NOTES AND CORRESPONDENCE

Evidence against an Antarctic Stratospheric Vortex Split during the Periods of Pre-IGY Temperature Measurements

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ABSTRACT

Historic upper-air observations from Antarctica are inspected to investigate the uniqueness of the vortex split in the Antarctic spring of 2002. No comprehensive meteorological observations are available prior to the International Geophysical Year (IGY) 1957/58, but stratospheric temperature observations from single stations provide evidence of varying strengths against the possibility of a split vortex in 1940 and in the early and middle 1950s.

1. Introduction

The major warming in the Antarctic spring of 2002, which is comparable to those observed in Arctic winters (Krüger et al. 2005), was an unexpected and unprecedented event. Since the announcement of the Antarctic ozone hole in 1985, maps of the vortex had been examined routinely and no split had occurred before the final warming in late spring. Roscoe et al. (2005) inspected Antarctic radiosonde temperatures in the lower stratosphere from 1957 to 2001 and found no vortex split. Simmons et al. (2005) examined 40-yr European Centre for Medium-Range Weather Forecasts (ECMWF) Re-Analysis (ERA-40) data for 1958–2001 and found no vortex split.

Comprehensive meteorological measurements in the Antarctic stratosphere began with the establishment of many stations on the Antarctic continent in the course of the International Geophysical Year (IGY) 1957/58. Several of these sites were frequently under the vortex core, and their measurements were used in the study by Roscoe et al. (2005).

In this paper, we examine the Antarctic stratospheric temperature measurements that covered complete winter and spring seasons between 1940 and 1956. Many of these measurements were made during expeditions, so that the datasets are of limited duration. Nevertheless, they were made with care—balloons were launched regularly with few missing flights—and the balloons usually reached the middle stratosphere even when the temperatures in the lower stratosphere were at their lowest.

We also use low temperatures to indicate vortex air in winter and spring, as adopted by Roscoe et al. (2005). The more reliable diagnostic of potential vorticity would have to be calculated from meteorological analyses, which are unreliable in the Southern Hemisphere in the presatellite era. Unlike in the Northern Hemisphere, the generally more symmetric southern vortex means that high temperatures are a useful guide to air from outside the vortex. This would only be untrue in the case of a severe vortex disturbance, so the observation of universally low temperatures would tend to exclude the possibility of a split vortex.

2. Pre-IGY observations

A detailed description of Antarctic and sub-Antarctic measurements prior to the IGY has been published by Godson (1963), which stimulated our work. Figure 1 shows the locations of the continental stations discussed by Godson, together with three other more recent stations. Godson (1963) obtained original
flight data directly from the agencies involved in the observations, but much of this is no longer available. Hence, the temperature values shown below have been digitized by hand from the Godson (1963) plots, which are universally 10-day running means.

The first temperature soundings inside the Antarctic Circle to reach heights of 17 km, and the first in winter, were made from Little America (78°28′S, 164°55′W) between April 1940 and January 1941, during the U.S. Antarctic Expedition 1939–1941 (Court 1942; Rubin 1953). In the 300-day period, 190 balloons were launched, and the observed temperatures were much lower than expected by scientists of the day. Figure 2 shows the 100-hPa temperatures, which have an undisturbed course in winter followed by what we now consider the usual rapid increase in late spring (the final warming). Figure 2 also shows the striking contrast of measurements at McMurdo (77°51′S, 166°40′E) in 2002 during the vortex split. The sites are within about 1° of latitude and 28° of longitude of each other, and both are often within the vortex in winter and spring.

Measurements from a single station may not be sufficient to confirm a vortex split, but a major split such as that of 2002 was observed at all three regular vortex core sites (Halley, South Pole, and McMurdo)—it was such a comprehensive feature that any one site observed it. More problematic is the negative result—if a site is not always within the vortex core, a warming associated with the vortex moving away and back could be interpreted as a split. The universally low temperatures at Little America in Fig. 2 show that no such vortex move occurred in 1940. Because the McMurdo measurements were similarly smoothed, Fig. 2 also vividly demonstrates that the smoothing of our pre-IGY data should not prevent us from seeing a similarly long-lived vortex split.

The next winters presented by Godson (1963) were 1948 and 1949, but these were from sub-Antarctic stations between 48° and 55°S, which are routinely outside the stratospheric vortex and hence are not helpful to our enquiry. In 1950 and 1951, measurements were made once again from a site south of the Antarctic Circle: 650 balloons were launched from Maudheim (71°03′S, 10°54′W) between April 1950 and January 1952. This was the base of the Norwegian–British–Swedish Antarctic Expedition of 1949–1952 (Schumacher 1955). Balloons were launched daily whenever weather permitted and many reached 50 hPa and a few 25 hPa, and record-low temperatures (below −90°C) in August 1950 and August 1951 were reported (Schmitt 1952). Figure 3 shows that there is no sign of a major temperature disturbance at Maudheim in winter or spring of either year, until the final warming that began around mid-October, although in 1951, some minor wave activity was apparent. Maudheim was very close to the modern station of Neumayer (70°40′S, 8°15′W). In 2002, the remnant of the split vortex stayed above
Neumayer for several days before its axis rotated sufficiently to see the large warming (Manney et al. 2005) at the end of September. Neumayer and Maudheim are normally more within the vortex core than McMurdo, hence their lower temperatures. So the warmings at Maudheim in mid-October of 1950 and 1951 do not preclude a similar vortex split in the first week of October, but the measurements are good evidence against an earlier vortex split in both years.

