Has the Antarctic Vortex Split before 2002?

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ABSTRACT

In late September 2002, the Antarctic ozone hole was seen to split into two parts, resulting in large increases in ozone at some stations and the potential for significant modification of chlorofluorocarbon (CFC)-induced ozone loss. The phenomenon was dynamical (a split vortex), causing large increases in stratospheric temperature above stations normally within the vortex. Temperatures at Halley, Antarctica, at 30 hPa increased by over 60 K, and temperatures at South Pole at 100 hPa increased by over 25 K. It is important to know if this has happened before, since if it happens in the future, it would significantly alter the total hemispheric ozone loss due to chlorine from CFCs, particularly if it happens in August or September. Temperatures in winter and spring measured at Halley or the South Pole since 1957 and 1961, respectively, show no other comparable increases until the final warming in late spring, except for two dates in the 1980s at Halley when meteorological analyses show no vortex split. There are very few periods of measurements missing at both Halley and the South Pole, and analyses in those few periods show no vortex split. Measurements in August and September at sites normally near the edge of the vortex show very few suspicious dates, and analyses of those few suspicious dates again show no vortex split. It is concluded that the vortex has probably not split before the final warming since Antarctic records began in the late 1950s, and almost certainly not in August or September.

1. The split ozone hole in September 2002

Maps of total ozone (Fig. 1) show that, in late September 2002, the Antarctic ozone hole (Farman et al. 1985) split into two parts, one of which later became reestablished over central Antarctica. The sequence of such maps and of dynamical indicators (e.g., Hoppel et al. 2003) shows that the phenomenon was dynamical—it was the vortex that had split; it was not some quirk of chemistry within a single vortex. At stations under the ozone hole, there was a large increase in ozone and a coincident large increase in stratospheric temperature. At Halley, ozone exceeded 300 Dobson units (DU; 1 DU = 2.69×10^{16} molecules cm^{-2}) (Fig. 2) for the first time before the final warming since the early 1980s, and temperatures at 30 hPa rose by over 60 K, an occurrence that was unprecedented since records began.

In this paper, we wish to answer the question of whether the Antarctic vortex has split since Antarctic temperature records began in the late 1950s. Although it is probable that an ozone layer existed since at least 0.5 Gyr before the present (Wayne 2000, his Fig. 9.3), so that a southern polar vortex may have existed since then, so far there is no proxy for a consolidated vortex in the geological or ice core records, and so we cannot identify a vortex split before modern temperature records began. It is important to know if the vortex has split before, and if so, how often, because if it splits in the future, it has the potential to alter ozone loss due to chlorine from chlorofluorocarbons (CFCs). This alteration could be particularly significant if a split occurs in August or September, as in 2002.

The altitude range of greatly reduced ozone within the ozone hole is normally between 100 and 50 hPa (e.g., Gardiner and Farman 1988). Temperature in this altitude range can be an excellent indicator of whether or not the air mass is within the vortex (e.g., Jones et al. 1998). Figures 1 and 2 illustrate this for today's Antarctic vortex in spring, where the vortex is synonymous with ozone-poor air. This is in contrast to many situations in the Arctic during spring, where continuous and rapid dynamical evolution often creates a significant horizontal displacement between temperature contours and vortex-following contours.

Hence in this paper, we use temperature as an approximate indicator of vortex air in the past. Most temperatures are derived from the database of Antarctic station temperatures assembled at the British Antarctic Survey as part of the Reference Antarctic Data for Environmental Research (READER) project (Turner 2003) of the Scientific Committee for Ant-

