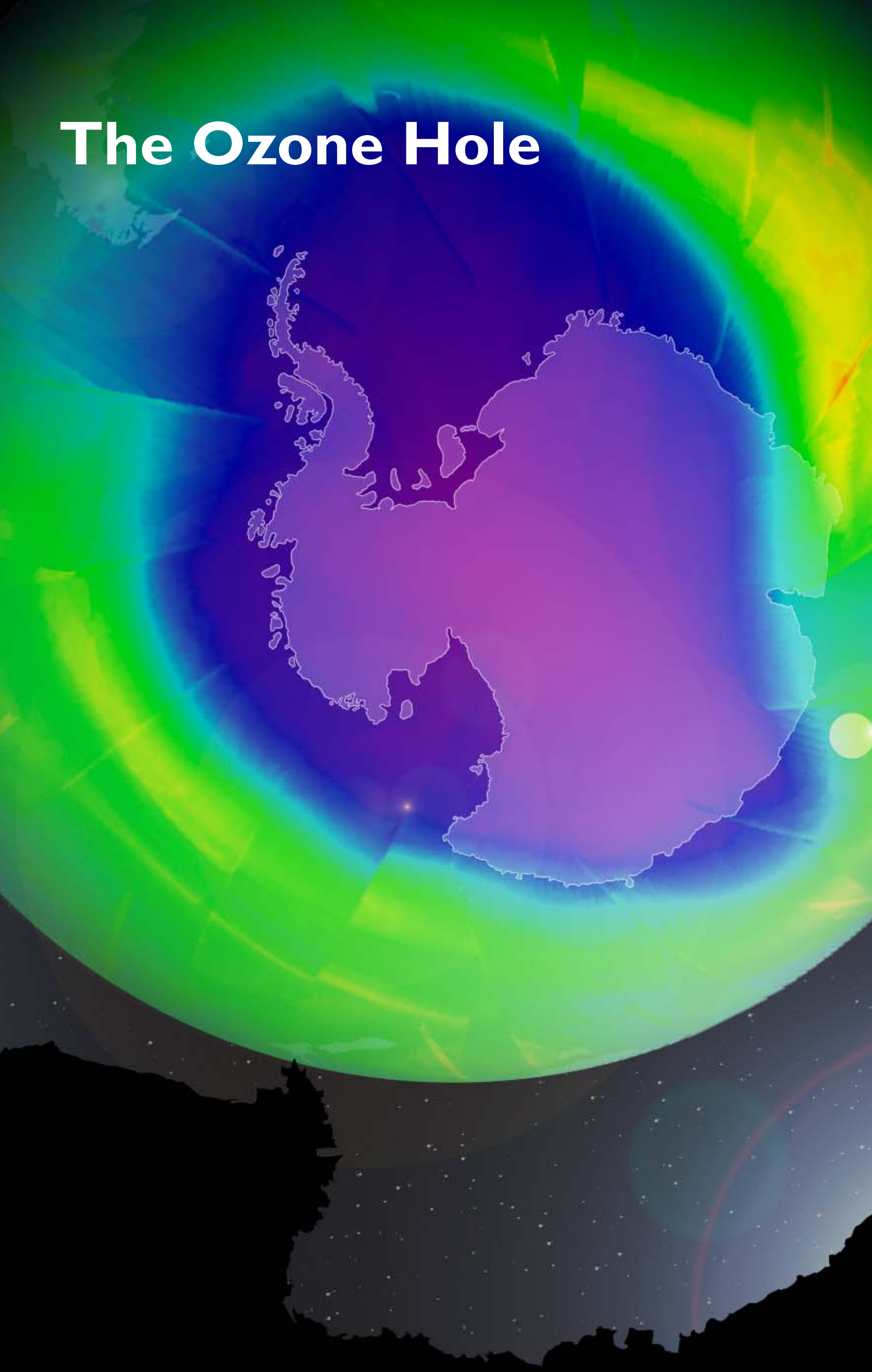
The Ozone Hole



British
Antarctic Survey

NATURAL ENVIRONMENT RESEARCH COUNCIL

High up in the Earth's atmosphere a thin layer of ozone protects us from the Sun's most harmful rays, safeguarding life on our planet. In 1985 a team of three scientists working for the British Antarctic Survey (BAS) discovered a hole in the ozone layer over Antarctica.

