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# The ozone hole and a phase change in lower stratospheric temperature

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## Abstract

Depletion of ozone over Antarctica was first observed in the late 1970s, and discovery of the Antarctic ozone hole was announced in the 1980s as having started in 1979. The ozone hole was defined as the area with total column ozone less than 220 Dobson units. Analysis of ozone, temperature, chlorofluorocarbon and nitrous oxide data from 1963 onwards suggests that the annual ozone minimum at the South Pole is related to lower stratospheric temperature independently of chlorofluorocarbons and nitrous oxide. There were ozone holes, ie. column ozone less than 220 Dobson Units, at the South Pole in several years before 1979 (the date that the ozone hole is reported to have first appeared) when chlorofluorocarbon concentrations were much lower than today and lower than in 1979. An early 1980s phase change in the lower stratospheric temperature at the South Pole at altitudes between 250 hPa and 100 hPa, and at some lower altitudes, coincides with a phase change in the annual South Pole ozone minimum. The phase change is not visible in chlorofluorocarbon or nitrous oxide data. This raises the possibility that, over a multi-annual or decadal timescale, lower stratospheric temperature has more effect than chlorofluorocarbons or nitrous oxide on atmospheric ozone concentration over the South Pole. Alternatively, temperature and ozone may both be reacting to some other influence.

**Keywords:** Ozone Hole; Phase Change; Temperature; Chlorofluorocarbon; CFC; Nitrous Oxide; $N_2O$; Lower Stratosphere; Lower Stratospheric Temperature; LST

## 1. Introduction

Depletion of ozone (O3) over Antarctica was first observed in the late 1970s, and discovery of the Antarctic ozone hole was announced in the 1980s as having started in 1979 [1]. The ozone hole was defined as the area with total column ozone of less than 220 Dobson units (DU). As NASA said: "The value of 220 Dobson Units is chosen since total ozone values of less than 220 Dobson Units were not found in the historic observations over Antarctica prior to 1979." [2]. In other words, the ozone hole was defined so that it started in 1979. If a different number had been used then the ozone hole could have started at a different date. The ozone hole was attributed to human emissions of chlorofluorocarbons (CFCs). Chapagain 2016 also identifies Nitrous Oxide ($N_2O$) as an important ozone-depleting agent [3].

This study analyses ozone, temperature, CFC and $N_2O$ data over a period that extends both before and after the reported start of the ozone hole. Since satellite data is only available from 1979 onwards, non-satellite data is used. The data used is as follows:

- Radiosonde daily temperature data is used for the South Pole at a range of altitudes and times of day (data is available from 1961 for temperature) [4].
- the USA's National Oceanic and Atmospheric Administration (NOAA) Amundsen-Scott (South Pole) station daily ozone data (from 1963) [5].

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- NOAA Southern Hemisphere annual CFC and $N_2O$ data (from 1765, although all CFC data is zero until 1936) [6].

## 2. Analysis

South Pole station data shows that there actually were ozone holes before 1979. They may have been less pronounced than in more recent years, but they occurred in 1964, 1966, 1969, 1974 and 1977.

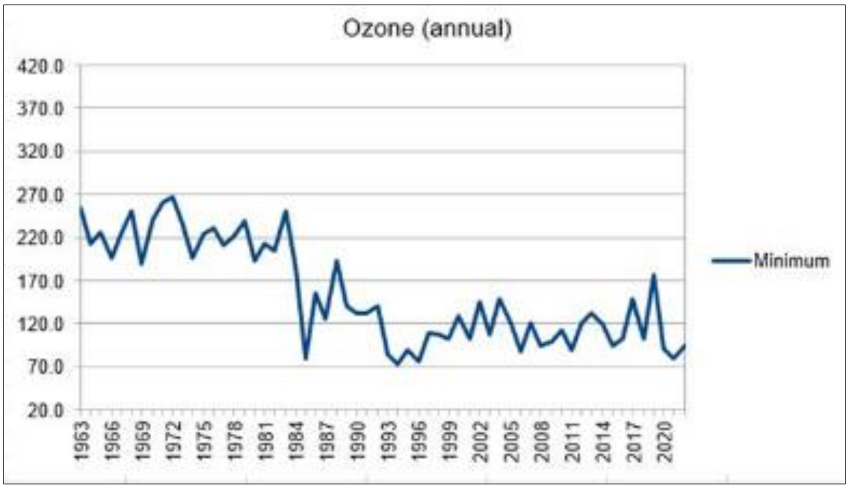


**Figure 1** Annual ozone minimum at the South Pole. Since the annual ozone minimum tends to be around October or November each year, for annual minimum purposes the year is treated as being from Apr 1 to the following year's Mar 31.