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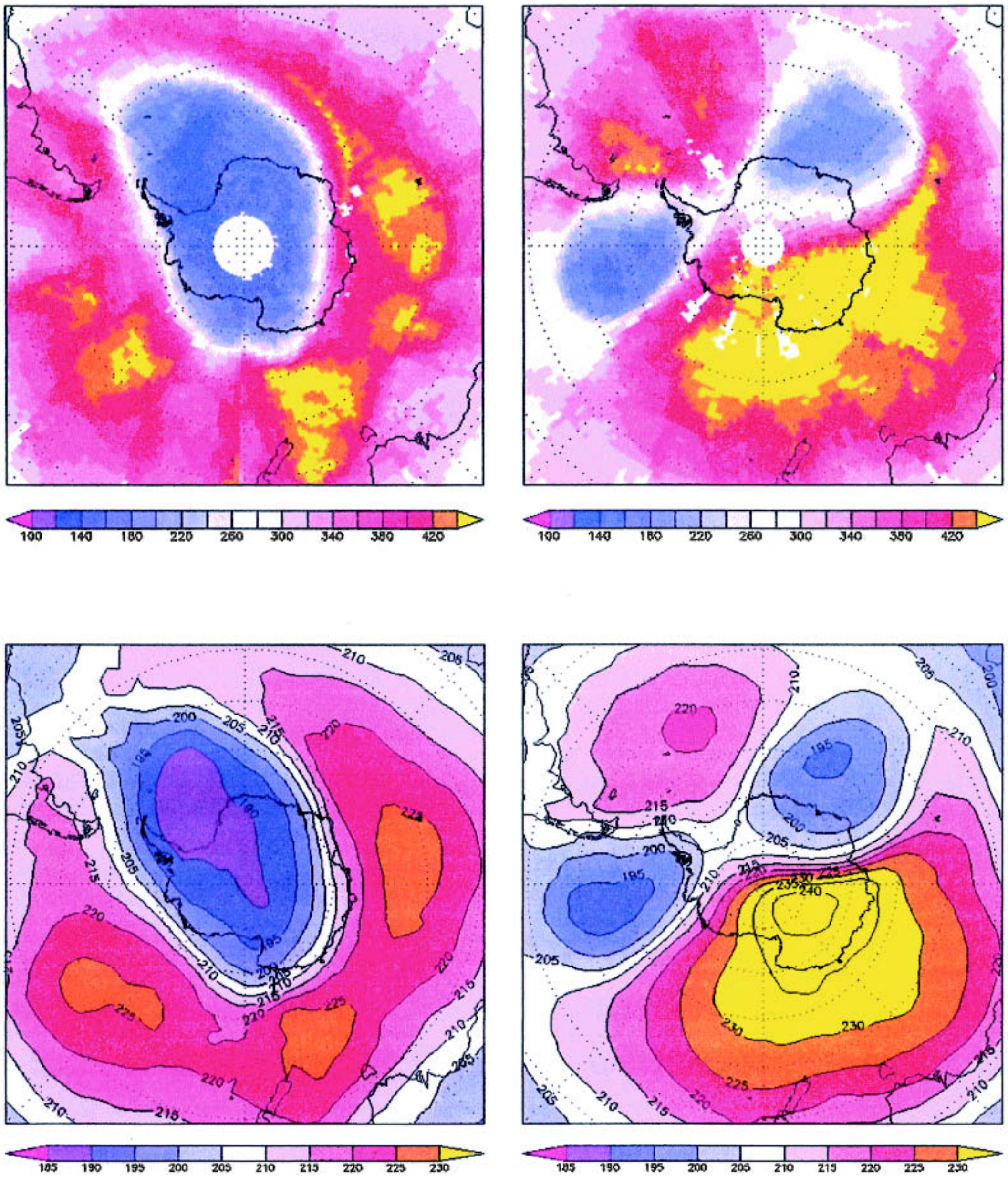

FIG. 1. Maps of (top) total ozone (DU) measured by the Total Ozone Mapping Spectrometer and (bottom) temperature (K) at 70 hPa from ECMWF operational analyses on (left) 19 and (right) 25 Sep 2002. Note how well temperature and ozone contours follow one another. White areas at the centers and elsewhere on the TOMS maps indicate missing data.

arctic Research (SCAR). We survey temperature records at 100 and 50 hPa from Antarctic stations since the late 1950s, to look for evidence of any sudden increases that might indicate a split in the vortex. We choose these levels rather than one at the midpoint of modern ozone loss at 70 hPa because 70 hPa is not a standard level for radiosonde reporting for parts of the record.

Maps of ozone, temperature, and other dynamical indicators have been widely studied since the ozone hole became routine in the 1990s, and it is clear that a vortex split has not occurred since 1990. We investigate earlier periods of suspect or absent Antarctic station temperatures by examining meteorological analyses of temperature from the 15-yr European Centre for Medium-Range Weather Forecasts (ECMWF) Re-Analysis (ERA-15; Gibson et al. 1996). We choose analyses at the central level of 70 hPa because it is a standard gridded product of ECMWF data from the British Atmospheric Data Center (BADC).

