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NOTES ON WEATHER ANALYSIS IN THE FALKLAND ISLANDS DEPENDENCIES, ANTARCTICA

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A. GENERAL NOTES

I. INTRODUCTION

THE organisation and methods of the Falkland Islands Dependencies Survey are described in detail by Fuchs (1953), and a further account of the meteorological work is given by Howkins (1949).

The meteorological observations obtained during the years 1944 to 1950 have been critically examined, and the results are discussed in detail by Pepper (1954); this paper includes extensive summaries of the seven years' observations, and contains a gazetteer of the Dependencies bases and the headquarters at Stanley in the Falkland Islands (Figure 1).

In 1941, the Naval Meteorological Branch established a forecasting office at Stanley; this was taken over by the Air Ministry, London, in 1947, and in 1950 became the headquarters of the Falkland Islands and Dependencies Meteorological Service. Local forecasts for the Falkland Islands were broadcast to the

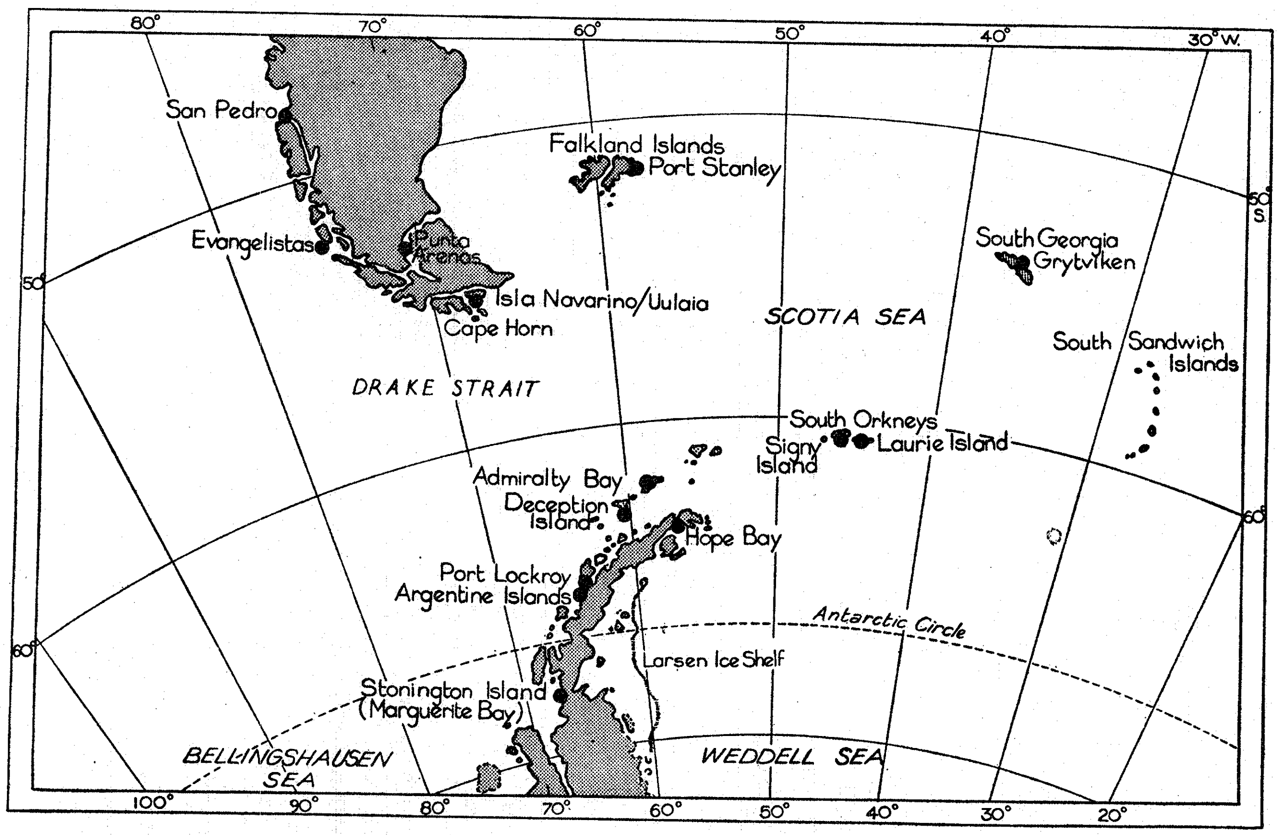


FIGURE 1. Falkland Islands Dependencies Survey bases open 1950–4; three Chilean stations included in the tables of air mass data are also shown.

general public and supplied to the Government Air Service, and from October 1951, forecasts were issued for the area 50° to 65° S. and 40° to 70° W. during each pelagic whaling season. Ships proceeding to and from the Falkland Islands were provided with forecasts on request.

The meteorological station at Grytviken, South Georgia, was taken over from the Compaña Argentina de Pesca on 1st January 1950, and by the end of the month weather forecasts, covering an area within a radius of 250 miles from the station, were being issued to local whaling communities. In December 1950, these forecasts were extended to cover pelagic whaling in the area from the Greenwich meridian to 60° W., between latitudes 50° and 65° S. In addition, supplementary forecasts covering the area from 25° to 45° W., between latitudes 45° and 55° S., were issued on request to ships approaching or leaving the island. During the winter season, 24-hour local forecasts were issued to the repair yard at Stromness and to the sealers operating from Grytviken.

The senior author served as a meteorologist at Grytviken from December 1950 until December 1951, and at Signy Island from February 1952 until March 1953; his co-author was a forecaster at Stanley from September 1951 until April 1954. The notes compiled on synoptic analysis in this sector of the Southern Ocean, together with a review of the current theories on southern hemisphere circulation, form the basis of this report.

II. Nature of Observations

The Falkland Islands Collective (FICOL), containing routine surface observations and occasional upper-wind information from all the bases, and surface observations and upper-air soundings from the Falkland Islands, provided data for the daily 1200, 1800 and 2300 G.M.T. charts; these observations were supplemented by reports from South American and South African stations. Few ships' reports were received directly, and only *Southern Harvester* and *Southern Venturer*, two pelagic whaling factories owned by Chr. Salvesen & Co., sent in observations regularly.

In October 1952, the South African Weather Bureau began to collect and re-broadcast weather reports from factory ships operating in the South Atlantic and Indian Ocean sectors; normally these broadcasts were received clearly in South Georgia and the Falkland Islands.

III. Methods of Analysis

The theories and techniques of northern hemisphere synoptic meteorology were successfully applied to the problems of forecasting in the Falkland Islands area from 1941 to 1950, and at South Georgia analyses were continued on the same basis. Since the use of these techniques presupposes a general pattern of hemispheric circulation and the recognition of principal air masses and frontal zones, an attempt has been made to record their seasonal changes; the interpretation of the surface observations is limited, however, by the lack of upper-air soundings.

IV. The Atmospheric Circulation of the Southern Hemisphere

a. The Zonal Westerlies and the Circumpolar Trough

Since January 1951, the Weather Bureau of South Africa has compiled a daily series of southern hemisphere weather charts; with data taken from these, monthly and seasonal mean pressure charts have been drawn up for 1951. These published charts (NOTOS, 1952) reveal that the trough of low pressure which surrounds the Antarctic continent contains from two to four distinct monthly mean lows; the centres of these mean lows are shown in Figure 2.

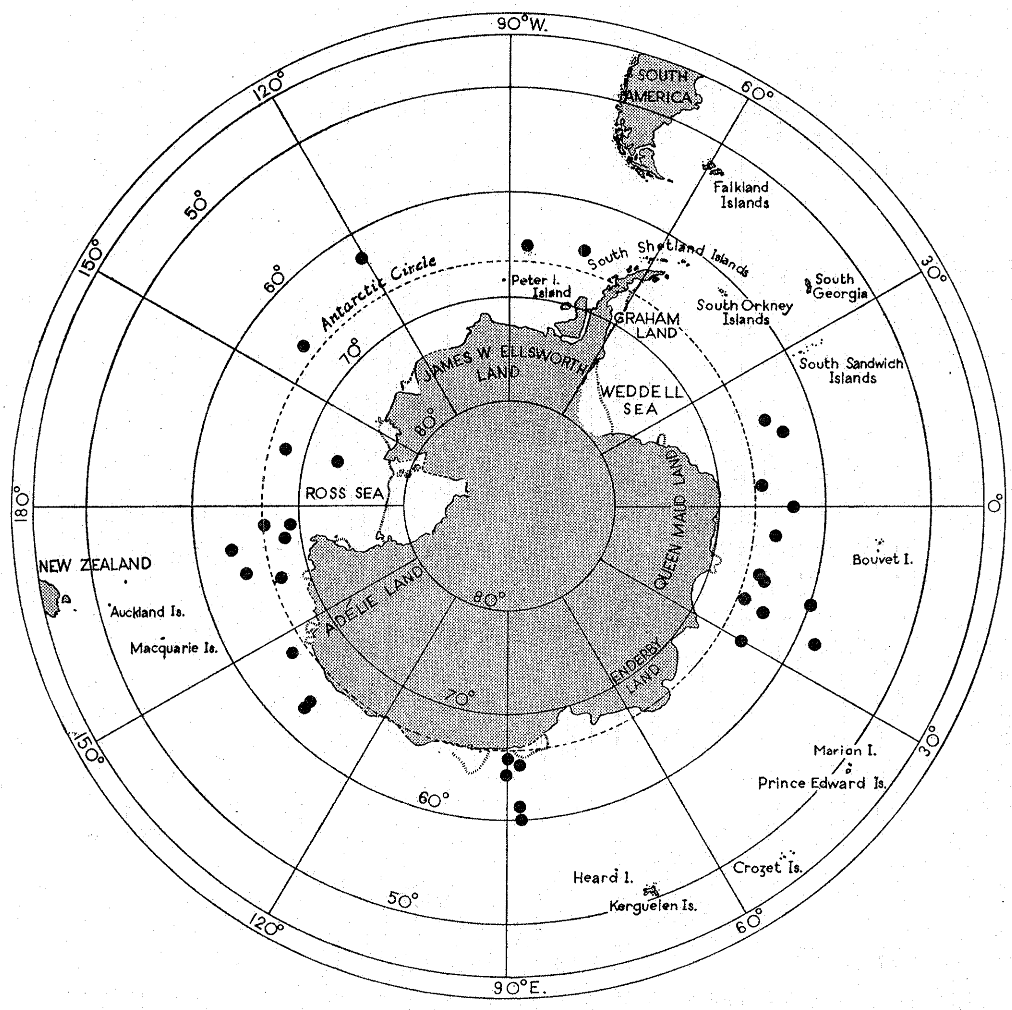


Figure 2. Distribution of monthly mean low pressure centres during 1951 (see *NOTOS*, 1, Nos. 1–4).

In a recent paper, Pepper (1954) has summarised observations made in the Falkland Islands Dependencies from 1944 until 1950, and has drawn suggested monthly mean isobars from 35° to 80° W., between 50° and 70° S. The presence of a monthly mean low pressure area to the west of Graham Land is apparent throughout the year and differs little in position from the mean lows plotted in Figure 2. In the eastern part of the Dependencies sector, the pressure pattern appears to be more complicated. Pepper has emphasised that the mean isobars are only estimates of pressure conditions, for some months during which pressure was abnormal have necessarily been included in the observations. The possibility of having isobars running from east to west in the South Georgia–South Orkneys area in January is shown.

The monthly mean pressure charts of the whole hemisphere (NOTOS, 1952) show that only in November during 1951 were the isobars in this area curved anticyclonically, and evidently they were drawn to fit in with the greater frequency of south-easterly winds during the month. (At Signy Island 25 per cent of all south-easterly winds for the year occurred in November; at South Georgia only 20 per cent.) Although it is difficult to generalise about pressure patterns in this region, it seems probable that weather sequences, and therefore mean pressures, are correlated with ice conditions from year to year. In 1951 ice never remained fast about the South Orkneys for more than a few weeks during the winter, yet in 1948, 1949 and 1950 the break-up occurred late in the season.

In every month, the strength of the zonal circulation of the westerlies between 40° and 55° S. is emphasised by the configuration of the mean sea-level isobars. There appears to be a weakening of this circulation in the South Pacific area between New Zealand and South America, and this is particularly noticeable in the May and June mean pressure charts (NOTOS, 1952); the accuracy of these charts may be limited, however, by the paucity of observations in this area. Schmitt (1952a) has investigated the upper-air circulation, and drawn maps of the "mean absolute topography" of the 500 mb. surface. He notes that the "predominant feature for the higher latitudes on these summer maps [December 1951, January and February 1952] is the powerful planetary frontal zone . . . between 45° and 55° S. approximately". The mean gradient measured between these latitudes corresponds to a wind velocity of 45 kt., with a maximum of 50 kt. just west of Marion Island, and a minimum of 35 kt. between the Falkland Islands and the South Sandwich group. There appear to be permanent upper-air troughs at this level to the east of the continents in the summer months, and the trough over Madagascar is particularly marked. The South Atlantic trough is evident, though not so well shown as the trough in the Pacific. Schmitt (1952b) considers that "cold fronts, after rapidly crossing the Falkland and southwest Atlantic regions, generally retard over the South Atlantic Ocean near Tristan da Cunha, . . . whilst the cold air proceeds gradually eastwards and northeastwards . . . thus extending the accompanying upper-air trough towards lower latitudes".

