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### SPRINGTIME ACCELERATED WARMING PHENOMENON IN THE ANTARCTIC STRATOSPHERE

By H. R. Phillpot

Mr. H. R. Phillpot of the International Antarctic Research Branch, Bureau of Meteorology, gave a review of the springtime warming phenomenon based on the IAAC Technical Report (No. 3) prepared by him, and supplemented by material prepared by Mr. L. A. Zhdanov.

In Technical Report No. 3, results for the spring period in each year from 1957 to 1963 were considered, whilst Mr. Zhdanov, who was the USSR representative to the IAAC from March 1964 to March 1965, made a detailed examination of events in the 1964 spring.

These studies have been particularly important to the IAAC because during the spring periods of both 1964 and 1965 (the International Quiet Sun Years) the Centre has been operating a STRATWARM service (in conjunction with the Central Analysis Office in 1965), i. e. issuing daily advices of Antarctic stratospheric warming periods for the benefit of all upper atmosphere research workers.

In general, the annual temperature cycle in the polar stratosphere is characterised by very low temperatures during the winter and relatively high values in summer. During the winter a stratospheric jet stream develops in the strongly baroclinic zone between the cold core over the Pole and the relatively warm mid-latitude zone, whilst in summer the stratospheric polar circulation is mostly weak.

The spring transitional period, when the polar vortex breaks down, is a most interesting one because of the complex nature of the transition.

The warming phenomenon can be more clearly detected at the highest levels, i. e. at 50 mb (20 km approx) and above, but unfortunately because of the very low stratospheric temperatures,  $-80^{\circ}$  to  $-90^{\circ}$  C, which prevail over the Antarctic during the winter and early spring, many radiosonde ascents do not reach 50 mb and maximum attention has therefore to be given to the 100 mb level (i. e. 15 km approx).

The late Dr. Harry Wexler was probably the first to regard the Antarctic warming as analogous to the "explosive" stratospheric warming first noted in the Northern Hemisphere by R. Scherhag in 1952, and in addition to Wexler, C. E. Palmer, K. J. Hanson, W. B. Moreland, J. Alt, R. C. Taylor, N. J. Ropar and T. I. Gray, and Miss E. Farkas have discussed it using mainly IGY and pre-IGY data, although W. L. Godson has used some post-IGY data in a more recent review.

The results obtained from the investigations may be summarised:

- (1) The available 100 and 50 mb temperatures at the Pole Station in the winter months of each year 1959-1962 show little variation and suggest that stratospheric warming is not observed over the South Pole in winter.
- (2) The 100 mb temperatures in each year 1957-1963 for 24 Antarctic stations show that in the period 1 September to 15 December:
  - (a) in 1959 (and to a lesser extent in 1961) no acceleration in the warming rate occurred;
  - (b) significant variations were observed in the warming rate from year to year;

- (c) warming at stations at the highest latitudes (Byrd, Vostok, Pole) was essentially more regular than at lower latitudes on the continent (e.g. as shown at Mirny, Wilkes), where short duration warming and cooling periods were superimposed on the general warming;
- (d) at Macquarie Is. (Lat.  $54^{\circ} 30'S$ ) marked variability was observed both during the season in any one year, and also from year to year.

The 1959 results were used to produce a series of curves which have been called "unaccelerated warming" curves, and are of considerable practical help in assessing the significance of reported temperatures at each station during the spring season.

At Macquarie Is. the smoothed seasonal temperature-change curve was based on the 10 years of available record.

- (3) Published 50 mb charts for 1957 and 1958, together with stream line/ isotherm charts drawn for selected days in each year 1959-1963, show the break-down of the polar vortex and that:
  - (a) the winter vortex is cold but the centre of the cold air does not usually coincide with the vortex centre;
  - (b) the cold air is most frequently displaced towards, or persists in, the South American quadrant, extending perhaps to about Long.  $40^{\circ}E$ ;
  - (c) accelerated warming over Antarctica appears to result from the invasion by warm air, principally from the Australian sector, although possibly also from the Indian Ocean (i.e.  $0^{\circ}-90^{\circ}E$ ) sector;
  - (d) at the 100 mb level the accelerated warming at a given station appears to be determined by the way in which warm air is advected across the continent;
  - (e) when, as in 1959, no general acceleration is observed in the warming rate, the main vortex is centred closer to the geographic pole, there is no marked shift of cold air into the South American sector and warming around the continent in Lat.  $50^{\circ}-60^{\circ}S$  is more symmetrical.
- (4) An examination of 100 mb winds and temperatures in the 1963 season showed:
  - (a) marked constancy in wind direction at each station,
  - (b) greatest wind speeds in the sector from about Mawson to Hallett,
  - (c) no apparent relationship between wind speed and temperature, except for the pronounced drop in speed when the summer regime is established,
  - (d) no evidence of the translation downstream of short period temperature changes.

