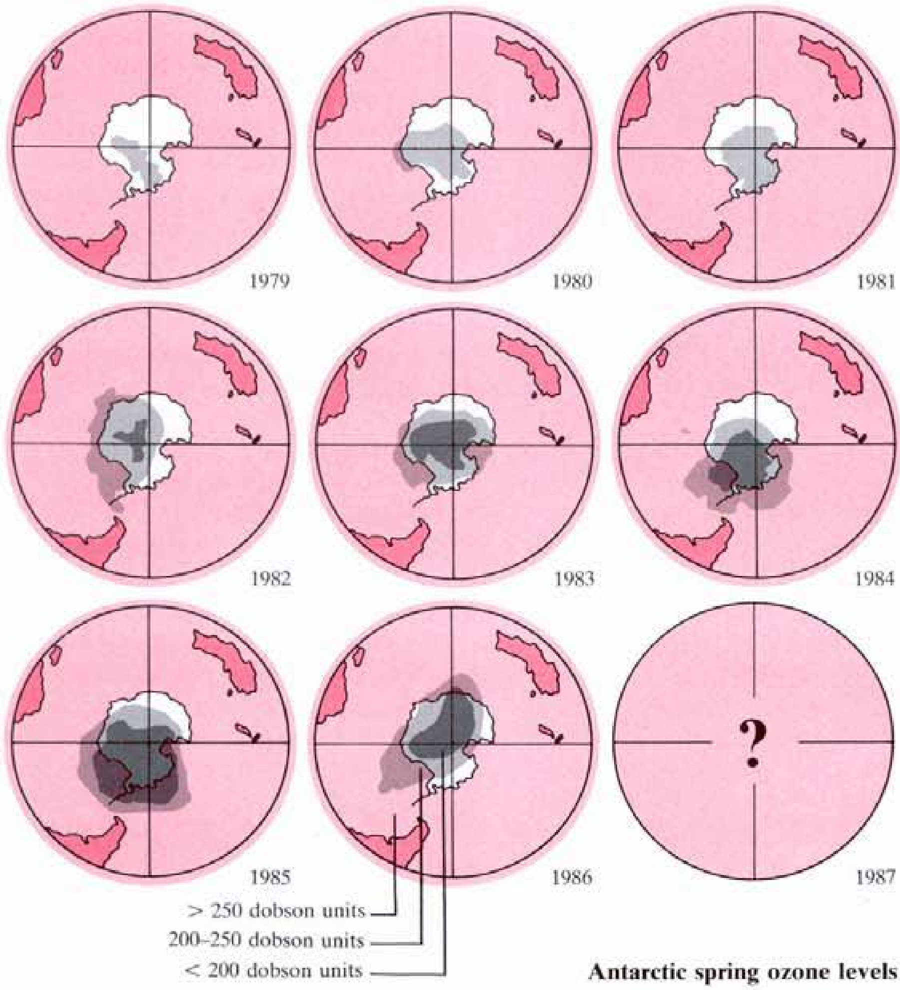
Mystery of the Antarctic 'ozone hole'

Despite the probings of an American expedition sent to the Antarctic in the depth of last winter to try to settle the question, the cause of the 'ozone hole' in the stratosphere over Antarctica remains a mystery. The latest findings don't fit neatly into any existing theory, and are taxing the ingenuity of atmospheric scientists.



Antarctic spring ozone levels

How the spring-time ozone hole has grown. Last year's measurements showed a slight turnaround; will this year's confirm it?

The 'ozone hole' is an annually recurring decrease, during the Antarctic spring, in ozone levels 12–20 km above the continent. Concentrations begin to decline in September as the sun returns after the long winter night, reach a low in October, and recover again in November. The decreases apparently began in 1979, and until last year the hole had been getting progressively deeper and wider each year, until by 1985 ozone levels were nearly 50% down over the entire continent.

However, last year the ozone layer staged a mild recovery (back to 1984 levels). This could be a turnaround, or just a temporary deviation from the trend. Another new development is the discovery of another ozone hole — smaller and less pronounced — over the Arctic.

Remarkably, it was only in March 1985 that scientists from the British Antarctic Survey first gave warning of a hole in the ozone layer. Their ground-based observations picked up the hole, whereas satellite monitoring had missed it because the data-processing system had been programmed to reject values below certain levels as a fault in the detection equipment. However, going back over the data tapes, scientists were able to verify the British findings. The ground-based observations demonstrate that the Antarctic ozone layer had been more or less steady for nearly two decades from 1957, and both data sets show that since 1979 the hole had been steadily developing.

