Unusual behaviour of the Antarctic ozone hole

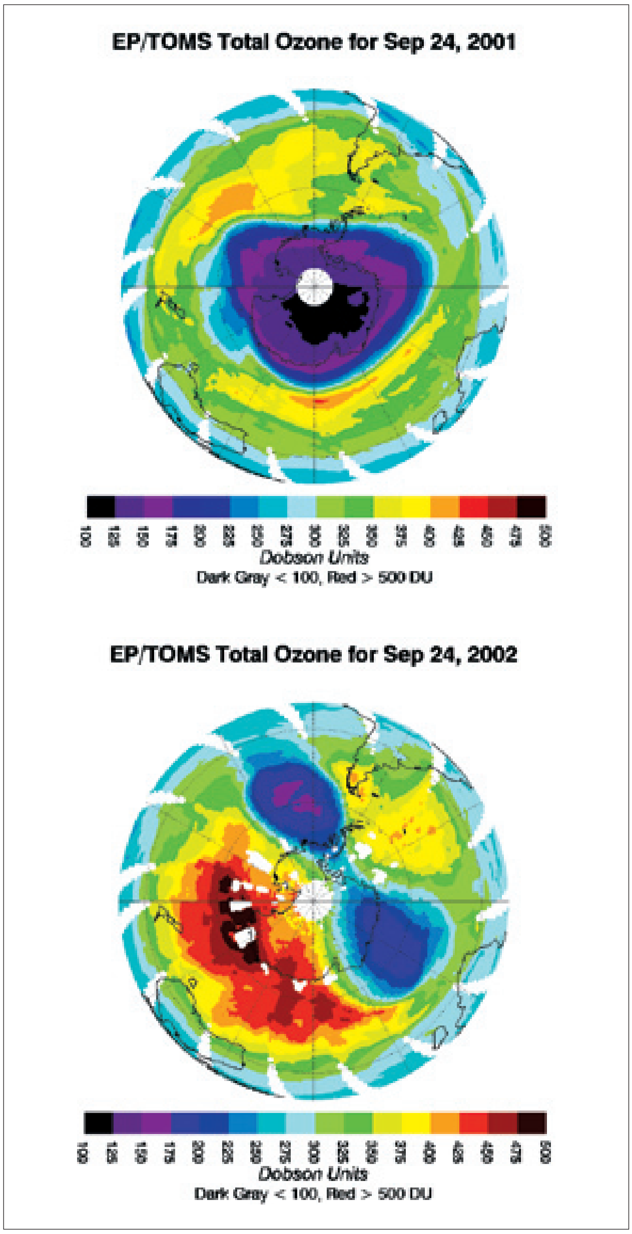
Since the mid-1980s, dramatic episodes of stratospheric ozone depletion have been observed each spring over Antarctica. Within these so-called 'ozone hole' events, total column ozone levels have been reduced by up to 70% compared with levels prior to the 1980s. The cause of the ozone hole has been conclusively linked with the release into the atmosphere of certain man-made gases, particularly chlorofluorocarbons (CFCs). Subsequently, we have also recognised a general decline in global ozone levels outside the tropics, as well as 'mini' ozone hole events in the Arctic. In 1987 the Montreal Protocol was enacted to phase out the world-wide production of CFCs and related ozone-depleting gases. However, due to the relatively long atmospheric lifetimes of the gases involved, and the time required for industry to adapt, the first significant signs of recovery in ozone levels are not expected until the end of the present decade. There have been recent indications that concentrations of certain ozone-depleting gases in the troposphere (ground to 10 km altitude) may have peaked. Despite cautious optimism, there is still significant concern as to the immediate and long-term trends in global ozone levels, and the implications for living systems and global climate.

The Antarctic ozone hole of 2001 was the second largest on record, only narrowly eclipsed by 2000. At the peak of the event, almost all ozone was destroyed in the altitude range 13-23 km over an area roughly three times the size of Australia. The hole in 2002 was a complete contrast, being the smallest observed since 1988, and two-thirds the size of the 2001 hole. However, this apparent improvement is not the result of mitigation produced by the Montreal Protocol, but rather a meteorological anomaly that caused the Antarctic stratosphere to be unusually warm during 2002.

Each year after the March equinox, a region known as the polar vortex forms in the stratosphere (10-50 km altitude) above Antarctica. Within the vortex, the polar air is effectively isolated from mixing with air from lower latitudes, and generally cools in the absence of sunlight during the polar night. Temperatures drop below minus 80°C within the vortex, and these conditions favour the formation of stratospheric clouds (at altitudes up to 25 km, near the peak of the ozone layer). The particles within these clouds promote a catalytic reaction that converts certain chemical species, including products derived from CFCs, into ozone-reactive forms. Some ozone loss takes place where the reactive chemicals are produced, but the largest losses occur when the reactions are enhanced by the return of sunlight during spring. The edge of the vortex becomes progressively more unstable during spring because of temperature and wind perturbations associated with planetary wave activity. Planetary waves are a natural form of atmospheric perturbation that are generated in the troposphere at mid and high latitudes and are able to propagate into the stratosphere during winter. Normally the vortex begins to break down in November allowing warm and ozone-rich air to enter from lower latitudes thereby repairing the ozone hole. By December, stratospheric ozone levels across Antarctica return to normal levels.

