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An exceptional situation in the Antarctic stratosphere in 2002

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Abstract.

1. Introduction

In late September 2002, the Southern Hemisphere stratosphere underwent an exceptional situation: its first recorded major stratospheric warming, splitting the vortex[1] and tearing the normally stable Antarctic ozone hole into two parts. As a consequence the ozone hole disappeared 2 months earlier than usual, and did not have time to develop as the precedent years. The occurrence of this "unprecedented event", in which the stratosphere suddenly warmed, contrasted with the trend observed during the last 20 years toward a strong, cold and long lasting Antarctic vortex, giving rise to large ozone depletion. The question is to know why a major warming occurred in the Southern Hemisphere? Was its occurrence related to ozone or climate trends, or was it simply a highly unusual meteorological event? What are the implications for future ozone trends? It will be shown that this dramatic split and subsequent breakdown of the polar vortex can be explained by an exceptional meteorological situation, which pre-existed the breaking. But it does not imply that the ozone hole will not be present again next year and for still quite a number of years. This paper, beside commenting this exceptional event, will try to answer some of the questions that astronomers going to work at Dome C in the future may ask about the expected recovery of the stratospheric ozone layer and the influence that the stratosphere has on the climate.

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[1] Vortex: In both hemispheres, the circumpolar wind (or jet) in the stratosphere creates the polar vortex which isolates the cold air within limits where the ozone destruction takes place.

2. What are the conditions leading to ozone destruction and to the creation of the Antarctic "ozone hole"?

The first cause of ozone depletion, as we have seen it in the last 25 years, is the accumulation of halogen gases, namely chlorine monoxide (ClO) and bromide monoxide (BrO), in the stratosphere. Their transport by air motion made those species to spread throughout the whole atmosphere, even over Antarctica, far from the industrial countries where they originated. Happily immediately after the discovery of the " ozone hole" in Antarctica in 1980,