Gibbs (1953) has analysed the distribution of cyclone and anticyclone centres on daily southern hemisphere charts for January and July 1949. In July, the maximum frequency of depressions occurred at 57° S., and Gibbs concludes from a comparison of the frequency distribution of the central pressure values of depressions with latitude that "individual vortices have circulations of comparable intensity in both hemispheres in winter". In midsummer, however, the median value of the central pressure of depressions for any given latitude south of 40° S. is lower in the southern hemisphere, "indicating that the individual vortices in high latitudes in midsummer have a considerably stronger circulation in the southern than in the northern hemisphere". This effect has been observed in the Falkland Islands Dependencies sector, for during the summer months depressions with a diameter greater than 1500 miles may form; their mode of formation and movement is discussed on page 18. Gibbs concludes that the "symmetry of occurrence of pressure systems indicates a symmetrical mean circulation. A possible exception to this is the likely deformation of the jet-stream in the vicinity of the South American Andes." Such streams, of mean speed 50 kt. in summer and 80 kt. in winter at the 200 mb. level in latitude 30° S., have been shown in the meridional cross-sections of the southern hemisphere in the region of 150° E. made by Loewe and Radok (1950), Hutchings (1950) and Gibbs (1953). A similar deformation probably occurs in the lower levels of the westerlies, though here the northward extension of the Graham Land peninsula apparently exerts the main effect on the symmetry of the circulation.

Cyclogenesis is frequent in the region between South America and Graham Land, though the majority of large depressions probably originate in about latitude 30° S. near the eastern coast of South America (Gibbs, 1953). The tracks of depression centres are farther to the north in this sector than for the remainder of the circumpolar area, and this is shown in Gibbs' analyses for 1949, though it must be emphasised that these are for single months during summer and winter only.

b. The Continental Anticyclones

In a detailed summary of the problems of antarctic atmospheric circulation, Court (1951) states that "in summer and winter, the surface [pressure] distribution may have the form of a large central anticyclone, or one with several pronounced lobes, or several cells around a weak centre: . . . in the upper air . . . the gradients apparently reverse with the seasons: temperature and pressure in winter decrease from middle latitudes to the Pole, while in summer their decrease stops at about Antarctica's margin . . . on the average Antarctica is overlain by a deep warm semi-permanent anticyclone in early summer. In the winter the tropopause disappears . . . creating over the surface anticyclone an upper level cyclone which deepens as the cooling progresses."

More recent work by Schmitt (1952a) indicates that the "upper-air observations at Maudheim during 1950 and 1951, often giving southerly and northerly winds up to the stratosphere, have demonstrated that during all seasons a strong zonal stream is not a predominant feature of the upper circulation in this area. Even during winter, upper-air troughs and wedges at times extend far to the south, and in some cases may even stretch across the South Pole region itself." Moreover, Schmitt states that "the individual maps [mean absolute topography of the 500 mb. surface] regularly show two or three major upper-air lows . . . some 50 to 60 degrees apart, generally moving eastwards between 55° and 65° S., and thus, in accordance with the Maudheim results of the preceding two years, causing the alternate occurrence of zonal and meridional upper winds at these latitudes. In the monthly and seasonal means [December 1951, January and February 1952] a shallow extended minimum results, which as far as the preliminary data may be regarded as reliable, would appear to be centred over the interior of Queen Maud Land and Enderby Land."

At the surface, anticyclonic cells appear in the westerly circulation only in small numbers and usually in the winter, and it is probable that most move equatorwards to the sub-tropical high pressure belt. Depressions, which in general follow the zone of maximum temperature gradient between the pack ice and the antarctic convergence, may be deflected far to the north or south by such pressure systems invading the zonal circulation. Schmitt (1952b) notes that "anticyclonic blockings with exceptionally strong thermal gradients in most cases, vigorous thermal wedges and troughs extending into the interior of Antarctica and to the equatorial regions respectively, have been observed repeatedly". Similar blocking action by anticyclonic cells has been observed by Gibbs (1953) in high latitudes in the Australian sector, though it is believed to be rare. Though the monthly mean isobars for Antarctica's margin seldom exceed 1005 mb. (NOTOS, 1952), much greater pressures may be experienced at coastal stations. Rubin (1952) notes that "winter-time pressures of as high as 1023 mb. have been observed in Adélie Land [Terre Adélie] . . . although the mean is considerably lower. At Maudheim [71° S. 11° W.] there have been observed pressures of 1019 mb., while the stations on Palmer Peninsula [Graham Land] have had pressures as high as 1030 mb., with definite evidence of occasional wintertime outbreaks of polar anticyclones that have reached as far as South Africa."

In Graham Land in 1952, pressure maxima were as high as 1035.3 mb.; all these maxima occurred about 10th June 1952 and are shown in Table I. The synoptic situations which caused these unusually high pressures are illustrated in Figure 3a–d.

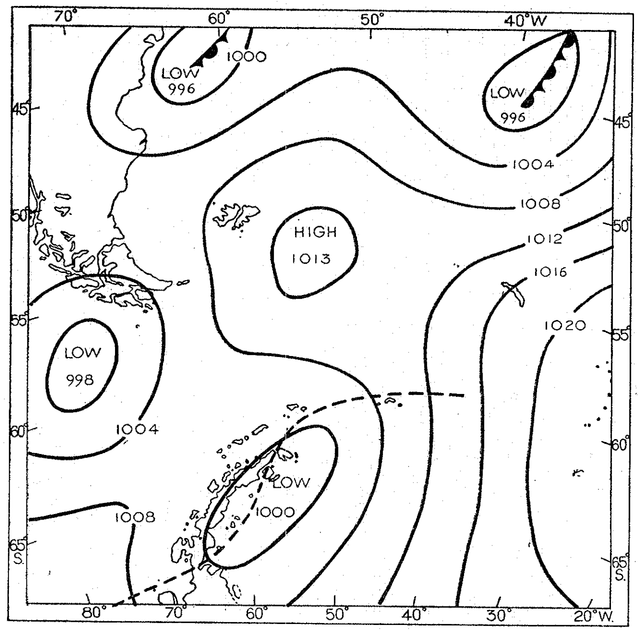
1952 Pressure maxima, in millibars*							
Port Lockroy	Deception Island	Hope Bay	Argentine Islands	Admiralty Bay	Signy Island	Grytviken, S. Georgia	Stanley, Falkland Is.
1035.1 10th June	1035.0 10th June	1031.6 10th June	1034.8 10th and 11th June	1034.2 10th June	1032.6 10th June	1032.0 11th June	1032.7 8th June

* All pressures are corrected to mean sea level.

TABLE I. 1952 Pressure maxima.

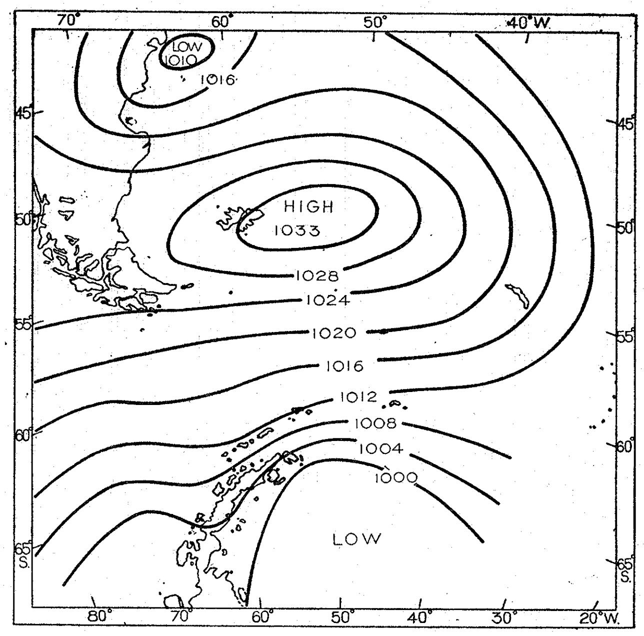
From the charts prior to 5th June, there appeared to be an anticyclone over Alexander Land, James W. Ellsworth Land and the southern Bellingshausen Sea, with a ridge north-eastwards just to the west of Graham Land. The ridge intensified eastwards and north-eastwards, and by 1200 G.M.T., 5th June

(Figure 3a), had developed into a separate anticyclonic cell which continued to intensify for five days (Figure 3a–d). The maximum pressure of the anticyclone appeared to be 1038 mb. and was maintained for at least 24 hours. The decline after 12th June was gradual and there appeared to be two separate centres, one moving to the north-east, and the other being absorbed into the Pacific anticyclone by way of Tierra del Fuego.



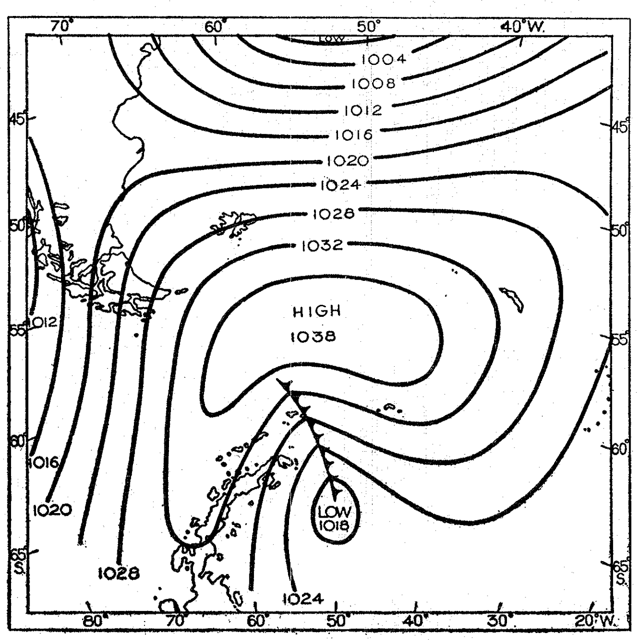
a

1200 G.M.T., 5th June



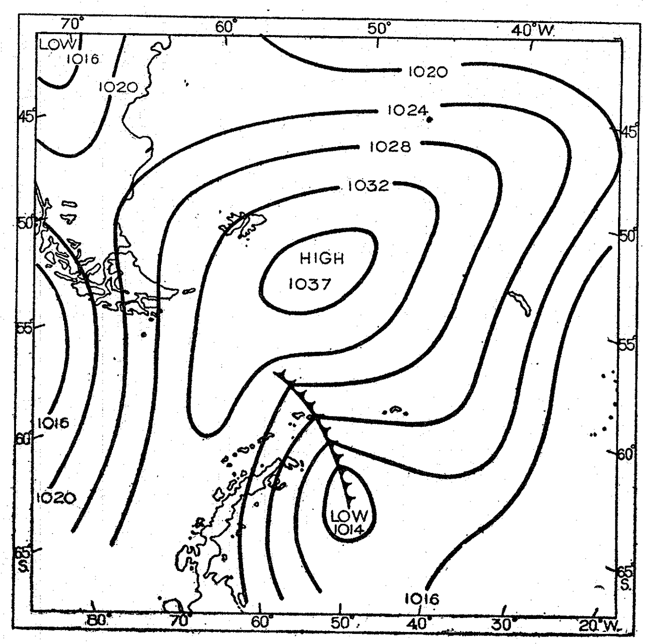
b

1200 G.M.T., 8th June



c

1200 G.M.T., 10th June



d

1200 G.M.T., 12 June

FIGURE 3. Synoptic sequence to illustrate the occurrence of unusually high pressures in the Scotia Sea. (In millibars.)

Station	Signy Island		Stanley		Stanley		Admiralty Bay		Signy Island		Stanley		Signy Island	
Date/Time	06/1400		08/1400		10/1400		10/1700		11/1400		12/1400		12/1400	
Height	dd	ff	dd	ff	dd	ff	dd	ff	dd	ff	dd	ff	dd	ff
1	34	05	04	20	09	26	34	02	19	09	08	17	24	07
2	30	11	02	15	08	27	24	11	18	13	08	15	21	11
3	29	13	02	15	08	28	24	21	20	17	07	14	21	14
4	27	11	02	15	08	31	24	19	19	21	07	15	20	17
5	25	09	03	15	09	33	25	15	19	24	07	18	20	23
6	25	09	02	18	09	33	23	14	20	25	07	15	20	27
8	22	07	02	20	09	31	25	11	19	28	08	16	19	29
10	18	15	03	18	09	28	24	14	20	23	08	20	18	31
14	18	21	03	19	09	35	24	21	21	19	06	26	19	33
18	17	29	01	15	08	28	25	25	22	17	07	27	18	32
20	17	33	01	15	08	25	26	20	22	19	06	26	19	21
24	15	37	02	15	07	20	25	23	22	18	06	30	19	53
27	16	39	03	15	07	15			23	08	06	36	19	44
30	15	38	04	21	06	12			22	13	05	46	20	37
35	16	41	03	20	03	07			22	22	05	43		
40			35	15	32	09			25	23	36	11		

TABLE II. Upper winds during the anticyclone of June 1952.

Time is G.M.T. Height in thousands of feet. Direction (dd) in tens of degrees and force (ff) in knots. Winds at Stanley obtained by radar tracking; other winds by pilot balloon ascents.

The upper air soundings at Stanley showed the characteristics of a warm anticyclone; notable features are the tropopause level of over 36,000 ft. from 7th to 11th June, and the shallowness of the surface layer of cold air (Figure 4). At Signy Island, South Orkneys, on at least two days (6th and 11th June) the tropopause appeared to be above 35,000 ft., as indicated by the upper winds (Table II). On 8th June cyclogenesis occurred in the col along the Patagonian coast (Figure 3b), and by 10th June (Figure 3c) this depression had developed into a deep and extensive circulation affecting eastern Argentina and Uruguay as far east as 35° W.; the east to west extent of the depression was some 1,200 nautical miles, and from north to south about 900 miles.

