M.O. 687





AIR MINISTRY

METEOROLOGICAL OFFICE

*Scientific Paper No. 7*

# Forecasting in the Falkland Islands and Dependencies

by S. D. GLASSEY

LONDON: HER MAJESTY'S STATIONERY OFFICE

PRICE 3*s.* 6*d.* NET

M.O. 687

AIR MINISTRY
METEOROLOGICAL OFFICE

*Scientific Paper No. 7*

# Forecasting in the Falkland Islands and Dependencies

by S. D. GLASSEY

*LONDON*
HER MAJESTY'S STATIONERY OFFICE
1961

U.D.C.
551·509·3 : 06 : 551·515

# Contents

# Forecasting in the Falkland Islands and Dependencies

by S. D. Glassey

## INTRODUCTION

In an earlier article Mansfield and Glassey[1]* outlined the principles of the synoptic technique used by the Falkland Islands and Dependencies Meteorological Service (FIDMS) in the South Atlantic. Here it is proposed to amplify the practical system adopted, with particular reference to detailed analysis and forecasting as opposed to the broad-scale patterns and more general aspects of the previous work.

Some weather sequences are analysed and described and local effects in and around the Grahamland archipelago are discussed. Despite a detailed study of five years' charts, with additional material taken from two subsequent years, only tentative conclusions may be drawn since the full effect of the Antarctic Continent on the surrounding oceans is, as yet, little known. The work confines itself to the South Atlantic Ocean, south of 35°S, and adjacent coastlines, including Antarctica, but it is believed that some of the influences noted may be applicable in other areas around the Continent.

The writer has been, for some years, a forecaster in Stanley, Falkland Islands, and was attached to the Falkland Islands Dependencies Aerial Survey at Deception Island, South Shetlands, in the summer season of 1955–56. In drawing on the personal experience of five years' routine forecasting in the area it is hoped that some of the suggestions and conclusions will be of assistance in formulating a synoptic technique for the whole of the southern oceans and the Antarctic ice-cap.

## MATERIAL EMPLOYED

Three main charts (1200, 1800 and 2300 GMT) for the years 1951 to 1955 covering the South Atlantic Ocean area, south of 35°S, have been studied together with additional material drawn from 1956 and 1957. Supplementary charts were drawn for the FIDMS area of Antarctica at 0600 GMT. Upper air soundings were available from the Air Ministry radio-sonde unit at Stanley throughout the period, and from Argentine Islands, Grahamland, from mid-1954.

Ship reports broadcast by the South African Weather Bureau during the summer seasons have proved immensely useful when available. A brief study of the 500-millibar thicknesses has been made for Stanley and Argentine Islands for the years 1955 and 1956. A map of the reporting stations of the FIDMS is shown in Figure 1.

## GENERAL

Sutcliffe[2] has noted that 'the general forecaster concerned with the synoptic evolution on a broader scale than the aviation forecaster and for a longer period will be concerned to keep in mind the main air-mass differences and may find a frontal marking helpful even where the transition is gradual and the dynamical activity slight or absent'. This general

---

* Superscript figures refer to Bibliography on p. 30.

approach to detailed synoptic analysis is considered of the utmost importance in the South Atlantic. The practising forecaster in this area should study the synoptic situation with the attitude of the general analyst in the first instance and, having decided upon the broad-scale pattern, detail the minor fluctuations which are associated with specific weather. Again, in this area it is considered necessary to maintain frontal marking even where a discontinuity is scarcely discernible. However lacking in apparent characteristics they may be, these transition zones should be borne in mind for possible 'rejuvenation' or 'development'.

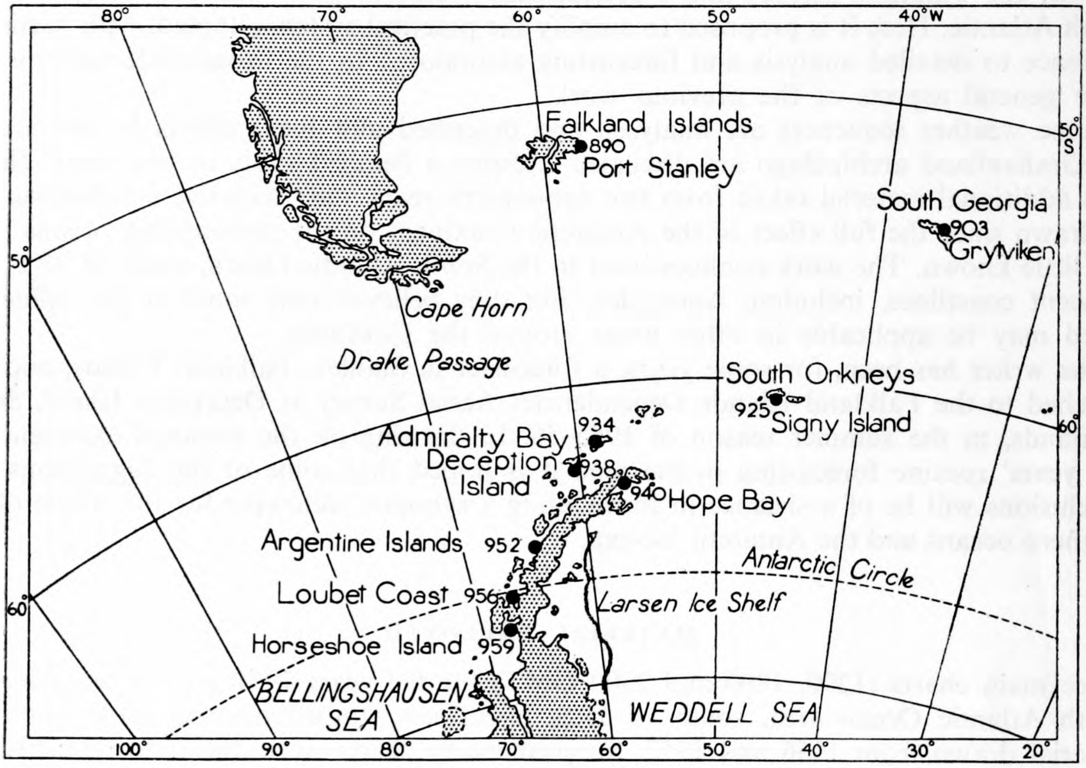



FIGURE 1. The Falkland Islands and Dependencies reporting stations

There are, in general, three fronts which are of importance in the area—the antarctic, the polar and the subtropical. This is obviously a somewhat simplified picture. On some occasions additional minor fronts can be identified and on others it is difficult to find any fronts at all. In the main the subtropical front lies to the north of the region so that normally the basic fronts to be considered are the polar and antarctic ones. At the surface the polar front is considered to lie usually between 35° and 45°S in the region of the northern oceanic convergence zone, while the antarctic front generally lies between 58° and 65°S which is just to the north of the permanent ice-belt and about the zone of the antarctic convergence (oceanic polar front).

To the north of the polar front lies the maritime polar air mass and to the south lies maritime antarctic air, while to the south of the antarctic front is the cold antarctic air of the ice-cap which is considered to be within the southerly limit of the isotherm of −2°C (Serra and Ratisbonna[3]). This propounds a three-front model for the southern hemisphere similar to that which has been given for the northern hemisphere by Anderson, Boville and McClellan.[4] The concept of the two-front model (subtropical and polar fronts) as propounded by Gibbs, Gotley and Martin[5] is considered inadequate. These authors assume that 'the antarctic front moving northward from the coastline of Antarctica, or the edge of the pack-ice fringing it, becomes the polar front of the Southern Hemisphere. Wave development occurring on this front in middle latitudes results in the development of a major depression which, on nearing the Antarctic coastline, causes the outbreak of a fresh mass of antarctic air with a new antarctic front as its forward boundary'. On page 25 a typical situation is explained in detail and it is shown that the antarctic and polar fronts can exist simultaneously. It may be argued that since no definable jet stream associated with the antarctic front has been found this front is of little consequence. In practice, however, it has been found that this front can be readily identified on the surface chart and since it is usually accompanied by a marked discontinuity it cannot be ignored.

Britton and Lamb[6] have suggested four main types of circulation applicable to Antarctica. They are:

(i) Warm anticyclones
(ii) Mixed situations
(iii) Travelling depressions
(iv) Cold depressions.

This is a suitable basis for the area under discussion but with the addition of cold anticyclones (*Kaltlufttropfen* or cold highs). A number of fast-moving high cells have been observed in the South Atlantic sector of Antarctica and these are believed to be of importance in the maintenance of the semi-permanent anticyclones of the South Atlantic and South Pacific Oceans.

Considering the five headings above it would be better to arrange them in order of importance to the South Atlantic area. It is felt that 'mixed situations' and 'cold depressions' play only a minor part in the synoptic situations of the area. Cold depressions are probably as common in the South Atlantic as in the North Atlantic. Although their effect on the broad-scale pattern is small they must not be excluded since they can produce intervals of bad weather in middle latitudes.

For the middle and high latitudes of the South Atlantic Ocean the following are given as the basis for analysis:

(i) Travelling depressions
(ii) Warm anticyclones
(iii) Cold anticyclones
(iv) Cold depressions
(v) Mixed situations.

In this area some 'local' effects are of interest in that they have counterparts in many places throughout the world and, although it is intended to present here only the influence of their peculiarities on the area, it is suggested that they would also be of interest in other countries as well as other parts of the Antarctic Continent.

