The Antarctic Ozone Hole: Didn't we fix that already?

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Abstract. The Antarctic ozone hole, a rapid depletion of ozone that occurs each spring over Antarctica, first formed more than 30 years ago. When discovered, it prompted international action, firstly to understand the mechanisms by which it formed, and then to control the production and use of ozone depleting chemicals, resulting in the Montreal Protocol and its subsequent amendments. This action appears to have been successful, and serves a model of the way that other global environmental issues could be addressed. Continued monitoring of the ozone hole is important to assess whether the continued "recovery" or lessening in the severity, of the ozone hole is occurring as expected, and to check our understanding of the processes and feedbacks involved.

Atmospheric scientists have often had to explain that ozone depletion and the resulting changes in ultraviolet radiation at the Earth's surface are not the same as the main issue of climate change, which is that increasing concentrations of some gases in the atmosphere that are altering the balance of long-wave or infrared radiation in the atmosphere, referred to as "greenhouse" gases, are producing a warming at the Earth's surface. However, as both ozone changes and greenhouse gas changes are composition changes that affect the chemistry, the temperature profile and the circulation in the atmosphere, there will be potential fcouplings between them.

Why in Antarctica?

The ozone hole arises from a combination of factors that occur in the Antarctic region. These are

- Isolation of the atmosphere over Antarctica caused by a meteorology pattern known as the polar vortex – a band of strong westerly winds that forms over winter around Antarctica and limits air exchange between inside and outside the vortex.
- A lack of incoming solar radiation in the polar night, in combination with the vortex, results in very low stratospheric temperatures (Figure 1)
- The temperatures are low enough for formation of polar stratospheric clouds (PSCs), made up of particles of frozen hydrates of nitric acid (HNO_3) or water ice.
- The surfaces of these particles provide reaction surfaces for the conversion of anthropogenic chlorine and bromine in the stratosphere into more chemically active forms.
- As sunlight returns in spring, the last step in this activation occurs by photolysis of chlorine and bromine
- The activated chlorine and bromine reacts with ozone and is replenished in catalytic cycles, causing rapid ozone loss. (Figure 2)
- Even after the chemical conversion has stopped, low values of ozone are maintained within the polar vortex until the vortex dissipates or breaks up.

This combination of conditions is unique to the Antarctic. The arctic does experience sufficient low temperatures, PSC formation and consequent ozone depletion but these conditions do not last long.

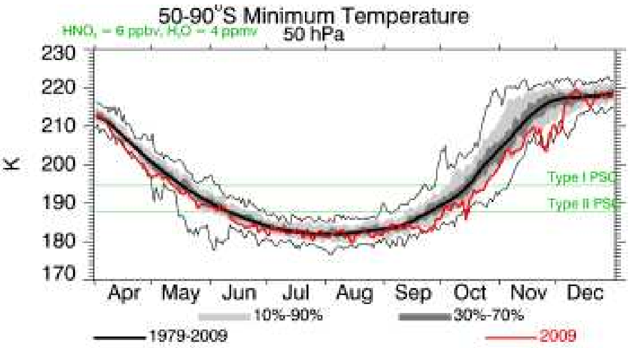

Figure 1. Minimum temperature measured poleward of 50° S at 50hPa (~20km altitude) showing the low temperature conditions for the formation of the ozone hole. Marked with green lines are the temperatures as which two different sorts of PSCs form for typical concentrations of nitric acid and water vapour.

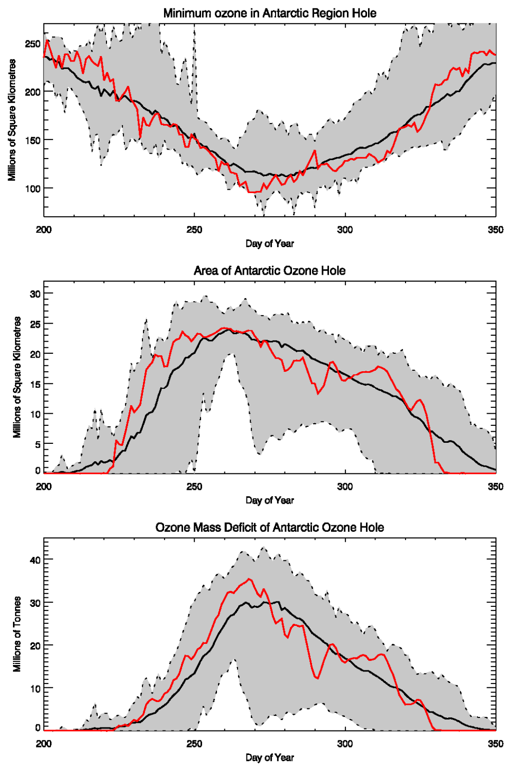

Figure 2. The minimum ozone, area and ozone depleted mass for the 2009 ozone hole (red lines) plotted against the means (black line) and extreme values (grey shaded area) for the period 1990-2009. The hole area is defined as

the area where total ozone is less than 220 Dobson units (1000 DU = 1 atmosphere-centimetre) and the mass deficit is the amount of ozone required to bring the total ozone up to 220 DU over the whole ozone hole area.