On 10th and 12th June (Figure 3c and d), the cold fronts crossing Graham Land and the South Orkneys were relatively weak, and there was evidently a lack of deep cold air capable of breaking down the anticyclone. Moreover, during the first few days of the period, the Pacific sub-tropical high penetrated unusually far to the south and east over Argentina, and it is possible that warm air was being fed to the anticyclone from the north.

Another factor contributing to the maintenance of this intensive anticyclone may have been the cyclogenesis to the north, for without the formation of such a deep depression, the anticyclone might well have moved to the northeast early in its development. Lamb (1952) has concluded that a stable anticyclone in south polar regions may well be persistent since there is little likelihood "of any deep colder airmass existing outside the anticyclonic area". However, in the situation just described, surface temperatures are not particularly low. It is believed that the pressure maxima quoted are the highest yet recorded in and around Antarctica. Court (1949) has tabulated many earlier observations, the highest of which is 1030.5 mb. at Commonwealth Bay, Terre Adélie in 1912. At Macquarie Island on 24th June 1948, a pressure of 1035.3 mb., reduced to mean sea level, was recorded.

The upper-air soundings at Maudheim during 1951 and 1952 have shown that at all seasons a strong zonal circulation is not a predominant feature. Lamb (1949) points out that "meridional transport does sometimes occur, even at great heights, and it is suspected that the anticyclones over the South Polar plateau depend upon occasional instances of such transport for their formation. The composite picture of atmospheric circulation which this implies suggests that the manner of formation of the antarctic continental anticyclones is similar to that of anticyclones in high northern latitudes, and yet explains why they seldom

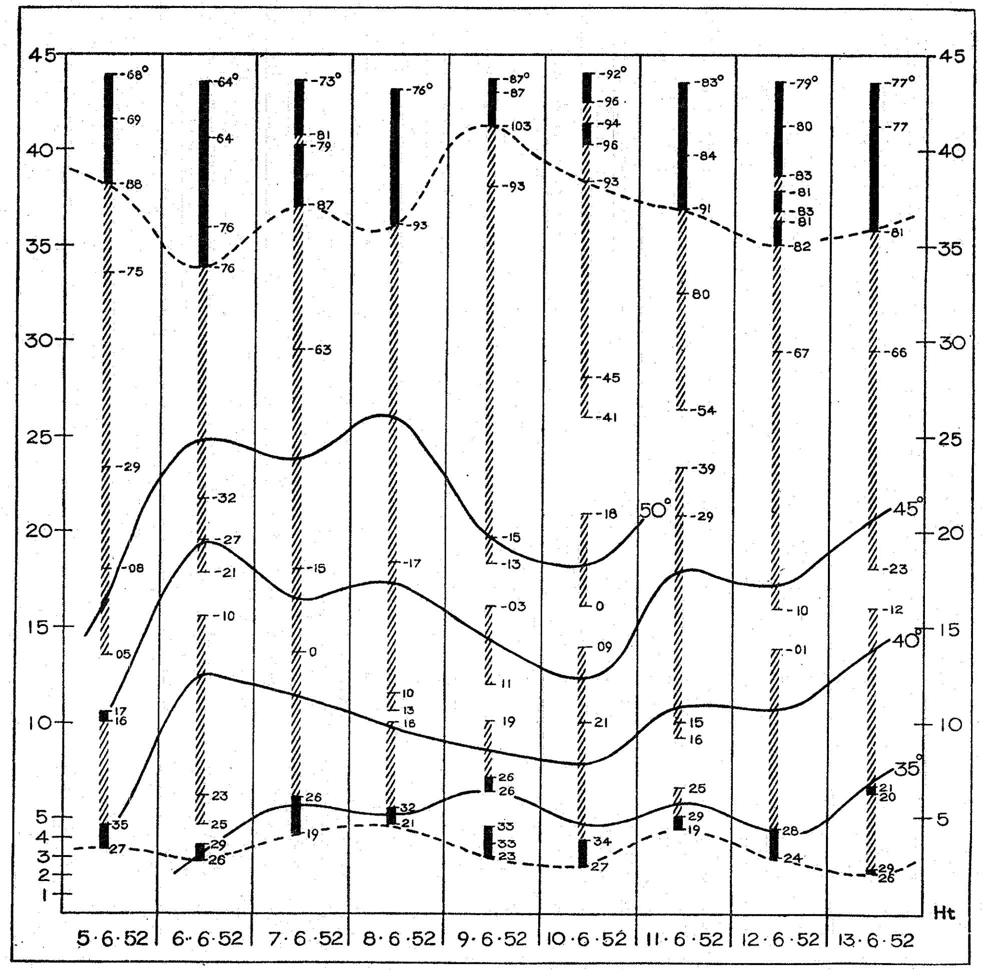


FIGURE 4. Aerological cross-section through the anticyclone of 5th to 13th June 1952, from upper-air soundings at Stanley.

Tropopause level and subsidence surface.

Isopleths of wet-bulb potential temperature.

Stable layers

Inversions and isothermal layers.

Heights are given in thousands of feet, and temperatures in degrees Fahrenheit; each sounding terminates at 150 mb.

reach the intensity of their northern counterparts." Part of the evidence for this transport of warm air aloft, is the fact that ridges and anticyclones observed in high southerly latitudes may have a relatively high tropopause (exceeding ten kilometres) characteristic of warm anticyclones, and this is confirmed by Schmitt (1952b).

The outbreak of anticyclones from the continent takes place in "those areas where anticyclonic lobes or cells form during moderate or low-index conditions" according to Court (1951), and other authors have suggested similar outflow paths (Figure 5). From an analysis of southern hemisphere weather charts (South African Weather Bureau, microfilmed copies) for 1951, the regions of recurring higher pressures around the edge of the continent have been determined (Figure 6), and these should be compared with the outflow paths given in Figure 5. In Figure 6 only a month's observations, representative of each season, have been

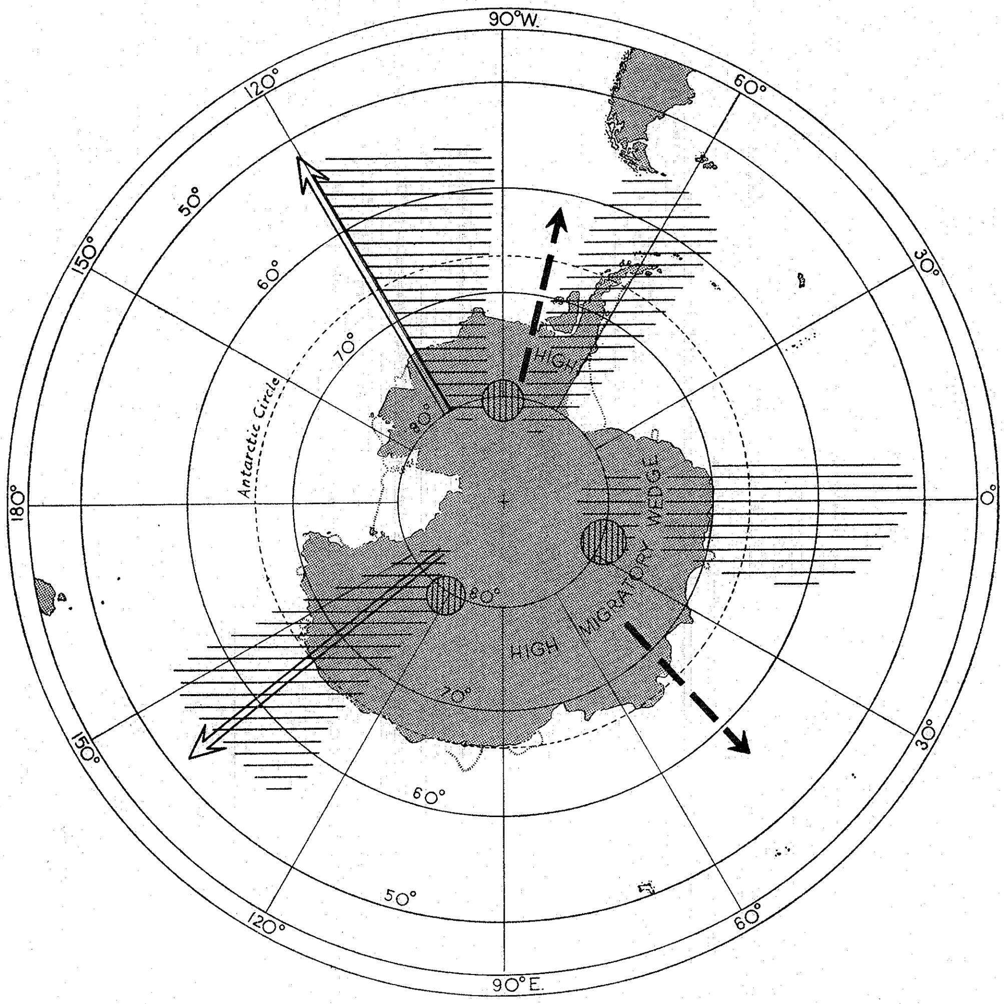


FIGURE 5. The Antarctic Anticyclones.

net outflow from "areas where anticyclonic lobes or cells form during moderate or low index conditions" (Court, 1951).

cells of the south polar anticyclone representing persistent outflows of cold air.

HIGH semi-permanent wedges of high pressure (both after "Operation Highjump" meteorologists; see Court, 1951).

suggested centres of mean sea level pressure greater than 995 mb. (Lamb, 1948).

regions of preference for outbreaks of deep cold antarctic air (Schmitt, 1952b).

examined in detail, and therefore only tentative conclusions may be drawn. In each season the preferred outflow of anticyclonic air lies between 60° and 150° E.; here the Antarctic continent extends well north of 70° S., and probably forms the major region of anticyclogenesis. Another outflow path appears to lie between 120° and 150° W. during the summer and autumn, although in winter and spring the greater frequency of high pressures is found farther to the east in the sector 90° to 120° W.; only in the latter seasons is there any real outflow from the Ross and Weddell Seas.

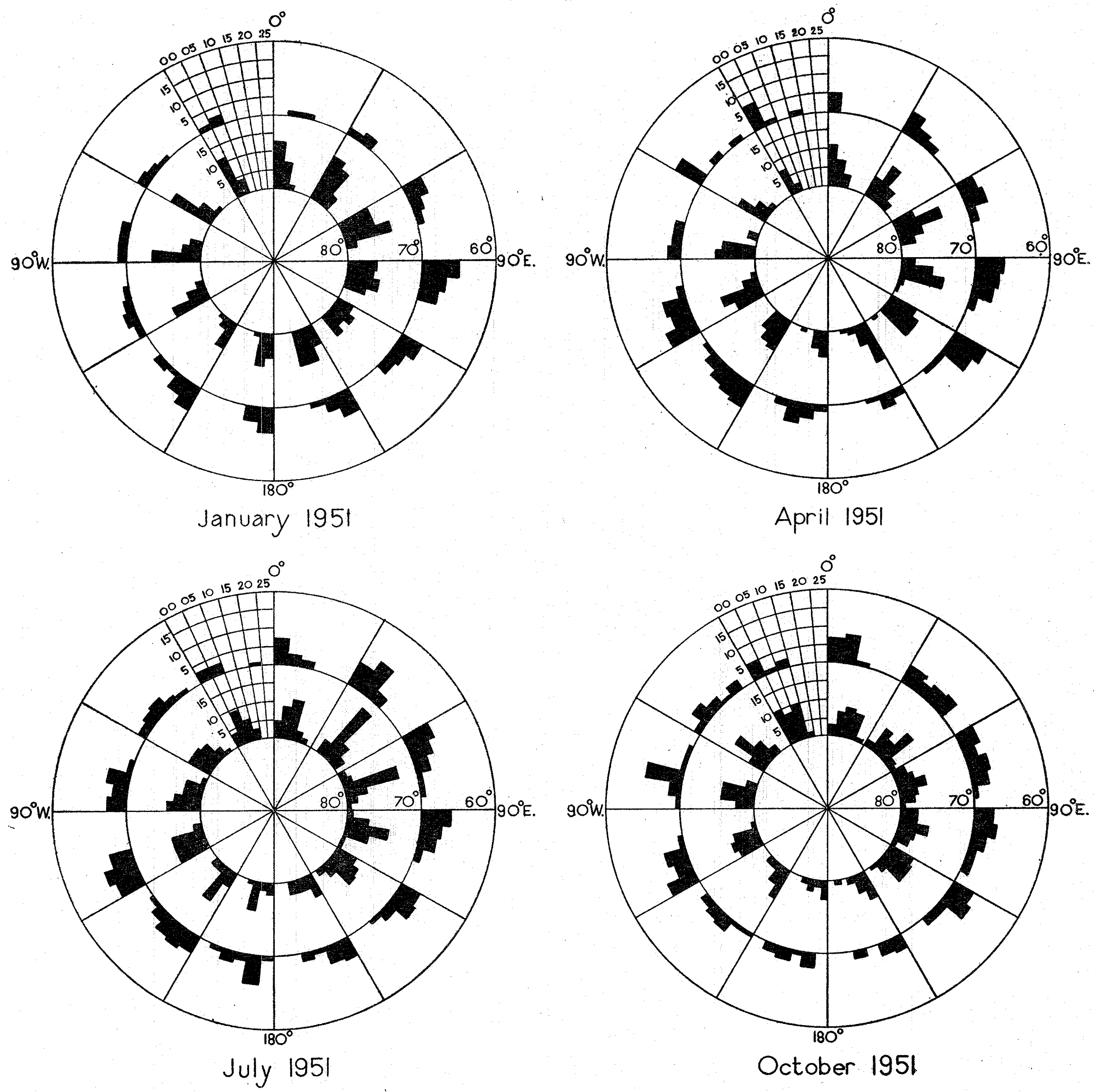


FIGURE 6. Frequency of occurrence of higher pressures between 60° and 80° S., arranged in 30° sectors of longitude.
Radial scale of histogram—no. of observations from 1200 G.M.T. charts.
Circular scale —maximum value of isobars in sector (less 1000 mb.).

