Record-High Temperatures in the Antarctic—A Synoptic Case Study

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ABSTRACT

During the period 25–29 December 1978 abnormally high temperatures were recorded at several Antarctic stations. New records were set at South Pole, McMurdo, and Vostok, and near record high temperatures were reached at coastal stations in East Antarctica. Synoptic scale events accompanying these unprecedented high temperatures were investigated using surface, satellite and radiosonde data. The high temperatures were associated with two intrusions of warm air which penetrated the continent from the Atlantic and Indian Ocean sectors. Warming at South Pole occurred with the passage of a jet-like feature and its accompanying baroclinic zone.

1. Introduction

Abnormally high surface temperatures in the interior of Antarctica are usually associated with strong inland advection of warm, moist air. Warm advection is an important item of the Antarctic heat budget. Poleward transport of sensible and latent heat is the major process which counters the radiative loss of heat in winter (Schwerdtfeger, 1970; Gabites, 1960). Alvarez and Lieske (1960) described a warm advection situation during which the surface temperature at the South Pole rose by nearly 40°C in four days during May 1957. Most such descriptions of synoptic processes in the Antarctic known to the author utilize surface and upper air data. This case study uses, in addition, satellite imagery to fill the large gaps in the conventional data network, and relates surface and aerological conditions to satellite-viewed features.

2. The high surface temperatures

It was unusually warm in several areas of Antarctica during 25–29 December, 1978. Record-high temperatures were measured at South Pole, Vostok, and McMurdo. At Halley the temperature rose to within a fraction of a degree of the record there, and the temperature at Davis reached a December record. Fig. 1 gives locations of these and other stations referred to in the text. The temperatures for these stations as derived from synoptic reports are graphed in Fig. 2.

At Halley, a temperature of +2.5°C was reached on the 28th, only 0.3°C below the 1956–78 high (January 1964 and January 1973). Daily maxima exceeded 0°C on each of the preceding three days (cf. 1956–78 mean daily December maximum temperature of −2.4°C).

At South Pole, the temperature soared during 25–26 December with a maximum of −13.6°C at 2212 GMT 26 December. This exceeded the previous highest of −14.7°C recorded in January 1958. Constant sun elevation at the Pole reduces the diurnal temperature variation so the temperature curve for that station is smoother than the others in Fig. 2.

In the McMurdo area, high temperatures were measured on 28 December. At 2130 GMT a new record high of +9.6°C was reached at McMurdo exceeding the previous 1956–78 record of +8.3°C set in January 1960. Record high December temperatures were reached at Scott Base (~4 km from McMurdo) and Vanda Station (130 km to the west in the Wright Valley).

Surface temperatures at Vostok rose dramatically on 24 December (see Fig. 2) to a record (1958–78) high of −17.7°C. The previous extreme maximum was −21.0°C (Petrossiants, Hydrometeorological Center, Moscow, personal communication). However, following temporarily colder conditions during 25–26 December the temperature climbed to an unprecedented −15.7°C on the 27th.

Coastal stations in East Antarctica also experienced warm conditions. Details of significantly high temperatures appear in Table 1. Although the Davis maximum (11°C) was not the highest on record, it exceeded the previous December extreme maximum of 10.0°C. Data from Molodezhaya were not obtained. Maximum temperatures from SANAE were not significantly above normal during this period.

The high temperatures described above occurred during the warmest part of the year. The annual

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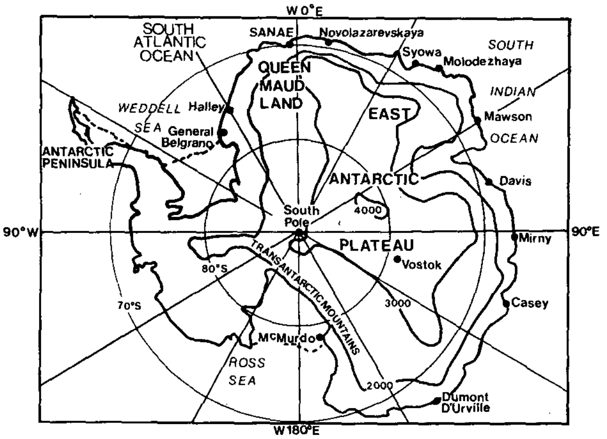

FIG. 1. Map of Antarctica showing the location of places referred to in the text. Contours are in m; the 1000 m contour is omitted for clarity.

march of temperature in the Antarctic is such that, on average, the warmest temperatures occur in a narrow peak during late December to early January. These high temperatures coincided with that peak. During the midsummer period the inversion over the plateau is not strongly developed (Schwerdtfeger, 1970), so its destruction does not give rise to the spectacular temperature rises which occur in winter during warm advection situations (e.g., Alvarez and Lieske, 1960; Dalrymple, 1966). Nevertheless, the synoptic processes related to this occurrence of extreme temperatures over such a wide area of the continent are worthy of further study.