## THE UPPER AIR

Until mid-1954 the only upper air reporting station, other than those making pilot-balloon reports, in the area, including South America, was that at Stanley. During 1954 the FIDMS

TABLE I. 1000–500 *mb thicknesses at Stanley and Argentine Islands in* 1955 *and* 1956

| | Stanley | | | Argentine Islands | | |
|---|---|---|---|---|---|---|
| | Mean | Extreme deviation | S.D. | Mean | Extreme deviation | S.D. |
| | | | *geopotential metres* | | | |
| 1955 | | | | | | |
| January | 5430 | +116 –229 | 75·1 | 5311 | +146 –143 | 66·8 |
| February | 5442 | +122 –119 | 70·9 | 5277 | + 73 – 82 | 39·0 |
| March | 5403 | +134 –143 | 76·8 | 5232 | +125 –183 | 72·6 |
| April | 5393 | +171 –119 | 73·2 | 5238 | +88 – 91 | 46·6 |
| May | 5354 | +232 –207 | 93·2 | 5238 | +119 –134 | 69·9 |
| June | 5302 | +149 –122 | 69·3 | 5168 | +165 –204 | 98·2 |
| July | 5293 | +213 –125 | 91·4 | 5159 | +137 –186 | 84·3 |
| August | 5287 | +323 –146 | 107·3 | 5122 | +199 –250 | 72·6 |
| September | 5305 | +161 –95 | 61·9 | 5189 | +116 –216 | 63·7 |
| October | 5375 | +134 –192 | 76·2 | 5150 | +186 –146 | 69·4 |
| November | 5378 | +149 –131 | 75·1 | 5177 | +91 –125 | 50·9 |
| December | 5357 | +140 –88 | 57·5 | 5229 | +122 –95 | 52·1 |
| 1956 | | | | | | |
| January | 5406 | +222 –165 | 91·5 | 5439 | +158 –85 | 58·8 |
| February | 5431 | +527 –135 | 128·2 | 5246 | +270 –134 | 76·7 |
| March | 5429 | +373 –153 | 104·5 | 5269 | +120 –86 | 57·1 |
| April | 5381 | +143 –178 | 83·3 | 5264 | +165 –153 | 79·2 |
| May | 5358 | +172 –172 | 90·2 | 5256 | +119 –145 | 61·9 |
| June | 5363 | +186 –206 | 92·3 | 5198 | +120 –198 | 67·1 |
| July | 5316 | +155 –131 | 65·8 | 5162 | +160 –264 | 89·6 |
| August | 5311 | +220 –120 | 84·8 | 5186 | +133 –204 | 79·8 |
| September | 5276 | +122 –143 | 60·6 | 5147 | +167 –238 | 102·6 |
| October | 5360 | +164 –133 | 73·4 | 5201 | +142 –129 | 69·9 |
| November | 5434 | +130 –117 | 59·6 | 5244 | +152 –109 | 70·9 |
| December | 5367 | +150 –122 | 71·5 | 5235 | +117 –72 | 42·7 |

$$\text{S.D.} = \sqrt{\Sigma \frac{(x-M)^2}{N}}$$

set up a new radio-sonde station at Argentine Islands, Grahamland, which reports upper temperatures and humidities daily. Upper winds are available only by visual observation of the radio-sonde balloon or by pilot balloon. Consequently little analysis of absolute and relative topography has been possible. Some attempt has been made to construct charts of typical situations but little has been achieved. Direct comparison of soundings is invaluable in confirming the surface analysis, but with two stations a thousand miles apart the occasions are not common.

The statistical summaries of the available soundings are published by the FIDMS in the *Annual meteorological tables.* Unfortunately, these otherwise complete tables give no information on the 1000–500-millibar thicknesses so this is tabulated here (Tables I and II).

TABLE II. *Seasonal mean thickness of the* 500 *mb level based on data for* 1955–56

| | Stanley | | Argentine Islands | |
|---|---|---|---|---|
| | Mean | Extreme deviation | Mean | Extreme deviation |
| | | *geopotential metres* | | |
| Summer Dec., Jan., Feb. | 5405 | +527 −229 | 5275 | +270 −143 |
| Autumn Mar., Apr., May | 5386 | +373 −207 | 5429 | +165 −183 |
| Winter June, July, Aug. | 5310 | +323 −206 | 5166 | +165 −264 |
| Spring Sept., Oct., Nov. | 5355 | +164 −192 | 5185 | +186 −230 |

Lamb[7] has concluded that the variations of 1000–500-millibar thickness over a snow- or ice-covered surface is distinctly smaller than at places away from the snow. The ideal situation exists at Stanley and Argentine Islands since, at the former station the sounding will be invariably over an open sea surface and at the latter almost always over snow or ice. The figures quoted here (Table I) for the two stations seem to imply that the same rule is applicable to this area although the difference is less than that found by Lamb. The standard deviation at Argentine Islands is approximately seven-eighths of that at Stanley whereas in the northern hemisphere Lamb found that the standard deviation at the edge of extensive snow and ice is about two-thirds of that for points further south.

Another possible reason for the difference in variation between Stanley and Argentine Islands is the difference in the air masses affecting the two stations but it is realized that predominating air masses and the presence or absence of snow cover must be related. Stanley is affected normally by maritime polar air but intrusions of subtropical air in summer and antarctic air in winter are by no means uncommon. Argentine Islands, on the other hand, is almost always under the influence of either maritime polar or antarctic air and intrusions of subtropical air are rare.

The standard deviation at Stanley shows no marked seasonal change. Argentine Islands standard deviation figures for the winter months are generally higher than for the summer (Table I). In the winter deep cold air from the Continent reaches Argentine Islands not infrequently, whilst in the same season, maritime polar air is not uncommon as well as relatively warm ridges.

One instance of an intrusion of subtropical air to the far south can be seen in the figures for February 1956 (Table I). The maximum positive deviation of 527 metres at Stanley occurred on the 7th, and that of 270 metres at Argentine Islands on the 8th.

From the soundings at Stanley in 1954, 1955 and 1956 an analysis has been made to find the level of the polar front jet. It appears to lie at about 300 millibars. This is the level of the greatest wind maxima as derived from the monthly summaries (*Annual meteorological tables, FIDMS* 1954, 1955 and 1956). The mean speed at 300 millibars in the three years was 57·6 knots and out of 1016 occasions there were 217 with wind speeds greater than 80 knots. This frequency is considerably higher than at any other level: 133 occasions at 200 millibars; 96 occasions at 400 millibars. From the data available an analysis of the west-wind maxima was not possible. But since the majority (70 per cent or more) of winds recorded at these levels were from nearly due west, and easterly winds are uncommon, it is reasonable to assume a fair accuracy for the figures quoted, if taken as relating to a west-wind maximum. Comparing the above with a mean tropopause pressure of 259 millibars, one may conclude that the polar front jet in this area lies just below the tropopause level.

From a study of available aerological cross-sections Lamb[8] has concluded that on consideration of the polar front jet at the 500-millibar level 'all the cross-sections indicate a secondary maximum of wind speed somewhere south of 45°S' and 'the summer and winter 500 mb maps . . . indicate some general northward shift of the zone of maximum wind from summer to winter. Speeds increase in the lower latitudes in winter, whereas in latitudes near 60°S the maximum is in summer as appears to be the case even at Falkland (52°S)'. Lamb's conclusions and those concerning the polar front jet here obtained are in general agreement.

The mean tropopause pressure of 259 millibars is also of interest in that it accords reasonably with northern hemisphere figures recently derived by Defant and Taba.[9] These writers have also mentioned two other important features of the tropopause in the northern hemisphere: 'In soundings through the polarfront jet no distinct tropopause could be found' and that 'through the subtropical jet two different breaks in lapse rate appeared suggesting a double structure of the tropopause'. The latter is of less importance in this area since the intrusion of the subtropical front is not common and south of 60°S is rare. However, on occasions of subtropical air at Stanley well defined double-tropopause structures have been recorded. The former conclusion is most important in view of the fact that occasions of indistinguishable tropopause are not uncommon in this area, more especially at Argentine Islands. Other instances have been reported at various stations, including ships, about the periphery of Antarctica. This phenomenon has been called 'tropopause disappearance' and it has been suggested by some that occurrences will be of much higher frequency further south. It is believed, however, that the tropospherical structure is more akin to that suggested by Defant and Taba.[9] These writers give the tropical tropopause level above 100 millibars, the temperate about 250 millibars and the polar about 350 millibars. At Argentine Islands, and this is considered applicable to other stations around the coast of Antarctica, the tropopause shows great variance due to the two main air masses to which it is subject and there are some occasions of no distinct tropopause. Normally true antarctic air at Argentine Islands can be shown to have a low but definite tropopause usually about 350 and occasionally as low as 500 millibars. An occasion of no distinct tropopause can often be related to the polar front jet but may also occur in antarctic air.

