Atmospheric Research

Improving projections of Antarctic ozone recovery

The Antarctic ozone hole is expected to recover sometime this century, but exactly how and when remains uncertain. ***Greg Bodeker*** *and the* ***IPY Team*** *are working to improve model projections of the recovery using data from the intensive measurement campaigns of the International Polar Year (IPY).*

The ozone hole is the largest impact humans have had on Antarctica to date. From the 1940s to the 1990s, industrial and domestic emissions of chlorofluorocarbons, hydrochlorofluorocarbons, halons, and methyl bromide significantly increased the concentrations of chlorine and bromine in the stratosphere. These two halogens are released from their source gases through chemical reactions within polar stratospheric clouds (PSCs), and then destroy large quantities of ozone. The ozone-destruction reactions are triggered by sunlight, so they peak in the spring when the Antarctic emerges from the winter polar darkness. The PSCs are confined within the Antarctic vortex, persistent westerly winds that encircle the continent in the upper stratosphere, such that the Antarctic ozone hole occurs poleward of the vortex. In recent years, almost all of the ozone in the Antarctic's lower stratosphere (16–22 km altitude) has been destroyed each spring.

'Ozone mass deficit' (OMD) is a measure of the severity of the Antarctic ozone hole. The minimum level of ozone scientists measured over Antarctica before 1980 was never below 220 DU (Dobson units); OMD is the mass of ozone that would need to be added to the stratosphere to bring levels back up to that 220 DU benchmark. Another important measurement is EEASC, or equivalent effective Antarctic stratospheric chlorine, the total concentrations of the ozone-destroying halogens.

The diagram on the next page shows the past thirty years and a look ahead to the next ninety, charting measured and projected OMD values together with EEASC. From 1979 to the late 1990s, the severity of the Antarctic ozone hole increased rapidly with increasing EEASC. More recently, as a result of the Montreal Protocol, emissions of ozone-depleting substances have declined considerably and EEASC is now decreasing. In response, the ozone layer over Antarctica is expected to return to 1980 levels sometime around 2060. However, the timing of the recovery is very uncertain due to feedbacks with climate change.

Modelling the recovery of the ozone hole

Scientists use global climate models (GCMs) to project future climate over many decades. For example, one group that uses GCMs is the Intergovernmental Panel on Climate Change (IPCC). However, such models are not suitable for projecting future ozone levels over Antarctica because they don't include the effects of future changes in stratospheric halogen concentrations or changes in stratospheric chemistry. The solution is to directly incorporate atmospheric chemistry in a GCM to create a so-called chemistry–climate model (CCM). At NIWA, we're operating two such models.

Watching the hole fill up

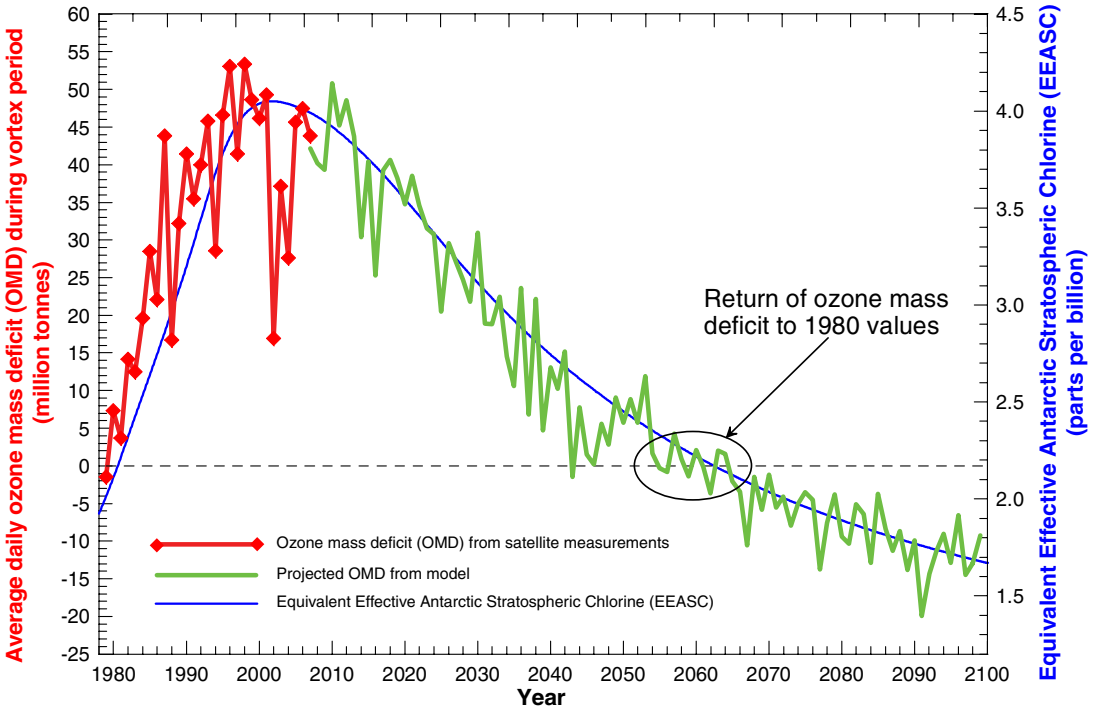
- Following the emissions controls imposed by the Montreal Protocol, the Antarctic ozone hole is expected to gradually shrink over the coming decades.
- Conventional global climate models are inadequate to project ozone recovery, so scientists turn to chemistry–climate models.
- The models can now be fine-tuned using the wealth of data collected during the International Polar Year.