Although this dramatic decrease in ozone levels is currently confined to high latitudes in spring, the worry is that what is happening in the Antarctic may be but a foretaste of what may happen over the entire globe — a catastrophic destruction of the protective ozone layer.

What is happening in the Antarctic may be a foretaste of what may happen over the entire globe …

… or it could be a transient natural phenomenon that will go away by itself.

Ozone, the three-atom form of oxygen, forms in the upper atmosphere from the action of sunlight, and shields us from 90% of the sun's damaging ultraviolet radiation. A 1% loss of ozone would lead to a 2% rise in UVB — the type of ultraviolet radiation known to cause skin cancer by direct damage to DNA (see *Ecos* 48) — and this could lead to a 4–6% rise in the incidence of some skin cancers. Certain plants and animals are especially vulnerable to damage from this source.

Ozone continually breaks down and reforms in chemical processes that have proved, in laboratory experiments, to be very sensitive to the presence of a number of reactive gases, in particular the chlorine monoxide radical (ClO°) formed when chlorofluorocarbons (CFCs) break down in the upper atmosphere. CFCs are being released to the atmosphere in increasing quantities from air-conditioning, refrigeration, foam plastics, some spray cans, and a growing range of industrial processes.

Ozone layer revisited

Fears for the integrity of the ozone layer began in the early 1970s, with concern over

gases released by supersonic jets and spray cans. The United States banned non-essential use of CFCs in spray cans in 1978, and Canada and the Nordic countries followed suit. In Australia, the National Health and Medical Research Council (NHMRC) and the Australian Environment Council (AEC) jointly called, in 1983, for industry to voluntarily convert from the use of chlorofluorocarbons in aerosol sprays to other propellants wherever possible.

Scientists have been monitoring the ozone layer and concentrations of CFCs in the atmosphere for many years. So far, a decrease in total ozone of only a few percentage points has been apparent, a trend that is hardly significant in view of large year-to-year variations. Swiss measurements, made since the 1920s, show an average ozone loss of 3%, most of it in the past 10 years. These results parallel world-wide ground-based observations of a 2–3% decrease at a height of 30–40 km between 1970 and 1980.

At Cape Grim, Tasmania, Australian scientists are monitoring the atmospheric concentrations of CCl_3F, CCl_2F_2, CCl_2FCClF_2, and $CHClF_2$ (CFCs that are used as aerosol propellants, refrigerants, foam-plastic blowing agents, and solvents) and the chlorocarbons CH_3CCl_3 and CCl_4

Releasing — at Wilkes, near Casey base in the Antarctic — a high-altitude balloon to probe the stratosphere.

(used as solvents, chemical intermediates, and fumigants).

Data published by Dr Paul Fraser of the CSIRO Division of Atmospheric Research show that concentrations at Cape Grim are increasing rapidly: 5% annually for CCl_3F and CCl_2F_2; 13% for CCl_2FCCF_2; 8% for $CHClF_2$; 5% for CH_3CCl_3, and 1–2% for CCl_4.

As aerosol use of CFCs has diminished, non-aerosol use has increased correspondingly.

Last January, CSIRO's research aircraft sampled atmospheric levels of CFCs near Darwin, as part of an on-going program to measure CFC levels throughout the troposphere. In a companion effort, a high-flying American plane flew into the stratosphere (20 km) to take direct readings of ozone levels. (The experiments were part of STEP — the Stratosphere Troposphere Exchange Project — which is sponsored by NASA.)

The problem is exacerbated by the long lifetimes of the pollutants. The stability of CCl_3F is such that it takes about 75 years for half of it to break down in the atmosphere. Other half-life figures are: 110 years for CCl_2F_2; 90 for $CCl_2FCCl_2F_2$; 20 for $CHClF_2$; and 50 for CCl_4. If we do confirm that these substances cause harm and curtail their use, it will take a long time for ozone to recover to normal levels.

Models of stratospheric chemistry have predicted that rising CFCs would result in a steady uniform depletion of ozone. Now that we are confronted with the unexpected — a sudden, localised disappearance many times worse than has ever been contemplated — scientists' interest in the ozone problem has been rapidly rekindled.