The thinning of the ozone layer is caused by a chemical reaction where man-made chemicals known as CFCs (chlorofluorocarbons) and halons are broken down into their constituent parts. These then react with ozone in the upper atmosphere.

Every Antarctic spring (September/October) ozone levels fall to less than half their normal amount and the ozone hole covers the entire continent. Sometimes it becomes elongated to extend across the tip of South America and the Falkland Islands.

The discovery of a hole provided an early warning of the damage being done to the ozone layer worldwide. It paved the way for international action and the signing of a successful agreement to counter the destruction – the 1987 Montreal Protocol.

Although the production of CFCs has now been banned globally, these long-lived chemicals have by no means disappeared. It will take up to 100 years for the ozone layer to fully recover.

BAS scientists are at the forefront of international efforts to monitor the state of the ozone layer, carrying out ozone observations from Halley and Rothera Research Stations. Ozone has been studied by BAS researchers for over fifty years – the longest record of ozone measurements in the Antarctic.

Image: *The midnight sun shines over a glaciology field camp on Pine Island Glacier, West Antarctica.*

The Earth's atmosphere

Viewed from space our atmosphere is very thin – extending just 100km or so from the Earth's surface. It is made up of 77% nitrogen and 21% oxygen along with a small amount of other gases such as ozone.

The atmosphere is divided into several distinct layers. The part we live in is called the troposphere; this contains clouds, weather and living things. The air temperature falls from the Earth's surface to the top of the troposphere. This level is known as the tropopause and is at an altitude of around 10km. Jet aircraft usually fly just below this height.

The layer above the troposphere is called the stratosphere. The stratosphere is very dry and contains most of the ozone in the atmosphere. The ozone layer is not really a single level but a broad band with ozone concentration increasing to reach a peak at around 20km from the Earth's surface.