3. Surface and satellite viewed events

Satellite imagery was used to trace synoptic events during the period of high temperatures. However, the contrast in the imagery between the cloud features and the underlying ice plateau of the Antarctic continent was found to be low (see Fig. 3). Therefore, to better portray cloud systems over the continent, nephanalyses are presented (Fig. 4). These were drawn from Meteor 2-2 and 2-3 imagery (visible data only) and from mosaics prepared by NOAA in both visible and infrared (IR) modes. The IR data allow qualitative estimation of cloud-top heights. Conventional synoptic weather observations from several stations were used to describe surface weather conditions.

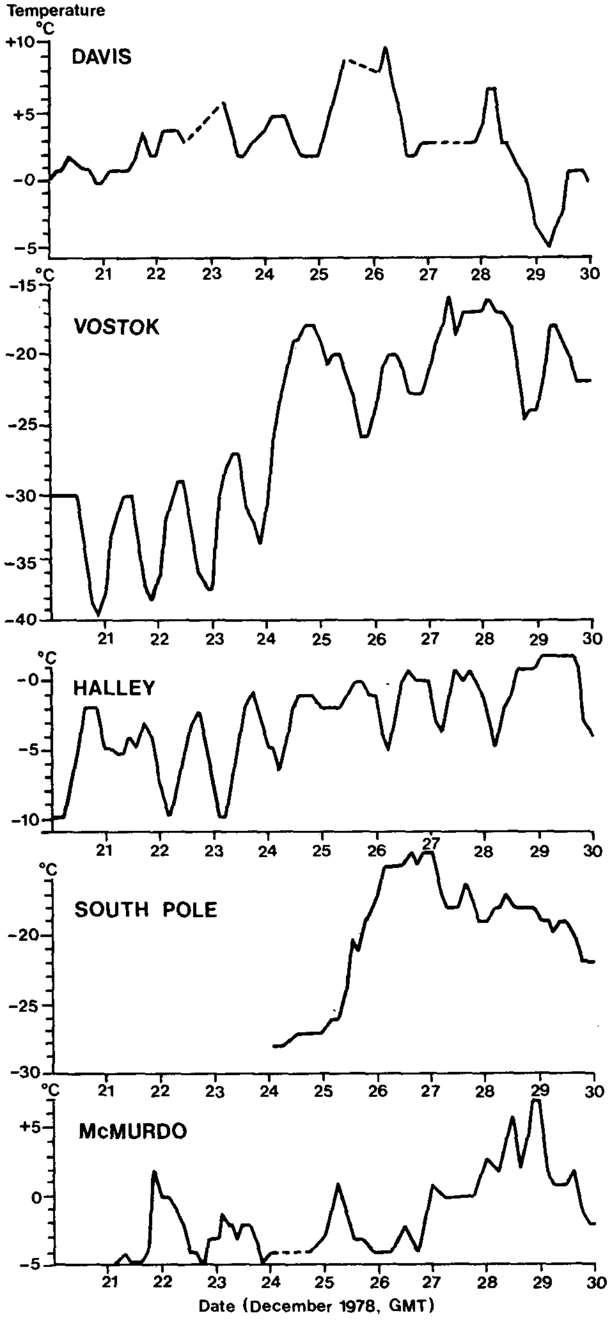

FIG. 2. Surface-air temperatures plotted from three-hourly synoptic weather reports for stations recording extreme or near extreme temperatures. Dashed lines cover periods of missing data, and dates are positioned at the 0000 GMT position.

The imagery shows the advance onto Antarctica of two multilayered cloud systems during 24–25 December, one onto Queen Maud Land (South Atlantic sector) and the other onto the South Indian Ocean sector of the continent. As the cloud system over Queen Maud Land advanced onto the continent during 24–25 December, there was a period of strong wind, snow, and rising temperatures at stations in this area (Halley, SANAE, and General Belgrano). The Meteor imagery at 0000 GMT 25 December (Fig. 3) shows a sharp, anticyclonically curved poleward edge to what appears to be cirrus cloud overlying lower cloud. In the IR imagery, extensive, anticyclonically curved cirrus streaks are visible in this area. Lee waves can be seen in the Meteor imagery

TABLE 1. Daily maximum temperatures (°C) for coastal East Antarctic Stations. Climatological data pertains to the period of records shown for each station. The Novalazarevskaya, Syowa, and Mirny climatological data are from Schwerdtfeger (1970).