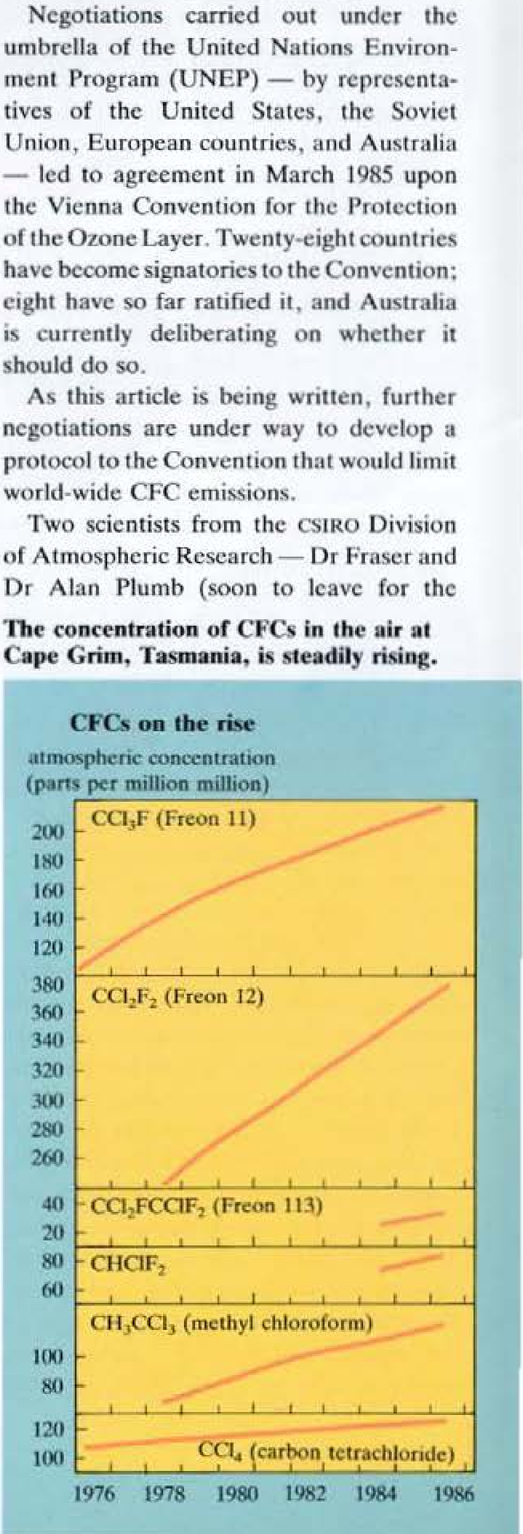
Of course, the hole could be a transient natural phenomenon that will go away by itself. But it would be foolish to place all our faith in that. Prudence is the main factor motivating many countries to move to place a limit on CFC emissions.

Negotiations carried out under the umbrella of the United Nations Environment Program (UNEP) — by representatives of the United States, the Soviet Union, European countries, and Australia — led to agreement in March 1985 upon the Vienna Convention for the Protection of the Ozone Layer. Twenty-eight countries have become signatories to the Convention; eight have so far ratified it, and Australia is currently deliberating on whether it should do so.

As this article is being written, further negotiations are under way to develop a protocol to the Convention that would limit world-wide CFC emissions.

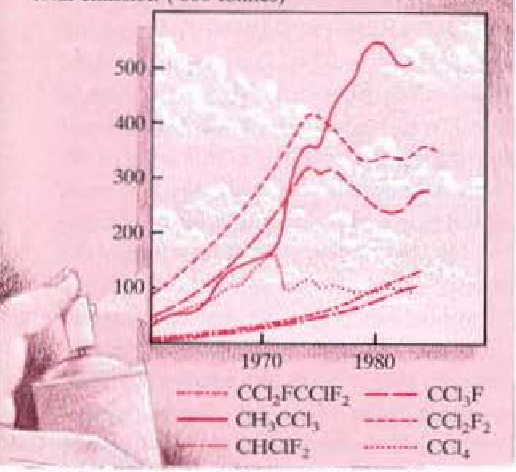
Two scientists from the CSIRO Division of Atmospheric Research — Dr Fraser and Dr Alan Plumb (soon to leave for the

The concentration of CFCs in the air at Cape Grim, Tasmania, is steadily rising.



Into the air they go

total emission ('000 tonnes)



World-wide emissions of CFCs still show a disturbing upward trend.

United States) — have had a close involvement with the ozone question.

Dr Fraser has represented Australia on UNEP's Coordinating Committee on the Ozone Layer. He is a member of GAGE — the Global Atmospheric Gases Experiment — which is a long-term international study of the detailed composition of our atmosphere. He also belongs to a reconvened NHMRC/AEC working party reviewing the use of CFCs in aerosol sprays, which has recently completed a report on the question.

Dr Plumb was Chairman of a World Meteorological Organisation working group that in 1985 contributed to 'Atmospheric Ozone 1985', a major assessment of the ozone issue. He provided a chapter on the atmospheric dynamics that govern ozone transport.

Both scientists agree that at present we don't have any adequate theory to account for the ozone hole.