V. AIR MASSES

a. Classification

Court (1951) has summarised the findings of several authors on the air masses of higher latitudes in the southern hemisphere, and notes that "there seem to be three such [antarctic] masses: continental antarctic (cA) in the interior, transitional antarctic (nA) along the coasts, and maritime antarctic (mA) over the pack ice and the ocean south of the pressure trough, convergence zone or antarctic front. To the north is a vast mass of maritime (mP) air." He also notes with some point that "proof of the existence of these masses, and better definitions and criteria, must come from meteorologists drawing regular synoptic maps of extensive antarctic and sub-antarctic areas".

At South Georgia and Stanley it was assumed that three air masses and their modifications (transitional types) were present, and frontal analyses were based on this assumption. Monthly mean surface temperatures for each air mass were obtained from the four main daily observations (Table III), and were considered to be representative except under calm anticyclonic conditions in winter. At South Georgia föhn winds caused non-representative temperatures and these are shown separately in Table IV.

STANLEY, FALKLAND ISLANDS

Month	A	$_t$A	$_t$Pm	Pm	$_t$Tm	Tm
January	—	—	7.0	8.9	11.7	—
February	—	—	6.1	9.1	11.4	13.2*
March	—	—	4.0	7.5	9.5	13.3
April	—	2.7*	4.5	6.5	8.9	—
May	—	−0.5	2.1	5.3	8.3	—
June	—	−0.1	0.9	3.5	5.0	6.6
July	—	−1.9	0.5	3.6	3.4	5.0
August	—	−2.7	1.5	3.9	4.9	—
September	—	−1.5	2.2	4.5	4.3	—
October	—	0.7	3.2	5.7	7.1	—
November	—	1.3*	4.2	7.7	9.7	—
December	—	—	5.7	8.5	12.1	15.0*

KING EDWARD POINT, GRYTVIKEN, SOUTH GEORGIA†

Month	A	$_t$A	$_t$Pm	Pm	$_t$Tm	Tm
January	—	—	2.5	4.3	6.7	—
February	—	—	1.3	4.4	5.3	9.1
March	—	—	4.0	2.9	4.7	9.9
April	—	−5.7*	0.3	2.2	2.7	—
May	−4.0	−3.7	−1.1	0.6	2.3	—
June	—	−4.1	−2.1	0.5	3.0	7.0
July	−11.7*	−5.8	−2.0	1.1	1.5	—
August	—	−4.8	−2.1	−0.5	−1.0	—
September	−6.3	−4.0	−2.1	−0.1	2.0	—
October	—	−2.5	−2.4	0.6	2.7	—
November	—	−1.3	0.1	1.5	6.6	—
December	—	—	3.7	3.1	5.7	10.3*

SIGNY ISLAND, SOUTH ORKNEYS

Month	A	$_t$A	$_t$Pm	Pm	$_t$Tm	Tm
January	—	—	0.3	1.7	4.1	—
February	—	—	0.1	1.7	5.5	—
March	—	−5.7	−0.8	0.9	3.7	—
April	−10.5	−6.0	−0.1	0.7	3.5	—
May	−18.5	−9.6	−3.7	0.1	2.0	—
June	−17.7	−9.6	−3.9	−0.1	2.0	—
July	−18.7	−10.9	−3.9	−1.4	0.7	—
August	−19.8	−9.2	−2.7	−0.2	1.0	—
September	−16.6	−9.1	−3.3	−0.3	2.7	—
October	−11.7	−8.7	−3.0	−0.1	2.4*	—
November	—	−5.9	−2.4	−0.1	3.7*	—
December	—	—	−0.9	1.1	3.3	—

* Few representative observations.

† N.B. Air mass temperatures at this station are often considerably modified by local föhn effects; such modified temperatures are not included in the above table (see Table IV).

ADMIRALTY BAY, KING GEORGE ISLAND, SOUTH SHETLANDS

Month	A	$_{t}A$	$_{t}Pm$	Pm	$_{t}Tm$	Tm
January	—	—	0.3	2.0	4.9	—
February	—	—	0.2	2.2	3.9	—
March	—	−6.3	−2.1	1.1	3.3	—
April	−8.9	−5.1	−0.9	1.3	4.3	—
May	−13.7	−6.9	−3.3	0.3	1.3	—
June	−13.8	−7.7	−2.7	0.3	1.6	—
July	−15.1	−7.5	−4.4	−1.1	0.3	—
August	−15.5	−9.9	−3.7	−0.3	1.0	—
September	−7.9	−7.4	−2.9	−0.6	—	—
October	−9.2*	−6.1	−2.9	−0.1	1.1	—
November	—	−3.7	−1.7	0.1	2.4*	—
December	—	—	−0.7	2.0	3.2	—

DECEPTION ISLAND, SOUTH SHETLANDS

January	—	—	0.7	1.7	3.9	—
February	—	—	0.9	2.1	3.6	—
March	—	−5.5	−1.3	1.0	3.1	—
April	−9.2	−3.7	−1.9	0.8	3.4	—
May	−15.3	−6.6	−3.4	−0.1	1.5*	—
June	−12.7	−7.5	−3.1	0.1	0.8	—
July	−12.9	−8.3	−4.9	−1.7	0.0	—
August	−15.7	−9.7	−4.8	−1.5	1.5	—
September	−9.7	−7.5	−3.9	−3.9	—	—
October	−10.3	−6.1	−2.9	−0.2	1.0*	—
November	—	−3.5	−1.6	−0.3	2.0*	—
December	—	—	−0.1	1.5	3.3	—

ARGENTINE ISLANDS, GRAHAM LAND

January	—	—	−1.1	0.6	3.9	—
February	—	—	−0.9	0.7	2.7	—
March	—	−5.5	−2.2	−0.3	3.1	—
April	−8.4	−4.1	−2.9	−0.7	1.7	—
May	−12.7	−8.3	−4.3	−0.7	—	—
June	−17.9	−8.4	−4.3	−0.9	−2.0	—
July	−19.1	−12.0	−6.3	−3.3	0.5	—
August	−20.1	−11.1	−2.8	−0.5	—	—
September	−20.4	−13.3	−4.5	−1.9	—	—
October	−18.7	−12.8	−4.1	−0.7	2.3*	—
November	−9.8*	−7.1	−2.3	−0.3	2.5*	—
December	—	−4.5*	−1.1	0.7	2.4	—

SAN PEDRO, CHILE (Station No. 85896). 1951 only

January	—	—	—	10.3	12.5	—
February	—	—	—	10.4	12.5	—
March	—	—	—	8.7	11.8	—
April	—	—	7.0	9.0	11.1	—
May	—	—	3.0	6.1	9.3	—
June	—	—	2.0	4.7	3.8	7.0
July	—	—	5.0	4.0	7.0	8.5
August	—	2.0*	6.7	7.5	—	—
September	—	—	6.0*	4.1	7.6	—
October	—	—	5.7	6.0	7.7	—
November	—	—	—	8.4	6.0*	—
December	—	—	—	10.4	12.6	—

* Few representative observations.

EVANGELISTAS, CHILE (Station No. 85930)

Month	A	$_t$A	$_t$Pm	Pm	$_t$Tm	Tm
January	—	—	6.9	8.3	10.3	—
February	—	—	—	10.7	10.4	12.5*
March	—	—	5.0	8.2	10.5	—
April	—	—	5.9	8.2	9.8	—
May	—	0.8*	3.9	6.1	7.4	9.3*
June	—	—	3.4*	6.1	8.0	—
July	—	2.7*	—	3.1	—	—
August	—	—	3.5	5.5	—	—
September	—	—	4.2	7.1	—	—
October	—	—	5.3	6.7	9.0	—
November	—	—	5.1	6.8	8.5*	—
December	—	—	—	8.0	10.4	—

ISLA NAVARINO/UULAIA, CHILE (Station No. 85968)

January	—	—	5.3	9.7	12.6	—
February	—	—	5.7*	9.5	13.4	15.7
March	—	—	3.7	7.7	11.7	13.3*
April	—	1.3	4.1	7.9	11.7	—
May	—	−1.9	1.8	4.8	7.5	12.7*
June	—	−1.7	0.6	2.9	5.1	—
July	—	−3.8	−0.3	3.4	6.5	—
August	—	−1.0	1.7	4.6	—	—
September	—	0.0	1.7	5.0	8.2	—
October	—	−3.0*	3.2	6.7	8.2	—
November	—	—	4.3	7.1	8.8	13.7*
December	—	—	4.9	9.4	12.3	15.3

* Few representative observations.

TABLE III. Average values of air mass temperatures in °C. for 1951 and 1952 (calculated from four main daily observations).

KING EDWARD POINT, GRYTVIKEN, SOUTH GEORGIA

Month	A		$_t$A		$_t$Pm		Pm		$_t$Tm	
January	—	—	—	—	2.2	—	5.0	—	5.9	—
February	—	—	—	—	2.0	—	5.7	—	4.0	—
March	—	—	—	—	4.0	—	4.1	7.7	4.1	—
April	—	—	—	—	1.5	3.6	2.7	6.6	2.7	13.7
May	−4.0	—	−2.9	—	0.1	2.5	0.7	5.7	1.0	10.1
June	—	—	−1.8	—	−1.0	—	1.6	—	3.0	—
July	—	—	−3.8	—	0.0	—	1.8	—	−1.0	—
August	—	—	−4.8	—	−0.7	—	—	—	−1.0	—
September	−6.3	−3.0	−4.0	−0.4	−1.1	1.3	−0.2	4.1	2.0	5.5
October	—	—	0.7	−2.7	−2.9	0.3	0.5	2.3	0.7	6.1
November	—	—	−1.3	1.0	0.6	3.0	0.9	5.7	—	4.3
December	—	—	—	—	3.7	—	4.0	—	3.9	—

TABLE IV. Average values of air mass temperatures in °C. for 1951 (calculated from four main daily observations); the values in the right-hand columns of each air mass were recorded in föhn winds.

b. Antarctic Air (A)

Recent work indicates that the concept of a permanent glacial anticyclone is untenable; nevertheless it is possible for a large mass of air near the surface of the continent and ice shelf to remain undisturbed for several days or longer, and during this period outgoing radiation and reflection from the snow surface will cause marked cooling and drying of the air. In the winter and spring months, the source region of antarctic air is greatly increased in area by the northward extension of the fields of consolidated pack ice, more particularly in the Bellingshausen, Weddell and Ross Seas. Gentilli (1949) has calculated the summer area of the source region to be about 8 million square miles; in winter this increases to 11 million square miles.

Serra and Ratisbonna (1942) define the source region of antarctic air as the area within "the isotherm of −2° C. at the surface of the sea in the warmest month (limit of the permanent ice-belt)". In the Falkland Islands Dependencies sector, particularly in the region east of Graham Land and to the south of South Georgia, the mean monthly isotherm for 28° F. shows an annual variation of latitude of about 5°, and this is correlated with the seasonal movement of the pack ice (Pepper, 1954).

c. Polar Maritime Air (Pm)

The zonal configuration of the mean sea-level isobars between 40° and 55° S. has already been noted, and consideration must be given to the surface temperature distribution in this region.

Surrounding the Antarctic continent between 50° and 60° S. is a zone where cold antarctic water meets warmer sub-antarctic water to the north. A sudden increase in sea-surface temperature of about 2° C. is experienced, usually in a short distance, when crossing this zone. This surface discontinuity is called the "antarctic convergence" by British and American hydrographers, and the "oceanic polar front" by the Germans; it results both from the circulation imposed by the prevailing westerly winds to the north, and from the convectional forces in the ocean arising from the difference in density between cold antarctic water, and warmer water farther north. The north-easterly trend of the convergence between 80° and 30° W. may be attributed both to the north-easterly movement of the bottom current from the south-west corner of the Weddell Sea, and the deflection imposed by the northward extension of the Graham Land peninsula.

Between 35° and 45° S. in the Southern Ocean, a second sharp increase in surface temperature occurs at the northern limit of sub-antarctic water. Here the sharp change depends on surface currents rather than on deep water movements, and may be two or three times as much as the change across the antarctic convergence.

Both periodic and non-periodic fluctuations in the position of the convergences have been recognised by the hydrographers of the Discovery Committee, and Deacon (1945) has stated that "frontal conditions [between water masses] can be compared with those between two air-masses, and it must be supposed that disturbances corresponding to depressions and occlusions, though on a smaller scale, are just as frequent. Changes in the wind direction north and south of the convergence are probably the chief causes of the fluctuations, and the front is probably of sufficiently low stability to allow irregular waves to develop very readily in the boundary surface." Such fluctuations may mask the "frontal" character of the convergences, and this is pointed out by Lamb (1949) who made ocean transects whilst steaming to and from the whaling grounds in the Southern Indian Ocean (approximately 35° S. 18° E. to 55° S. 35° E.): "identification of the classical temperature discontinuities known as the sub-tropical and antarctic convergences from these observations would be difficult; the curves suggest rather a varied situation with three well marked discontinuities passed on the southward voyage in November, and no major but several minor discontinuities on the return voyage in April".

Deacon (1945) recognises the antarctic convergence as a climatic boundary, and postulates that "the relations between the sea and air are more straightforward in the southern hemisphere, and the not very distant future may show whether antarctic, sub-antarctic and sub-tropical air-masses can be distinguished with the same confidence as the corresponding water-masses, and whether the convergences are paralleled by air-mass fronts possibly with some relations to the high levels like that of the antarctic convergence to the deep levels".