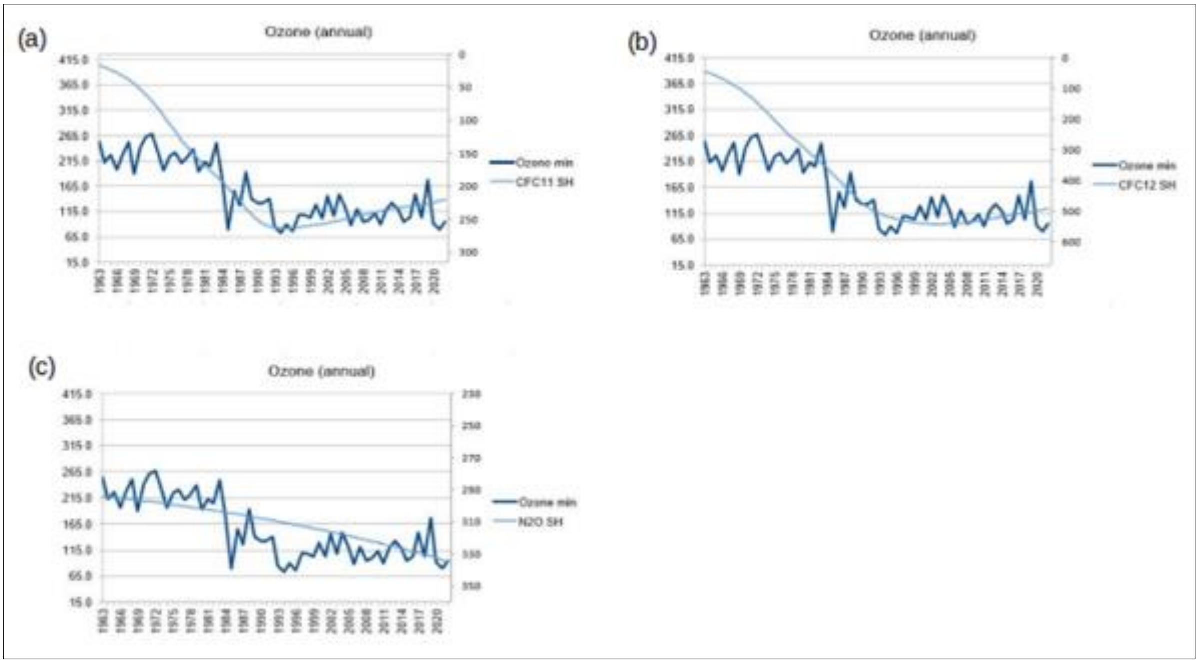


**Figure 2** Annual ozone minimum at the South Pole, with (a) CFC-11 Southern Hemisphere (SH), (b) CFC-12 SH, (c) $N_2O$ SH. CFCs and $N_2O$ are on a reverse scale (R.H. axis) for easier comparison.

Ozone minima below 220 DU before 1979 are clearly visible in Figure 1. Note that a minimum of 220 DU or larger does not mean that there was no Antarctic ozone hole that year, it only means that if there was an ozone hole then it did not cover the South Pole on a date when South Pole ozone was measured. Conversely, a minimum smaller than 220 DU at the South Pole in any year does mean that there was an Antarctic ozone hole that year. Some of the early data is quite sparse, so there may have been other years with an ozone hole not shown in Figure 1. In other words, some actual ozone minima could be lower than in Figure 1 but, if the given measurements are correct, none can be higher. Every annual minimum charted in Figure 1 that actually occurs in Jan-Mar of the following year is above 220 DU and could reflect missing Oct-Nov data rather than an actual annual minimum. While ozone minimum and CFC-11 and CFC-12 data have a reasonable correlation from 1980 to 2020, there is clearly no correlation before 1980. There is no correlation with $N_2O$. Maybe CFCs do not have an effect until they reach a certain level, but no reference to that has been found in the literature. Ozone minimum has also deviated briefly from measured CFCs after 2020.