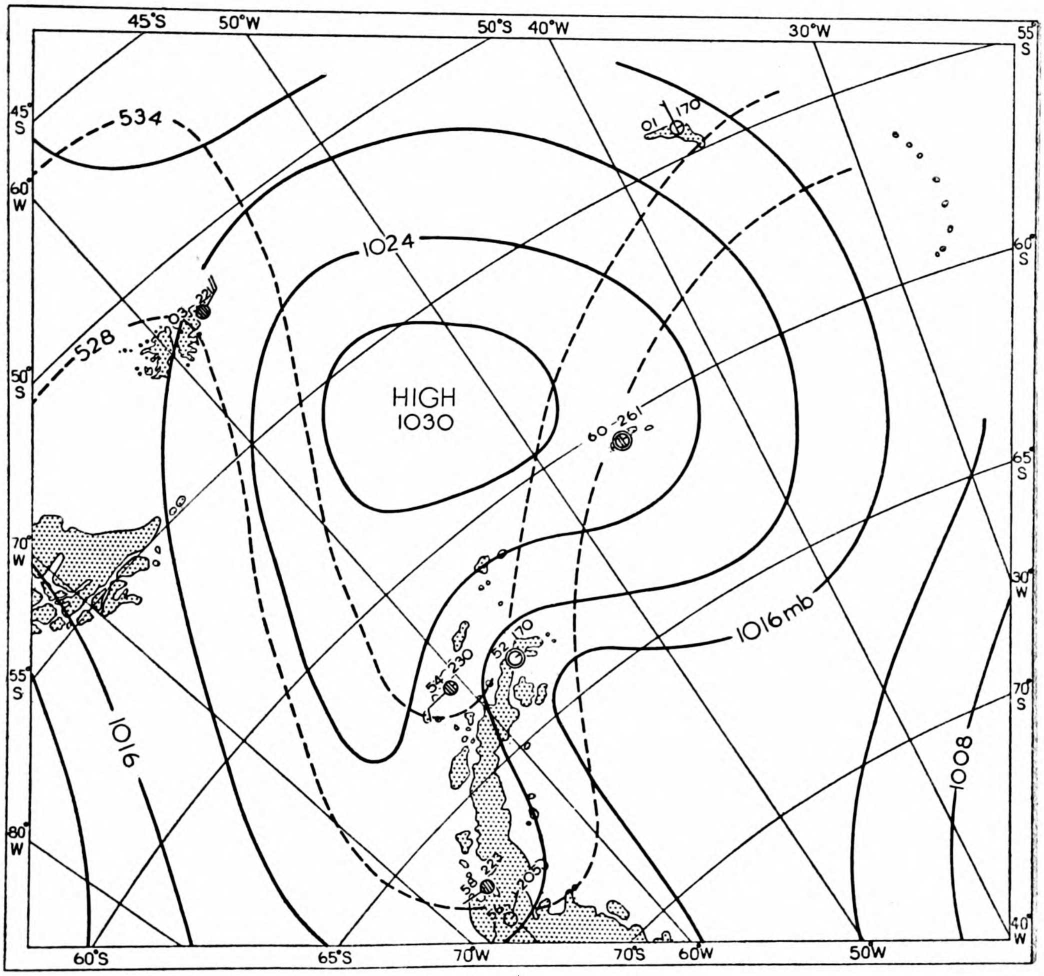



FIGURE 2(*a*). Surface synoptic chart with thickness pattern (broken lines) in geopotential decametres, 1800 GMT, 22 August 1956

Observations of wind, pressure, temperature (°C), total cloud amount and present weather are plotted in Figures 2(*a*), (*b*), (*c*) and (*d*).