Station	Date (December 1978) 21	22	23	24	25	26	27	28	29	30	Mean Dec max	Extreme max	Years of record
Novolazarevskaya	1.3	3.1	4.2	4.4	6.4	3.9	3.0	4.2	3.8	1.8	1.1†	6.6**	—
Syowa	0	2	2	4	—	6	—	5	3	3	—	8.1†	—
Mawson	5	4	5	6	5	8	7	6	4	4	2.4	10.6	1954–78
Davis	5	5	6	8	9	11	7	7	3	4	2.2	13.0	1957–78
Mirny	—	0	0	0	4	1	1	—	7	2	—	8.0	1956–67
Casey/Wilkes	3.0	4.2	6.0	3.5	7.0	6.4	2.0	5.0	4.0	4.4	1.5	8.0	1960–78

* 1966–78 data.
** 1961–67 data.
† Six years' data between 1957–67.

(Fig. 3) over Queen Maud Land just to the east of Halley. Measurements of these waves made on the imagery yield a wavelength of ~1.3 × 10^4 m averaged over six waves. Using an average from the formulas of Corby (1957) and Georgii (1967) as quoted by Cruette (1976) yields a mean tropospheric wind of 23 m s^{-1} from a northeast direction (normal to the waves). These lee waves are thought to have been produced by the mountains to the northeast of Halley which are ~200 m in elevation. It was not possible to verify this wind estimate from a Halley sounding as no upper wind observation was made at that time, but the next nearest station, SANAE, had a mean tropospheric wind of 24 m s^{-1} from the north-northeast at this time. Lee waves also were visible during 27–28 December over the Transantarctic Mountains as shown in Fig. 4.

Rising surface temperatures at Pole during December 25 (see Fig. 2) coincided with the arrival of this cloud system there. Snowfall, which commenced early that day continued intermittently for the following 24 h. The highest temperature at Pole late on 26 December appeared from the imagery to occur beneath a deck of low stratus cloud after the main band of middle and high cloud had passed to the grid[1] south of Pole, and largely dissipated.

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[1] Directions at South Pole in this paper are in degrees grid, all other directions are degrees true. Grid north at South Pole is the direction of the 0° meridian, grid west is the direction of the 90° west meridian, etc.

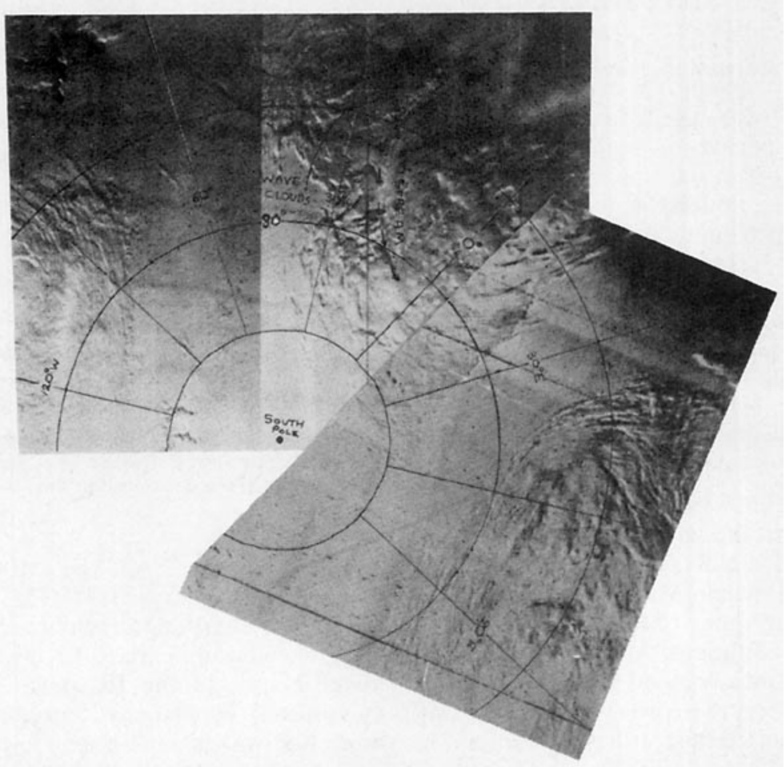

FIG. 3. Copy of Meteor imagery for 0000 GMT 25 December 1978.