Three theories

There are almost as many explanations as there are workers in the field, but basically they can be grouped into three theories. All draw on the unique meteorological isolation and extreme cold of the Antarctic stratosphere.

The first theory says that CFCs are to blame. According to Dr Susan Solomon, leader of the United States National Science Foundation team that went to Antarctica in 1986 to study the ozone hole, sunlight releases chlorine and fluorine, which react with the ozone. The reaction most widely entertained calls for a surface on which to bring all the required chemical species together and enhance their reactivity. A possible candidate for this is water (liquid or crystalline) in polar stratospheric clouds. The stratosphere lacks appreciable moisture, and normally no clouds form there — except in the Antarctic, where temperatures in winter and early spring fall so low (−80°C) that whatever water vapour is present freezes out.

One comment Dr Plumb makes on the publicity surrounding this theory concerns psychology. If it proves wrong, and the publicity has been a case of crying 'wolf', there is a danger people will dismiss the link between CFCs and ozone and abandon any restraint on CFC emissions. However, on a global scale, the threat of ozone depletion is still real (whether or not CFCs are responsible for the Antarctic ozone hole), and we could place ourselves in jeopardy by ignoring restraint.

Dr Plumb points out that the very presence of ozone in polar regions is a result of transport from the tropics where ozone is formed. He is therefore inclined to favour the second theory — a dynamical one. This theory suggests that the stratospheric circulation has changed in recent years.

In favour of this dynamic explanation, Dr Plumb points to dramatic temperature decreases of about 20° at heights of about 30 km that have been associated with the ozone hole. A change in circulation — perhaps caused by stratospheric aerosols from volcanic eruptions — appears to be the only plausible explanation, in his view. It's difficult to see how chemical changes could lead to a big drop in temperature.

Even if release of CFCs can be confined to 1984 levels, American calculations suggest that these chemicals will, by themselves, cause a 6% reduction in the ozone layer after some decades. However, when the countervailing effect of trace 'greenhouse' gases (carbon dioxide, methane, and so on) is considered, a reduction of less than 5% is more likely.

If CFC release goes on ...

halocarbon	atmospheric lifetime (years)	relative ozone destruction efficiency (per kg released)	quantity released in 1984 (tonnes)	calculated eventual effect on ozone if 1984 release rate continues
CCl_3F	75	1·00	280 000	−2·0%
CCl_2F_2	110	0·86	360 000	−2·0%
CCl_2FCClF_2	90	0·80	130 000	−0·7%
$CHClF_2$	20	0·05	110 000	−0·1%
CH_3CCl_3	6	0·15	510 000	−0·6%
CCl_4	50	1·11	100 000	−0·8%
		totals	1 490 000	−6·2%

Observations by Dr John Gras and colleagues at the Division of Atmospheric Research have shown that the stratospheric aerosol in the Southern Hemisphere increased by a factor of 5–10 following several major eruptions in 1982. Volcanic activity remains high, but, according to this theory, the ozone hole should disappear when it quietens down.

The third theory, put forward by NASA scientist Dr Linwood Callis, is that increased solar activity underlies the ozone depletion. We have just emerged from the second-most active solar cycle in 250 years, which reached a sunspot maximum in 1979. Dr Callis maintains that solar protons bombarding the top of the atmosphere have created much higher levels of nitrogen oxides (NO_x) in the mesosphere (50–80 km); the nitrogen oxides are being transported down to the stratosphere during the polar night, where they destroy ozone. The severest ozone depletion is reckoned to occur several years after the sunspot maximum.

Satellite observations have confirmed that levels of nitrogen dioxide at altitudes of 25–40 km have increased by up to 75% between 1979 and 1984. Dr Callis believes that his model of this chemical interaction also closely matches actual observations of the size of the ozone hole, its rate of increase, and the timing of its appearance. By his calculation, the hole should now have reached its worst, and ozone should be beginning to recover. Indeed, as mentioned earlier, the observations from last spring appear to conform with this pattern.

However, results, as given in a preliminary announcement, don't fully confirm the solar-cycle theory (or any existing theory for that matter). Balloons sent high into the stratosphere to measure 15 different trace gases found much lower levels of nitrogen oxides than the solar-cycle theory would permit.

Furthermore, sensors on the balloons recorded low levels of chlorine — which is not consistent with the CFC-blaming theory. And, as if to spite everybody, only small quantities of tropospheric trace gases, N_2O for example, were found in the stratosphere, making it hard to maintain the volcanic theory.

However, scientists are disputing the interpretation of the N_2O measurements, so the last word on this issue hasn't been said. This spring, an even bigger contingent of scientists is planning to go to the Antarctic to observe the ozone minimum. Possibly, these new and better measurements will give us the answer.

Andrew Bell