Stratospheric Ozone: Depletion and Recovery

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Overview

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- The discovery of the ‘Ozone hole’
- Effects of ozone depletion on plants
- Chlorofluorocarbons and the Montreal Protocol
- Stabilising the trend
- Future progress?

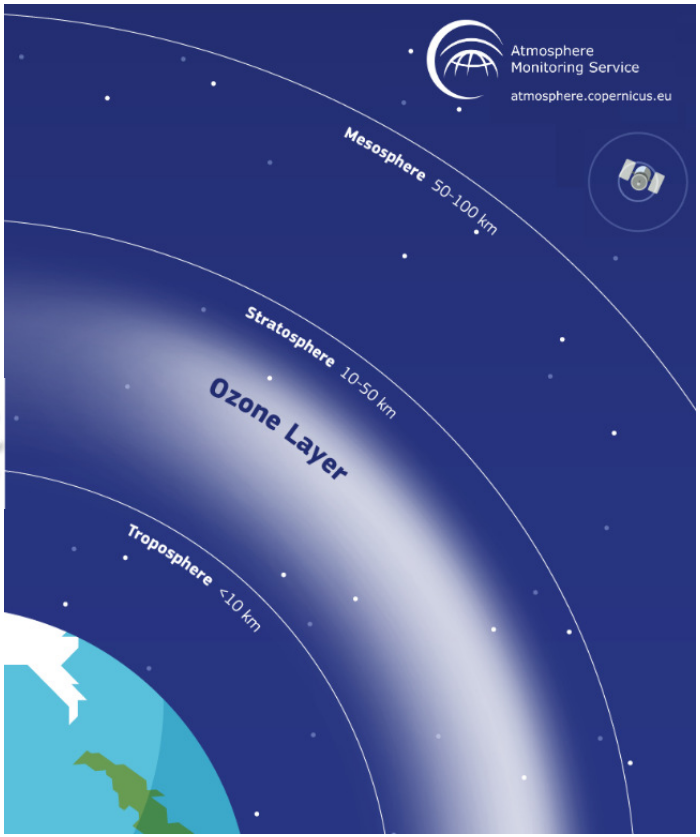
Introduction

- Ozone is a gaseous molecule of oxygen with formula O_3. It is highly reactive and polluting when it occurs in the troposphere, close to earth
- 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
- UV radiation causes cataracts, sunburn and several types of skin cancer in humans
- Weber *et al* explain that ozone levels in the stratosphere are naturally very variable, being affected by many factors including the Southern hemisphere El Niño oscillation, the 11 year solar cycle, and volcanic aerosol emission
- Barnes, Williamson *et al* 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

Weber *et al*,

https://doi.org/10.5194/acp-18-2097-2018

Barnes, Williamson *et al*,
https://doi.org/10.1038/s41893-019-0314-2



Copernicus, https://atmosphere.copernicus.eu/monitoring-ozone-layer

The discovery of the ‘Ozone hole’ (1)