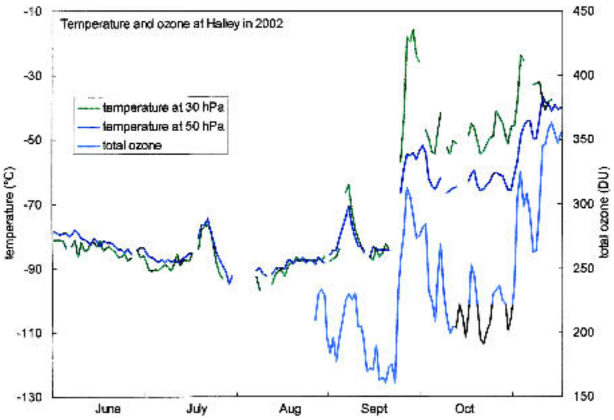

FIG. 2. Total ozone measured by the Dobson spectrophotometer and temperatures at 30 and 50 hPa measured by radiosondes at Halley (76°S) in winter and spring 2002. Such large amounts of ozone at Halley in Sep (over 300 DU) are unknown since the ozone hole began to appear in the early 1980s and in recent years would be characteristic of air normally between 45° and 50°S. Such high temperatures at 30 hPa in Sep are unprecedented since records began at Halley in 1957.

2. The stratospheric temperature records at the South Pole and Halley

There have been regular measurements of temperature from radiosondes on small balloons from Halley (75.6°S) and the South Pole (Amundsen–Scott station) since 1957 and 1961, respectively. In principle, soundings were recorded daily at times, and twice daily at times, from the South Pole. Figures 3 and 4 show some records in winter and spring from each site. We have chosen 100 hPa at the South Pole because the measurement record is more complete and there was a large signature at 100 hPa in 2002. We have chosen 50 hPa at Halley because, in late September 2002, the temperature at 100 hPa only rose a few degrees, probably due to the slight skewness of the split vortex with altitude (Hoppel et al. 2003). Except for 2002 and until the final warming in late spring, the figures demonstrate that the

(a) temperatures at 100 hPa at the South Pole show no sudden increase greater than 5 K, compared to an increase of over 20 K in September 2002; and
(b) temperatures at 50 hPa at Halley show no sudden increase greater than 5 K, compared to an increase of over 15 K in September 2002, except in two periods in the 1980s.

Examination of the detailed Halley record shows that these other dates of temperature increase were 18 October 1986 and 25 September 1985. Figure 5 shows meteorological analyses at 70 hPa on these dates; it is very clear that there is no split in the vortex. Examination of the detailed Halley record also shows that, at Halley at

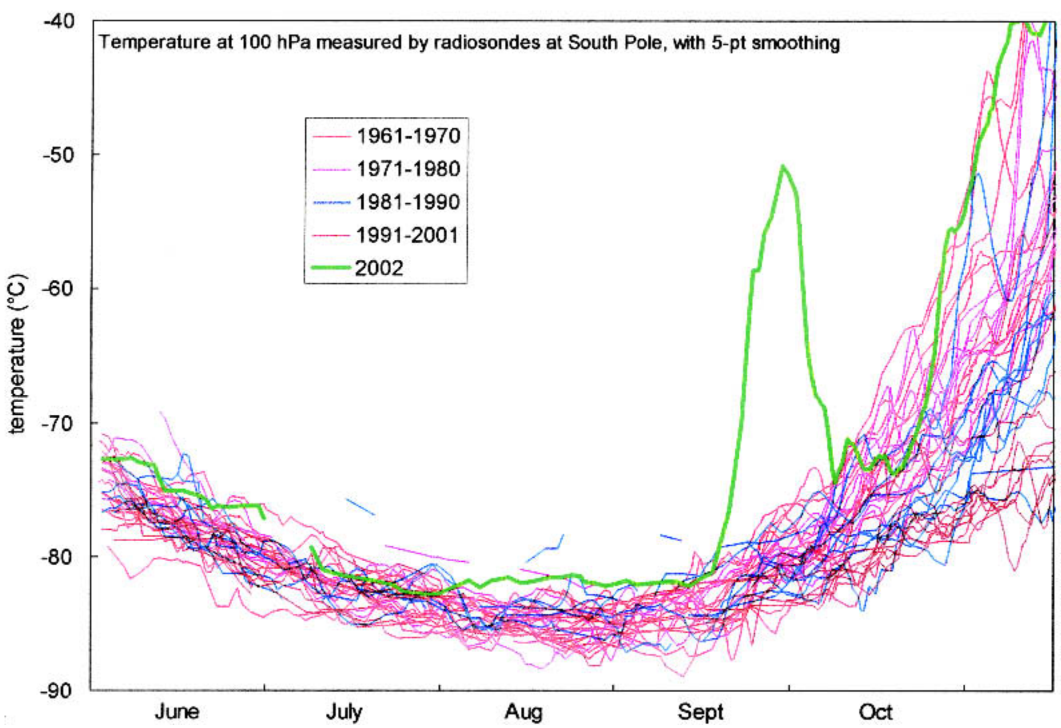

FIG. 3. Temperatures in winter and spring measured by radiosondes from the South Pole (Amundsen–Scott station) at 100 hPa since 1961. The thicker line is 2002, showing an increase of over 20 K around 25 Sep. Other lines are previous individual years, color coded by decade; note the significant cooling in late spring in recent decades due to the ozone hole. Consecutive measurements have been smoothed by a five-point running mean to help guide the eye, except where gaps exceeded 5 days.

