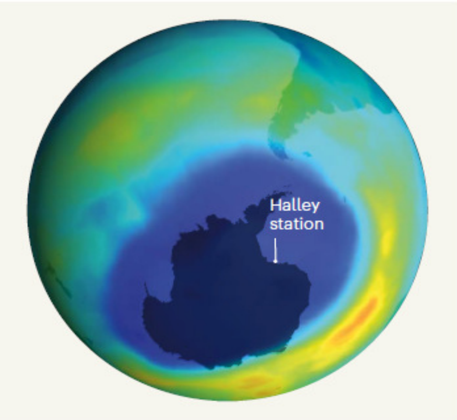
Stratospheric Ozone: Depletion and Recovery

Introduction

Ozone is a gaseous, highly reactive molecule of oxygen with formula O_3, which is a pollutant in the troposphere (the lowest level of the earth's atmosphere). However ozone in the stratosphere, 10 – 50km above the earth, forms a protective layer that shields us from some of the ultraviolet (UV) radiation from the sun. This is significant because UV radiation causes cataracts, sunburn and several types of skin cancer in humans. Weber *et al* [1] explain that ozone levels in the stratosphere are naturally very variable, being affected by many factors including the 11 year solar cycle, the Southern hemisphere El Niño oscillation, and volcanic aerosol emission. Barnes, Williamson *et al* [2] report that ozone depletion, UV radiation and climate change are interlinked in complex ways, and have effects on human health, and food and water security, among others.



This map shows a satellite ozone map for 10 Sept 2000, when ozone depletion was close to its maximum: blue indicates low ozone levels; red, high levels. The position of the Halley station is indicated

The discovery of the 'Ozone hole'

Measurements of ozone in the Southern hemisphere have been recorded since 1957, at several stations including Halley Bay, Antarctica. Farman *et al* [4] noted a dramatic decrease in the October (Spring) readings from the early 1970's, which was not observed in readings taken in March (autumn). The extremely low temperatures and prevailing weather patterns in Antarctic Spring account for this difference. Farman *et al* plotted ozone observations and chlorofluorocarbon concentrations on the same graph, showing the close correlation. Solomon [3] reflected on the Farman *et al* paper in 2019. She commended their robust methods in using two different instruments to collect the data, and their careful study of the seasonal variation. Previous studies had not considered that any regions could be a special case, and Farman *et al* prompted further data-gathering and analysis that confirmed their conclusion. The map [3] (above) shows the ozone hole in 2000, close to the peak of depletion - blue are the lowest ozone levels; red the highest.

Effects of ozone depletion on plants

An example of the effect that increased solar UV-B can have on plants in a natural ecosystem was described in a paper by Musil & Wand [5] in 1993. They grew 3 different Ericaceae (heathers) in a greenhouse for 4 months, subjecting them to different daily levels of UV-B radiation. These corresponded to the level of UV-B received under then current ozone conditions, and 10% and 20% ozone depletions. They found that higher levels of UV-B significantly reduced pollen germination, indicating that the resulting reduction in seed production could threaten the re-establishment of ecosystems in the frequent wildfire, nutrient-poor environment they are native to (South Africa).

Since plants directly or indirectly provide the food that we eat, Adams & Rowe [6] attempted to quantify the financial cost of ozone depletion on agricultural crops in the USA in 1988. They studied the main food crops soybeans, corn and wheat under different depletion scenarios to 2100, and concluded that more research was needed, as their model predicted significant effects from ozone depletion.

Chlorofluorocarbons and the Montreal Protocol

Chlorofluorocarbons (CFCs) are halogenated compounds whose attributes make them good solvents and refrigerants, and give them many uses in the manufacture of aerosol sprays, foams and packaging materials (Elkins [7]). Being non-toxic, nonflammable and inert when released in the troposphere, they were widely used from 1930 onwards. However once CFCs reach the stratosphere they react, releasing chlorine which catalyses the breakdown of ozone, damaging the stratospheric layer. To avert this problem, '**The Montreal Protocol on Substances that Deplete the Ozone Layer**' was adopted in 1987 (UNEP [8]). Being one of the rare international treaties that was universally ratified, it phased down the production and use of CFCs and other ozone-depleting substances. Barnes, Bornman *et al* [9] report that the Montreal Protocol has been "highly effective" at protecting the ozone layer.

Stabilising the trend

Weber *et al* [1] marked the 30th anniversary of the signing of the Montreal Protocol in 2018 with a paper that gathered observations from five different datasets over the period 1979 – 2016. One dataset (WOUDC) was ground-based (500+ stations worldwide). Two were gathered by NASA and NOAA satellite observations, and the remaining two (GOME GSG, GOME GTO) by European satellite spectrometers. They applied a multiple linear regression (MLR) model to establish trends in the ozone observations. Their results showed the depletion trend over Antarctica up to the year 2000 and the beginning of the recovery trend.

Future progress?

Montzka *et al* [10] report that, although the atmospheric concentration of one of the most damaging halogen-containing compounds, trichlorofluoromethane (CFC-11) declined at a constant rate from 2002 to 2012, that rate of decline then slowed. They concluded that this must relate to new emissions in the northern hemisphere, originating in East Asia. While it is a setback if emissions are happening in breach of the Montreal Protocol, it is encouraging if these breaches can be detected and reported on.

A final quote: "ongoing and projected changes in UV-B radiation and climate still pose a threat to human health, food security, air and water quality, terrestrial and aquatic ecosystems, and construction materials and fabrics" Barnes, Bornman *et al* [9].

References

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Additional references from the presentation

European Commision,The Copernicus Atmosphere Monitoring Service, https://atmosphere.copernicus.eu/monitoring-ozone-layer {accessed 09 March 2023)

The photos of heathers were from the South African National Biodiversity Institute (SANBI):

Erica curvirostris Salisb.	http://pza.sanbi.org/erica-curvirostris
Erica fairii Bolus	http://pza.sanbi.org/erica-fairii
Erica nudiflora L	http://redlist.sanbi.org/species.php?species=1820-619