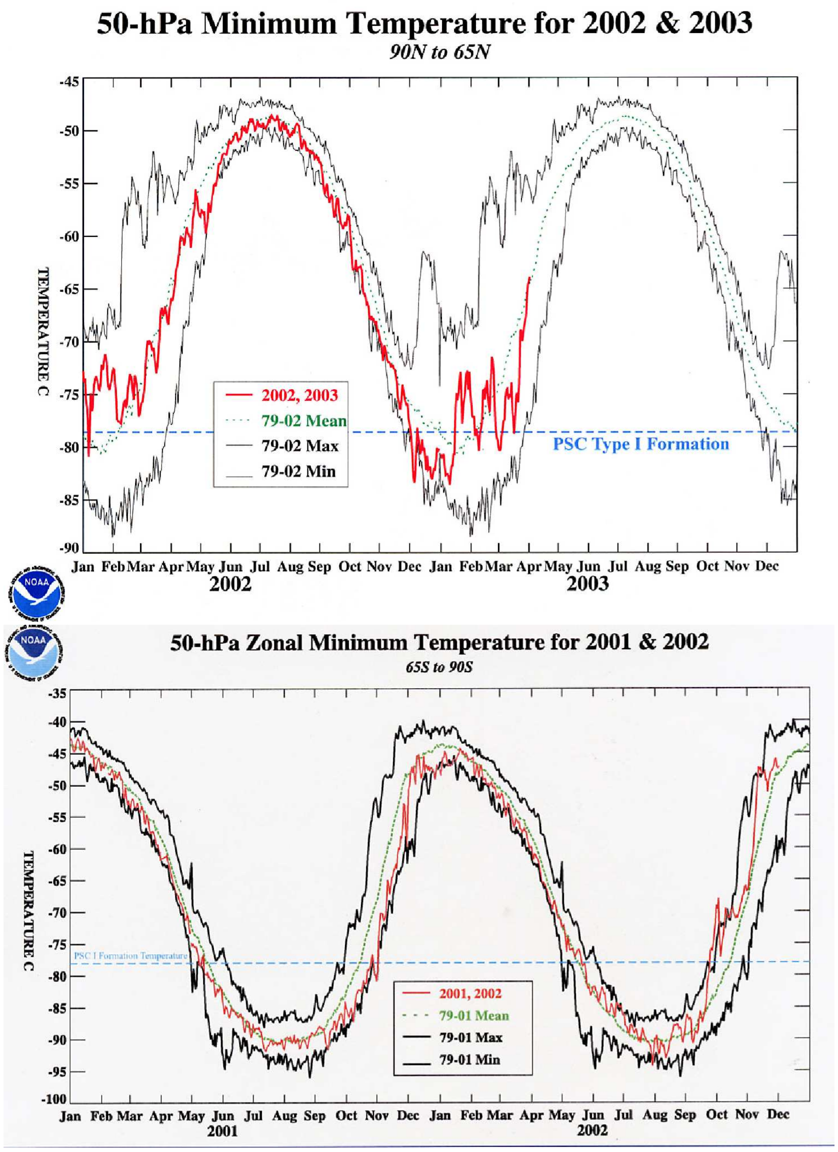

Fig. 1. Daily minimum temperatures at 50 hPa (approximately 19 km) in the latitude bands from 65°N to 90°N (a) and from 65°S to 90°S (b) for recent years shown in red, compared to the average minimum values (dashed green) and the extreme minimum values for any year (lower solid black) and highest minimum values for any year (upper solid black). The dashed blue line denotes the temperature (-78°C) below which PSC form. (Ref: Selected indicators of stratospheric climate, NOAA Reports, December 2002 and April 2003)

the human made emissions responsible for this problem (among them the CFC's) have been controlled and for most of them banished by the Montreal Protocol and its successive amendments. As a consequence, the concentrations of those species are starting to decrease in the stratosphere. However the complete ozone recovery is only expected in about 50 years. In supplement for the halogen gases to cause a severe ozone loss, two conditions are required: first a very cold temperature (below -78 °C) to allow heterogeneous chemistry on ice clouds called "polar stratospheric clouds" (PSCs) to operate, and second the presence of UV radiation to trigger the chemical destruction. These 2 conditions are only fulfilled over the poles at the beginning of spring.

3. What explains the difference between the ozone depletion in the Arctic and the Antarctic?

Stratospheric air temperatures in both Polar Regions reach their minimum values in winter. Over the Arctic, the minimum average temperature is around -80°C in January/February, values which are very close to the temperature of formation of PSCs and such values do not occur each year and then significant ozone loss does not occur. Antarctic temperatures reach lower values (-90°C) which are also more stable during 2 or 3 months from mid-June to mid-September (figure 1a and 1b). This occurs, in part because of the differences between the 2 hemispheres in the distribution of land, oceans and mountains at mid and high latitudes. These South Hemisphere temperatures being low enough to form PSC's, ozone depletion is very efficient over Antarctica. These low temperatures are confined in a sort of cylindrical container which edges are defined by the strong winds (called jet) which isolates the cold stratospheric air, creating what is called the polar vortex. The Antarctic vortex is quite stable and symmetric around the pole, whereas the arctic vortex is very irregular and is often broken by planetary waves early in the winter. After such an event, called a "stratospheric warming", the warm air can penetrate into the container and conditions to destroy ozone are no more present.

4. What has been recently the situation with the Antarctic ozone hole?

The observations from balloonborne ozone sondes have shown that in the last 5 years in the Antarctic spring, i.e. from mid-September to December, the ozone has been totally destroyed in the altitude range from 14 to 22 km. This leads to a destruction of about 2/3 of the total ozone integrated column. The extent of this ozone depletion covers on the average a surface as large as 20 Millions km^2 over the Antarctic continent. This recurrent phenomenon called the "ozone hole" has been observed since 1980 and is clearly seen from satellite image of Antarctica as shown in Figure 2 a. As a comparison, the highly variable situation in the Arctic is shown in figure 2b. It shows however that mini ozone holes are present in the arctic on some years, as in 1990, 93, 94 and 97.

5. What was different in 2002?

Figure 3 shows time evolution of the total ozone field during September 2002 over Antarctica. The ozone hole became very elongated after September 20 and split into two parts, with the smaller part equatorward of the north-west side of the Antarctic Peninsula disappearing by the end of September. This behaviour has never been observed since continuous observations have been performed. This early breaking of the vortex could have been predicted several months before from the behaviour of the temperature, which went out of its usual range, shown on figure 1b. Furthermore the study of the zonal wind field at 60°S in the 3 precedent months, and the comparison with other years showed an unusual large activity of planetary waves which explain the early breaking of the vortex. This behaviour was very similar to what happens usually in the Arctic and is due to meteorological conditions usual in the Northern Hemisphere, but unusual in the South Hemisphere.