The annual ozone minimum at the South Pole (Figure 1) suggests that there may be a phase change starting around 1980:

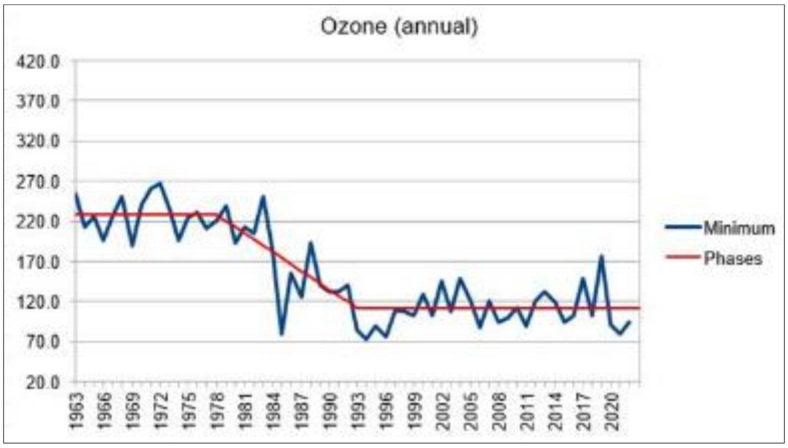


**Figure 3** Annual ozone minimum at the South Pole, with a possible phase change starting around 1980. The phase lines are a least-squares fit of three contiguous line segments meeting at variable dates with the first and third line segments having constant ozone.

Lazzara et al 2012 detected an early 1980s phase change in South Pole surface temperature [7]. A phase change is also visible in South Pole radiosonde temperature data:

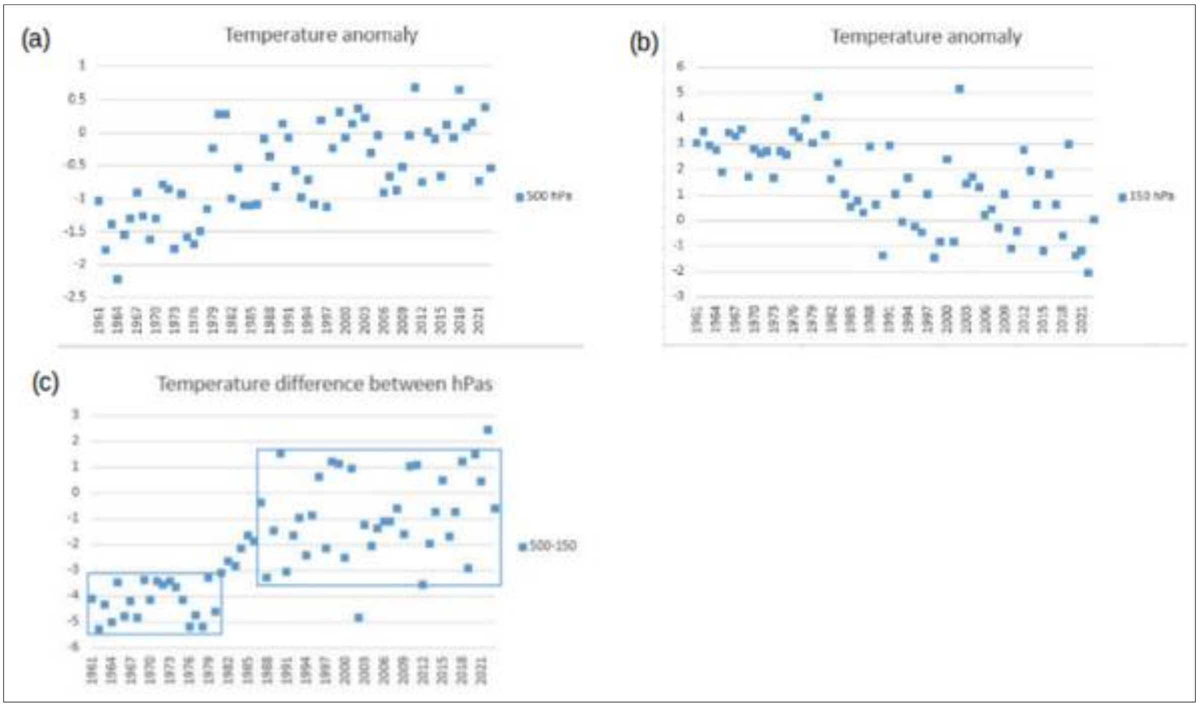


**Figure 4** Nighttime (hour = 0) temperature anomalies at the South Pole, (a) at 500 hPa (altitude approx 5,000m), (b) at 150hPa (approx 13,000m), (c) difference between the two with rectangles added as a visual aid. Nighttime temperatures are used because there are far more readings than for daytime. It is understood that nighttime readings are more reliable.

In Figure 4, temperature anomalies are used in order to minimise errors from missing data. The anomalies are based on the 25-year period 1997-2021 because that period has the most temperature data. This anomaly data is consistent with Qing-Bin Lu's finding that "all the datasets show that significant O3 or LST [Lower Stratospheric Temperature] reductions only occurred in the 1980s and 1990s with no significant trends over the past ~25 years. This is similar to the observation by Polvani et al. and that reported in the newest IPCC AR6. The latter states "most datasets show that lower stratospheric temperatures have stabilized since the mid-1990s with no significant change over the last 20 years" "[8].