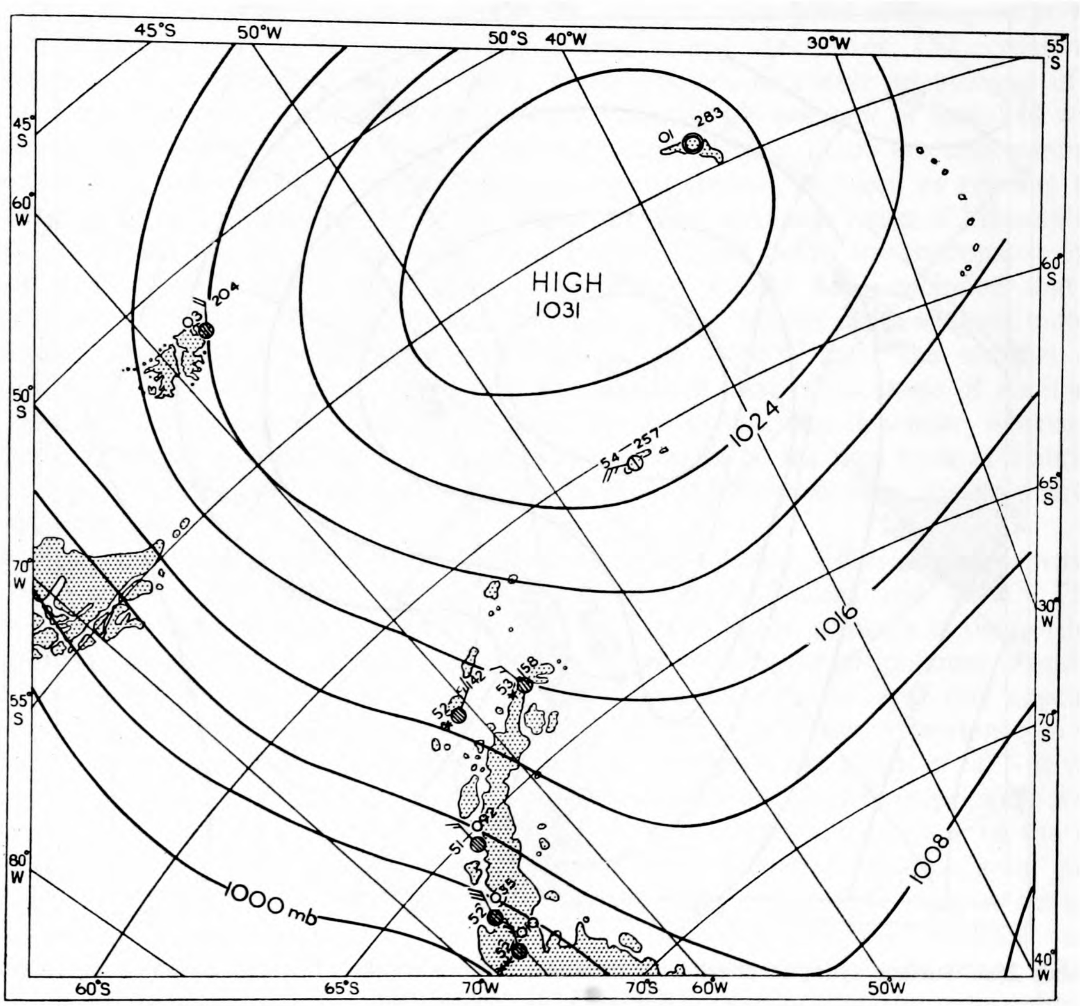



FIGURE 2(*b*). Surface synoptic chart, 1800 GMT, 23 August 1956

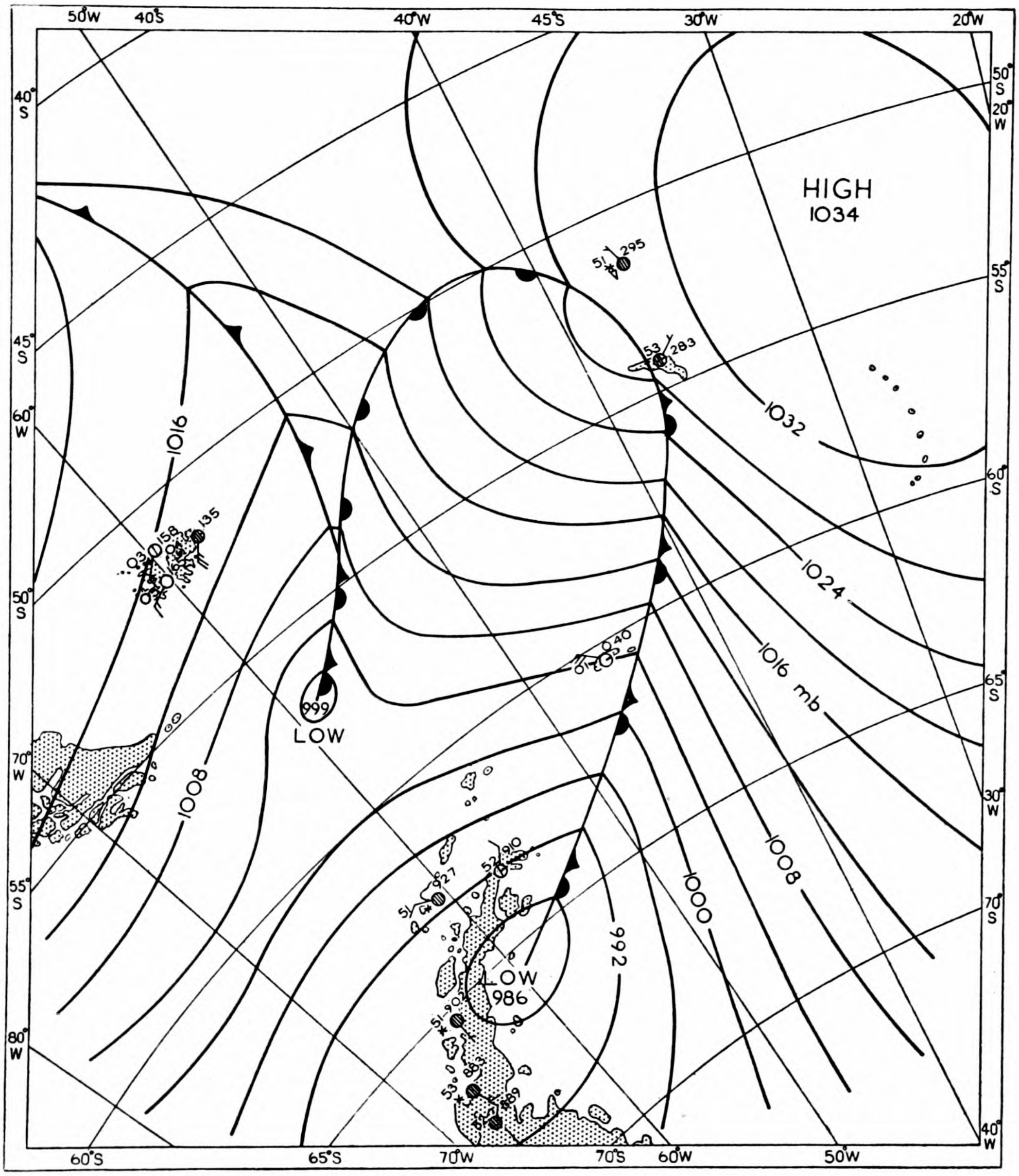



FIGURE 2(c). Surface synoptic chart, 1200 GMT, 25 August 1956

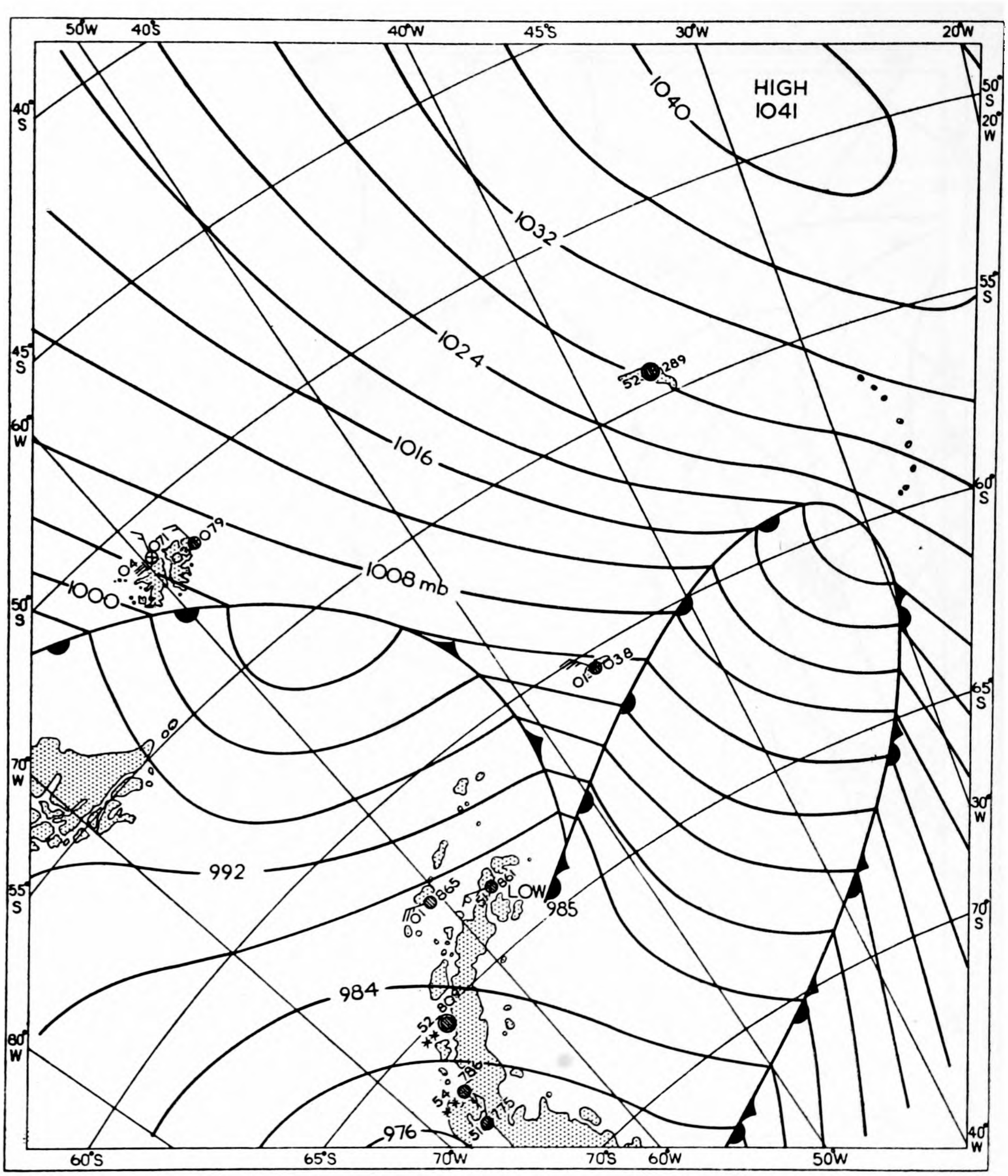



FIGURE 2(*d*). Surface synoptic chart, 1200 GMT, 28 August 1956

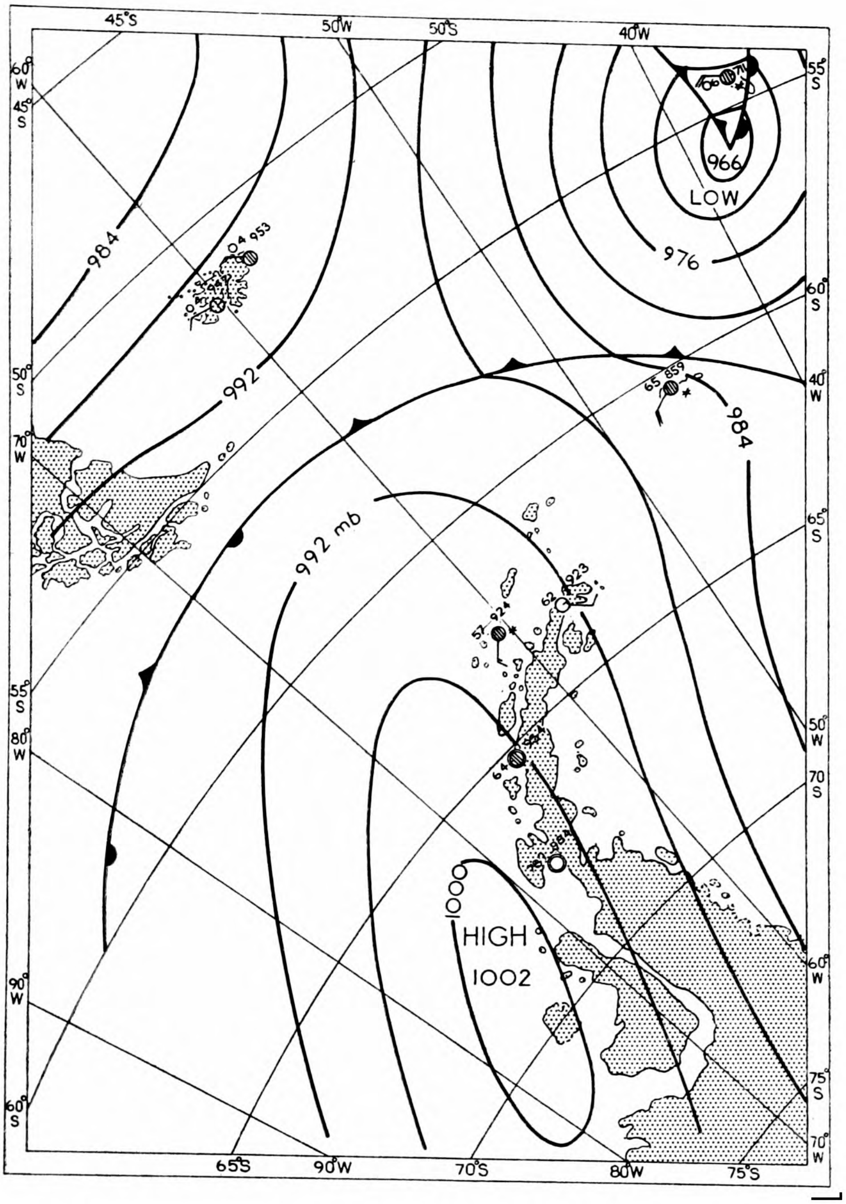



FIGURE 3(*a*). Surface synoptic chart, 1200 GMT, 9 July 1956

Observations of wind, pressure, temperature (°C), total cloud amount, present and past weather are plotted in Figures 3(*a*), (*b*) and (*c*).

