly as there have been no major volcanic eruptions during this period (sulphur dioxide from the recent Icelandic eruption hasn't reached up high enough to affect the ozone layer). Assuming that all of the restrictions of the Montreal Protocol are followed, Antarctic springtime ozone levels are expected to return to those first measured in the 1950s by 2080.

Perhaps the most startling lesson from the ozone hole is just how quickly our planet can change. Given the speed with which humankind can affect it, following the precautionary principle is likely to be the safest road to future prosperity. Although the focus is on climate change at present, the root cause of all of our environmental issues — a human population that overburdens the planet — is growing. Future historians may note that although humanity solved one unexpected environmental problem, it bequeathed many more through its failure to take a holistic approach to the environment. ■

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See ozone celebration at go.nature.com/2XzJCC. Further reading accompanies this article online at go.nature.com/AxyeGM.