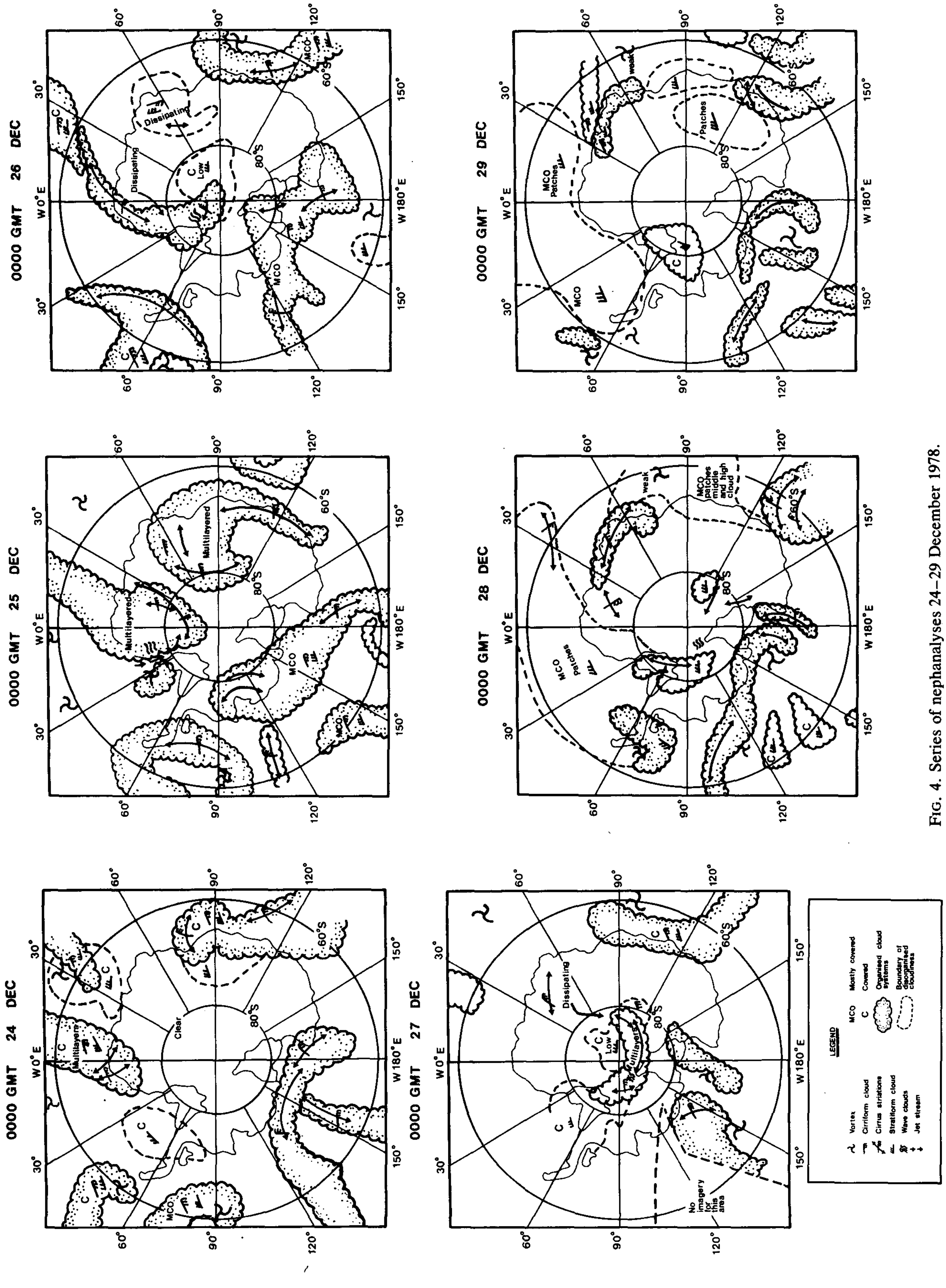

FIG. 4. Series of nephanalyses 24–29 December 1978.