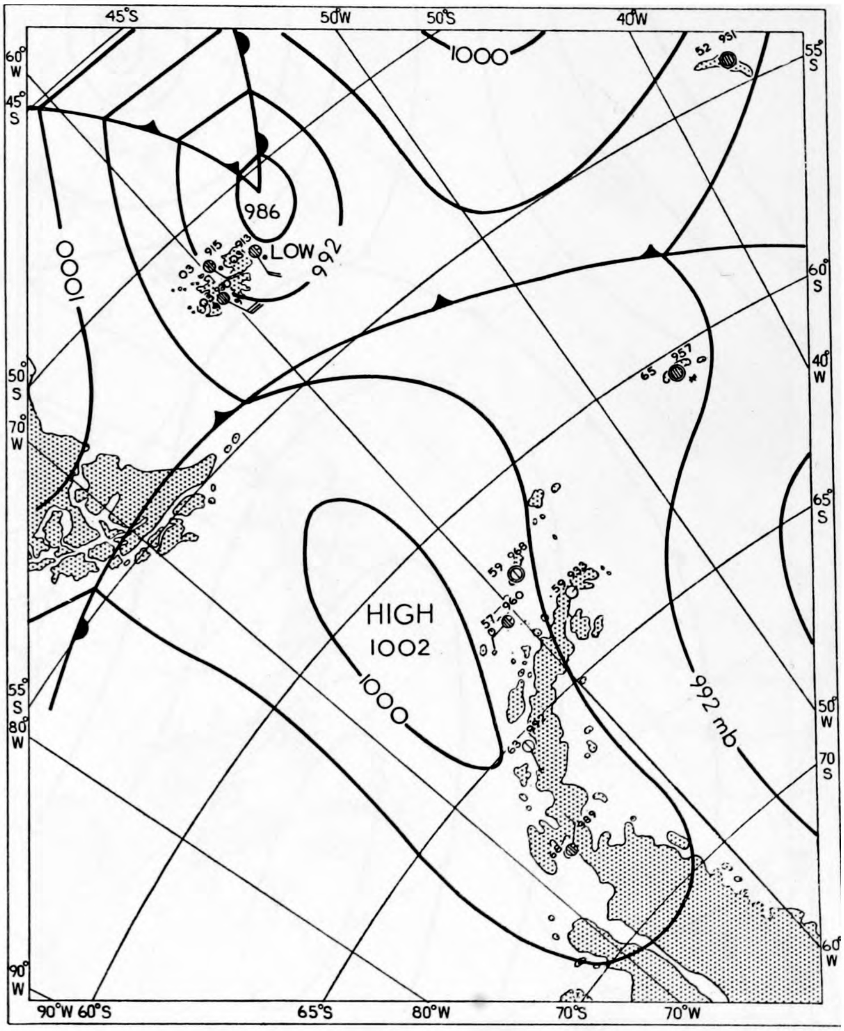



FIGURE 3(*b*). Surface synoptic chart, 1200 GMT, 10 July 1956

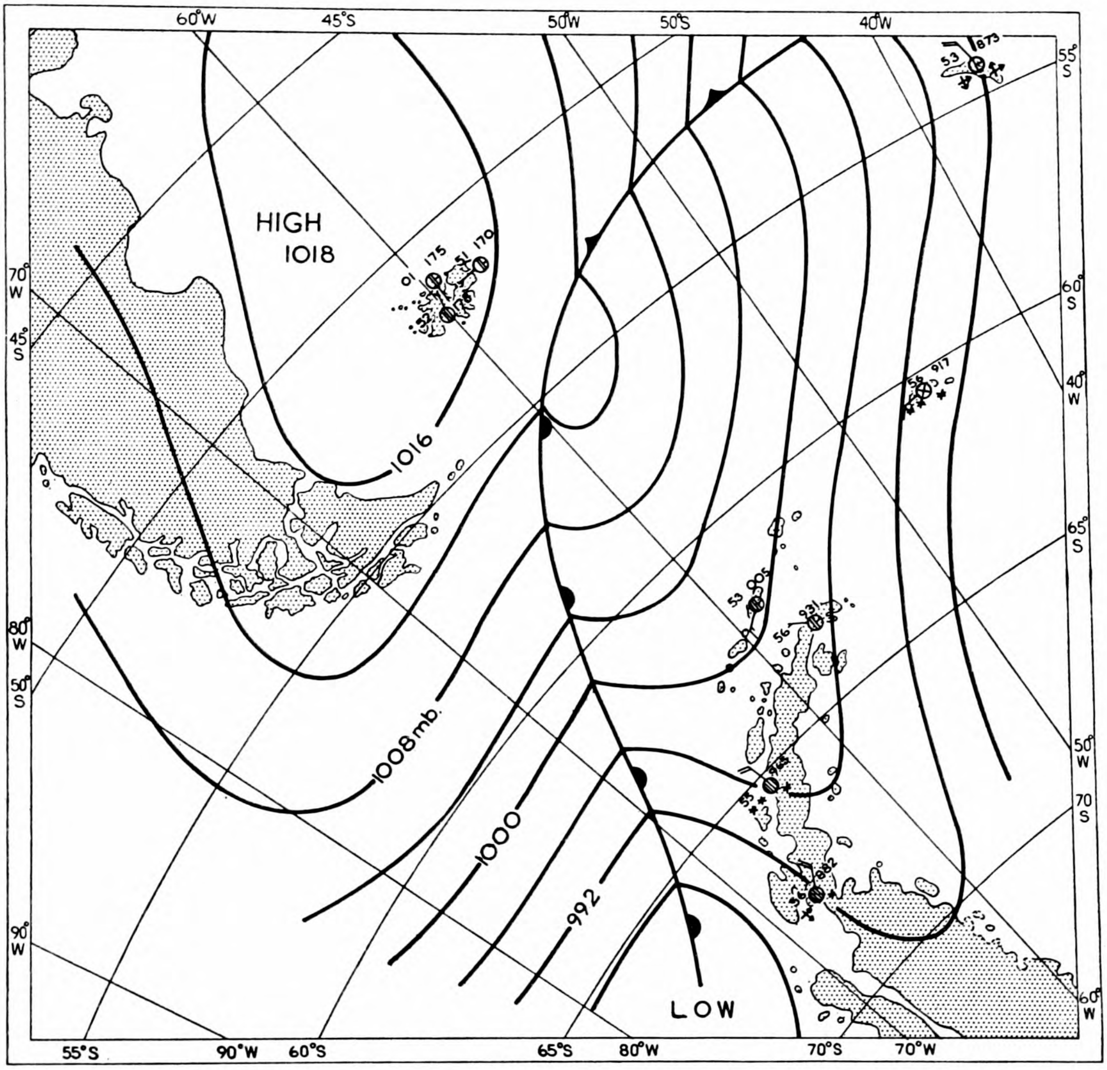
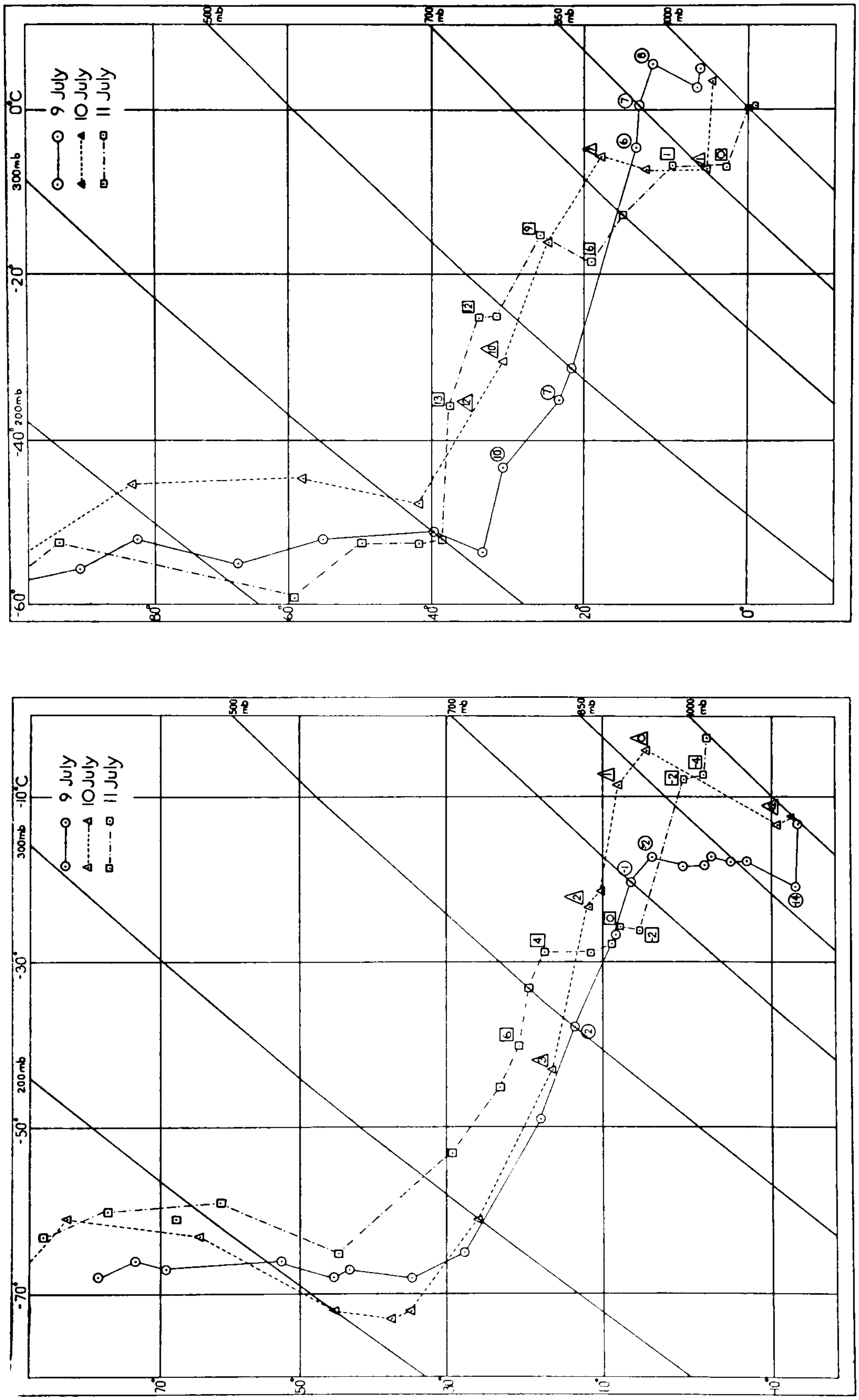



FIGURE 3(*c*). Surface synoptic chart, 1200 GMT, 11 July 1956




(*a*) Argentine Islands

(*b*) Stanley

FIGURE 4. Tephigram of upper air soundings at 1500 GMT on 9, 10 and 11 July 1956

Values of wet-bulb potential temperature enclosed in circles, triangles and squares are for 9, 10 and 11 July respectively.