The prevailing westerlies between latitudes 45° and 55° S. tend to move along the isotherms of the underlying sub-antarctic zone of surface water, producing an air mass of polar maritime character. A situation particularly favourable to this development occurs when a large sub-tropical anticyclonic cell is moving slowly eastwards, though under these uniform conditions there is no sharp distinction between tropical and polar maritime air. In the southern portion of the low pressure trough surrounding the continent, air masses move northwards from ridges of high pressure or separate anticyclonic cells to the south; these are directed against the pronounced gradient of surface temperatures, and have their properties rapidly transformed.

d. Tropical Maritime Air (Tm)

In the centre of the sub-tropical anticyclones the air is stagnant and the encircling currents are divergent. The properties attained by the central mass of air will be spread laterally, and horizontal homogeneity over large areas will result; subsidence in the central region of the anticyclone will stabilise the air mass. This type of air is usually "transitional" when it reaches the Falkland Islands and South Georgia. At the South Orkneys, and along the coasts of Graham Land, this transitional type may be encountered in many months of the year, though it is rapidly modified as it moves farther south.

Old tropical storms in the Pacific and Indian Ocean sectors may move south-eastwards into the zonal circulation of the westerlies, and tropical air from this source may reach as far as 60° S. Lamb (1952, personal communication) states that tropical air is not always stable in the upper levels following storms in these sectors, for he has observed altocumulus castellatus in old Indian Ocean tropical air in latitude 60° S. in the cloud sequences accompanying a former tropical storm which had acquired frontal structure.

Low Cloud Types	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total	Average amount oktas.
1	1	5	1	1	4	3	4	1	8	5	7	1	42	3.6
2a	13	7	13	3	2	1	2		1	1	3	1	47	5.6
2b	46	22	15	3	4	4	1	6	12	7	2	6	128	6.4
3	1	1											2	5.5
8	9	2			2	3	4	1	3			7	31	6.3
	70	37	31	7	12	11	11	8	25	13	12	15	251	

TABLE V. Number of observations (3-hourly) of convective low cloud types at Signy Island, South Orkneys for 1951.
Low cloud type 2 has been sub-divided in the table as follows:

2a—towering cumulus only (or predominating).

2b—towering cumulus cloud with much strato-cumulus, the latter type predominating, often covering most or all of the sky.

VI. TRANSFORMATION OF AIR MASSES

a. Antarctic Air

In the winter months, the average air mass temperature at Maudheim was −32° C.; this value was most representative of air cooled under relatively calm anticyclonic conditions. During blizzards the air temperature was much higher and this was probably due to the increased turbulence establishing a normal lapse rate of temperature in the lower layers. In this connection Schumacher (1952) notes that there is "a marked correlation between the wind speed and temperature. This became quite apparent when studying the values for July of both years."

With increased insolation in summer, surface cooling is less pronounced, and the increased absorption of radiation in the lower levels results in an air mass temperature of between −5° and −10°C. At this season too, the air mass must be relatively shallow, except where large scale geographical features favour its vertical development (e.g. the range of mountains in Queen Maud Land is an effective barrier to the outflow of antarctic air from the interior of the continent).

The type of air mass which results from the outflow of antarctic air from its source region will be determined by the extent to which heat and moisture become transferred along the vertical, and the effect of subsidence.

At the commencement of outflow from the source region, subsidence will exert the predominating effect. Over the consolidated pack ice, surface cooling will be less pronounced due to the conduction of heat from the warmer sea-surface beneath, but drying out of the surface air will continue. This will result in clear skies and marked mirage effects, especially where surface features enable cold air to accumulate readily. Over the sea, rapid uptake of moisture results in the formation of stratus or strato-cumulus clouds, and occasionally cumulus of the fair weather type. Frost smoke is not uncommon at the edge of the pack ice, and is occasionally observed when extensive leads appear in otherwise consolidated pack ice.

When subsidence exerts little influence on the air mass, increased turbulence will tend to establish a normal lapse rate of temperature, and heat and moisture can then be absorbed over a deep layer. Over the pack ice conditions will tend towards instability, but the lack of moisture will greatly limit the development of convective clouds.

Over the sea, conditions quickly become favourable for the development of instability, and strato-cumulus, cumulus, and cumulo-nimbus clouds will form and often result in heavy showers of snow; the degree of instability will depend on the difference in temperature between the sea and air, the trajectory of the air with relation to the sea surface isotherms, and the time during which surface heating has been allowed to operate.

For an average of three to four months during the period May to November, the South Orkneys, South Shetlands and the Argentine Islands are surrounded by close or consolidated pack ice, and in effect they become an integral part of the source region of antarctic air. This is shown in the tables of air mass data, in which air of antarctic origin first begins to affect the South Orkneys and the Argentine Islands in May, and the South Shetlands in June.

In winter, temperatures in antarctic air may be lower at Admiralty Bay than at Deception Island farther south; this results in part from the sheltering effect of the Graham Land peninsula when south-easterly or southerly winds are blowing from the Weddell Sea.

The Argentine Islands are often sheltered in the same way, and a reversed meridional gradient of temperature of as much as 4° C. may result.

During October and November, when the ice edge is generally retreating southwards, antarctic air may continue to affect South Georgia, the South Orkneys, and the Graham Land bases, though it is modified in its effect. This transitional antarctic air may also reach the South Orkneys in March, when the pack ice has retreated almost to its southerly limit, but only when a very strong west to east pressure gradient exists. The weaker gradients which occur in the summer months are usually not strong enough to permit a rapid transference northwards of antarctic air, and surface warming can then exert its full effect. Convective activity is slight, and strato-cumulus becomes the characteristic cloud type of this air mass, particularly at the South Orkneys. The frequency of occurrence of convective cloud types at the South Orkneys has been extracted from the observations made in 1951, and the data are shown in Table V. The greater frequencies of types 2, 3 and 8 in the summer months is correlated with the presence of open water about the islands; in the winter months convective cloud is infrequent, and generally stratus and strato-cumulus prevail.

Strong pressure gradients occasionally bring antarctic air to South Georgia, and minimum temperatures are then reached. Strong, gusty föhn winds usually accompany such outbursts of cold air at King Edward Point, and the surface temperatures are non-representative; transitional antarctic air may affect both the Falkland Islands and Tierra del Fuego. Surface heating results in marked instability, and cumulus and cumulo-nimbus clouds with showers of snow and hail are frequent; occasionally extended instability "fronts" occur.

Lamb (1949; 1952) gives several examples of convective instability observed over the Southern Ocean during the summer months. On 5th April 1947 a depression, emerging from the continent between 75° and 95° E., gave large cumulus and cumulo-nimbus clouds and squally showers some 200 miles off the coast. Also on 8th March, towering cumulus and alto-cumulus, with tops probably reaching 20,000 ft. over the coastal mountains in 114° to 116° E., were observed in presumably continental antarctic air in a stagnant situation. Lamb remarks that the ascents "dispel the idea that we can speak of a prevalent surface inversion over the cold waters of the far south, at any rate in the sector visited [Southern Indian Ocean], even in summer. Subsidence inversions between 2000 ft. and 4000 ft. were usually indicated in fine weather; at other times unstable air masses often separated by thin stable layers were common."

b. Polar Maritime Air (Pm)

A homogeneous polar maritime air mass is produced over the zones of surface water bordering the antarctic convergence when there has been a long flow of air parallel with the surface isotherms, and the seasonal variation of air mass temperature approximates to the average seasonal temperature change across the convergence. This change is about 3° C., from 1°–3° C. in winter to 4°–6° C. in summer. The average seasonal temperature differences in polar maritime air at the stations shown in the tables of air mass data are as follows:

Stanley	4.9° C.	Admiralty Bay	2.6° C.
South Georgia	3.7° C.	Deception Island	3.2° C.
Signy Island	2.2° C.	Argentine Islands	2.5° C.

The value for South Georgia is probably an over-estimate since air tends to stagnate in King Edward Cove, especially in air streams of polar maritime origin in the winter months. Maritime air from nearer the pack ice is termed transitional polar maritime air ($_t$Pm), and may have originated either as antarctic, polar maritime or tropical maritime air.

c. Tropical Maritime Air (Tm)

Air of sub-tropical origin occurs only at San Pedro in the winter months when anticyclonic cells come far to the south; the occluding of many warm sectors of tropical maritime air by the Andean massif probably explains why unmodified tropical maritime air rarely occurs further south than San Pedro.

When a cell of high pressure has moved across the continent of South America, it is often followed by a slow-moving trough, and this may become accentuated by the diurnal variation of pressure, particularly in the summer months. This invariably forms a strong north to north-westerly air stream which brings a modified form of tropical maritime air far to the south; this is extremely stable in the lower levels, and fogs and low stratiform cloud are prevalent. Over the open sea the air becomes progressively cooled under the inversion, and near the edge of the pack ice temperatures of −1° and −2° C. are usual. On windward coasts where sufficient uplift occurs, orographic rain may fall, and this results in temperatures a little above freezing. Fog is common in the sea area between the South Orkneys and South Georgia, and Vowinckel and Oosthuizen (1953) note that "the characteristic feature for the Weddell Sea sector is the predominance of weather types favouring high meridional components especially N. and N.W. situations which are both typical for fog conditions in different parts of the sector".

At Signy Island in the South Orkneys, enough orographic effect may be produced by the higher Coronation Island to the north to break the inversion and establish a normal lapse rate of temperature in the lower levels (Robin, 1949); occasionally a slight föhn effect is also produced. Weather conditions at the Argentinian base at Laurie Island may afford a useful comparison, for on 19th December 1951, the 1200 G.M.T. temperature at Signy Island was 6° C. greater than the temperature at Laurie Island in the same $_t$Tm air mass from the north. A similar breaking of the surface inversion is experienced at South Georgia when transitional tropical maritime air is moving from a west to west-north-west direction. Then a föhn wind results, and temperatures as high as 21° C. may be recorded at King Edward Point.

VII. Frontogenesis

a. The Principal Frontal Zones

The location of frontal zones will depend both on the temperature gradient and the wind or pressure field, and on the extent to which adjacent air masses become heated or cooled during the formation of fronts. Where a maximum gradient of temperature exists together with a frontogenetic wind field, and where air masses of very different origin are brought quickly together, a marked frontal zone will be found.

In the South American quadrant of Antarctica during the winter months, a maximum gradient of mean surface temperature occurs between the edge of the pack ice and the warmer water to the north of the antarctic convergence; the difference may amount to 6° to 7° C. in 200 miles in the Scotia Sea, between the South Orkneys and the Falkland Islands. During the summer months the gradient is less marked, averaging 3° C. over the same zone. Throughout the year the zone of maximum temperature gradient lies in the northern portion of the extended pressure trough surrounding the antarctic continent, and in the autumn and winter months the maximum frontogenetical effect is to be found in this region. The northward extension of Graham Land aids in frontogenesis, for the mean limit of the pack ice shows a marked northward trend in this sector of the Antarctic, and the temperature gradient to the north is increased.

In the spring and summer, when temperature differences are least, a strong deformative wind or pressure field is necessary for frontogenesis to occur; at this time of year the trough in the mean pressure field induced by the mountain ranges of South America and Graham Land is the active source of frontal activity. Many depressions reach the Chilean coast in an advanced stage, and it is assumed that the normal meridional temperature gradient may supply the thermal contrast necessary for frontogenesis to occur.

Deacon (1945) has speculated that the sub-tropical convergence may well be paralleled by an air mass frontal zone in the same region; here a surface temperature gradient of as much as 10° C. in one mile has been found.

The deformation field between the Atlantic and Pacific sub-tropical anticyclones occupies a mean position over South America between 35° and 45° S., and it has been assumed by Serra and Ratisbonna (1942) and later authors that the so-called Atlantic Polar Front originates here. Thence the front extends almost zonally, but eventually turns south-eastwards in mid-Atlantic towards the Antarctic continent. A similar polar front is found in the Pacific Ocean, and originates near the south-western edge of the sub-tropical anticyclone somewhere in the region of the Tuamotu group near Tahiti; the position of the sub-tropical convergence is uncertain in this area owing to insufficient observations. This distinction between the antarctic front and the polar fronts over the oceans is not maintained by Gibbs, Gotley and Martin (1952) for they assume that "the Antarctic Front, moving northward from the frontogenetical area [the coastline of Antarctica, or the edge of the pack ice] becomes the 'polar front' of the Southern Hemisphere. Wave development of a major depression, on nearing the Antarctic coastline, causes the outbreak of a fresh mass of Antarctic air with a new Antarctic Front as its forward boundary".

The vertical extent of the frontal zones will be determined by the mode of formation of each air mass. In tropical maritime air from the sub-tropical anticyclone, and polar maritime air formed in the northern part of the transitional zone under steady conditions, the vertical extent will probably reach a maximum. The depth of antarctic air is variable; in general, an air mass formed under stagnant conditions and cooled from below will be shallow relative to air of sub-tropical origin, especially in summer. As noted on page 15, however, bounding mountain ranges act as barriers to invading air masses, and enable a deep layer of cold air to accumulate. In winter, the observed temperature extremes and absolute temperature range at standard levels over the continent at Little America III (Court, 1951; Figure 2) show that pronounced cooling occurs at all levels, and the tropopause eventually disappears. Similar observations have been made over Queen Maud Land, and stratosphere temperatures as low as −90° C. have been recorded (Roots, 1952).

At all seasons, temperature changes at both continental and oceanic stations may be sudden and often extreme. Table VI shows the temperature differences between the warmest and coldest air masses which affected the Falkland Islands and bases in the Dependencies during 1951 and 1952; the cold air source of the Weddell Sea is indicated by the high values at Signy Island in the winter and spring months.