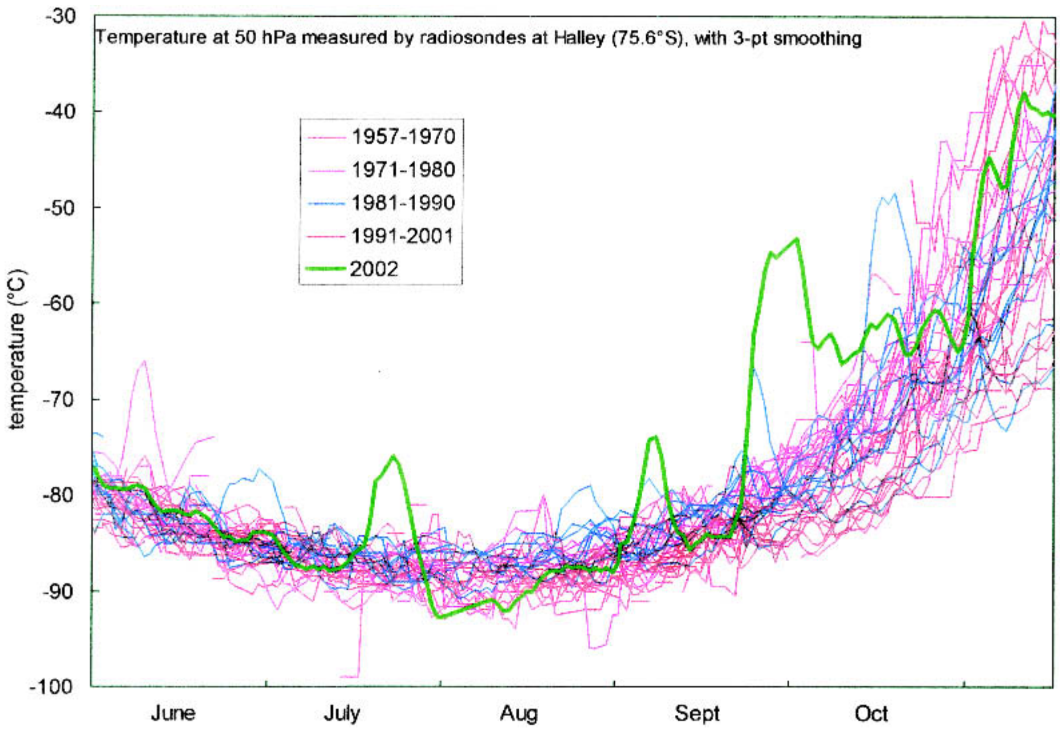

FIG. 4. Temperatures in winter and spring measured by radiosondes from Halley at 50 hPa since 1957. The thicker line is 2002, showing an increase of over 15 K around 25 Sep. Other lines are previous individual years color coded by decade. Consecutive measurements have been smoothed by a three-point running mean to help guide the eye, except where gaps exceeded 3 days. Note the two sudden increases in temperature in the 1980s, smaller than 2002 but of similar style. Also note the earlier warm periods in 2002.

100, 50, and 30 hPa, temperatures in September 2002 were the highest in September since records began.

Figure 4 also demonstrates the unusual nature of the temperatures in 2002 before the vortex split in late September—there are also significant warm periods in late July and early September 2002. These are the periods of significant wave activity implicated in the later vortex split, as discussed by Newman and Nash (2005).