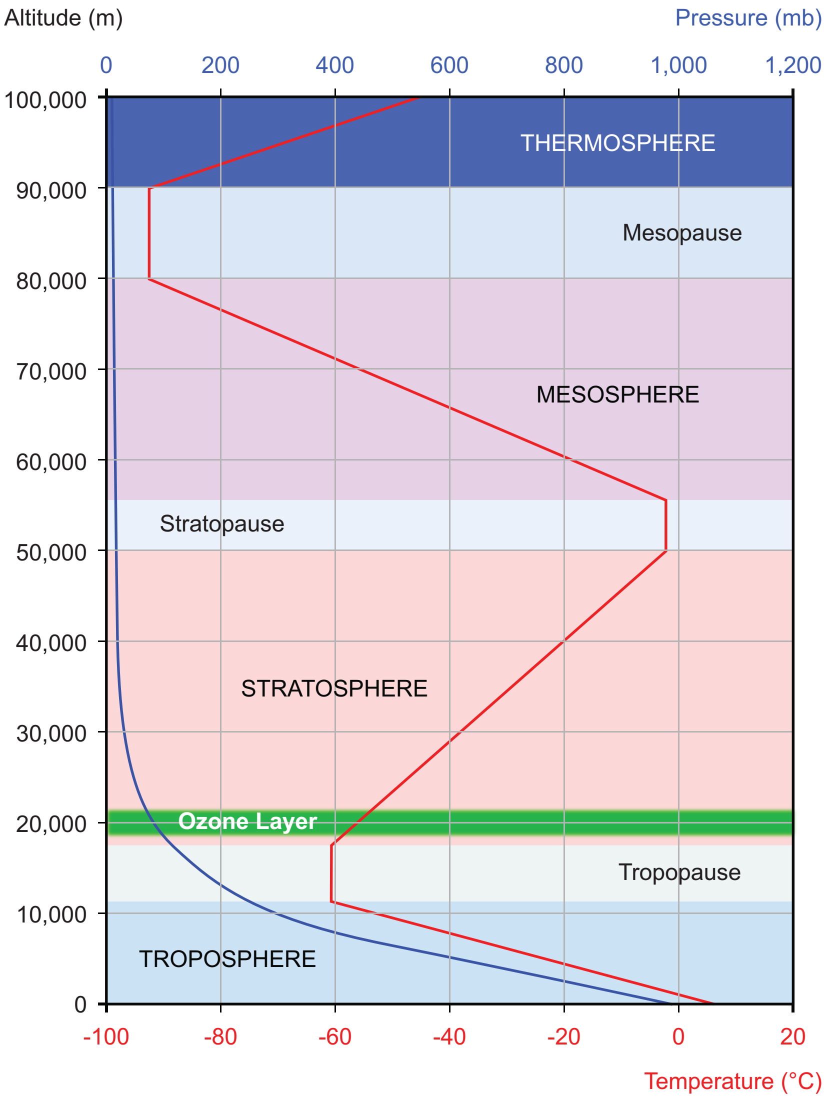


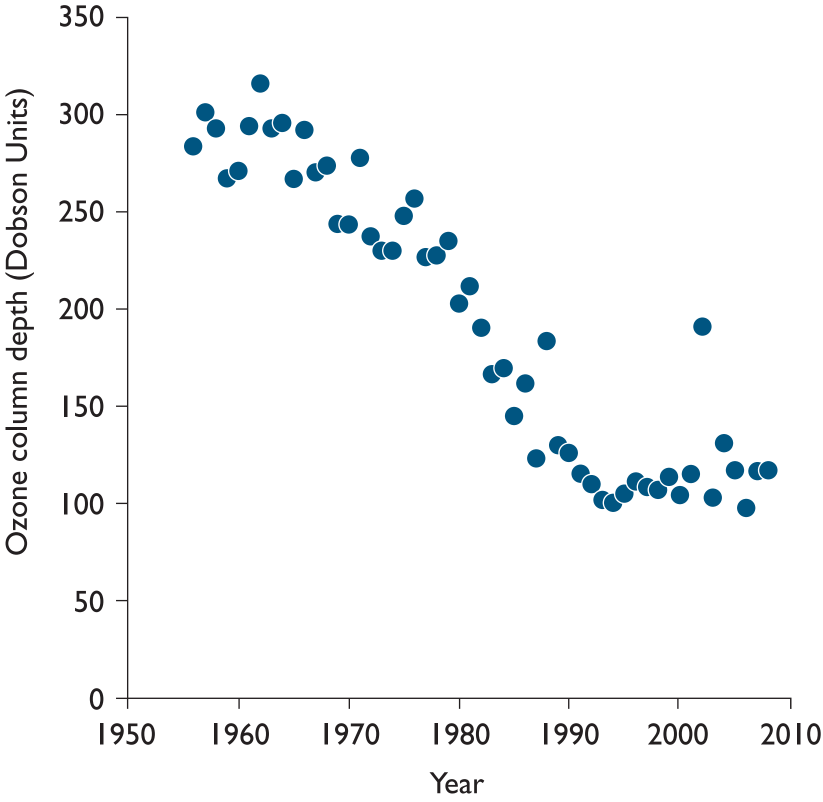
Image: *An illustration showing the layers of the atmosphere.*

Ozone

Ozone is a molecule consisting of three oxygen atoms. It is a relatively rare gas, even in the ozone layer there is less than one ozone molecule for every 100,000 molecules of air.

Ozone is also an unpleasant gas as it is toxic and irritating. In the polluted air from large cities, particularly in summer time, high concentrations of ozone at low levels can cause severe health problems.

In its proper place in the stratosphere, ozone provides a safety screen against harmful ultra-violet light from the Sun, which can cause sun-burn, skin cancers and cataracts. The ozone layer also acts as a temperature control because it can absorb some of the Sun's radiant energy.



🛈 The Sun and the Earth

The Sun gives us light and warmth. Without it there would be no life on Earth. But there is a downside. The Earth is being continuously bombarded by billions of charged particles along with every possible wavelength of radiation. Around half of the energy from the Sun comes to us as infra-red radiation – heat. 41% is visible light and around 7% of the energy output is invisible ultraviolet radiation. The ultra-violet part is divided by scientists into different categories depending on wavelength: UV-A, UV-B and UV-C. The latter is almost totally absorbed by the atmosphere. The most damaging to us is UV-B, for which the ozone layer offers partial protection.