Month	Temperature differences in °C.					
	Stanley	Grytviken	Signy Island	Admiralty Bay	Deception Island	Argentine Islands
January	4.7	4.2	3.8	4.6	3.2	**5.0**
February	7.1	**7.8**	5.4	3.7	2.7	3.6
March	9.3	5.9	9.4	**9.6**	8.6	8.6
April	6.2	8.4	**14.0**	13.2	12.6	10.1
May	7.8	6.3	**20.5**	15.0	16.8	12.0
June	6.7	11.1	19.7	15.4	**20.7**	17.0
July	6.9	13.2	19.4	15.4	12.9	**19.6**
August	7.6	4.3	**20.8**	16.5	17.2	19.6
September	5.8	8.3	**19.3**	7.3	8.8	18.5
October	7.8	5.2	14.1	10.3	11.3	**21.0**
November	11.0	7.9	9.6	6.1	5.5	**12.3**
December	**9.3**	6.6	4.2	3.9	3.4	6.9

TABLE VI. Temperature differences between the warmest and coldest air masses affecting the Dependencies' bases in 1951 and 1952.
Highest values are in bold type.

b. Formation and Movement of Depressions

A cell of high pressure, after its migration across South America, may be followed by a trough which often becomes deep enough to bring a north to north-west transitional tropical maritime air mass over the Falkland Islands and South Georgia, and occasionally to the South Orkneys and South Shetlands; this trough may be aided in development by the diurnal effect of insolation. Coyle (1942) has noted this, and states that "there is significance in the fact that the cold air intrudes at the point between the high pressure cells of the Atlantic and Pacific Oceans, and . . . that a trough extends equatorward over the continent of South America, thus forming a likely corridor for passage of the cold air from its source region in Antarctica. Two main points of entry for cold air will be outstanding; one to the south directly, and the other to the south-west. Entry of air from the south-east is very rare." The whole area is favourable for cyclogenesis, and Palmer (1945) has observed that "young wave cyclones on the South Atlantic . . . Polar Front can frequently be detected in their early stages over the continent of South America".

In the area north and west from the Falkland Islands to the coast of Argentina, the mean surface isotherms are close together, and warm frontogenesis frequently occurs. A well-marked isallobaric low centred near latitude 50° S. on the Argentine coast, and the appearance over the Falklands of cirrus and cirrostratus followed by altocumulus and altostratus, are indicative of this frontal formation. Cirriform clouds at the top of the frontal slope may develop as far as 700 miles in advance of the surface front. The centres of the larger systems usually form to the west and south-west of the Falkland Islands, and rapid deepening may lead to a depression as much as 1500 miles across. The speed of these depressions may be as fast as 500 to 600 miles per day initially, but they appear to slow down quickly as they pass to the east of the South Sandwich Islands. Since the air masses involved are normally of great vertical extent, frontal effects are at a maximum. Vowinckel (1953) in summarising this recent work on depressions in the Southern Ocean states that "cyclogenesis clearly shows the paramount importance of the South American continent. The cyclone tracks of all regions are relatively similar, and the depressions move to the east-south-east towards the polar region, where they disappear in the sub-antarctic low."

Cold fronts are delayed over the western slopes of the Andes, and the period of precipitation is prolonged as the upper cold frontal surface steepens. The passage of the front across Argentina is usually indicated by rapidly rising pressure and gusty winds, and may be preceded by altocumulus and altostratus of warm frontal type. The specific humidity reaches low values, and dew-points are correspondingly low; dry-bulb temperatures may be increased by 8°–12° C. with adiabatic heating as the dry air descends to the plains. Partially occluded depressions passing through Drake Strait are usually quickly occluded as they pass eastwards; Schmitt (1953) notes that these "disturbances which reach Southern Chile and Tierra del Fuego can more easily be traced back to the cyclogenetic region of Tahiti". In the pressure trough over Argentina which accompanies these occlusions, frontogenesis often occurs, and the upper surface of the warm front, which is unaffected by the mountain barrier, builds down again to sea-level (Figure 7a and b).

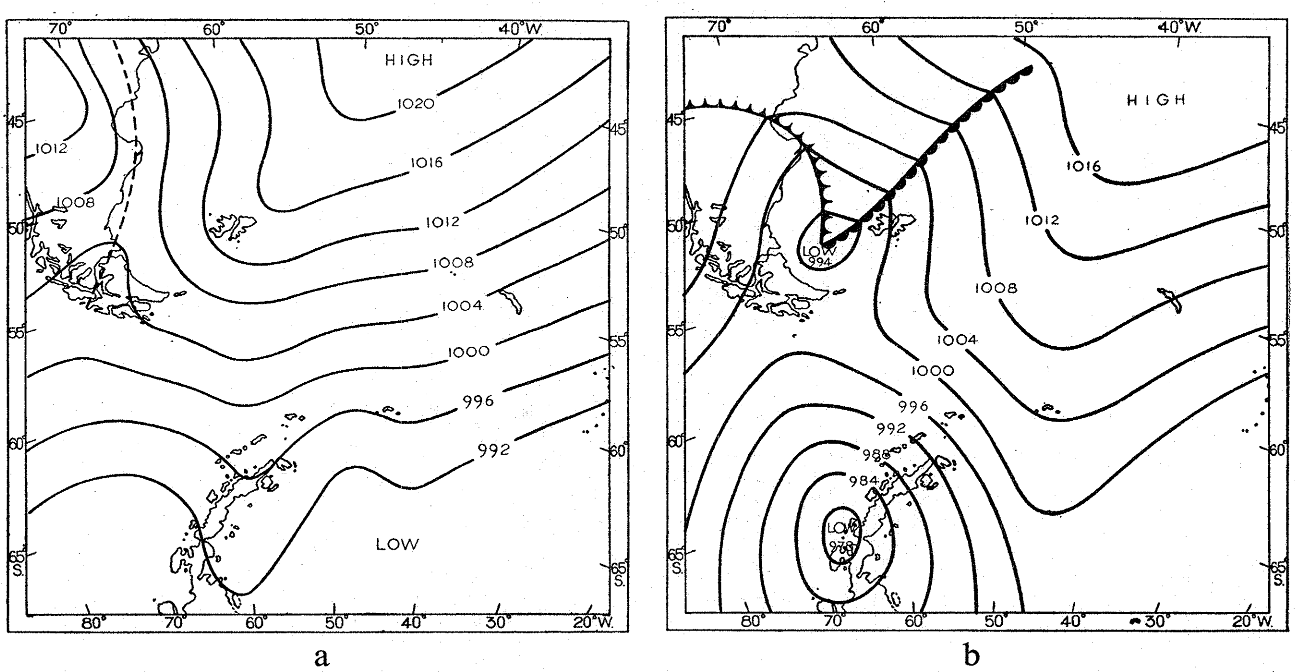


FIGURE 7. Warm frontogenesis after the passage of an old occlusion across Argentina. (In millibars.)

The Graham Land plateau also retards depressions approaching from the west, and cold frontogenesis takes place as the centre passes across the Weddell Sea. This effect is most marked in late autumn, winter and early spring, for in these seasons the area of consolidated pack ice extends northwards beyond the South Shetlands and South Orkneys, and the north to south temperature gradient across the area is at a maximum. When the pressure gradient is increased quickly from the north-west, and the isobars are aligned parallel to the mean surface isotherms, strong frontogenesis may occur. This situation often arises after a ridge from the sub-tropical anticyclone has pushed to the south down the west coast of Chile; pressures of more than 1020 mb. are not uncommon as far south as Tierra del Fuego even in midwinter. Serra and Ratisbonna (1942) note that a feebly developed thermal anticyclone forms over southern Brazil

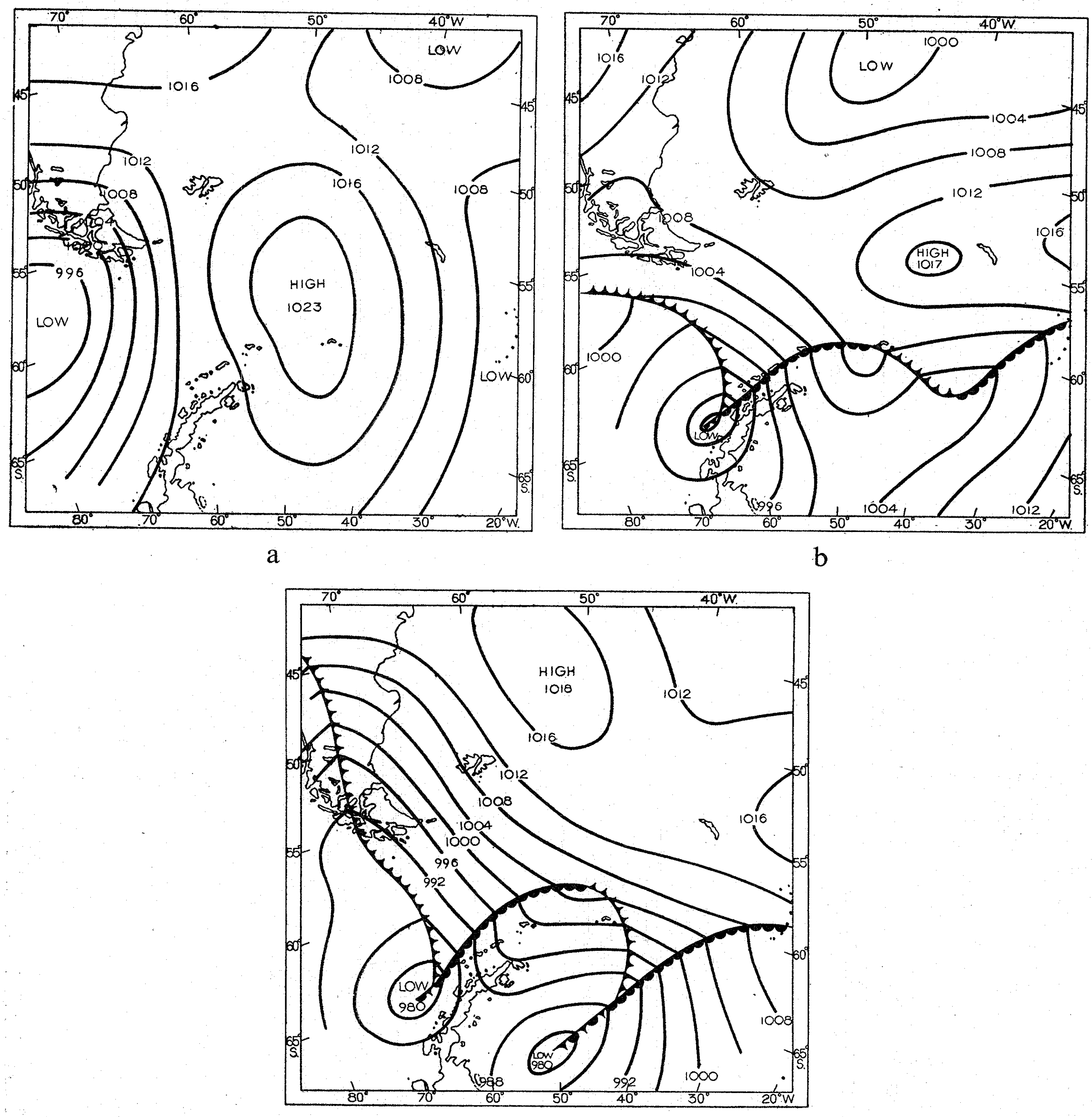


FIGURE 8. Wave formation on the antarctic front. (In millibars.)

and Uruguay in winter, and it appears that even farther south the relatively cold continent, in spite of its small area, does exert some influence on the mean pressure pattern. A marked ridge may develop to the south between the Falklands and South Georgia when such anticyclonic cells have moved away eastwards from the continent.

In winter, rapidly deepening waves are formed on the antarctic front and a "family" of three or four depressions is generally initiated, the first-formed centre seldom being the most active (Figure 8a–c). As the depressions move eastwards from Graham Land, often with speeds of 40 kt., further waving of the cold front may take place as fresh cold air is drawn up from the Weddell Sea. The cold fronts from these depressions may sweep up to the north of Argentina, and produce strong winds and line-squalls or *pamperros* (Figure 8c). Secondary cold fronts, appearing in the elongated pressure trough in the rear of the depression centre, may also affect Argentina in the same way. Cold fronts may affect northern Argentina in spring and summer, but pressure gradients are rarely so steep; the fronts move eastwards from Chile, and produce gusty and often dust-laden winds with little or no precipitation. In the summer, the frontal trough accentuates the thermal low over northern Argentina and thunderstorms are common. The antarctic front is less active at this time, and depressions which form to the west of Graham Land, and in the South Shetlands and South Orkneys area, are usually weak; they may become absorbed in the deeper trough which develops over South America.

At all seasons of the year, medium cloud layers are formed frequently over west Graham Land in slow-moving streams of polar maritime air from the west or north-west, and it appears that frontal lift may occur in the region of the antarctic convergence. A quasi-stationary front, giving medium cloud types, may form in a similar way between South Georgia and the South Orkneys.

Although depression tracks appear eventually to follow the zone of maximum temperature gradient between the pack ice and the antarctic convergence, they may be deflected far to the north or south by neighbouring pressure systems.