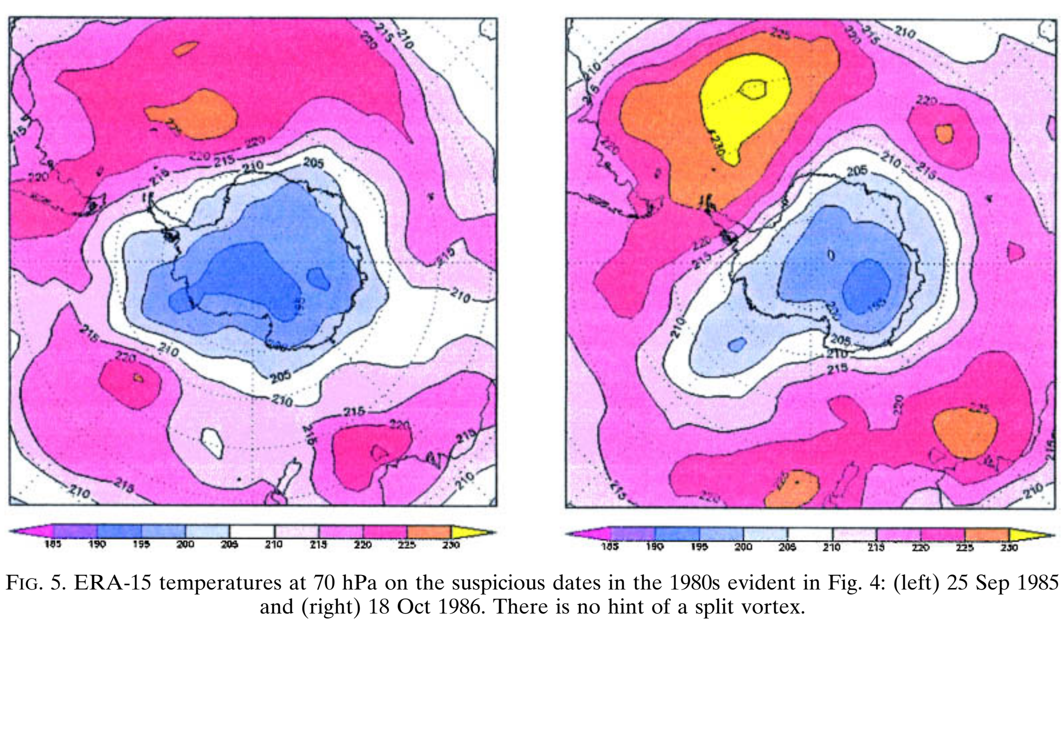

FIG. 5. ERA-15 temperatures at 70 hPa on the suspicious dates in the 1980s evident in Fig. 4: (left) 25 Sep 1985 and (right) 18 Oct 1986. There is no hint of a split vortex.

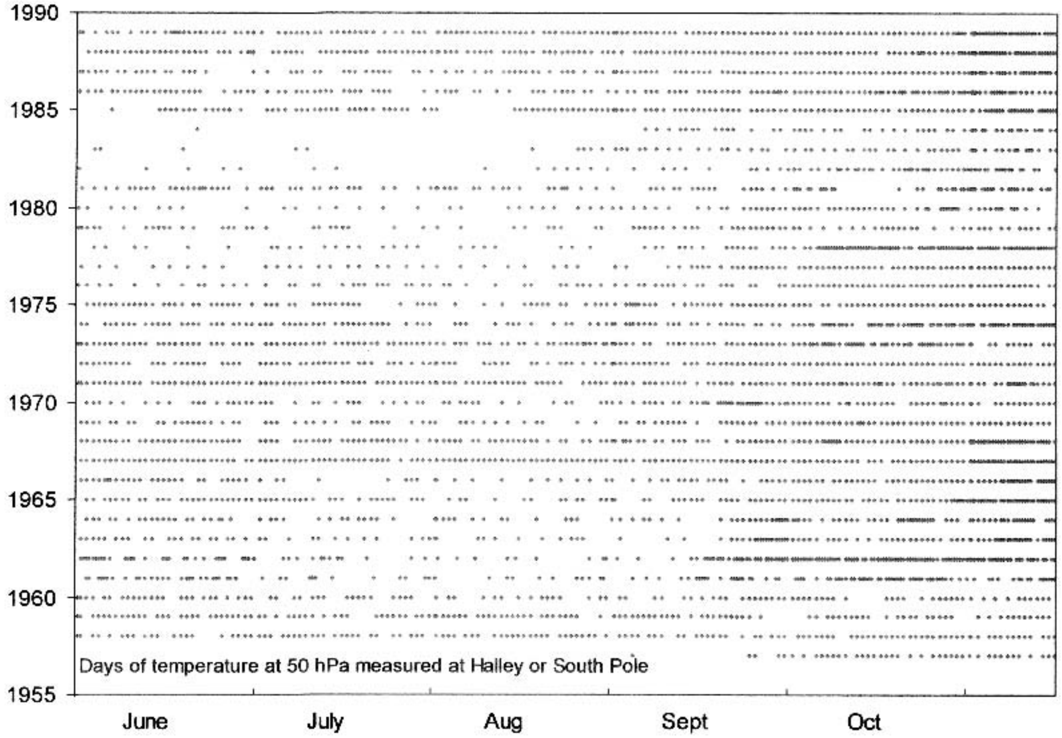

FIG. 6. Dates before 1990 when temperatures were measured in winter and spring at 50 hPa from either the South Pole or Halley. There are several periods of missing data of more than a 7-day duration in Aug in 1982–85 and in early Sep 1984. Other periods of missing data are of less than a 7-day duration.