Image: *The minimum October ozone level over the UK's Halley Research Station, Antarctica, between 1956 and 2009.*

Measuring the ozone layer

UK scientists have been measuring the Antarctic ozone layer since 1956 when the first Halley Station was established for the International Geophysical Year of 1957-58.

The ozone layer was originally studied because of its influence on the temperature of the atmosphere and was used as a measure of air circulation. It was not until the 1970s that ozone became the focus of attention as an indicator that long-term changes might be taking place in the atmosphere.

Ozone is measured using an instrument called a Dobson Spectrophotometer. The ground-based device works by comparing the intensities of two wavelengths of ultra-violet light from the Sun. One wavelength is strongly absorbed by ozone and the other is only weakly absorbed. The ratio between the two tells scientists how much ozone there is in the atmosphere.

The amount of atmospheric ozone is measured in Dobson Units (DU). A normal measurement would be around 300DU. This means that if you took all the ozone in a vertical column above the instrument and brought it down to sea level it would form a layer just three millimetres thick. Since the discovery of the ozone hole, measurements of ozone are now occasionally dropping below 100DU.

The cleanest place on Earth

Halley Research Station is one of the best places on Earth to measure global pollution. All the buildings and vehicles are kept to the west of monitoring instruments so that if an easterly wind blows the air has not been contaminated for many hundreds of kilometres. BAS uses sensitive filters to extract pollutants and aerosols from the air. As well as the paper filters, scientists collect weekly snow samples and an air sample. The sampling equipment is so sensitive that researchers have to hold their breath when they use it.

Image: *Halley VI Research Station provides an ideal environment to measure ozone concentrations.*

Discovery of the ozone hole

By the 1970s there was a suspicion that man-made chemicals might be damaging the ozone layer.

This was backed by a study published in the scientific journal *Nature* in 1974 which warned of the developing threat to the ozone layer from the use of CFC gases. Paul Crutzen, Mario Molina and Sherwood Rowland later went on to win the Nobel Prize for this pioneering work.

In Antarctica the amount of ozone overhead follows a regular seasonal pattern. The Antarctic ozone layer did so for the first 20 years of BAS measurements but then clear deviations were observed. In each successive spring the ozone layer was weaker than before and by 1984 it was clear that the Antarctic stratosphere was progressively changing.

In 1985 BAS scientists Joe Farman, Brian Gardiner and Jonathan Shanklin published their findings in *Nature*. Their work was confirmed by satellite data and greeted with concern around the world.

A major international study of the Antarctic ozone hole took place during the southern spring of 1987. Flights were made in specially equipped high-altitude research aircraft along the Antarctic Peninsula and toward the South Pole. Other researchers used microwave experiments and laser radar, or lidar, to fire pulsed laser beams into the atmosphere to probe its composition.

Together the evidence showed conclusively that the ozone layer was being damaged and pointed to chlorine compounds as the culprit. More recent studies from the Space Shuttle and satellites confirmed that the source of the chlorine is CFCs and halons.

ℹ Monitoring the atmosphere

Every day at Halley, BAS scientists launch a balloon carrying meteorological instruments. It records temperature, humidity and pressure to a height of more than 20km. A more complete picture of the upper atmosphere can be seen from space. Several satellites carry sensors which make global measurements of atmospheric changes. Over a year these spacecraft are able to 'see' the ozone hole forming in the spring and recovering each summer.

Image: *From left to right; Joe Farman, Brian Gardiner and Jonathan Shanklin, the BAS scientists who first discovered the ozone hole.*

CFCs

The Antarctic ozone hole begins to form when sunlight returns at the end of the Antarctic winter and reaches its largest extent every spring. By mid-summer it has disappeared again.

The hole is caused by reactions between chlorine or bromine in the atmosphere and ozone. The chlorine and bromine come from chlorofluorocarbons (CFCs) and halons.