B. THE WEATHER OF SOUTH GEORGIA

(with special reference to King Edward Point, Cumberland East Bay)

I. Modification of Air Masses Affecting the Island

The characteristics of the principal air masses affecting South Georgia have been described in sections V and VI, but the more local effects have yet to be considered.

a. Antarctic Air (A and $_{t}$A)

Where subsidence exerts the predominating effect (e.g. from a ridge of high pressure extending northwards over the Weddell Sea) low stratus cloud prevails; precipitation is slight and may be sufficiently localised to give the impression of showers. Where subsidence is less marked, several stratiform layers are formed, and often a chaotic sky results. Where there is little subsidence and a strong meridional circulation (e.g. after an extensive depression has moved across the area and is slowing down to the east), marked instability occurs, and convection may reach to great heights. This is frequent in winter, and extended instability fronts may give periods of two or three hours' continuous precipitation; anvil cirrus is sometimes observed in association with such convective clouds.

b. Polar Maritime Air (Pm and $_{t}$Pm)

Instability is less marked in air of this origin, but showers may become frequent if the trajectory has much of a southerly component. In polar maritime air from a northerly source, stratiform cloud is predominant and may be accompanied by extensive fog-patches. If there is strong subsidence, especially in ridges extending far to the south from the sub-tropical anticyclones, low cloud may not form but fog-patches still occur. In the summer and early autumn months, when pressure gradients are weak and sea and air temperatures are at a minimum, stratiform cloud may persist for long periods until further cyclonic activity brings in new air masses.

c. Tropical Maritime Air (Tm)

Low stratiform cloud and extensive areas of fog are prevalent in this air mass, except when subsidence is very strong.

II. WIND

Since topography plays a large part in determining local conditions at South Georgia, a description of the land surrounding Cumberland East Bay is included (Figure 9).

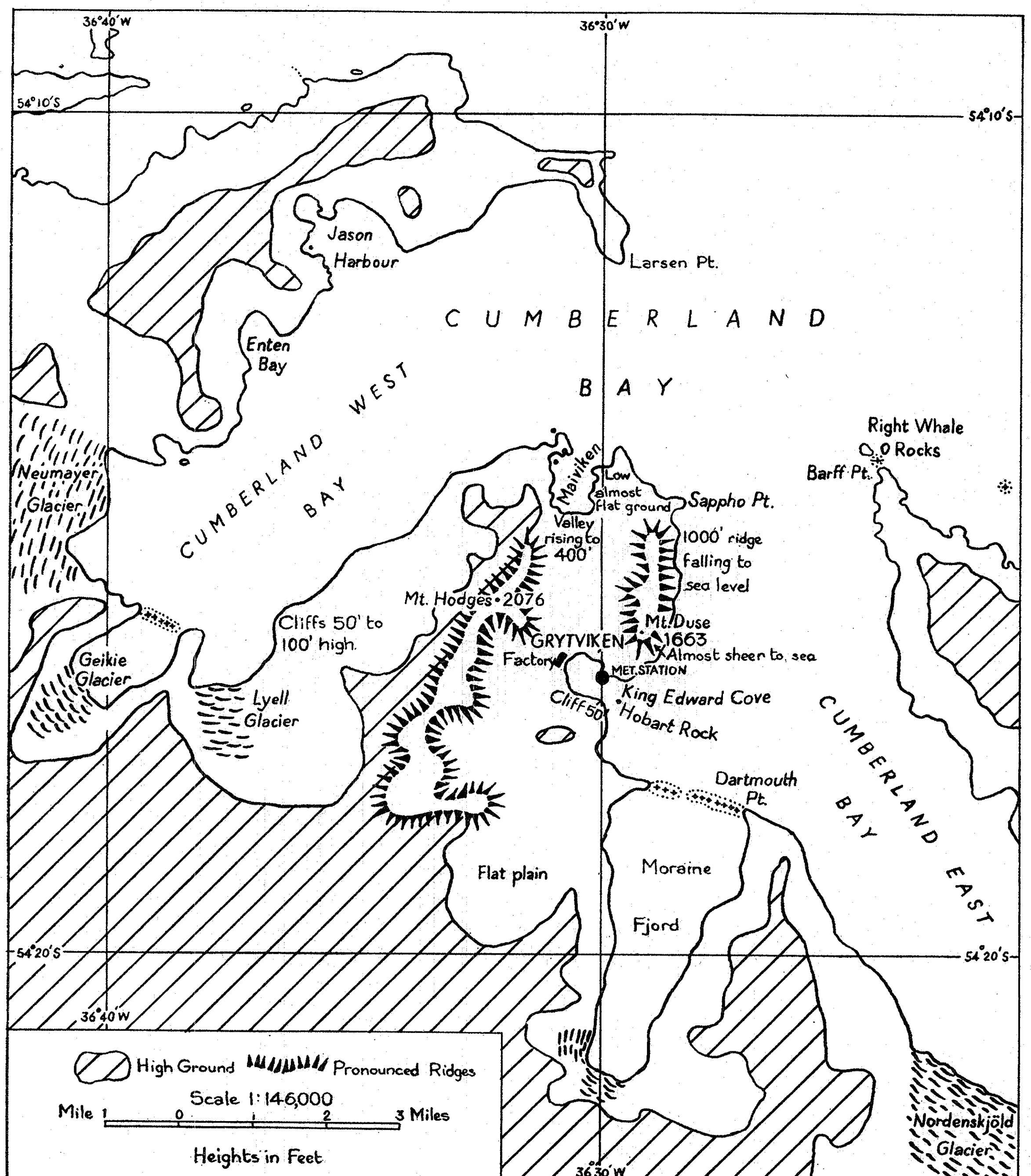


FIGURE 9. Topography of Cumberland East Bay, South Georgia.

From north-east through west to south-east, the ground rises quickly to high peaks, ranging from Mount Duse (1663 ft.) due north, to Mount Hodges (2076 ft.) in the west; then to Mount Sugartop (7623 ft.) to the south-west. Ten miles to the south is the main peak of the Allardyce Range, Mount Paget (9625 ft.); from east to south-east is the open water of Cumberland East Bay flanked by high peaks (2000 ft.) at a distance of four to five miles.

When the gradient wind is between west-north-west and south and is stronger than 15 kt., warm gusty föhn winds result; their onset is sudden, and the temperature may rise extremely quickly as the cold stagnant air in King Edward Cove (Grytviken) is swept away. For example, there was a temperature rise of 10.5° C. in 30 minutes on 19th January, and 12.2° C. in 10 minutes on 17th April 1951 (see Figure 10a and b). Föhn winds occur in antarctic, polar maritime and tropical maritime air masses and the greatest average rise in temperature has been recorded in transitional tropical maritime air (Table IV). Specific humidity and dew point are occasionally very low (R.H. of 5 per cent on 19th January 1951), and tables of hygrometric data may be necessary for computing relative humidities since extreme values cannot be covered by the present Bilham Humidity slide rule (Mark III).

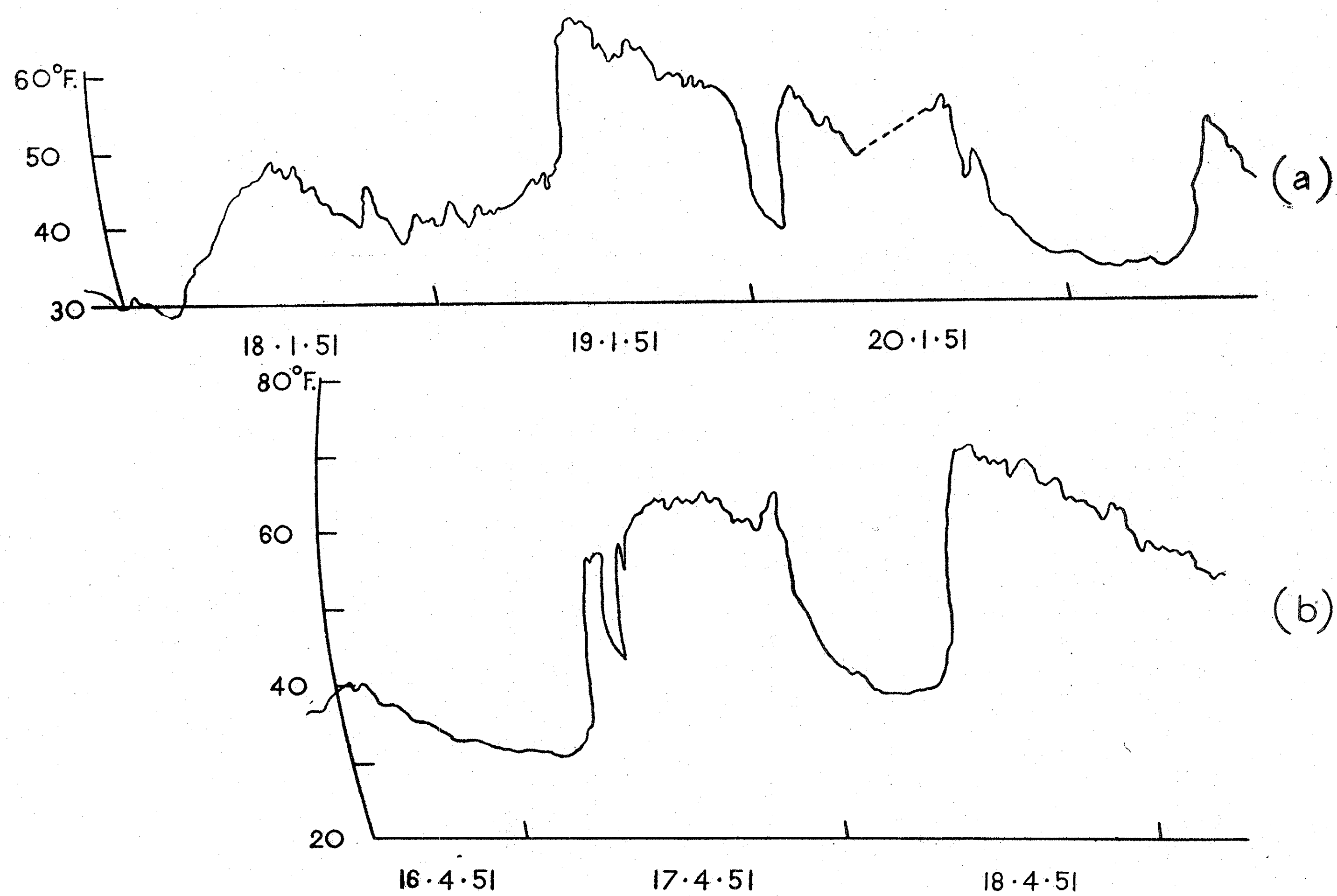


FIGURE 10. Distant reading thermograph traces showing temperature rises in föhn winds.
(a) polar maritime air.
(b) transitional tropical maritime air.

Marked funnelling of the true winds from these directions produces a west to north-west wind at King Edward Point, but a south-west wind results if the pressure gradient is steep and turbulence is marked. Föhn winds from the south are rare. Where subsidence causes a temperature inversion or wind-shear aloft, there may be light winds or a calm at King Edward Point, but as soon as a normal lapse-rate of temperature is established in the lower levels, a föhn wind results. In very unstable air streams, particularly from a southern quarter, strong gusts are frequent; the gradient wind to maximum gust ratio appears to be about 60 to 70 per cent. Pilot balloon ascents show that föhn winds are usually confined to the first 1000 ft. above the surface; at greater heights they veer and decrease quickly in speed. In moderately unstable airstreams the Allardyce Range acts as a barrier to cloud development, and to the north in the lee of the mountains the weather may be fair or fine as far as 50 miles from the coast. The presence of convective activity on the windward side of the mountains is shown by a compact bank of orographic cloud which envelops all the higher peaks in the range; increased instability results in shower activity affecting leeward slopes as well.

Under more stable conditions in south to south-west air streams, surface winds in King Edward Cove are light and variable; a moderate northerly component is often found between 3000 and 6000 ft., and this appears to be a large-scale eddy in the general airflow across the mountains. In air streams with a south to south-east trajectory, föhn winds do not occur, and the surface wind at King Edward Point is calm or light and variable. In east to south-east air streams a true wind is experienced, but winds from this quarter are infrequent; they usually arise when an elongated trough in the rear of a depression centre has passed to the north. There is little gustiness, and temperature conditions remain uniformly low; diurnal variation of temperature remains at a minimum, since a complete cover of stratiform cloud usually prevails (Figure 11).

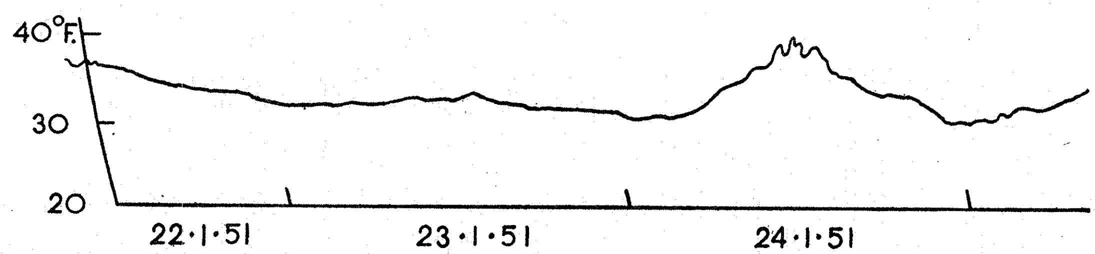


FIGURE 11. Distant-reading thermograph trace showing the effect of a continuous cloud cover on diurnal variation of temperature; the wind is south-easterly.

Gradient winds from east to north-east are generally deflected to east or south-east, but they are variable both in speed and direction; this distinguishes them from the steady winds produced locally in east to south-east gradients.