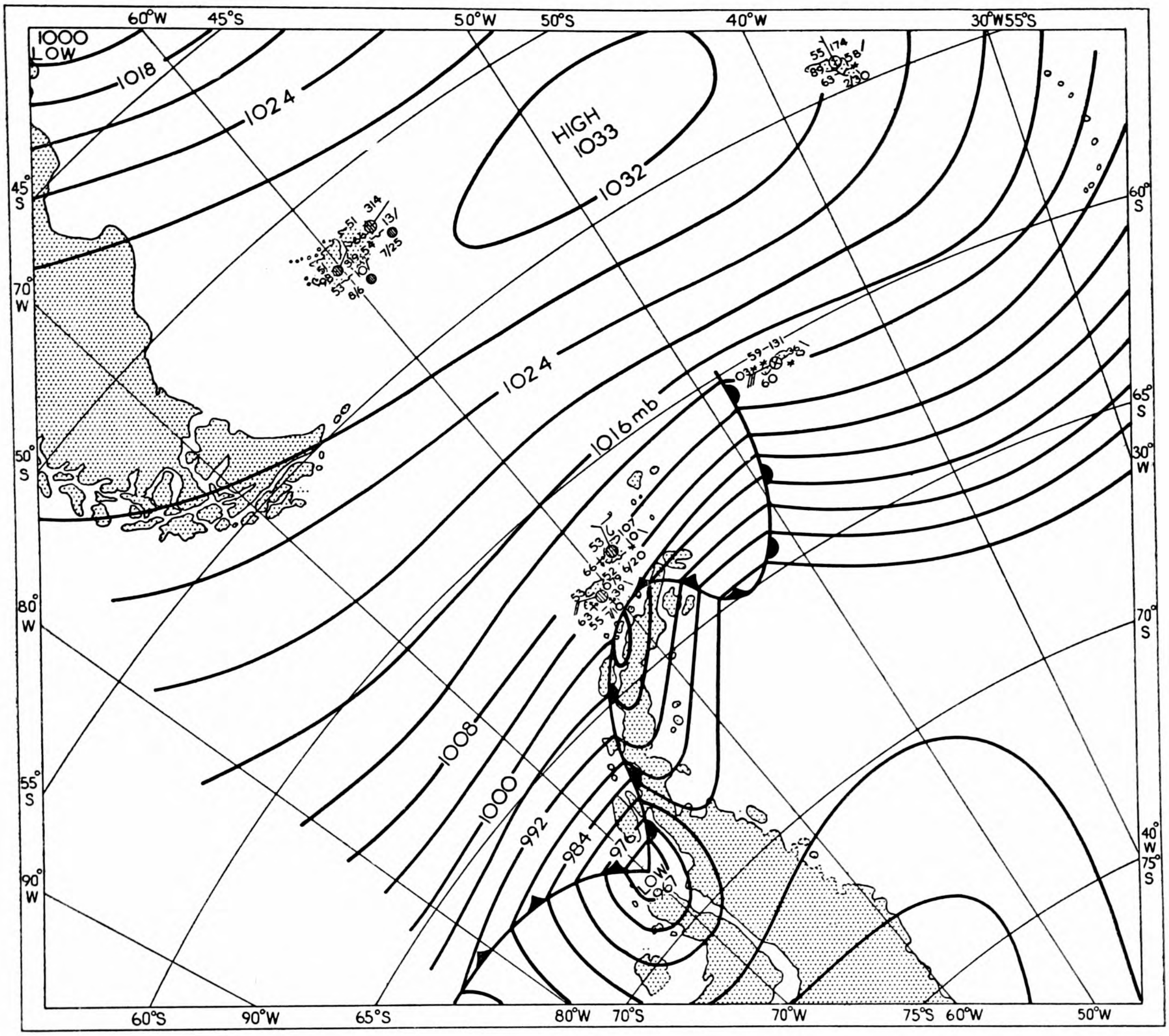



FIGURE 5(*a*). Surface synoptic chart, 1200 GMT, 29 July 1957
Observations for some stations are plotted in the standard model.

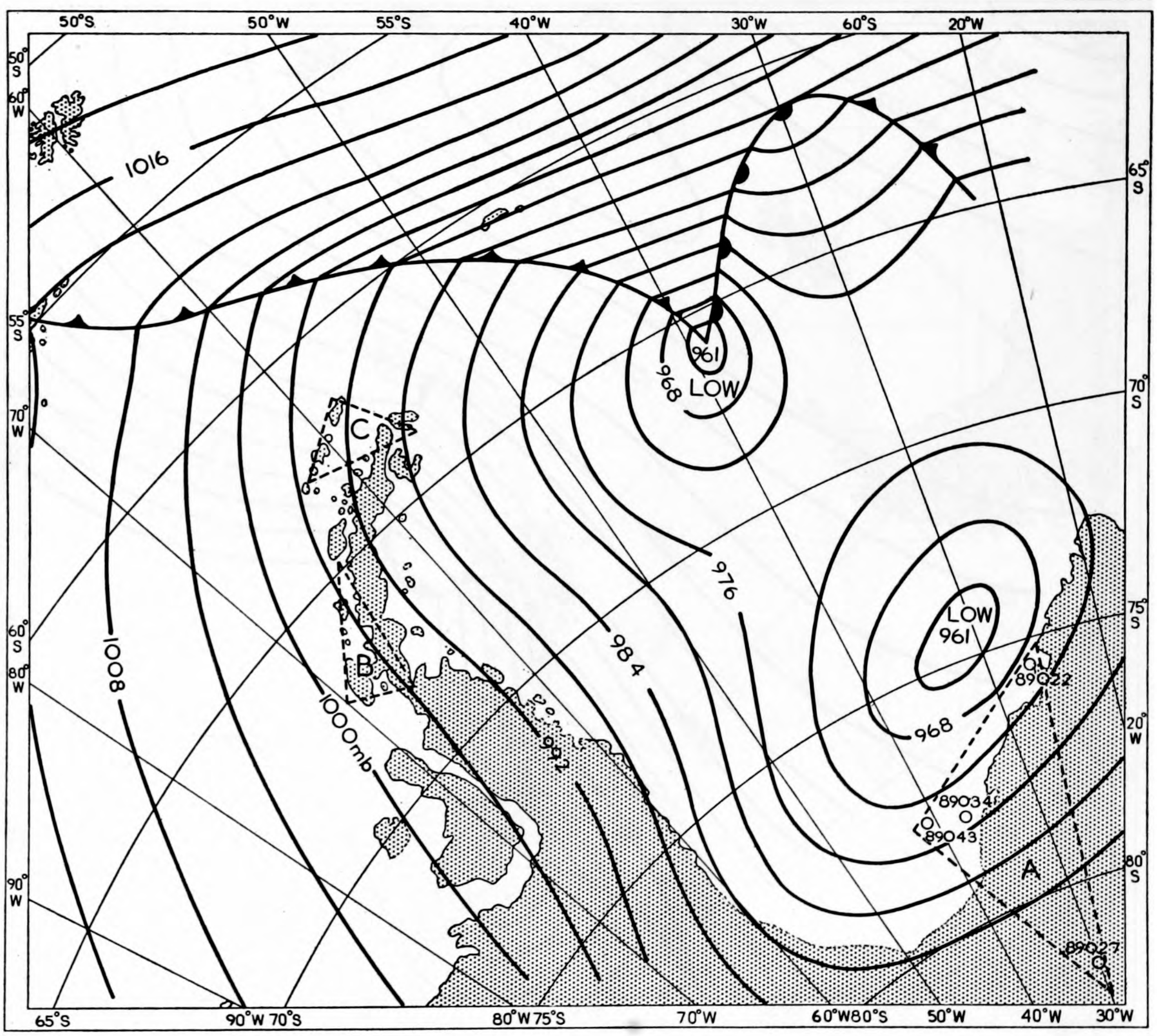



FIGURE 5(*b*). Surface synoptic chart, 1200 GMT, 30 July 1957
Broken lines enclose areas referred to on page 24.

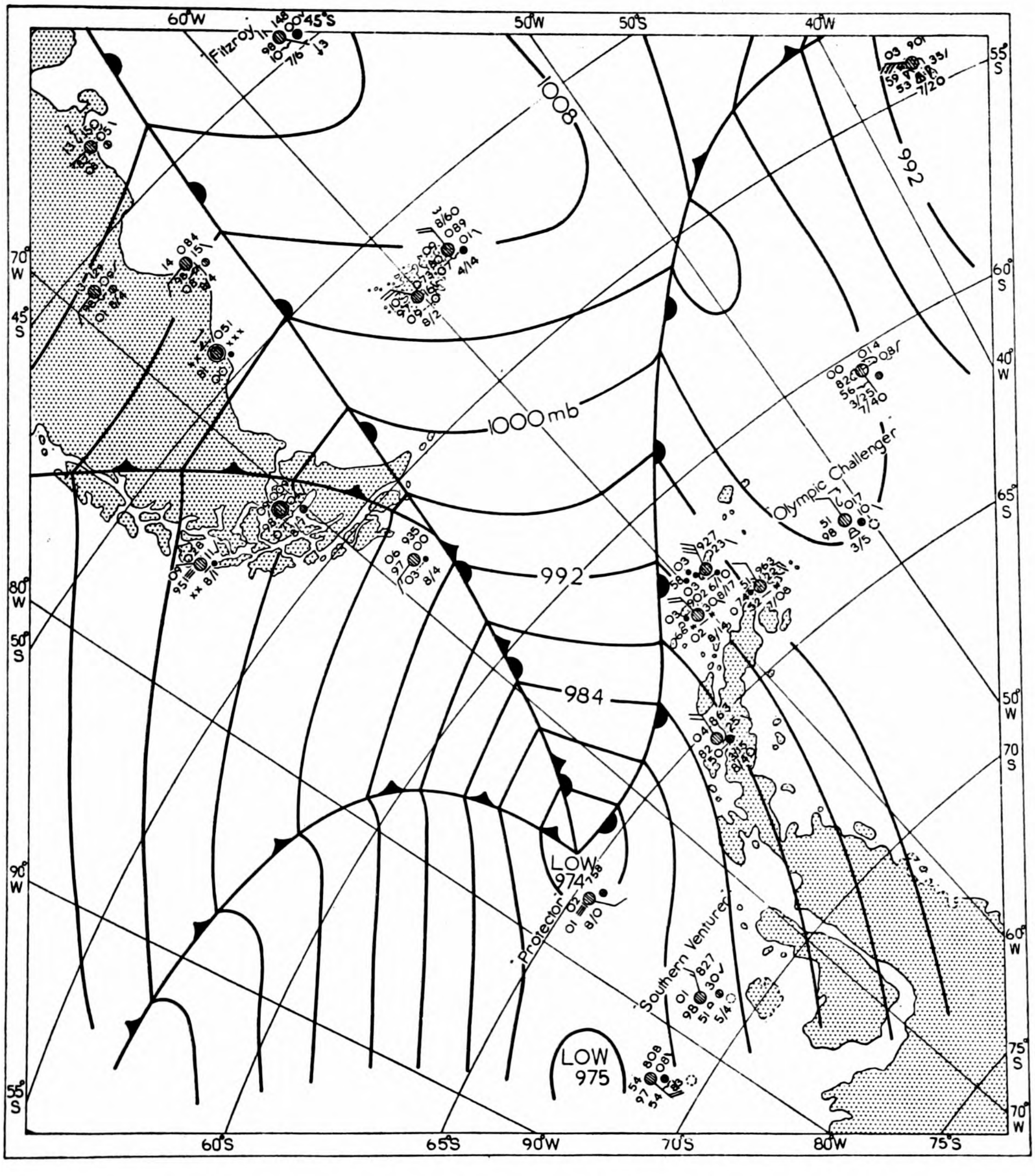



FIGURE 6(*a*). Surface synoptic chart, 1200 GMT, 28 February 1956
Observations for all available ships and stations are plotted in Figures 6(*a*), (*b*) and (*c*)