- (5) Examination of temperature changes at pressure levels other than 100 mb in October and November 1963, showed that the complex temperature behaviour at 100 mb at stations like Mirny, Wilkes and Hallett is observed also at levels above this, and that the warming is evident first at high levels and in lower latitudes, and is propagated both downwards and to some extent polewards with time.
- (6) Short period temperature fluctuations make the commencement of accelerated warming difficult to identify at stations on the coast-line of Eastern Antarctica, but it is relatively easy at latitudes higher than about 75°S.
- (7) Although no evidence of wintertime warming was found at the Pole station, the high level results for Byrd, Wilkes and Campbell Is. in the July period of 1962 showed that in this month warming at the last-named station may occur above the 50 mb level, and over the coastal area of Eastern Antarctica between 90°E and 180°E near the 10 mb level, whilst further south it is not observed near the 10 mb level before late September.
- (8) Ten-day running mean 100 mb temperatures for the Antarctic stations in 1963 demonstrated that the accelerated warming could be observed at Campbell Is., Hobart and Melbourne, in addition to the Antarctic stations.

In studying the period July-November 1964, L.A. Zhdanov prepared charts of:

- (i) trajectories of cyclones and anticyclones at various levels,
- (ii) sea level pressure and absolute topography, on both a mean basis, and for specific occasions, at levels up to 10 mb,
- (iii) meridional and time-sections (some of these were prepared by Mr. P. Males),
- (iv) position of mean axes of jet streams,
- (v) the boundary of the area containing all centres of warm and cold pools at and above the 100 mb level.

In summary he considered that:

- (i) there is marked conformity between the position of the stratospheric warming areas and the general mean tracks of sea level cyclones, and
- (ii) stratospheric warmings occur during periods of increased cyclonic activity;

basing the first conclusion on his studies of cyclone tracks in the Southern Hemisphere, and the fact that in the Northern Hemisphere the positions of the warming areas conformed to the general cyclone tracks from Japan to the Aleutians and from USA to Greenland or Iceland. The second conclusion was based in part on the observation that there appeared to be a small temperature increase up to the 100 mb and 50 mb levels prior to the onset of warming periods.

He was unable to evaluate rates of movement of cyclones and anticyclones in 1964, and therefore used a result he had established earlier, namely that there is a two-yearly cycle in Antarctic atmospheric circulation, and accordingly he applied results obtained in 1962.

His third conclusion was that stratospheric warmings first appear over the extreme eastern part of the Antarctic continent, i. e. from Mawson to Dumont d'Urville, where cyclones which develop in low latitudes reach the Antarctic coast with maximum frequency. He regarded the strong polar vortex as a powerful process which suppressed warm intrusions, and that the warmings over Western Antarctica, i. e. that portion of the Antarctic continent extending from the Ross to the Weddell Sea, and finally in the Atlantic sector, could only follow well-developed and strong warmings in the Mawson-d'Urville sector.

The fourth conclusion was that the Antarctic circumpolar vortex does not break down into two centres during stratospheric warming periods, as does the Arctic vortex which is considered to result from the ability of the powerful Northern Hemisphere storms to penetrate to the central Arctic, whereas continental orography precludes this in the south.

Two further points were established:- the first that an occurrence of strong warming was observed at McMurdo without marked solar activity being reported, showing that this is not a necessary associated condition; and the second that the cold and warm areas of the Northern and Southern Hemispheres approximately coincide when superimposed in the same sense, and that the stratospheric warming areas gravitate towards the respective magnetic poles.

Mr. Zhdanov also considered the positions of the stratospheric anticyclones and pointed out that centres developed first in the Indian Ocean at and above the 50 mb level in August and were rapidly displaced southwards during a warming wave of 20-27 August and in the area south of the Great Australian Bight and also over the Pacific in September, being displaced southward and of greater intensity in October.

A difference in viewpoint emerges from these two papers. Whilst Mr. Phillipot believes that the warming is mainly a stratospheric event, Mr. Zhdanov believes it to be associated with increased tropospheric cyclonic activity.

Although both agree that warmings occur first in the Mawson-d'Urville area, Mr. Phillipot believes that since Byrd, the only regularly reporting high level radiosonde station in Western Antarctica, is at Lat.  $80^{\circ}$  S, latitudinal differences prevent any conclusions being drawn about the warming in Western Antarctica following that in Eastern Antarctica. Clearly much more remains to be established.