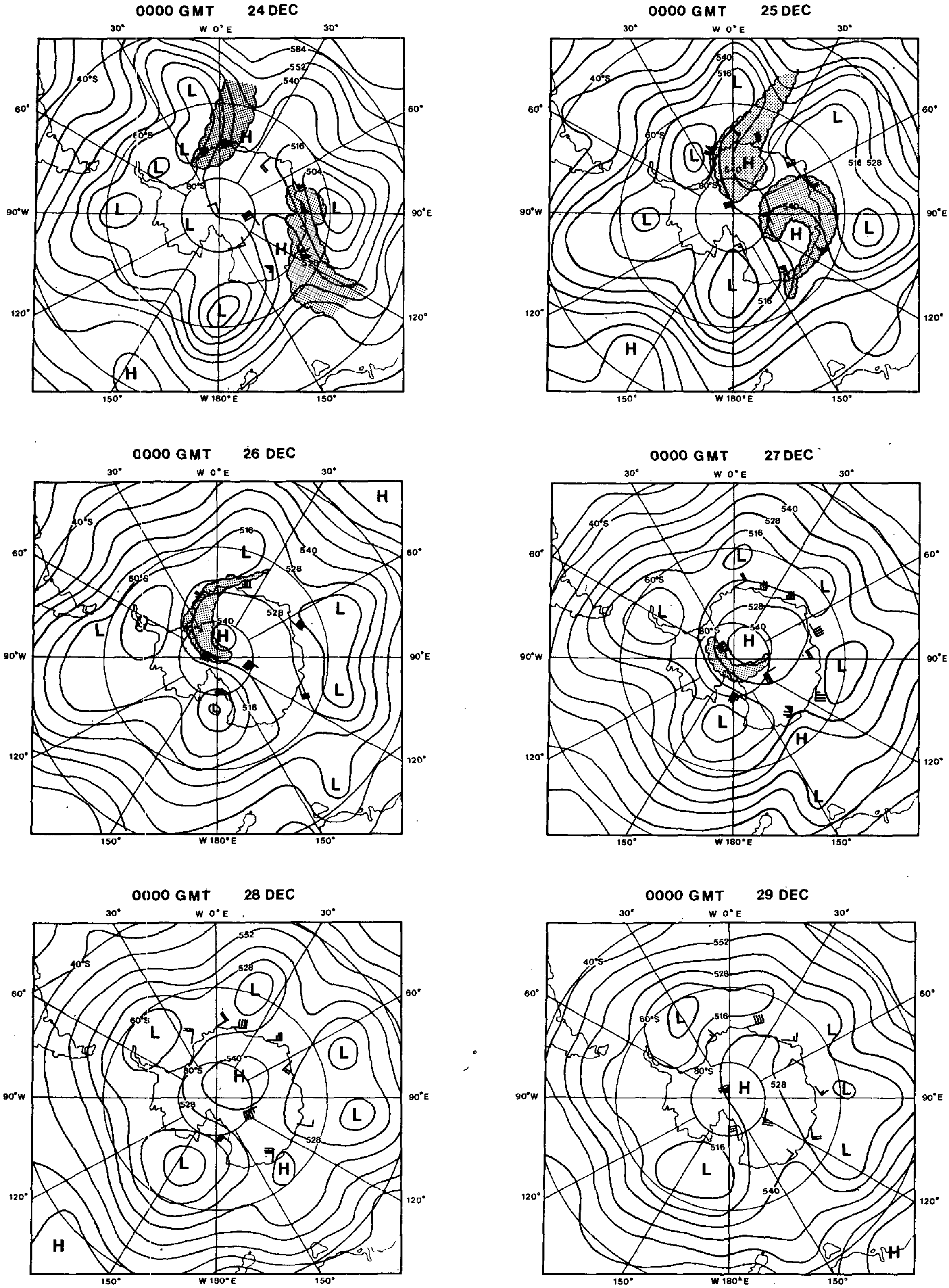
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FIG. 5. Series of 500 mb Southern Hemispheric analyses 24–29 December 1978. Wind observations are plotted in kt (1 kt = 0.515 m s^{-1}). Halley wind data are for 1200 GMT on the indicated date.

Schwerdtfeger (1970) shows that at interior Antarctic stations there is a positive (all wave) net radiation budget on cloudy days in summer due to the increased back radiation from the cloud layer. This effect may have heightened the temperature rise.

The other cloud intrusion over the Indian Ocean sector of Antarctica was associated with unsettled weather at coastal stations (Mawson, Davis, Mirny and Casey) during the period 22–26 December. At Casey, light rain and strong wind occurred throughout much of this period, and snow and strong wind occurred intermittently at the other stations. Drizzle occurred at Mawson on the 24th. The occurrence of liquid hydrometeors, rare at Antarctic stations, shows the abnormal warmth of the atmosphere during this time. The inland advance of the cloud brought rapid warming and light snow to Vostok early on the 24th. However, this cloud over the plateau dissipated during the 25th.

By December 28, only patches of middle and high cloud remained from the cloud system which had earlier crossed the South Pole. The direction of cirrus streaks at this stage over the East Antarctic plateau suggests the presence there of an anticyclone at the cirrus level. Also, at this time a vortex was evident in the northwest Ross Sea, which appeared from the imagery to extend through most of the troposphere. Strong surface southerlies experienced intermittently at McMurdo during 26–29 December are consistent with the presence of low pressure in this area. Spectacular lenticular cloud formations were seen during this period over the mountains in the vicinity of McMurdo.

4. Upper air conditions

500 mb analyses (Fig. 5) are based on Bureau of Meteorology, Melbourne 500 mb Southern Hemispheric analyses, modified in the Antarctic area. The modifications were necessary to incorporate further data which were not utilized by the Melbourne analysts, and were also aided by interpretation of the satellite imagery already described. The 500 mb analyses show the poleward advance during 24–26 December of two intensifying ridges onto the continent. These occurred in conjunction with the two cloud intrusions previously described, as illustrated in Fig. 5. The strong northeasterly anticyclonic flow onto western Queen Maud Land during 24–26 December occurred between the intensifying ridge over Queen Maud Land and an elongated trough projecting northeastward from a low in the Weddell Sea. The existence of a low in the Weddell Sea at 0000 GMT 25 December is indicated by a vortical formation in the middle-level cloud visible in the satellite imagery (see Fig. 3). Over East Antarctica a strong northeasterly flow occurred at coastal stations between the building ridge over the continent, and an extensive cyclonic circulation offshore. By 27 December, the two ridges had merged to form a single anticyclone at 500 mb. This persisted for several days, with anticyclonic flow covering almost the entire East Antarctic Plateau. A rise in the height of the 500 mb contour at South Pole from 5170 m at 0000 GMT on the 24th to 5410 m 72 h later is consistent with this development. The low in the Ross Sea allowed air to flow northwards in the area about and west of McMurdo. Thus, air flowing between the anticyclone and the Ross Sea low could either flow northward around the low, or continue around the high.