CFCs have been widely used in refrigeration and air conditioning systems as well as for producing industrial solvents. Halons (bromofluorocarbons) were used in fire extinguishing systems. CFCs have a number of advantages for industrial use – they are generally odourless, non-toxic, stable and non-flammable. Most CFCs and halons have been released in the northern hemisphere then spread throughout the world, diffusing into the stratosphere to be broken down to release chlorine or bromine.

Antarctica's climate provides conditions for the processes that break down the ozone layer. During the Antarctic winter a strong westerly circulation around the continent, known as the circumpolar vortex, builds up in the stratosphere. This has the effect of cutting off the interior of the continent, allowing stratospheric temperatures to cool to below -80°C. Thin clouds form in the stratosphere, where chemical processes take place.

Some of these can be complex but the simplest involves the combination of chlorine with ozone to form chlorine monoxide and oxygen. Bromine is chemically similar to chlorine and tends to react with ozone in a similar way.

Image: *Polar stratospheric clouds, also called nacreous clouds, above Rothera Research Station in the Antarctic Peninsula.*

A world without the ozone layer

The ozone layer protects life on Earth against UV-B radiation from the Sun.

The reason UV-B is so damaging is that it can be readily absorbed by DNA – the molecule within the cells of our body that contains our genetic code. When DNA is disrupted the instructions cannot be read properly. As the amount of UV-B entering the cell increases then so does the risk of genetic damage. If it gets too bad it can result in disease or even death.

For Antarctic organisms such as algae, lichens and mosses, too much UV-B can lead to bleaching of photosynthetic cells. Other plants and animals can have their metabolic processes disrupted or cells damaged by this high-energy radiation. The most common human impact of UV-B radiation is skin cancer, which accounts for more than 1,000 deaths each year in the UK.

Human skin cells produce brown melanin to protect against sun-burn but we can also protect ourselves against the Sun's harmful rays by using sun-screens. Many plants and animals have evolved their own defences. A variety of sun-screen pigments are produced by Antarctic organisms on land, in freshwater and in the sea. Some lichens and microbes even live inside translucent rocks to shelter from high radiation levels.

A worldwide thinning of the ozone layer would have very serious implications for all life on Earth. Effects would range from an increased incidence of skin cancer and other diseases in humans, to crop damage and disruptions to fragile ecosystems. The medical, environmental and economic costs would be tremendous.

Image: *Protection must be taken against the effects of increased UV radiation when beneath the ozone hole.*

International action

In 1987 a comprehensive agreement was drawn up to limit the production and use of CFCs. The Montreal Protocol has been hailed as one of the most successful international agreements ever implemented.

Originally aimed at halving the use of CFCs by 1999, reviews of the Protocol went further, imposing stringent controls. As a result, developed countries agreed to phase out the production of CFCs and halons by the year 2000. In the UK, consumption of CFCs had ceased by 1995, except for essential uses including metered dose inhalers for medical conditions such as asthma. By the end of 2009, all the UN member states had signed the basic Protocol. CFC production anywhere should have stopped by 1st January 2010.

CFCs have been replaced in many applications by HFCs (hydrofluorocarbons) and HCFCs (hydrochlorofluorocarbons). These have the same advantages as CFCs but do not damage the ozone layer as much. A few countries still use CFCs in essential health products. Most countries have strict provisions in place for the recycling of products, such as refrigerators, which contain CFCs

Studies from the National Oceanic and Atmospheric Administration (NOAA) suggest that as a result of the Montreal Protocol, concentrations of the principal ozone-depleting CFCs in the atmosphere are declining. Unfortunately the ozone hole will not immediately disappear. CFCs are such stable gases that they will remain in the atmosphere for decades to come.

ⓘ Is the ozone hole dangerous to humans?

The intensity of ultra-violet light at Antarctic stations is about the same as on a tropical beach at midday. In the Antarctic the Sun is much lower in the sky so sunlight takes a longer path through the atmosphere. This means more of the Sun's energy is absorbed before it reaches the ground. However, sun-burn is a serious problem in the Antarctic as sunlight is also reflected from the snow surface. Even on overcast days, for anyone working in Antarctica, high factor sun-creams are essential.

The ozone layer and global warming

Global warming and ozone depletion are two separate environmental problems but there are links between the two.