Temperatures in the winter of 1951 were also measured at Port Martin (66°40'S, 140°01'E; now called Dumont d’Urville), showing a strong warming in late September (Fig. 3), but Dumont d’Urville is frequently outside the vortex edge (Godin et al. 2001) so that such a warming could merely be a vortex move. Godson (1963) concluded from the additional observations of two midlatitudinal stations in the Australian sector that this was the beginning of the final warming. In 2002, Dumont d’Urville was often outside the vortex throughout the spring. It shows, however, a large warming much earlier than Port Martin in 1951, so the lack of distributed sites mostly in the vortex means we cannot claim more than good evidence.

After another 2 yr of no continental data, the U.K. station, the Argentine Islands (65°15'S, 64°16'W; later called Faraday), began operation in 1954 (Dewar 1958); the station Mawson (67°36'S, 62°52'E) started in 1955; and Mirnij (66°33'S, 93°01'E), McMurdo, and Little America started in 1956. The first three sites are not routinely in the vortex core, so they may have warmings that are merely the vortex edge moving above them. However, Argentine Islands in 1954 did not show any such disturbance (Fig. 4). In 1955, some more temperature variations were apparent at the Argentine Islands and at Mawson at the opposite side of Antarctica. The almost antiphase nature of the warmings at the two sites is evidence of an eccentric vortex (planetary wave disturbance of wavenumber 1) whose axis is rotating about once per month (Godson 1963), rather than of any vortex split. Since 1983, including in 2002, there have been no radiosondes from the Argentine Islands. For comparison, we have plotted the 100-hPa temperature evolution at the nearest grid point (65°S, 65°W) from the ECMWF operational analyses together with the 2002 observations at Mawson and McMurdo in Fig. 5. The strong warming at the end of September 2002 is evident at the site of the Argentine Islands in contrast...
to the observations in 1954 and 1955. At Mawson, the large warming of 2002 began later because the remnant of the split vortex stayed above Mawson, as it did at Neumayer.

The winter of 1956 seems to have been the most disturbed of all, although it is always possible that this is an artifact of the increase in measurement sites in preparation for the IGY. The wave activity started earlier than in 1955 but had similar phase differences, suggesting again a typical planetary wavenumber-1 disturbance of the vortex. In September, the warming was first noticeable at Mawson and Mirnij, later at McMurdo, and at the end of the month at the Argentine Islands (Fig. 6). The same occurred again in October before the final warming started in late October/early November. A time–height section of winds and temperatures during late September at McMurdo presented by Godson (1963) indicates a typical minor warming event with no weakening of the polar night jet. Wind speeds at 50 hPa at McMurdo exceeded 60 m s\(^{-1}\) throughout the week in late September and increased with increasing height when temperatures went above \(-60^\circ\text{C}\) at 100 hPa and above \(-30^\circ\text{C}\) at 20 hPa. The much stronger temperature signals during the 2002 vortex split at McMurdo, Mawson, and the ECMWF grid point near the Argentine Islands can be seen in Fig. 5.

3. Discussion and conclusions

We are aware of the uncertainties arising from the use of lower-stratospheric temperatures from single stations. From our knowledge of the variety of different stratospheric warmings observed in the Northern Hemisphere (minor and major warmings of wavenumber-1 and -2 type; see, e.g., Krüger et al. 2005), we would not expect a clear relation between local temperatures at 100 hPa and a disturbed circumpolar circulation in the stratosphere. This is different in the Southern Hemisphere with a generally more symmetric vortex.

One may make a vigorous case for the absence of a vortex split if three stations approximately evenly distributed around Antarctica show no warming, and all are cold enough to be routinely sampling air from the vortex edge region or the vortex core. If only one sta-
tion is available, meteorological analyses must be con-
sulted to show that such episodes were not a vortex split
because minor warming periods may occur even at sites
usually in the vortex core.

In the pre-IGY era, analyses are available from 1948
onward from the National Centers for Environmental
Prediction–National Center for Atmospheric Research
(NCEP–NCAR) 50-yr reanalysis project. However, be-
cause of the lack of observations in the Southern Hemi-
sphere in the first decade, the reanalyses are mostly a
model forecast (Kistler et al. 2001). Accordingly, most
of the pre-IGY winters exhibit an undisturbed, strong
polar vortex tightly coupled to the cold center and sur-
rounded by a warm belt at latitudes 40°–50°S. The
warmest winter in the reanalyses of this period was in
1956, reflecting the improved observations discussed
above and agreeing with them as expected. Hence, ex-
cept for 1956, these reanalyses are not useful in estab-
lishing our case that there was no vortex split from
pre-IGY measurements.

However, the observation of universally low tem-
peratures at an Antarctic station throughout the winter
and spring shows that it was always within the vortex.
This suggests evidence for an undisturbed circulation
and the absence of a vortex split. Thus, the inspection
of stratospheric temperature observations prior to the
IGY supports the hypothesis that there was no vortex
split before the final warming, in any of the years 1940,
1950, 1951, and 1954. There were some minor warmings
in 1955, but observation of their phases shows them to
be consistent with a rotating eccentric vortex rather
than a vortex split. In 1956, the temperature measure-
ments showed more significant warmings, starting ear-
erlier and of larger amplitudes, as in 1955, but with similar
phase differences, suggesting again a typical wavenum-
ber-1 disturbance of the vortex. Wind measurements
showed no weakening of the polar night jet during
warmer periods, consistent with the theory that there
was no vortex split before the final warming.

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