Vertical time sections (Fig. 6) are used to illustrate changes in the thermodynamic and dynamical structure of the troposphere and lower stratosphere. At Halley, marked tropospheric warming occurred after 1200 GMT 23 December as the strong northeasterly flow spread onto Queen Maud Land. The lee waves previously described were within this flow, and conditions favorable to lee-wave formation (an increase of wind with height, direction varying little with height and normal to the mountain range producing the waves, and a layer of static stability near the mountain top level) were exhibited by the SANAE sounding at 0000 GMT 25 December (Fig. 7) and that at Halley 12 h later (Fig. 6). The South Pole sounding 24 h later (see Fig. 7) showed similar characteristics. Indeed, this was the only South Pole sounding with marked vertical wind shear (see Fig. 6). Wave clouds also were visible in the satellite imagery over the Transantarctic Mountains to the grid southwest of the South Pole on the 27th and 28th (Fig. 4). It is therefore inferred that the strongly sheared flow which generated lee-wave formations over Western Queen Maud Land on the 25th had advanced to the Pole on the 26th and passed to the grid south of the Pole by the 27th.

The upper tropospheric wind maximum as it passed the Weddell Sea stations (Halley, SANAE) and South Pole had the hallmarks of a typical polar jet stream (Berggren *et al.*, 1958; Anderson and Veltishchev, 1973). First, it was associated with cirrus cloudiness having a sharp anticyclonically curved poleward edge, as noted in the previous section. The presence of a moist layer around 300 mb at SANAE on 25 December at 0000 GMT (Fig. 7) is consistent with the presence of a cirrus cloud cover. The strongest winds near the tropopause level were observed more or less beneath this poleward edge, except at SANAE which lay a little to the east. Second, it lay over a region of tropospheric baroclinicity. At 0000 GMT 26 December when the upper level wind maximum occurred at the South Pole, vertical wind shear was strong, and parallel