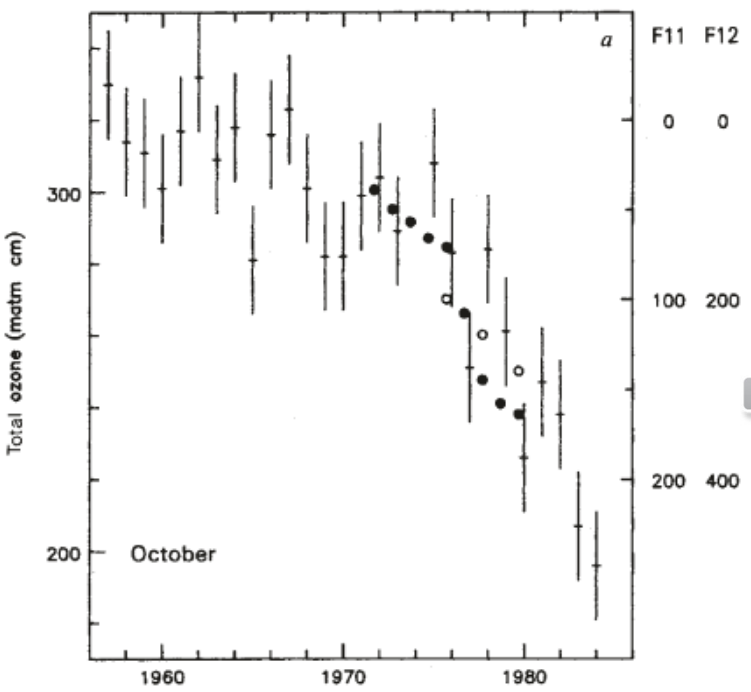


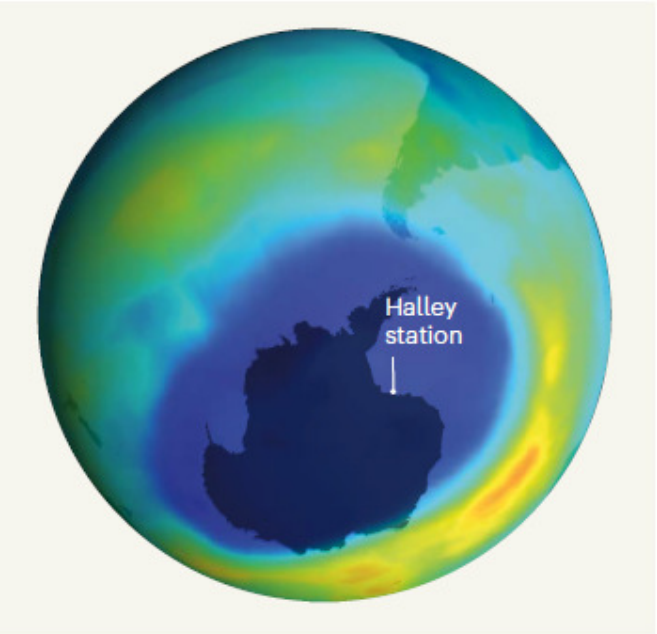
Fig. 2 Monthly means of total O_3 at Halley Bay, and Southern Hemisphere measurements of F-11 (●, p.p.t.v. (parts per thousand by volume) $CFCl_3$) and F-12 (○, p.p.t.v. CF_2Cl_2). *a*, October, 1957–84. *b*, February, 1958–84. Note that F-11 and F-12 amounts increase down the figure.

- Measurements of ozone in the Southern hemisphere have been recorded since 1957, at several stations including Halley Bay, Antarctica
- In 1985, Farman *et al* noted a dramatic decrease in the October (Spring in the Southern hemisphere) 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 seasonal difference
- In this plot of October readings from 1957 - 1984, the points with error bars are the ozone measurements, read on the left scale
- The black and white points are measurements of concentrations of two chlorofluorocarbons, read on the (descending) right scale
- There is a clear correlation between rising chlorofluorocarbon concentration and ozone depletion

Farman et al, https://doi.org/10.1038/315207a0

The discovery of the ‘Ozone hole’ (2)

- Solomon reflected on the Farman *et al* paper in 2019. She commends them for the robustness of their methods in using two different instruments to collect the data, and their careful study of the seasonal variation
- Previous ozone studies had not considered that polar regions could be a special case, and Farman *et al* prompted further data gathering and analysis that confirmed their conclusion
- This map represents the ozone hole in 2000, close to the peak of depletion, measured at the Halley station in Antarctica - blue are the lowest ozone levels; red the highest
- It should be noted that the ozone hole over Antarctica was an extreme effect of ozone depletion; however the ozone layer suffered from thinning globally



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.

Solomon, https://doi.org/10.1038/d41586-019-02837-5

Effects of ozone depletion on plants

Erica curvirostris Salisb.

E. fairii Bolus

E. nudiflora L.

- A detailed example of the effect that increased UV-B radiation can have on plants in a natural ecosystem was described in a paper by Musil and Wand in 1993
- They grew three different Ericaceae (heathers) in a greenhouse for 4 months, subjecting them to different daily levels of UV-B radiation, corresponding to the level 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 and Rowe 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

Musil and Wand, https://doi.org/10.1016/0098-8472(93)90069-R
Adams and Rowe, https://doi.org/10.1016/0301-4797(90)90026-S

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
- 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 break down, releasing chlorine which catalyses the breakdown of ozone
- '**The Montreal Protocol on Substances that Deplete the Ozone Layer**' was adopted in September 1987
- One of the rare international treaties that was universally ratified, it phases down the production and use of CFCs and other ozone-depleting substances
- Barnes, Bornman *et al* report that the Montreal Protocol has been "highly effective" at protecting the ozone layer