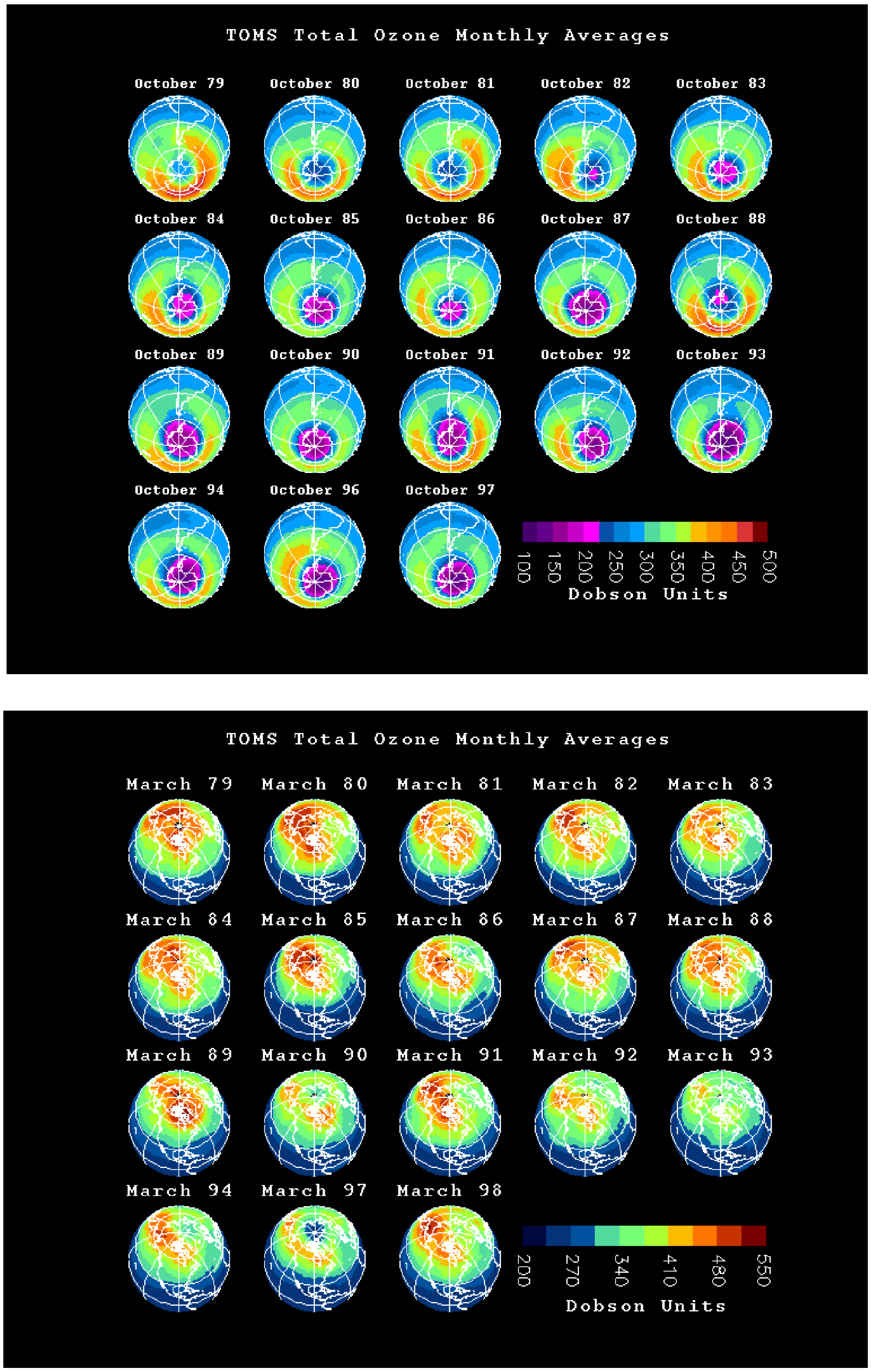

Fig. 2. TOMS Total ozone monthly averages for successive years since 1979 over Antarctica (a,top) and Arctic (b, bottom).(Ref: Selected indicators of stratospheric climate, NOAA Reports, December 2002 and April 2003)