Note that the annual ozone minimum has also stabilised since the mid-1990s (see Figure 3). The temperature pattern for 400 hPa is similar to 500 hPa, and 250, 200 and 100 hPa are similar to 150 hPa. At the lower altitudes the temperature starts to increase around 1979, whereas at higher altitudes it starts to decrease. The difference between the two, given in Figure 4(c) shows the phase change quite clearly. Lazzara et al 2012 observed an obvious increase in surface temperature variability after the early 1980s, and increased variability (but no trend) is also seen then in the temperature data at higher altitudes.

## 3. Discussion

All analysis here needs to be viewed cautiously, as the data and especially the earlier data is incomplete and there is no guarantee that all of the given data is accurate. However, a study in 2017 found that radiosonde temperature data from 250 to 100 hPa appeared to be reliable within about 0.2C (Ingleby 2017 Fig.3.5) [9]. While there is a limit to how much information can be derived from data at a single place, in this case the South Pole, nevertheless the patterns observed in temperature, CFCs, $N_2O$ and ozone do suggest that ozone at the South Pole relates to the early 1980s phase change in temperature, and they do show that the annual ozone minimum does not correlate with CFCs before 1979. They also show no correlation with $N_2O$. This raises the possibility that temperature has more effect than CFCs or $N_2O$ on atmospheric ozone concentration over the South Pole, or possibly of course that something else is driving both. The relevant temperature is likely to be that of the lower stratosphere, ie, between 250 and 100 hPa, where the early 1980s phase change to a lower temperature coincides with a phase change to lower ozone concentrations.

Angell 1986 records an "impressive" multi-annual and seasonal relationship between low-stratospheric temperature and total ozone in Antarctica [10]. But in the context of this study it is not that simple, and here's why:


**Figure 5** Lower stratosphere (250 to 100 hPa) temperature and ozone concentration 10 days before and after ozone minimum, averaged over all years with ozone minumum on or after September 1st.

Figure 5 shows an impressive short term correlation between temperature and ozone. But would temperature really affect ozone that fast? Figure 5 shows that although changes in temperature and ozone are generally simultaneous, around 8 to 4 days before ozone minimum an ozone change precedes the temperature change by a couple of days. This suggests that on such a very short timescale it is ozone that drives temperature, or possibly of course that something else is driving both. But on longer timescales, as in the phase change described above, it appears that temperature has a major influence on ozone (or something else is driving both). In any case, the phase change in both temperature and ozone bears no relation to CFC concentration. Note also that if some of the annual ozone minima before 1979 are actually lower than shown in Figure 1 because of missing data, this would reduce correlation with CFCs even further.

Several studies have reported that ozone concentration influences lower stratospheric temperature or vice versa, for example Dameris 2010, McCormack and Hood 1994, Gillett et al 2011 [11] [12] [13]. The above analysis confirms that there is clearly a relationship between lower stratospheric temperature and the ozone minimum, although it is not linear on an annual timescale, ie, there is little annual correlation between the ozone minimum in Figure 3 and the lower stratospheric temperature in Figure 4. The early 1980s phase shift which occurs in both may be an important clue to the relationship. There could, of course, be another phase change in future.

It may take a long time for this to be resolved, ie, before a trend can be identified in ozone levels that clearly correlates with one of temperature and CFCs more than with the other. This is in line with the (unfortunately unattributed) statement "The full extent of the damage that CFCs have caused to the ozone layer is not known and will not be known for decades" [14].

## 4. Conclusion

Ozone, temperature, CFC and $N_2O$ data from 1963 onwards suggest that ozone at the South Pole has a relationship to the early 1980s phase change in temperature, and they do show that the annual ozone minimum does not correlate with $N_2O$, or with CFCs before 1979. The data suggests that the annual ozone minimum at the South Pole is related to lower stratospheric temperature independently of chlorofluorocarbons and nitrous oxide. There were ozone holes, ie. column ozone less than 220 Dobson Units, at the South Pole in several years before 1979 (the date that the ozone hole is reported to have first appeared) when chlorofluorocarbon concentrations were much lower than today and lower than in 1979. An early 1980s phase change in the lower stratospheric temperature at the South Pole at altitudes between 250 hPa and 100 hPa, and at some lower altitudes, coincides with a phase change in the annual South Pole ozone minimum. The phase change is not visible in CFC or $N_2O$ data. This raises the possibility that, over a multi-annual or decadal timescale, lower stratospheric temperature has more effect than CFCs or $N_2O$ on atmospheric ozone concentration over the South Pole. Alternatively, temperature and ozone may both be reacting to some other influence.

## Compliance with ethical standards

### *Acknowledgments*

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