In air streams from north-east to north-north-west, calms or light variable winds are most common at King Edward Point. Air masses from the north are generally stable, and there is little or no turbulence in the lower levels. Observations suggest that in gradient winds greater than 20 kt., a calm area may form to windward of the main mountain range, which acts as a barrier to normal streamline flow. (For example, on 25th January 1951 the surface wind at 53° S. 37° W. was northerly force 7, yet it was calm in Cumberland East Bay which is exposed to winds from the north.) A further indication of northerly air is a line of very low stratus or fog patches moving along the east shore of Cumberland East Bay. On the few occasions when the airflow is turbulent in the lower layers, light winds from between north-east and north-west are produced at King Edward Point.

In air streams from west-north-west to north-north-west, a gusty variable wind from between north and north-west blows locally; relative humidity and dew point are little affected, in contrast to the low values observed in föhn winds produced in southerly air streams.

III. TEMPERATURE

During calm periods at King Edward Point, air in the cove stagnates. Under anticyclonic conditions with clear skies, the increased radiation results in minimum temperatures; this effect is greatest in winter when there is a complete snow cover, and no insolation reaches the station. At night time a katabatic wind may blow, but it never exceeds 5 kt. During the spring and summer months, when snow is absent from the lower ground, the land may become sufficiently heated for a sea breeze to set in; this causes many small fluctuations in the temperature as the cool air moves in from the sea (Figure 12). The estimated height of the snow line on the north coast of South Georgia is about 2500 ft. in midsummer.

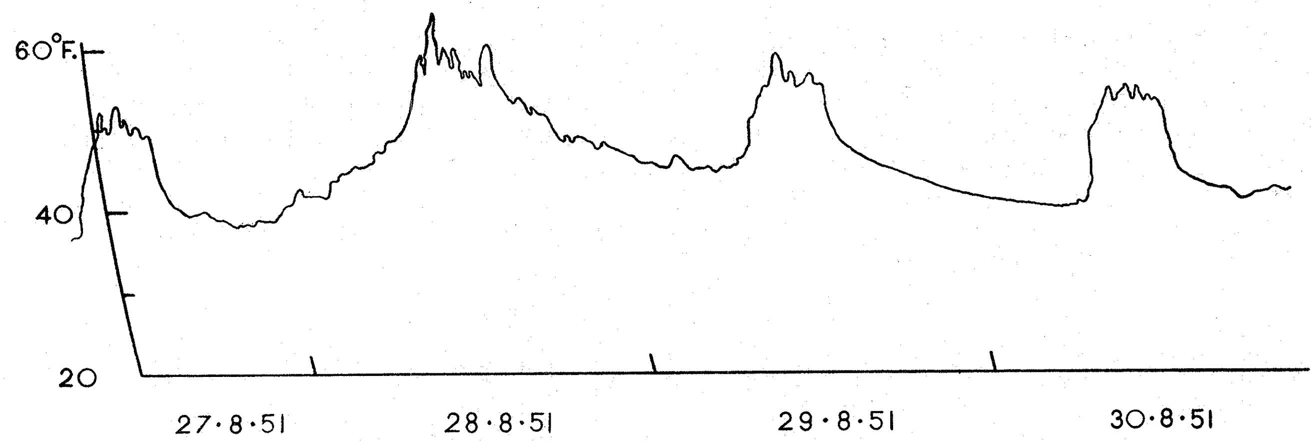


FIGURE 12. Distant-reading thermograph trace showing the effect of insolation during anticyclonic conditions in summer; fluctuations about the maximum temperature show that a slight sea breeze is blowing.

Temperature inversions produced under "radiation skies" are often plainly marked by smoke from the chimneys of the whaling station at Grytviken. The inversion level generally lies between 800 and 1500 ft., and the smoke spreads out horizontally at this level.

IV. Frontal Effects

Warm fronts associated with extensive depressions forming in the Argentine pressure trough during the spring and summer months usually show a full sequence of cloud types, since the air masses forming the frontal surface have normally a great vertical extent. As the gradient wind in advance of the front backs from north-west to north-east, the wind speed at King Edward Point decreases and becomes light and variable or calm. Snow falling under these conditions is loosely packed, and can easily drift in the gusty winds which may follow the passage of a cold front. Precipitation from warm fronts may be prolonged, and it has been observed to commence as far as 400 miles ahead of the depression centre; in such situations a preliminary warm front probably precedes the main front, but its mode of origin is uncertain. The sharp transition of sea surface temperatures at the antarctic convergence may be a factor in aiding this preliminary frontogenesis. Warm fronts associated with the smaller but more intense depressions which form on the antarctic front in the winter months generally show a smaller cloud sequence, for cirrus cloud is often absent; the surface front is often preceded by a belt of fog from 50 to 100 miles wide.

When the isobars in the warm sector of a depression are aligned from north-west to south-east, the following weather sequence may be observed at King Edward Point: a light to moderate north to north-westerly wind blows, the sky partially clears of stratiform cloud, and the temperature and pressure show little change. If the depression is still deepening, the barograph trace will continue to show a fall. In most warm sectors the isobars are more nearly aligned from west to east, or from south-west to north-east; the warm air mass must then traverse the main ridge of the island before reaching King Edward Point, and this may result in a föhn wind which effects a surprising clearance of weather.

Cold fronts are more usually associated with föhn winds, for the air stream in the rear of the front often has a southerly component; the passage of the front is marked by a rise in pressure, generally accompanied by a rise in temperature and decrease in relative humidity, and local clearance of cloud. This is especially noticeable in air which has had a long trajectory southwards around a ridge from the sub-tropical anticyclone before affecting South Georgia from the west. When the air mass is very unstable, showers of rain or snow affect King Edward Point; in winter the air masses intruding behind secondary cold fronts are sufficiently unstable to give periods of two or three hours continuous precipitation.

V. Standing Waves

In stable air streams normal to the mountain range, a characteristic cirriform cloud sheet is formed. This extends parallel with the mountains at a distance of two to five miles, and has a sharply defined, apparently rolled-up inner edge. In air streams flowing across the mountains at an angle to the normal, the cloud becomes separated into several lenticular elements. At medium heights, parallel bands of altocumulus, extending up to 15 miles from the mountains, may form in the same way. The most commonly recurring clouds at this level are "whalebacks" (Shackleton, 1909; Appendix V). They are small lenticular clouds with a laminated structure and are often linked in pairs by a narrow neck; they are usually observed in the ridge of high pressure intruding behind a cold front. "Whalebacks" are more common in air of southerly origin, whereas the higher form at cirrus levels occurs in similar situations but in air of polar maritime origin; this may show the relative shallowness of antarctic air.

C. SUMMARY

IN January 1950, a forecasting service for local and pelagic whaling factories was started at South Georgia. Weather observations from the bases of the Falkland Islands Dependencies Survey, the Falkland Islands and South America, together with a small number of ships' observations, formed the basis of the analysis.

The principles of weather analysis based on northern hemisphere practice were successfully applied to the chart sequences for this small sector of the southern hemisphere. The limited scope of the analyses prevented more than a broad generalisation of southern hemisphere circulation being made, and the findings of recent authors have been summarised in order to complete the account. Subsequent observations on the preferred paths of anticyclonic outflow from the Antarctic continent, and the blocking effect of separate cells of high pressure, have shown that the strong zonal circulation of the westerlies may become considerably weakened, particularly during autumn and winter. Meridional transport of air, even at great heights, suggests a similar mode of origin of the polar anticyclones in both hemispheres.

The main features of wind and water circulation favour the production of three types of air mass: antarctic air formed over the continent and ice-shelf, polar maritime air formed over the sub-antarctic surface water in the zonal westerlies, and tropical maritime air from the sub-tropical anticyclones. Monthly mean surface temperatures for these air masses were obtained for eight southern stations. The cold air source of the Weddell Sea is apparent from the data for Signy Island in the South Orkneys.

Rapid modification of air masses occurred particularly with strong meridional gradients; the antarctic convergence was believed to accentuate the effects. The most pronounced changes occurred in cold antarctic air which was moving northwards, and marked instability was common in this air mass. The prevalence of north-westerly components in the circulation during the summer months gave stable air mass weather, and frequent fogs in the South Georgia–South Orkneys area.

The zone of maximum temperature gradient between the northern edge of the pack ice and the sub-antarctic water to the north of the antarctic convergence was recognised as the region of maximum frontogenesis in late autumn and winter. In late spring and summer, when temperature differences were least, frontogenesis occurred in the trough in the mean pressure field induced by the mountain ranges of South America and Graham Land.

Most new depressions in autumn and winter originated off the west coast of Graham Land, but in spring and summer the Argentine pressure trough caused more centres to form north and west of the Falkland Islands. Other authors regard the area between 35° and 40° S. on the east coast of South America as the origin of the Atlantic polar front, but few centres were located in this area on the charts examined because of the scarcity of ships' observations in the area between South Georgia and Rio de la Plata.

At King Edward Point, South Georgia, the topography caused marked local variations in the temperature, and wind speed and direction. Föhn winds were common when gradient winds from between south and west-north-west were blowing over the open sea, and very high temperatures were occasionally reached in transitional tropical maritime air. The only true wind direction recorded at King Edward Point was from east to south-east. Calms were frequent, and then air could stagnate in King Edward Cove. In winter, surface cooling and lack of insolation gave lower surface temperatures than were considered normal for the air masses concerned. In summer, in slack pressure gradients, enough surface heating of the snow-free lower slopes occurred to give weak sea breezes.

Characteristic cloud forms occurred in the lee of the main mountain range; standing waves were common in stable air streams, both at medium and high levels.

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E. REFERENCES

COURT, A. 1949. Meteorological Data for Little America III. *mon. Weath. Rev., Washington, Supplement* 48.

———. 1951. Antarctic atmospheric circulation. *Compendium of Meteorology*, Amer. met. Soc., 917–41.

COYLE, J. R. 1942. *A Series of Papers on the Weather of South America*, Part 1. Rio de Janeiro, Pan American Airways (NAVAER—U.S. Navy Reprint).

DEACON, G. E. R. 1945. Water circulation and surface boundaries in the oceans. *Quart. J. R. met. Soc.*, **71,** Nos. 307–308.

FUCHS, V. E. 1953. Organisation and methods [of the Falkland Islands Dependencies Survey]. *Falkland Islands Dependencies Survey Sci. Reps.*, No. 1.

GENTILLI, J. 1949. Air masses of the southern hemisphere. *Weather*, **4,** 258–61; 292–7.

GIBBS, W. J. 1953. A comparison of hemispheric circulations with particular reference to the western Pacific. *Quart. J. R. met. Soc.*, **79,** No. 339, 121–36.

GIBBS, W. J., A. V. GOTLEY, & A. R. MARTIN. 1950. *A.N.A.R.E. Reports*, Series D., Met. **1,** Part 1(a), Antarctic Div., Melbourne, 1950. Meteorology—Heard and Macquarie Islands, 1948.

———. 1952. *A.N.A.R.E. Rep.*, Series D., **1,** Part 1(c), Antarctic Div., Melbourne.

HOWKINS, G. A. 1949. Developments in the Antarctic. *Weather*, **4,** 157–8.

HUTCHINGS, J. W. 1950. A Meridional Cross-Section for an Oceanic Region. *J. Met.*, **7,** 94–100.

LAMB, H. H. 1948. Topography and weather in the Antarctic. *Geogr. J.*, **III,** 48–66.

———. 1949. Scientific results of the Balaena Expedition, 1946–7, Meteorology. *Met. Mag. Lond.*, **78,** 104.

———. 1952. South polar atmospheric circulation and the nourishment of the antarctic ice cap. *Met. Mag. Lond.*, **81,** No. 33, 282.

LOEWE, F. & U. RADOK. 1950. A meridional aerological cross-section in the south-west Pacific. *J. Met.*, **7,** 58–65.

NOTOS. 1952. *Atmospheric Project, Southern Hemisphere.* Weather Bureau, Pretoria, **1.**

PALMER, C. E. 1945. Southern hemisphere synoptic meteorology. In *Handbook of Meteorology* by F. A. Berry, Jr., E. Bollay, & N. R. Beers; New York.

PEPPER, J. 1954. *The Meteorology of the Falkland Islands and Dependencies*, 1944–50. London.

ROBIN, G. de Q. 1949. Notes on synoptic weather analysis on the fringe of Antarctica. *Met. Mag. Lond.*, **78,** 216–26.

ROOTS, E. F. 1952. The Norwegian-British-Swedish Antarctic Expedition, 1949–52. *Sci. News, Harmondsworth*, **26.**

RUBIN, M. J. 1952. Letter to the Editor. "South polar atmospheric circulation." *Met. Mag. Lond.*, **81,** No. 963.

SCHMITT, W. 1952a. Preliminary mean absolute topography, 500 mb., southern hemisphere, 70° W. to 120° E., Summer 1951–2. *NOTOS*, **1,** 7–17.

———. 1952b. Two intensive polar outbreaks in the Southern Oceans. *NOTOS*, **1,** 193–201.

———. 1953. Upper air analysis for the southern hemisphere. *NOTOS*, **2,** 20–27.

SCHUMACHER, N. J. 1952. The Maudheim Expedition, 1949–52. *Weather*, **7,** 327.

SERRA, A. & L. RATISBONNA. 1942. As massas de ar da America do Sul. Rio de Janeiro, Servicio Nacional de Meteorologia. (*NAVAER* 50-1R-79, Aerology Section, Chief of Naval Operations, 1944—Translation).

SHACKLETON, E. H. 1909. *The Heart of the Antarctic.* **2,** London.

VOWINCKEL, E. 1953. Zyklonenbahnen und Zyklogenetische Gebiete der Südhalbkugel. *NOTOS*, **2,** Nos. 1/2, 28–36.

VOWINCKEL, E. & C. M. Oosthuizen. 1953. Weather types and weather elements over the Antarctic Ocean during the whaling season. *NOTOS*, **2,** 157–82.

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