CCMs are very complex computer models, often exceeding a million lines of code. The developers of these models try to incorporate all processes known to be important to the problem being addressed. The models divide the atmosphere into hundreds of thousands of boxes and calculate the changes in chemistry and dynamics within each box. A typical size of a box would be 3.75° of longitude by 2.5° of latitude and 1 km thick; this would cover about half of the South Island and contain about 80 000 cubic km. Many processes in the atmosphere occur on smaller scales (for example, clouds, convection, thermals, and atmospheric waves) and therefore cannot be explicitly included in the model. Their effects on the atmosphere need to be 'parameterised' which means described by a simplified mathematical equation that can be evaluated within each of the model's boxes.

Diagnosing and improving chemistry–climate models

'Diagnosing' a model means determining where or how a model may be deficient in some respect so that it can be improved to better mirror reality. A CCM's myriad processes and interrelated parameterisations make it very difficult to diagnose. (See 'Tuning the parameters' for an example of one such diagnostic.)

From 2007 to 2009, scientists around the globe are participating in the IPY, collecting unprecedented data from both polar regions. For atmospheric research, IPY has meant an array of improved stratospheric measurements of ozone and the trace gases affecting ozone. Now we're using novel diagnostic tools and the improved data to probe some of the key chemical processes within our CCMs, improving the models to provide more reliable projections of Antarctic ozone recovery.



Measured and projected recovery of the Antarctic ozone hole. Plotted in red against the left Y-axis is the seasonal average OMD calculated from satellite-based measurements of total column ozone (the amount of ozone in a column from the Earth's surface to the top of the atmosphere). The green line shows a projection of OMD based on a simple model. Plotted in blue against the right Y-axis is the EEASC. The weaker ozone holes from 2001 to 2005 resulted from elevated stratospheric temperatures.

We intend to apply such diagnostic tools not only to our own CCMs, but also to those used by the international research community. Specifically, we're contributing to CCMVal, a process-oriented validation of chemistry–climate models under the auspices of SPARC (Stratospheric Processes And their Role in Climate), a core research project of the World Climate Research Programme.

Improved projections of Antarctic ozone hole recovery are important not only for knowing what will happen to surface UV radiation in the future, but also because the future evolution of ozone over Antarctica will have important implications for surface climate change in the Antarctic. W&A

Further reading and useful links

Austin, J.; Bodeker, G.; Struthers, H. (2002). Predicting the future of global ozone. *Water & Atmosphere 10(2)*: 24–25.

McKenzie, R.; Bodeker, G. (2007). The 2006 WMO/UNEP Ozone Assessments: what they mean for New Zealand. *Water & Atmosphere 15(2)*: 12–15.

Renwick, J.; Thompson, D. (2006). The Southern Annular Mode and New Zealand climate. *Water & Atmosphere 14(2)*: 24–25.

Introduction to the Antarctic ozone hole: en.wikipedia.org/wiki/Ozone_hole

SPARC website: www.atmosp.physics.utoronto.ca/SPARC

CCMVal project: www.pa.op.dlr.de/CCMVal

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The NIWA IPY Team comprises Greg, Dr Petra Huck (Christchurch), Dr Sam Dean (Wellington), and Dr Hamish Struthers, Dan Smale, Dr Guang Zeng, and Stefanie Kremser (Lauder).

Tuning the parameters

An important step in the annual formation of the Antarctic ozone hole is the conversion of chlorine-containing molecules from types that don't destroy ozone to those that do, specifically the conversion of HCl (hydrochloric acid) and $ClONO_2$ (chlorine nitrate) molecules to ozone-depleting ClO (chlorine oxide) and Cl_2O_2 (chlorine dioxide) molecules, which are jointly referred to as ClO_x. This conversion requires the presence of polar stratospheric clouds and sunlight to initiate the photochemical reactions. The whole process can be simply captured in the formula:

$$\frac{d\,ClO_x}{dt} = \alpha\,(Cl_y - ClO_x) \times FAP \times FAS - \beta\,ClO_x$$

where:

$d\,ClO_x/dt$ represents the change in ClO_x from one day to the next.

Cl_y is the total amount of chlorine available in the Antarctic stratosphere – very much like the EEASC shown in the diagram above.

FAP is the fraction of the Antarctic vortex which is covered by PSCs. If there are no PSCs this number is 0 and if the vortex is filled with PSCs this number is 1.

FAS is the fraction of the Antarctic vortex currently in sunlight – remember that during the period that the Antarctic ozone hole forms (June to November) large parts of the Antarctic are in polar darkness.

α and β are unknown parameters. The first tells us how sensitive the activation of the chlorine is to PSCs and sunlight. The second tells us how quickly the ClO_x returns to its inactive forms.

We first 'fit' the equation to observations by tuning the α and β parameters until the ClO_x time series produced by the equation best matches measurements of ClO_x. We can then do the same with the output from one of our CCMs. By comparing the α and β from reality with the α and β from the model we can sensitively diagnose how well the model is simulating the activation of chlorine in the Antarctic stratosphere. If the model is inadequate, we can then see which of the terms in the equation are being incorrectly simulated and track down how to fix those.

A similar equation tracks the influence of ClO_x on ozone using IPY measurements of ozone loss rates in the Antarctic stratosphere.