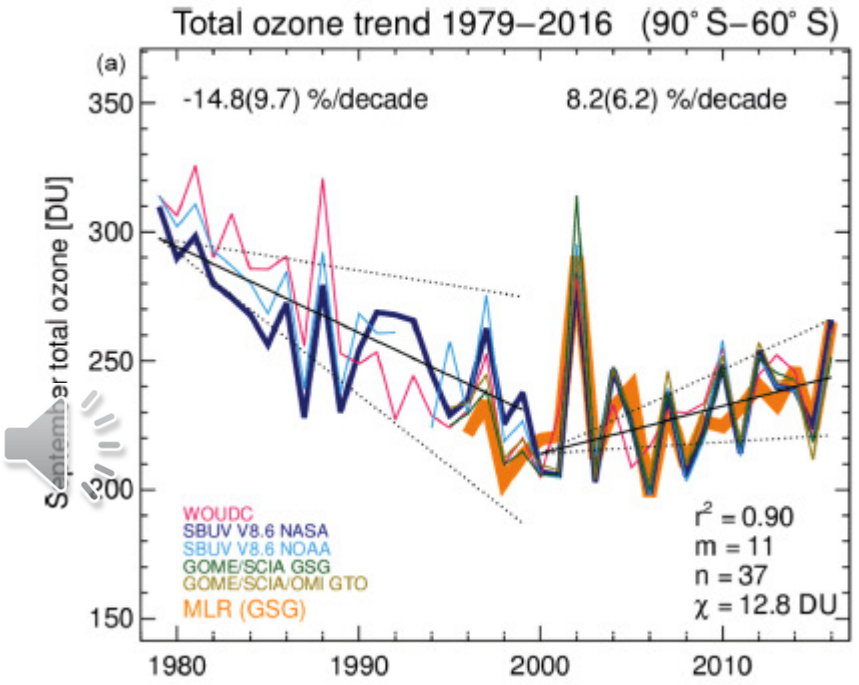
Elkins, https://gml.noaa.gov/hats/publictn/elkins/cfcs.html

Barnes, Bornman *et al*, https://doi.org/10.1111/gcb.15841

UNEP, https://www.unep.org/ozonaction/

Stabilising the trend

- Weber *et al* 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 (thick orange line, GSG data)
- Their results include this graph showing the depletion trend over Antarctica up to the year 2000 (2σ uncertainty), and the beginning of the recovery trend
- From the signing of the Montreal Protocol in 1987, it took about 10 years for the effect to be noticeable over most of the globe, and another 3 years to affect the Antarctic ozone hole



Weber *et al*, https://doi.org/10.5194/acp-18-2097-2018

Future progress?

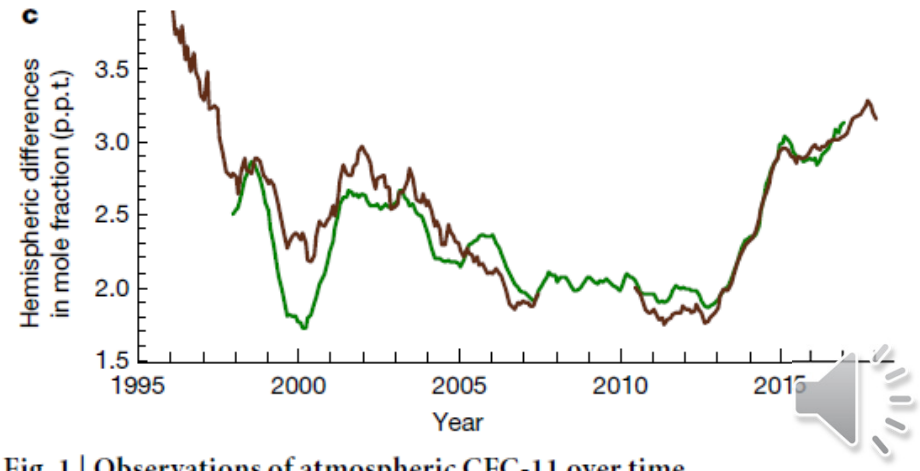


Fig. 1 | Observations of atmospheric CFC-11 over time.
c, Measured differences in hemispheric mean mole fraction of CFC-11 (North Hemisphere − South Hemisphere). In **b** and **c**, colours represent results from flask GC–MS (brown lines), flask GC–ECD (green lines)

The graph shows a steady decline in CFC-11 from 2002 – 2012, but then an unexpected increase. **Green** and **brown** lines indicate measurements from different detectors

Montzka et al, https://doi.org/10.1038/s41586-018-0106-2

- Montzka *et al* 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 conclude that this must relate to new emissions in the northern hemisphere, originating in East Asia
- While it is a setback if emissions of these chemicals into the atmosphere is happening in breach of the Montreal Protocol, it is encouraging if these breaches can be detected and reported on

"…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*