Examination of dates when temperatures were measured at 100 hPa at either site shows that there are some periods of missing flights, although they are rarely coincident at the two sites. There are also frequent occasions of balloons bursting between 100 and 50 hPa. In case a previous vortex split was skewed enough to allow little temperature increase at 100 hPa at both sites, we examine periods when there are no measurements at either site at 50 hPa. Figure 6 shows the results up to 1990; confining ourselves to periods after the end of July, when a significant alteration to the vortex would have serious implications for ozone loss in the modern atmosphere; the periods of missing data longer than 7 days are 1–8 and 10–17 August 1982, 1–16 August 1983, 1 August–5 September 1984, and 1–13 August 1985.

We have examined meteorological analyses at 70 hPa at intervals of 6–7 days during these periods (Fig. 7 shows 1985 as an example), and it is very clear that

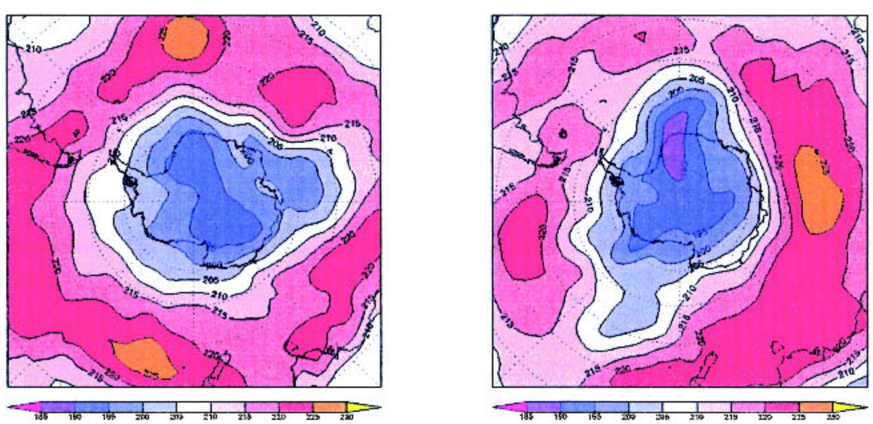

FIG. 7. ERA-15 temperatures at 70 hPa during the longer periods of missing data in Fig. 6 in 1985. Dates are (left) 4 and (right) 10 Aug. There is no hint of a split vortex on either date.

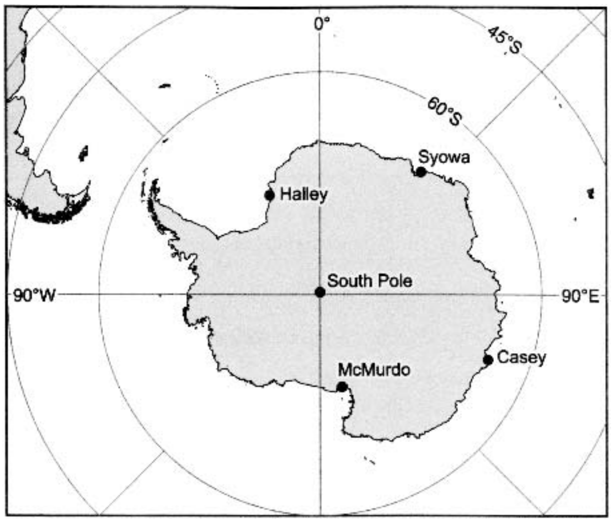

FIG. 8. Map showing Antarctic radiosonde launch sites discussed in this work.

there was no split in the vortex. It is fortunate that there were no periods of missing data before 1979, as it is doubtful that reanalyses from before the satellite era are useful (e.g., Simmons et al. 2005), particularly in periods when there was no data input from these two critical sites.

3. The stratospheric temperature records near the normal vortex edge

It could be argued that Halley and the South Pole are not a sufficiently comprehensive set of sites to be certain that a vortex split had not occurred. Furthermore, the condition of a measurement at either site, for points to be displayed in Fig. 6, means that on some dates, a split could have left a remnant that covered one of the sites when the other had no measurements. Accordingly, we also examined the temperatures at sites with long records and which are normally near or at the edge of the vortex (McMurdo, Casey, and Syowa). Figure 8 shows that they are well distributed around the edge of Antarctica, so that the possibility of a vortex split eluding notice at any of the sites is very remote.