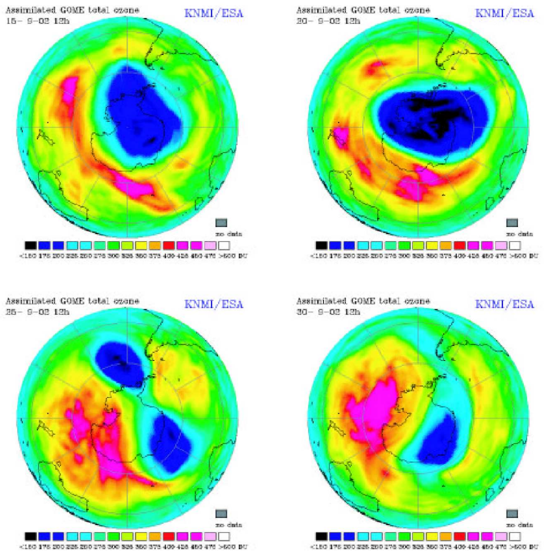

Fig. 3. Time evolution of the total ozone field assimilated at KNMI: September 15, 20, 25 and 30 in 2002 Baldwin M.P. et al. (2003).

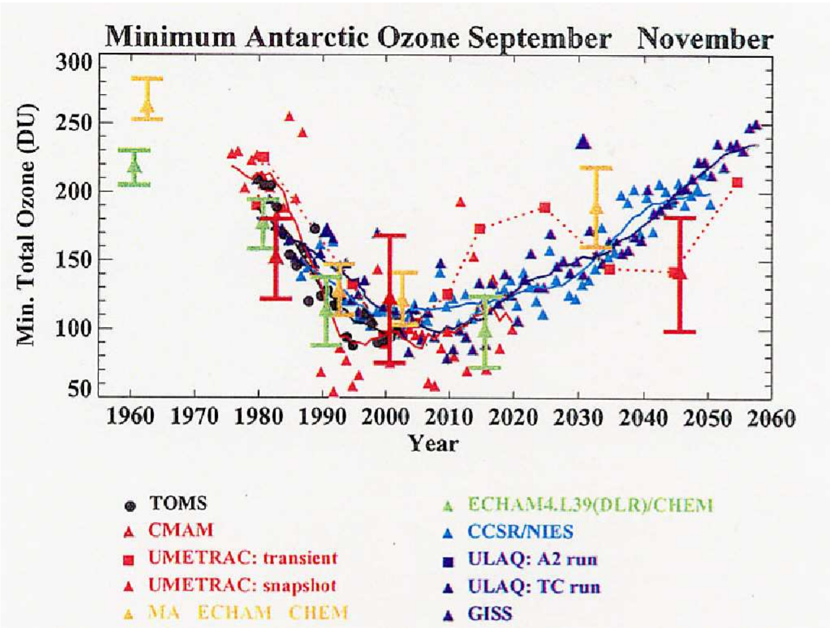

Fig. 4. Minimum Antarctic (Sep./Nov.) total ozone for different models. TOMS data (black dots) are used for comparison. (Ref: WMO-UNEP Scientific Assessment of Ozone depletion: 2002.)

6. Is that a sign of ozone recovery?

The exceptional situation of last Antarctic winter can be perfectly well understood by this unusual meteorological situation and is not at all related to the sudden disappearance of the causes of ozone destruction over Antarctica. Therefore it should not be interpreted as an early sign of ozone recovery. As a matter of fact a return to the situation existing before 1980 where the ozone hole was first detected is expected only to occur around 2050. The prediction as made by different models for the future 50 years is shown on figure 4 and the comparison between the models and the depletion as observed by the satellite TOMS for the period 1979-2002 show a very good agreement. The expectation concerning the surface covered by the ozone hole is given in figure 5. This is of interest to situate the average position of the ozone hole compared to the position of Dome C.

7. Several reasons why the knowledge of the behaviour of the stratosphere can be useful for astronomers working at Dome C:

The transparency of the atmosphere in the ozone absorption bands.