The temperature structure of the atmosphere is determined by a balance between heating and cooling. In the Antarctic winter stratosphere, cooling is due largely to the loss of energy to space by thermal radiation at infrared wavelengths, while the main heating sources are the absorption of incoming solar ultraviolet light by ozone, and adiabatic compression of the atmosphere due to downwelling. The latter process is governed by the Second Law of Thermodynamics; as a parcel of air descends and thereby moves to a region of increasing pressure, the resulting compression does work on the gas which raises its temperature. Downwelling in the polar stratosphere is restricted to the winter, and is driven by circumpolar planetary wave activity. In the winter polar night, this process is the dominant source of heating.

There is evidence from a variety of global and local observational data sets, including balloon, lidar, radar and optical measurements at Davis, that planetary wave activity at high southern latitudes during the spring of 2002 was unusual. This activity is likely to have contributed to elevated stratospheric temperatures over Antarctica



NASA GODDARD SPACEFLIGHT CENTER

Figure 1: Southern Hemisphere total ozone concentration for 24 September 2001 and 2002 measured by the TOMS instrument on NASA's Earth Probe satellite. Smaller Dobson Unit values represent lower ozone concentrations. In the lower image, the split in the ozone hole during 2002 is visible as the two regions of low ozone concentration (values below 220 Dobson Units) south of South America and Africa. The region of high ozone concentration towards Australia is also unusual, and was associated with warmer than normal stratospheric temperatures.

STOP PRESS: Large ozone hole predicted

A large ozone hole is expected to form over Antarctica this coming spring.

At the end of July, trends in the temperature and dynamics of the Antarctic stratosphere were starting to creating conditions favourable for a large ozone hole to form.

The trends were similar to those observed in 2000 when the ozone hole was of record size, and in complete contrast to 2002 when the hole was the much smaller.

At Davis, stratospheric clouds were detected in late May, which was about six weeks earlier than they were seen in 2001 and 2002. This is directly related to atmospheric temperatures, which this year have generally been a few degrees below average throughout the Antarctic stratosphere.

When the sun returns to Antarctica in the spring, the atmosphere becomes disturbed. The level of disturbance is variable from year to year, and this impacts on the final magnitude of the ozone hole. However, present indications are that the hole this year will be large.

and major disturbances to the polar vortex. Significantly, the vortex broke down during October, several weeks earlier than expected. An unprecedented event occurred on 23 September 2002 when a sudden warming in the vortex caused the ozone hole to split into two components. One part of the hole drifted towards South America and dissipated, while the other portion re-centred itself over the pole before dissipating a few weeks later (Figure 1).

Was 2002 an unusual year and what can we expect in the future? It is possible that 2002 provided us with an example of natural variability in the atmosphere that acts on decadal or longer timescales. Modelling of best-estimate greenhouse gas and ozone depletion scenarios suggest that planetary wave heating of the polar stratosphere should be decreasing. However, a recent analysis of more than 50 years of assimilated stratospheric data for the Arctic found no evidence to support this view. Interestingly, what is becoming clearer is the strong upward dynamical link, driven by planetary wave activity, that exists between the troposphere and stratosphere over the winter pole, and the importance of teleconnections (recurring and persistent large-scale patterns of pressure and circulation anomalies that span vast geographical areas, an example being the El Niño phenomenon) in the global climate system. The 'smoking gun' for 2002 may well be found in a geographical region outside Antarctica.

The Antarctic ozone hole appeared more benign during 2002, but the problem is far from solved.

Andrew Klekociuk, Space and Atmospheric Sciences Program, AAD

Antarctica Online

Australian Antarctic Division ozone fact file: <http://www.aad.gov.au/default.asp?casid=2850>

Other website references:

Scientific Assessment of Ozone Depletion: 2002, United Nations Environment Programme; <http://www.unep.org/ozone/index-en.shtml>

The Ozone Hole Tour, Cambridge University: <http://www.atm.ch.cam.ac.uk/tour/index.html>

Ozone data at NASA/Goddard: <http://toms.gsfc.nasa.gov/ozone/ozone.html>

Investigating ozone depletion above Davis

A new program of stratospheric ozone studies has been established at Davis by the AAD's Space and Atmospheric Science (SAS) group and the Bureau of Meteorology (BoM). This effort represents the first time Australia has made in-situ measurements of stratospheric ozone in Antarctica, and is part of the larger investigation of the composition, dynamics and climate of the middle atmosphere being undertaken at Davis by the SAS program.

The program makes use of balloon-borne ozonesondes launched by BoM staff at Davis to profile ozone concentration from the ground to altitudes of up to 35km. Ozonesondes are a well-established means of measuring ozone, and are regularly launched at about 40 stations world-wide, including 9 in Antarctica. At the heart of each ozonesonde is a chemical cell containing a dilute solution of potassium iodide. Air is passed through the cell by a pump, and a reaction takes place between ozone and the solution which produces an electrical current proportional to the ozone concentration. A standard meteorological radiosonde is incorporated in the balloon payload, and this provides additional data on pressure, temperature and humidity during the flight. The readings, together with signals from an on-board GPS receiver which provide location information for the determination of wind speed and direction, are telemetered to a ground receiving station.

The operational aspects of the Davis program are being coordinated by the Bureau's Ozone Monitoring Unit (OMU). Through the OMU, the Bureau


MARTIN CROWE

Davis Bureau of Meteorology personnel (L-R) Cathie Saunders, Geoff Fulton and David Morgan watch the first ozonesonde ascend.