When the Sun's energy hits the Earth, some of it is reflected back into space. However, some of this energy is trapped in the atmosphere by clouds or gases such as carbon dioxide. This natural process is called 'the greenhouse effect'. As humans increase the amounts of carbon dioxide and other 'greenhouse' gases this effect becomes stronger – this is known as global warming.

As well as damaging the ozone layer, CFCs are also greenhouse gases and contribute to global warming. Since the introduction of the Montreal Protocol there have been increased concentrations in the atmosphere of their replacement – HFCs and HCFCs. Unfortunately, although HFCs and HCFCs cause less damage to the ozone layer, they are greenhouse gases.

There is also another connection between ozone depletion and global warming. Although the greenhouse effect warms the Earth's surface it also allows the higher atmosphere, where ozone is present, to cool. This means that more stratospheric clouds may form, increasing the damage to the ozone layer and delaying its ultimate recovery.

ℹ Why isn't there an Arctic ozone hole?

Unlike Antarctica, which is a mountainous continent surrounded by oceans, the Arctic is an ocean surrounded by mountainous continents. The upshot is that the stratospheric circulations in the Arctic are much more irregular and the temperature does not normally fall as low as around the South Pole. As a result, the conditions are less favourable for the formation of a deep ozone hole. However, if CFCs had not been controlled, it's likely that a large hole could also have appeared over the Arctic.

Image: *The Dobson Spectrophotometer has been used to measure ozone concentrations for over 50 years at Halley Research Station.*

The ozone hole today

If CFC releases had continued at the high rates of the mid-1980s, not only would we have a hole over the Antarctic, but there would also be a seasonal Arctic hole extending down to populated areas of Northern Europe and North America. Evidence indicates that CFC levels peaked in 2001 and are now declining.

Nevertheless, despite the success of the Montreal Protocol, the Antarctic ozone hole continues to appear each summer. In 2011 the hole exceeded 25 million square kilometres in size – one of the largest on record. Measurements at Halley (in Dobson Units) dropped to 102 DU from approximately 300 DU in mid-July. In the northern hemisphere, there has also been a general decline of some 5-10% in stratospheric ozone and in the spring of 2011 there was almost a full-blown ozone hole, when cold conditions in the stratosphere led to the destruction of around 40% of the ozone.

BAS scientists continue to monitor the state of the ozone layer above Antarctica and its wider impacts. Members of the survey's Meteorological and Ozone Monitoring Unit (MOMU) carry out regular ozone observations at Halley and Rothera Research Stations. Researchers are also investigating the biological impacts of ozone depletion on Antarctic plants and animals.