Because of the larger variability of the temperatures at these sites, we choose simpler diagnostics, namely, the maximum temperature in the month and the standard deviation of the temperature in the month. Both diagnostics give similar results, so we focus on the maximum monthly temperature. Figure 9 shows the results in August and September; October had too much variability to be useful except perhaps at McMurdo.

Figure 9 shows that the only suspicious dates before the 1990s are in the years 1987 and 1988. Examination of the daily records shows that these maximum tem-

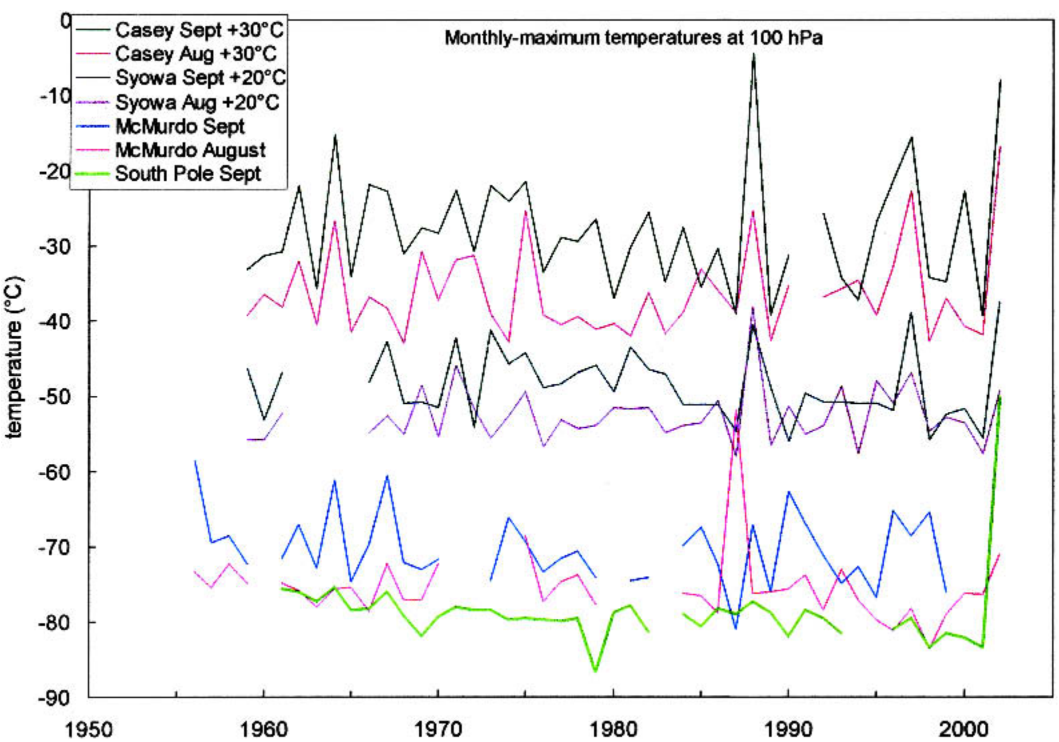

FIG. 9. Monthly maximum temperatures at 100 hPa in Aug and Sep measured by radiosondes at McMurdo, Syowa, and Casey. The lower thick line shows the South Pole in Sep for reference. Values for Syowa and Casey have been displaced upward by 20° and 30°C, respectively, for clarity. Before the 1990s, only 1988 (Syowa and Casey) and Aug 1987 (McMurdo) have suspicious maxima.

peratures occurred on 1 August 1987 (McMurdo), 31 August 1988 (Casey and Syowa), 26 September 1988 (Casey), and 30 September 1988 (Syowa). Meteorogical analyses from these dates are shown in Fig. 10, and again it is clear that there was no vortex split. The analyses also show why the temperatures on those dates in 1988 were unusual—the vortex was displaced well away from Syowa and Casey. Again, it is fortunate that none of these suspicious dates occurs before 1979, so that reanalyses from before the satellite era are unnecessary.

Figure 9 also shows that there are some years with no data in the month at some stations, but fortunately there are no years where this occurs simultaneously at more than one station. A more serious potential omission with this analysis is the possibility of missing data of less than a month but more than a week and thereby possibly long enough to miss a vortex split if it reformed more quickly than in 2002. With this in mind, we examine the record in August and September at each site, to see when there were whole weeks with no data. Results are as follows:

(a) Syowa: 3 weeks in 1960 (plus the complete absence of data from 1962 to 1965 evident in Fig. 9).
(b) Casey: 1 week in 1976.
(c) McMurdo: 3 weeks in 1956 and 1963, 1 or 2 weeks most years from 1966 to 1970, and many missing