The Montreal Protocol

The protocol to limit the production of ozone depletion substances has resulted in the level of anthropogenic chlorine and bromine in the atmosphere beginning to decrease. For details see Figure 3 and discussion in the accompanying paper by G. Bodeker. Without the protocol ozone depletion would have continued unchecked. It is now predicted that the ozone hole will slowly recover, and this has begin to be observed (Figure 3). Full recovery is still expected to take several decades.

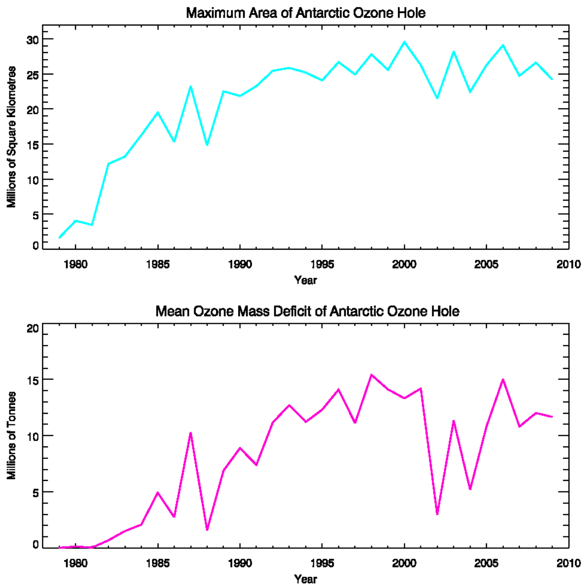

Figure 3. Top plot: the maximum area of each year's ozone hole, defined at for figure 2. The areas grew rapidly during the 1980s and 1990s but have now levelled off. The large year to year variations are due to variations in meteorology. Bottom plot: the ozone mass deficit of each hole averaged over the period mid-July to late December each year. Apart from unusual years in 2002 and 2004, this measure more clearly shows a recovery in ozone hole severity.

Interaction of the ozone hole with Mid-latitudes

Ironically, when the ozone hole is at its maximum extent in spring, southern mid-latitudes experience the highest amounts of ozone of their annual cycle (Figure 4). The effect of the ozone hole is felt later in the year when the polar vortex and hence the ozone hole breaks up. Up until that point the hole may move around in a sloshy, rotating motion that may distort the area into elongated shapes, driven by planetary scale wave motions. When the hole does break up the effect is to dilute the ozone in the region around Antarctica. Hence mid-latitude regions experience their lowest ozone values in the mid to late summer.

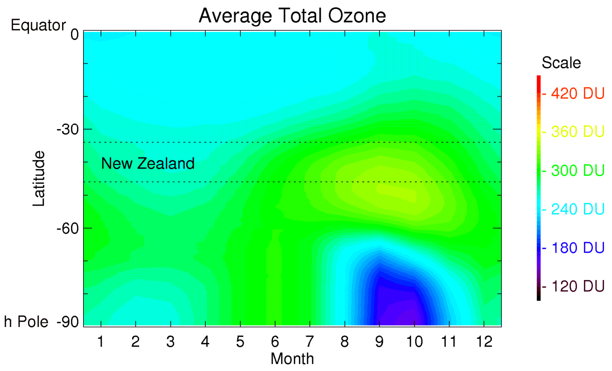

Figure 4. Average zonal total ozone in the southern Hemisphere. At the time of the ozone hole many places at mid-latitudes have their maximum seasonal ozone. It is later in the summer that minimum ozone values occur at these places.

Ozone and climate Change

Climate and atmospheric circulation are important influences on ozone, as illustrated by the mix of dynamical and chemical factors contributing to the ozone hole. However, ozone is an important driver of atmospheric circulation and climate as it is the principal source of heating in the stratosphere. There are significant interactions between the two. For example, the ozone hole is thought to have contributed to the strong contract between the observed temperature trend over the bulk of Antarctic which have been very nearly flat, and those slightly further north over the Antarctica peninsula, one of the fastest warming regions on the planet. There may still be surprises and influences we still don't understand

References

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