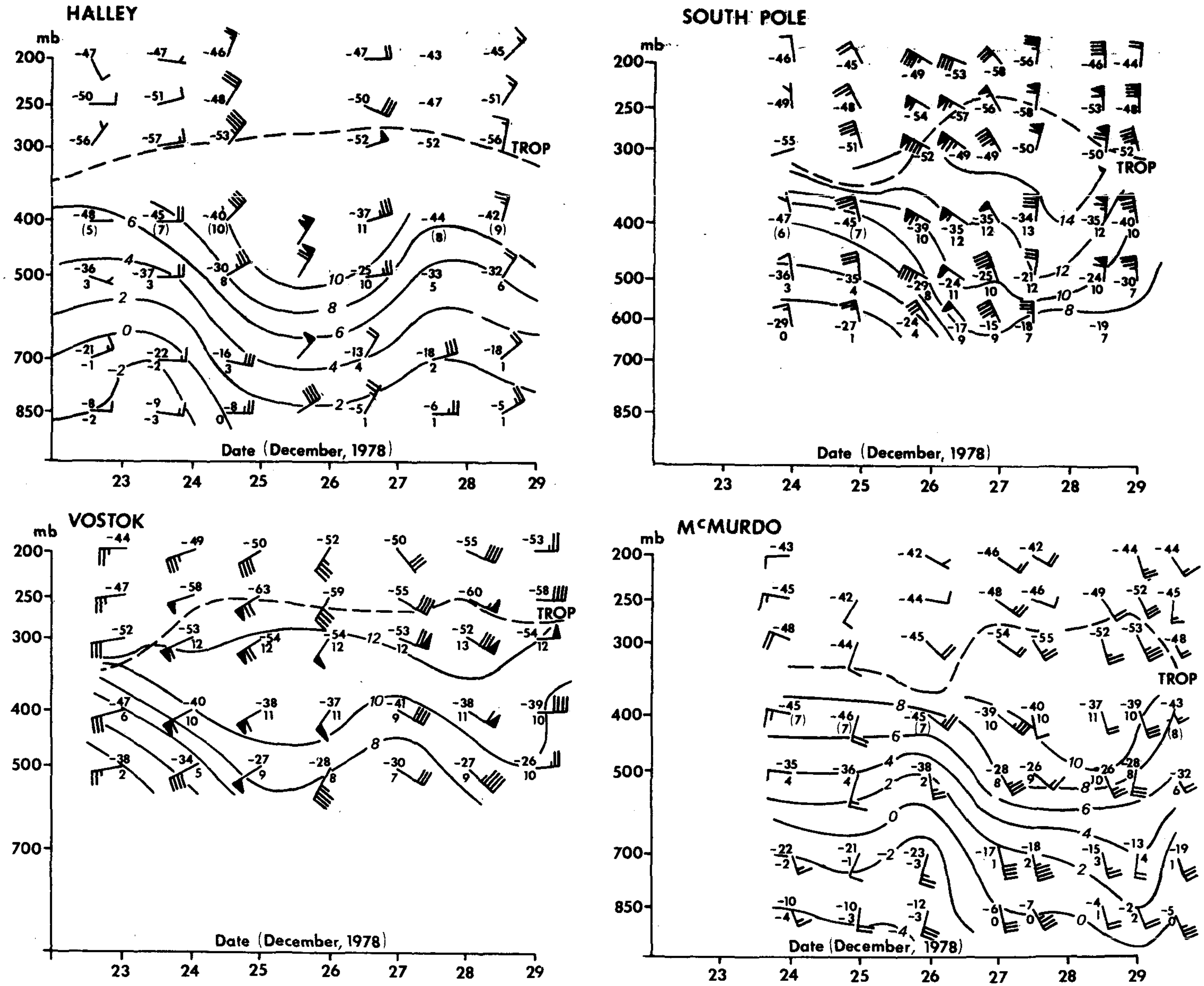

FIG. 6. Vertical time sections for selected stations. Winds (kt), temperature (to left of wind shaft, °C) and wet-bulb potential temperature (below temperature, °C) at standard levels are shown. Isopleths of wet-bulb potential temperature (solid lines) and the tropopause (dashed lines) are shown. Wet-bulb potential temperature data in brackets have been derived for levels with missing humidity data by assuming a dew point depression of 5°C. Dates are positioned on the horizontal axes at the 0000 GMT position.