The knowledge of the total amount of ozone above Dome C, which is documented daily by satellite, for example by TOMS (Total Ozone Mapping Satellite), can be used to calculate the transparency of the sky. The spectral domains affected by ozone absorption are situated in the UV (280 315 nm), the visible (400 nm) and in part of the IR (around 9-10 microns). At the maximum of the "ozone hole", the total ozone content is decreased to 1/3 of what it was prior to 1980.

The Southern Oscillation and the weather pattern

It has been shown recently that large circulation anomalies taking place in the upper stratosphere, and may be originating at higher altitudes, propagate downward to the lowermost stratosphere and influence tropospheric weather pattern. This has been well documented for the Arctic, where this stratospheric pattern is called the Arctic Oscillation (A.O.) (Baldwin M.P. et al. (2001)). Sign of the existence of an equivalent pattern in Antarctica, the SH annular mode, and its influence of surface temperature has been also shown by (Thompson D.W.J. et al. (2002)). The fluctuations of the strength of the circumpolar vortex could therefore be used to make an extended prediction of the weather, as the one done in the Northern Hemisphere by ECMWF (European Centre for Medium range Weather Forecast).

The position of the polar vortex and of the jet

In the lower stratosphere, the jet (or strong winds) around Antarctica is responsible for the creation of the vortex in which ozone depletion is taking place in the early spring. As sharp wind gradients are sources of turbulence, the quality of the seeing is strongly dependent upon the relative position of Dome C and the edge of the vortex. This one can be visualised by the position of the ozone hole, which is always within the limit of the vortex. Therefore during 2-3 months, the observation of the ozone hole as seen daily by the satellites TOMS could give an idea of the position of the jet compared to the position of Dome C. (see the website: http://jwocky.gsfc.nasa.gov/ozone/today.html)

Archive of the jet position to help building wind climatology above Dome C

In the recent years the use of data assimilation together with a numerical model is a successful way to integrate the different types of measurements (ground, radiosondes, satellites) in order to obtain the atmospheric parameters on a global scale. Even though the network of radio-soundings over the Antarctic is not very dense, they are being used together with the model and satellite data, to provide a global distribution of the winds. Those assimilated winds can be used to establish a climatology over the site of Concordia, while it will take years to be

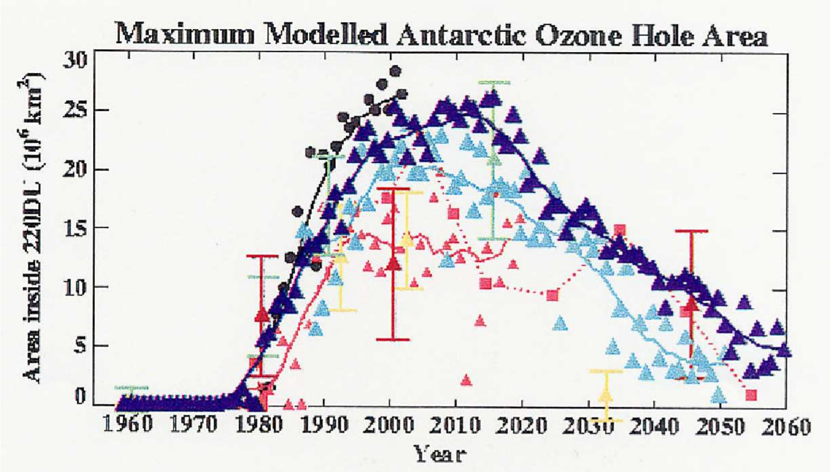

Fig. 5. Maximum area of the Antarctic ozone hole as given by the 220 Dobson Units, from TOMS data (black dots) and models. (Ref: WMO-UNEP Scientific Assessment of Ozone depletion: 2002.)

obtained a statistically significant all year climatology from local radio-soundings.

8. Conclusion

This exceptional split and subsequent breakdown of the polar vortex can be explained by a rare meteorological situation, which pre-existed the breaking, and does not imply that the ozone hole is disappearing. On the other hand, such a situation, corresponding to a weak vortex, may influence the meteorological pattern at the surface for the following months. The archive of wind data either indicated by the position of the polar vortex and the subsequent position of the ozone hole within it or by the ECMWF assimilated data could help documenting the conditions of seeing at Dome C.

References

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