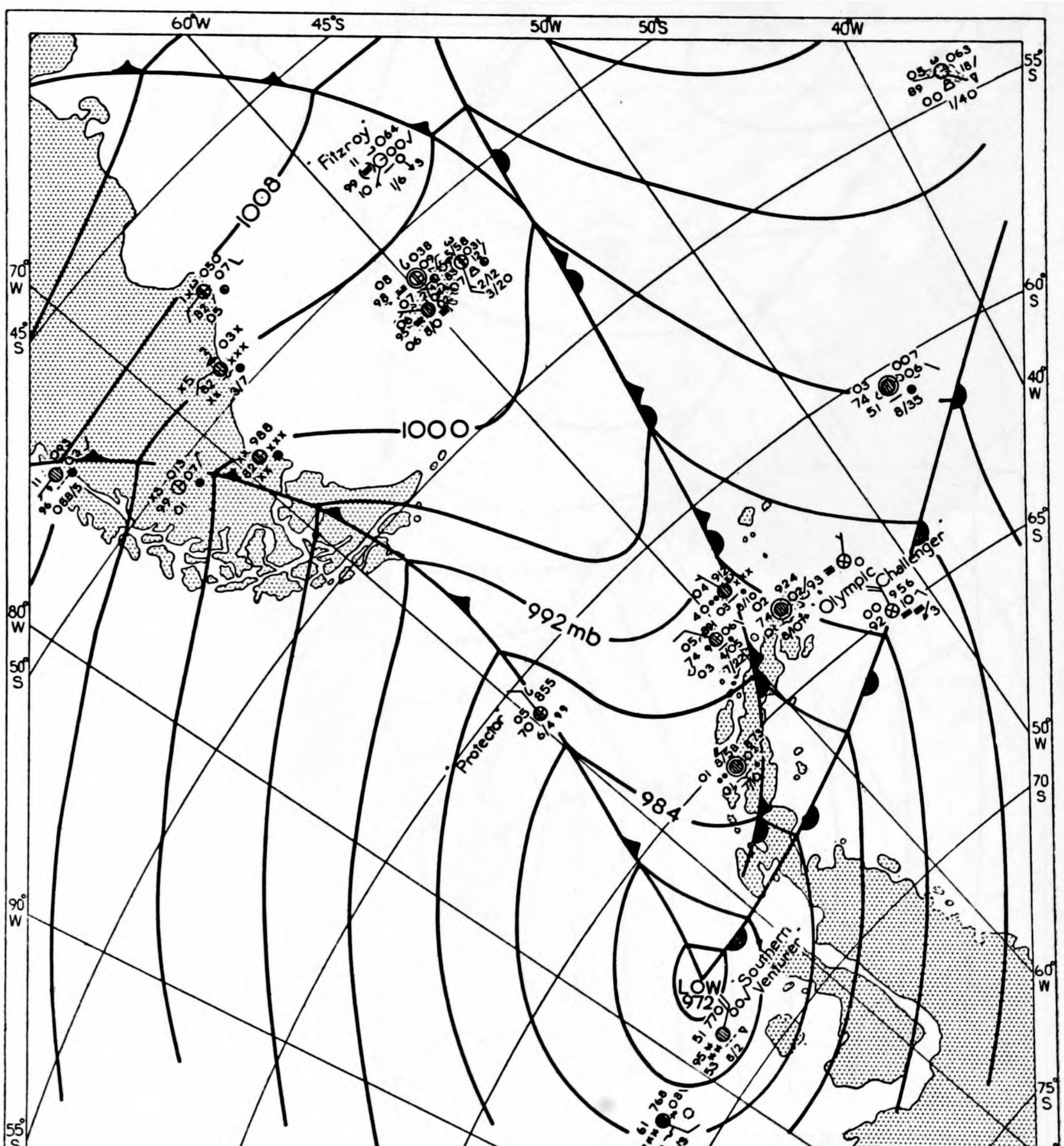



FIGURE 6(*b*). Surface synoptic chart, 1200 GMT, 29 February 1956

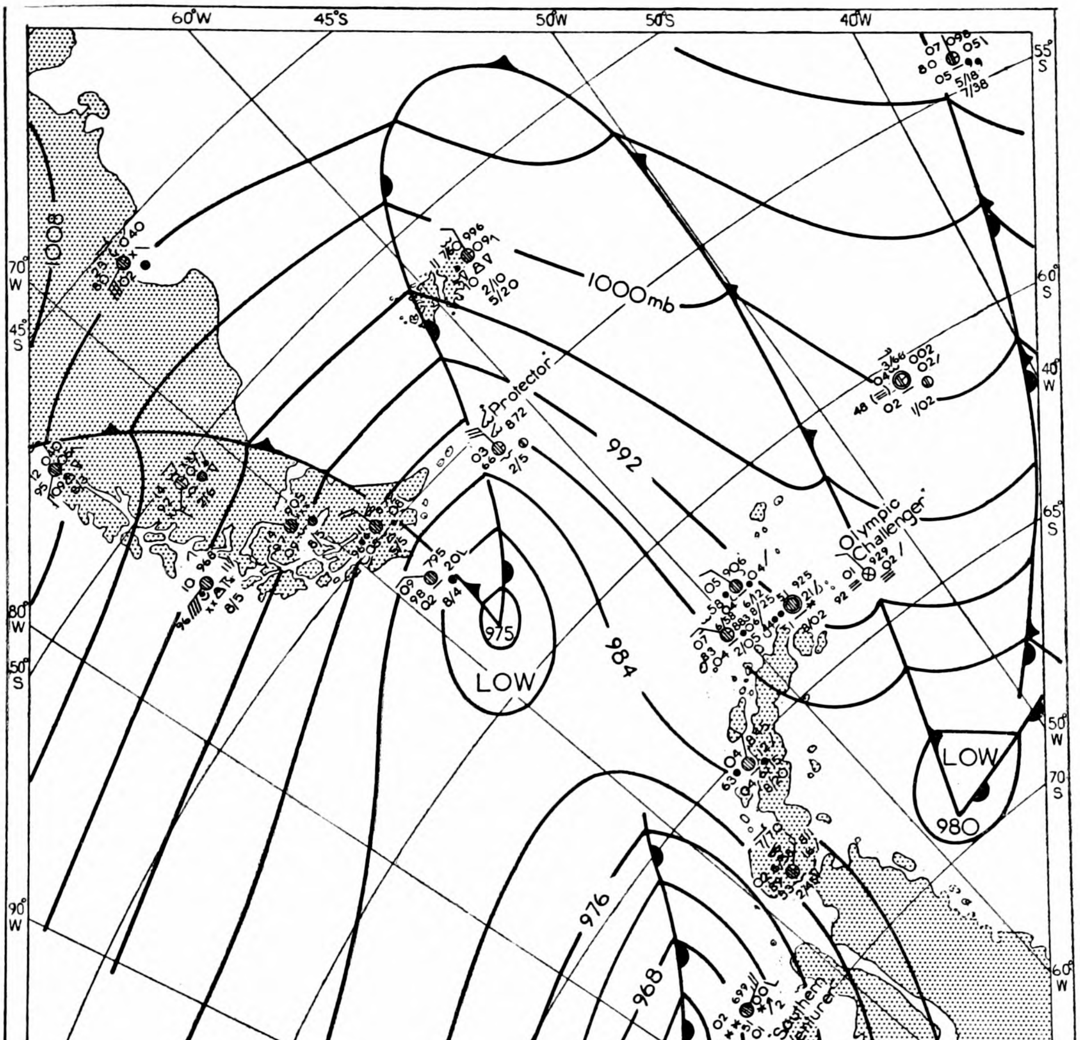



FIGURE 6(c). Surface synoptic chart, 1800 GMT, 1 March 1956

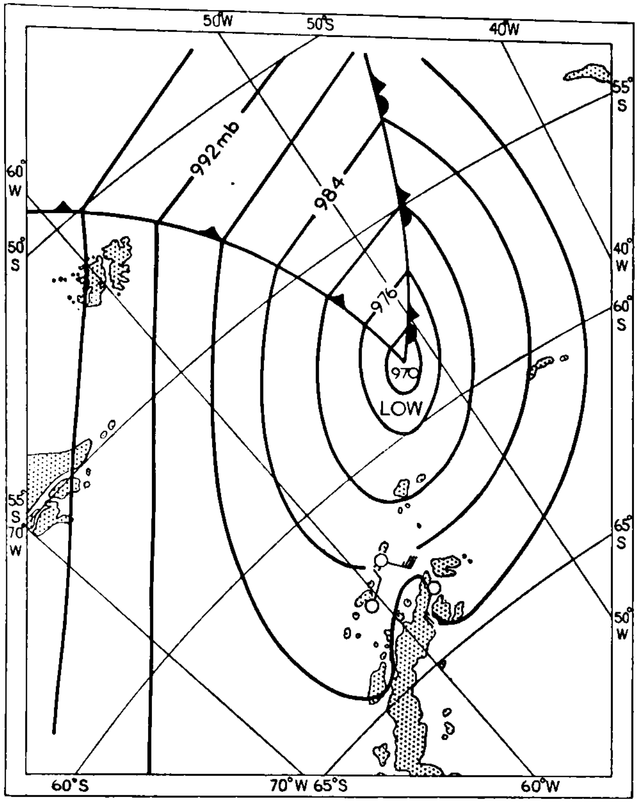



FIGURE 7(*a*). Surface synoptic chart, 1800 GMT, 24 February 1956
Wind arrows are plotted at three stations.