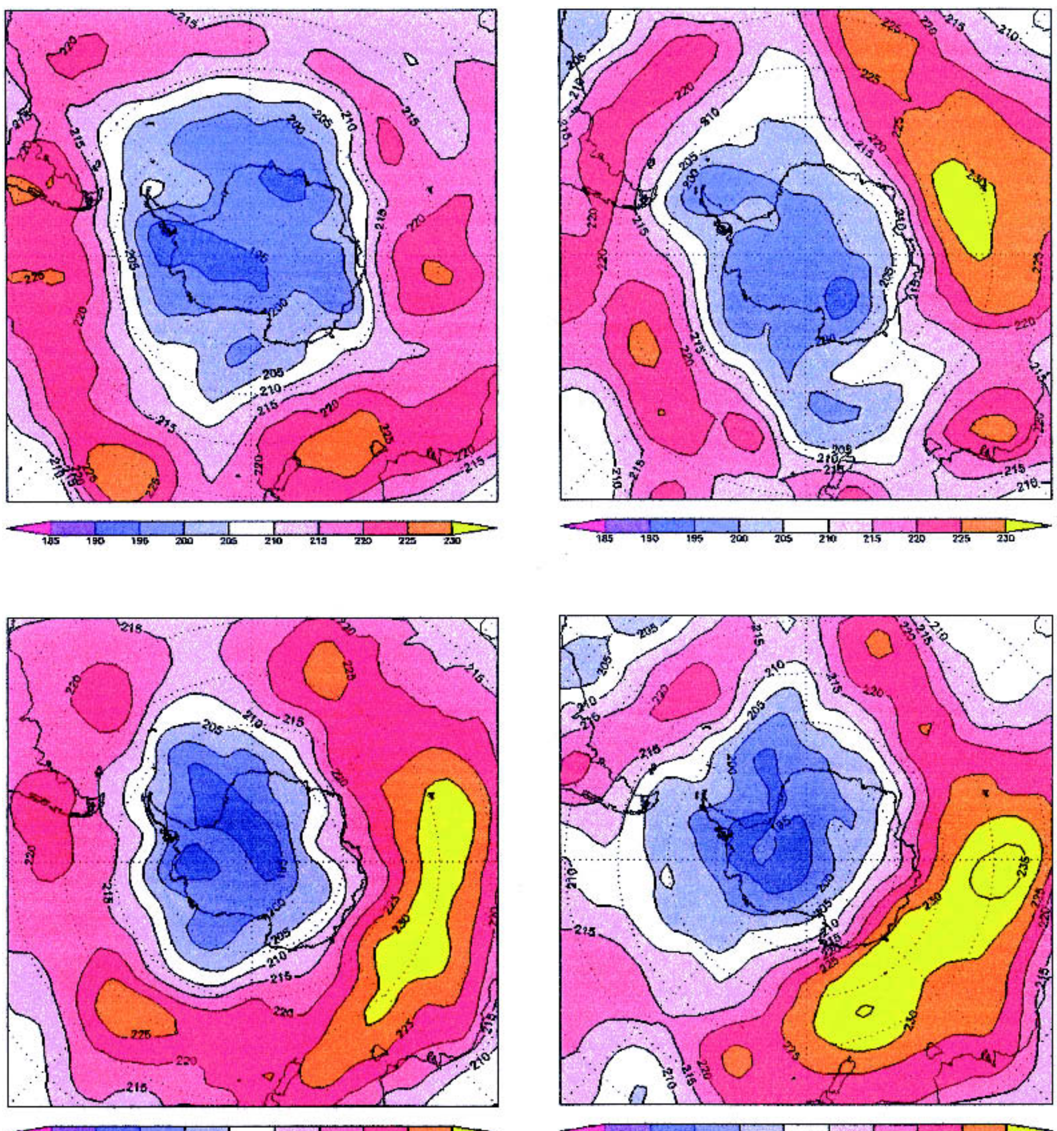

FIG. 10. ECMWF reanalyses at 70 hPa on the suspicious dates evident in Fig. 9. Dates are (top left) 1 Aug 1987, (top right) 31 Aug 1988, (bottom right) 26 Sep 1988, and (bottom left) 30 Sep 1988. There is no hint of a split vortex, although it is displaced well away from Syowa and Casey in 1988.

weeks after 1970 (plus the complete absence of data in 1960 evident in Fig. 9).

Hence, since 1957, there has been good coverage at one of the sites and at two of the three sites except in 1960 and 1963.

4. Conclusions

There is an inescapable conclusion from all of the above: excepting 2002, the vortex has almost certainly not split before the final warming since Antarctic records began in 1957, particularly in August or September when such a split has the potential to dramatically alter ozone loss in today's atmosphere.

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