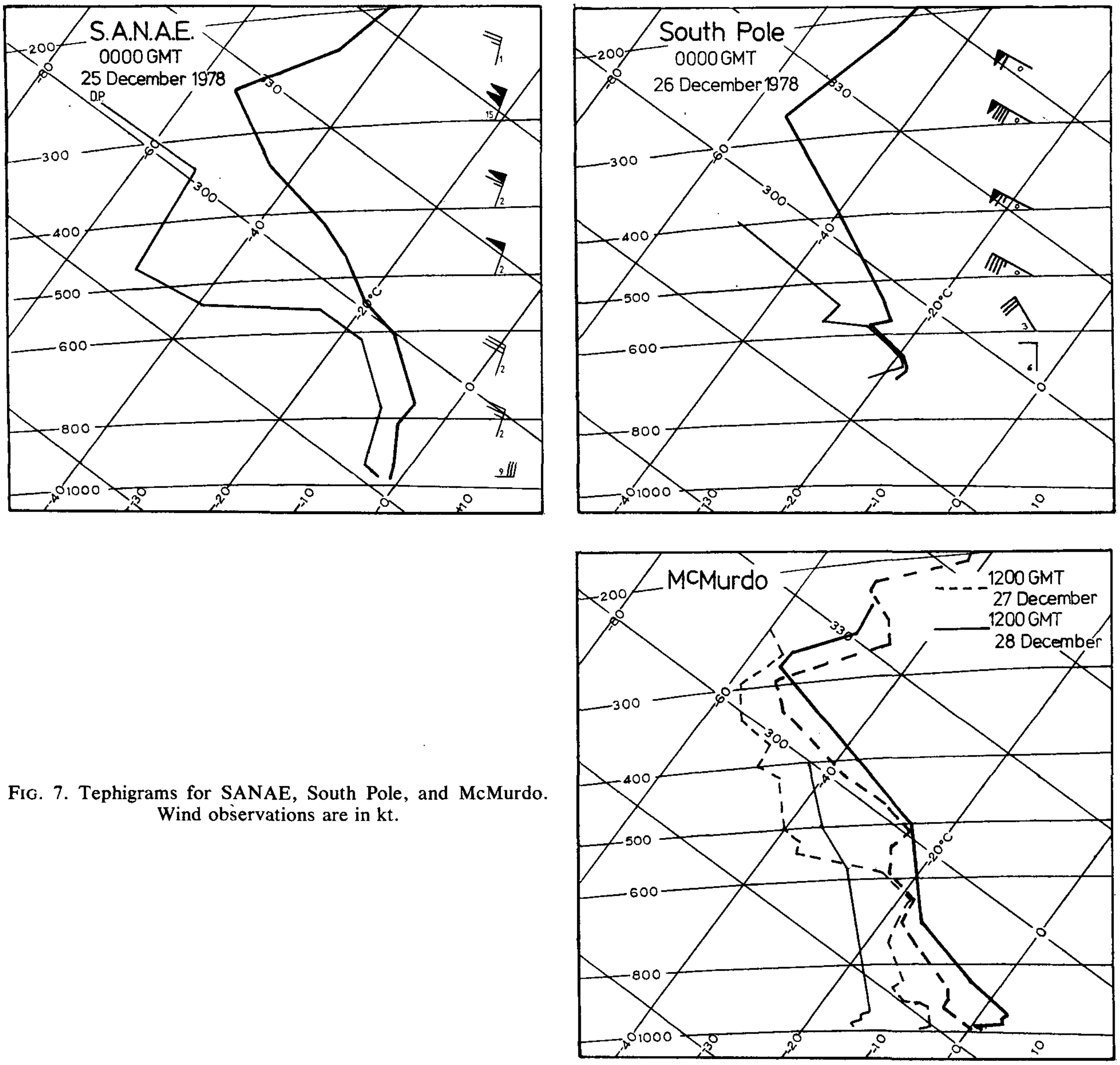

FIG. 7. Tephigrams for SANAE, South Pole, and McMurdo. Wind observations are in kt.

to the direction of flow. Twenty-four hours before and after this time, tropospheric wind shear was small. This, and the rapid warming illustrated in Fig. 6 suggest the passage across Pole of a narrow zone of baroclinicity with the horizontal temperature gradient normal to the flow. In the warm air to the grid north of the baroclinic zone, the tropopause was higher and colder than in the cold air. Stratospheric cooling occurred with the passage of this zone.

At levels above 500 mb the warm air which affected Halley and South Pole had wet-bulb potential temperature (WBPT) values characteristic of mid-latitude air. The abnormal warmth of this airmass is attributed to its long southward trajectory (see Fig. 5). The poleward flow across the eastern Weddell Sea and Western Queen Maud Land was strong so that heat loss during its journey south would be expected to be small. The presence of the low in the Weddell Sea and the development of the ridge over Queen Maud Land during 24–26 December were essential factors in accelerating the northerly flow in this sector.

At Vostok, marked tropospheric warming occurred during 23–24 December as warm air penetrated inland from the south Indian Ocean sector. Warm air had been affecting the coast prior to this. At Casey, the WBPT was above 10°C throughout the middle and upper troposphere from 21 December. The inland advance of this warm air occurred as the anticyclonic flow and associated cloud advanced onto the plateau. Slight cooling during the 26th was followed by further warming during the 27th. This later warming is attributed to the arrival at Vostok of air from the Queen Maud Land warm intrusion. This assertion is supported by the presence of flow with strong vertical shear during 27–28 December at Vostok (Fig. 6). Vertical wind shear was a hallmark of the warm flow which had earlier affected South Pole and Halley. The intensification of the high to the grid northeast of Pole was accompanied by the wind change from southwest to southeast at Vostok which marked the advent of the sheared flow.

Following the warming at the South Pole, the continued grid southward progression of the baroclinic belt is indicated by the appearance previously noted of wave clouds to the grid southwest of Pole, and the grid southward motion of the associated cloud band prior to its dissipation during December 27. The tropospheric warming evident at McMurdo (Fig. 6) during 26–27 December is attributed to the advection of warm air from the area to the grid south of the Pole. This air was directed northward by the low in the Ross Sea. Thus, the warm air which reached the South Pole on the 25th was advected simultaneously toward Vostok and McMurdo due to the flow diffluence between the anticyclone over the East Antarctic plateau and the Ross Sea low. The similarity of the South Pole sounding for 0000 GMT 26 December and that for McMurdo at 1200 GMT 27 December (see Fig. 7) would appear to support this argument. Furthermore, WBPT maxima at each level at and above 500 mb at McMurdo and Vostok are similar level for level, and only about 2°C lower than those recorded at South Pole. This difference can be explained by slight radiative cooling or entrainment by the flow of adjacent cooler air masses.

The greatest rise in surface temperature did not occur at McMurdo until late on December 27 (Fig. 2), i.e., after the change of air mass indicated by the rise of WBPT. Soundings during this surface warming (Fig. 7) suggest subsidence as a mechanism for this warming which continued until the 29th. The rising temperatures below 500 mb during the illustrated period were accompanied by only small rises in WBPT, and considerable drying. Furthermore, a stable layer characteristic of subsidence is evident in the earlier sounding in Fig. 7. Thus, the record-high temperature at McMurdo on the 28th can be ascribed to subsidence within an airmass which was already abnormally warm. Subsidence also was evident at the South Pole in the Fig. 7 sounding; this may have contributed to the high surface temperatures there.

5. Summary

The high temperatures resulted from strong warm advection. The strong flow onto Queen Maud Land and the plateau was reinforced by the Weddell Sea low. Cyclogenesis at this high latitude and simultaneous intensification of anticyclonic flow further east seemed to be necessary conditions for this intense poleward advection. Further advance of the warm air accompanied by subsidence led to the extreme temperature at McMurdo. A similar incursion of warm air gave rise to high temperatures at stations in East Antarctica.

Invasions of warm air of the intensity and scale described herein would be expected to have an important effect on the heat balance of the Antarctic.

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