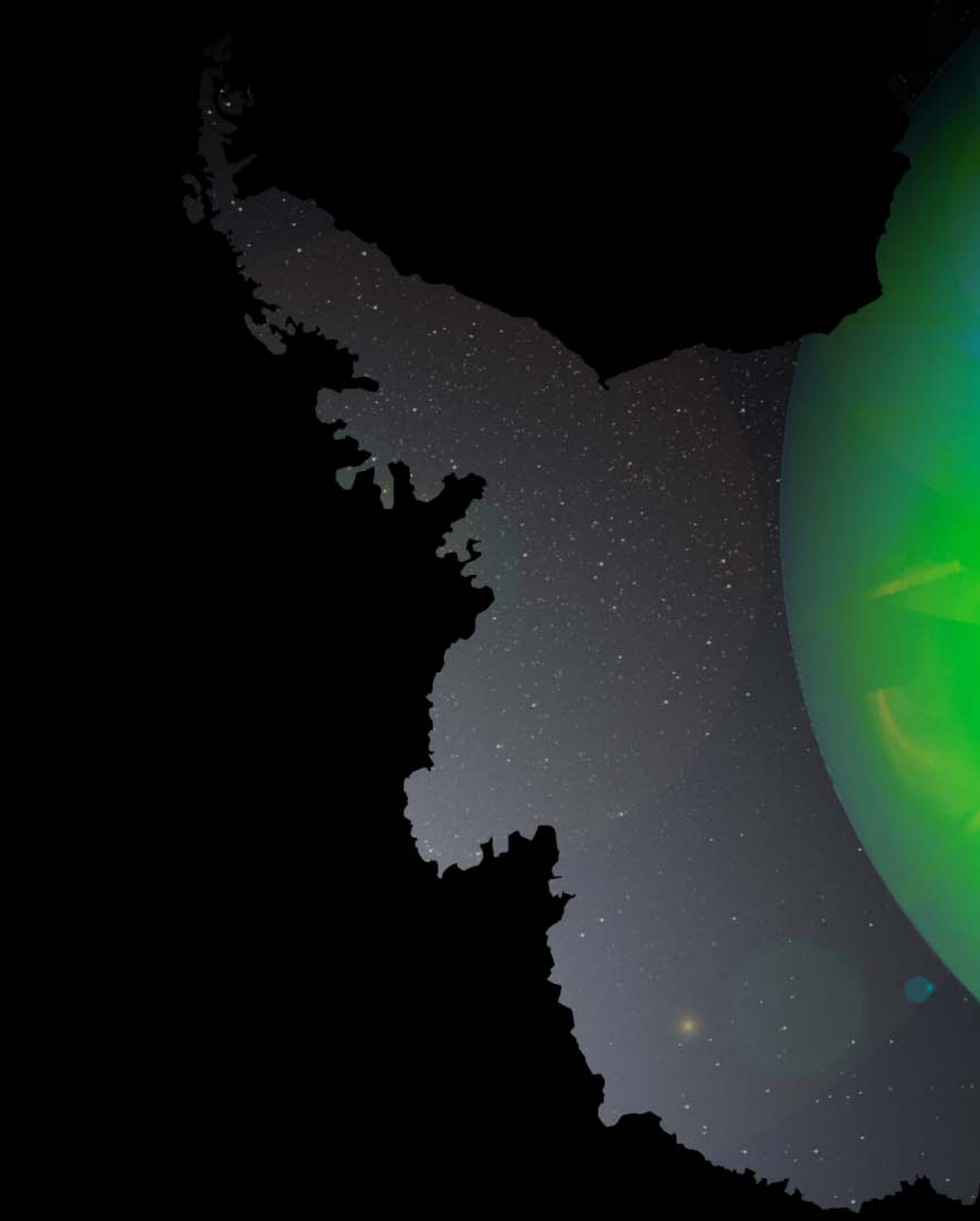
It's only in recent years that the impact of the ozone hole on the atmospheric circulation across the Antarctic has become clear. When the ozone hole forms in the spring, temperatures drop in the stratosphere, but during the summer and autumn this temperature anomaly descends to lower levels. Since 1980, many of the research stations have experienced a small decrease in temperature at this time of year. This cooling has increased the temperature difference between the Equator and the pole, resulting in an increase in surface wind speeds over the Southern Ocean of about 15%. In addition, the lower temperatures have given a small increase in the extent of sea ice around the Antarctic, which is in marked contrast to the large loss of sea ice that has been observed in the Arctic.

Internationally, the United Nations Environment Programme has an Ozone Secretariat which will continue to oversee the complete phasing out of CFCs. Studies suggest that it will take until at least 2070-2080 for ozone levels to return to their natural levels.

ℹ Fixing the hole

The only way to mend the ozone hole is to stop releasing CFCs and other ozone depleting gases into the atmosphere. Many other suggestions have been made, but turn out to be difficult or dangerous to put into practice. Examples include using supersonic transport planes to take ozone up to the Antarctic stratosphere. Unfortunately, it would take numerous flights, and the exhaust gases would probably do more harm than good. Another idea is to replenish ozone using balloons but it's estimated that more than 100 billion would be required – creating an even bigger environmental problem!

Cover image: NASA



British Antarctic Survey (BAS), a component of the Natural Environment Research Council, delivers and enables world-leading interdisciplinary research in the Polar Regions. Its skilled science and support staff based in Cambridge, Antarctica and the Arctic, work together to deliver research that uses the Polar Regions to advance our understanding of Earth as a sustainable planet. Through its extensive logistic capability and know-how BAS facilitates access for the British and international science community to the UK polar research operation. Numerous national and international collaborations, combined with an excellent infrastructure help sustain a world-leading position for the UK in Antarctic affairs.

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