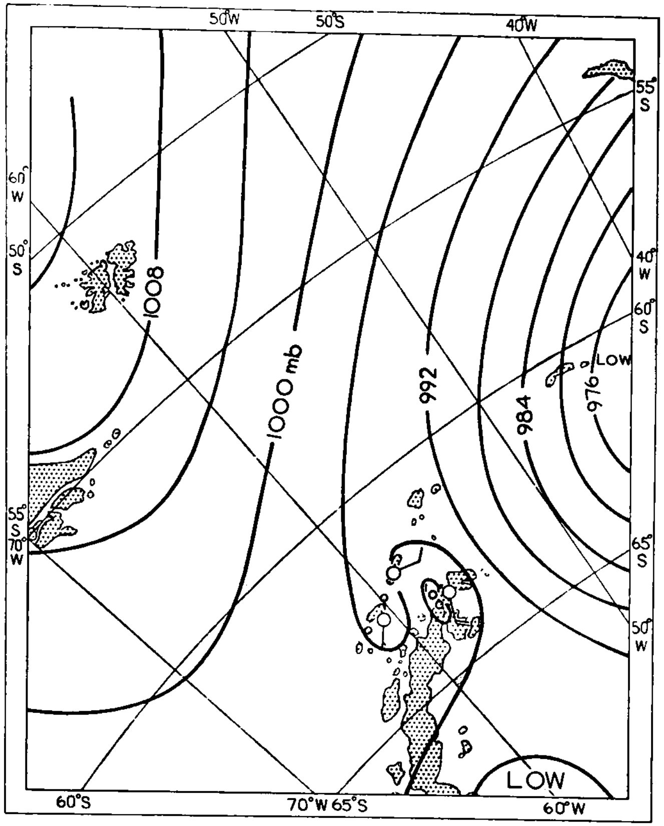



FIGURE 7(*b*). Surface synoptic chart, 1800 GMT, 25 February 1956
Wind arrows are plotted at three stations.

## DEPRESSIONS

For the purpose of analysis covering the years 1951 to 1955 inclusive, travelling and cold depressions have been considered together in determining the speed of movement and amount of change in low pressure centres. All centres of these depressions in the sector 50° to 70°S and 60° to 70°W were determined and followed through to the sector 50° to 70°S and 30° to 40°W. It was found that almost all depressions deepened in their eastward movement in this area, the mean amount of deepening being 6·45 millibars over an approximate average distance of 950 nautical miles. The mean low pressure was 970·9 millibars. The lowest pressure of all depressions was 938 millibars while the highest was 999 millibars. The seasonal means are shown in Table III.

TABLE III. *The amount of deepening of depressions*

| | Mean pressure at centre | | | |
|---|---|---|---|---|
| | winter June to Aug. | spring Sept. to Nov. | summer Dec. to Feb. | autumn Mar. to May |
| | | *millibars* | | |
| In sector 60° to 70° W | 972·7 | 973·7 | 977·1 | 974·1 |
| In sector 30° to 40° W | 965·4 | 967·8 | 970·9 | 967·7 |
| Pressure change | 7·3 | 5·9 | 6·2 | 6·4 |
| | | Number of lows analysed | | |
| | 93 | 85 | 84 | 89 |

The mean speed of movement of depressions is about 25 knots; speeds vary from 18 knots to 30 knots, generally, but occasionally speeds up to 50 knots occur. It is uncommon for depressions to move more slowly than 18 knots in this area but there are indications of stagnation in the Weddell Sea at times. In other respects lows in this area behave much as those of the North Atlantic although, perhaps, slower movement is observed more frequently there. Again westward-moving depressions may be encountered in the North Atlantic but few are observed in the South Atlantic. This is in keeping with the strong upper westerly flow indicated throughout the area and noted by Lamb[8] and others. In the Weddell Sea it is probable that some lows move westward, either because of a blocking anticyclone over Queen Maud Land, or because of the 'dumb-bell' rotation of two associated depressions. The fact that no such cases came to light in this survey is almost certainly due to the lack of suitable observations.

## WARM ANTICYCLONES

Anticyclones of the 'warm' type, that is with anticyclonic circulation to great height and a warm core of descending air, may be expected at any time of the year in this area. A detailed report of one occurring in June 1952 is given by Mansfield and Glassey,[1] and others have been observed to have a relatively high tropopause level, usually exceeding ten kilometres. These anticyclones are responsible for 'blocking', a state particularly noted just east of South Georgia and the South Orkneys when approaching depressions are deflected southwards to the Weddell Sea. One such instance is shown in Figures 2(*a*) to 2(*d*). Following a cold outbreak an anticyclone developed in the Drake Passage and while still of the cold type moved north-east to the position shown in Figure 2(*a*) at 1800 GMT on 22 August

1956. The thickness pattern, although somewhat tentative owing to few upper air observations, suggests that a warm core from the southward-extending ridge will become cut-off in later stages of development. The anticyclone became slow-moving round South Georgia over the period 0600 GMT, 23 August 1956 to 1200 GMT, 25 August 1956, but eastward-moving depressions from the Pacific Ocean pushed the block further to the east on 26 and 27 August 1956, where it was maintained until a final break-through on 29 August 1956. The depressions responsible for the break-down were turned south-east and frontal activity was much weakened in intensity.

This occurrence and that of June 1952 both appeared to originate with cold highs moving out from the Antarctic Continent and developing on the fringe of the semi-permanent subtropical anticyclone of the Atlantic Ocean. The positions of the subtropical high are important to the development of a quasi-stationary situation to the south in that they provide ready access to warm air aloft. Although blocking situations are uncommon they seem more likely to occur in winter than in summer; Van Loon[10] has remarked that there is a 'pronounced maximum in late winter–early spring' and Lamb[8] considers the preference for the winter season 'is presumably linked with maximum amplitude of the troughs'. In the same paper Lamb concluded 'it is found that quasi-stationary anticyclones south of 40°S are limited to positions over Antarctica and to just three sectors of the surrounding ocean namely:

(i) From close to the south coast of Australia to a wider range of latitudes in the western Pacific probably as far as the region near 60°S, 120°–140°W.

(ii) Near the tip of South America and southeast thereof over the region of the Scotia Sea in 60°–65°S; they are known to occur on rare occasions in longitudes further east in the South Atlantic sector 50°–60°S.

(iii) The region southeast of South Africa about Marion and Crozet Islands in 40°–50°S in the west of the Indian Ocean sector'.

## COLD ANTICYCLONES

During the years 1951 to 1955 inclusive, fifty high cells were analysed as moving out from the Grahamland Peninsula either towards South America and the Falkland Islands, or over the South Atlantic in the general direction of South Georgia, but the first mentioned movement would appear to be the preferred track. Most of these cold cells occur from May to September in each year and the remainder principally in April and October. They are very uncommon but not completely unknown in other months of the year. From the short analysis by Mansfield and Glassey[1] of the charts of the southern hemisphere for 1951 drawn by the South African Weather Bureau, it was concluded that 'another outflow path [of anticyclone cells] 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'. The more recent analysis from 1951–55 gives confirmation to that tentative conclusion. It is suggested that the snow-covered Grahamland Peninsula provides a suitable path along which high cells may penetrate well over the Southern Ocean. The rate of transfer and development of these cells may be very high as can be seen in Figures 3(*a*), (*b*) and (*c*). Here a small cell moved northwards from the Ellsworth Highland close to the Grahamland coast and continued on a north-north-east track to north of the Falklands. Between 1200 GMT on 11 July 1956 and 1200 GMT on 12 July 1956 it moved quickly to the north-east, then becoming absorbed into the semi-permanent high of the subtropics. The overall speed of movement was 25 knots during the 72-hour period. In the forty-eight hours covered by the charts the average speed was the same, while the centre intensified from 1002 to 1018 millibars. Figures 4(*a*) and 4(*b*) show the upper air soundings of Argentine Islands and Stanley for 9, 10 and 11 July 1956. The tropopause height at Argentine Islands was near to 10 kilometres each day while at Stanley it rose from 8½ kilometres to just over 11 kilometres. The structure suggests developing subsidence and that descending warm air was becoming more evident. Transport of warm air aloft from outside sources during the development is not evident.

This occasion is similar to many others in characteristics and track. Although the occurrence had developed some of the features of a warm anticyclone by the time it reached the Falklands, normally these highs appear to have little depth. Generally the cells amalgamate with the semi-permanent subtropical high and may temporarily cause a change of position of its centre and to some extent intensify it. In the days following the sequence shown the subtropical high of the South Atlantic was intensified with the centre farther to the south and west. Occasionally these high cells may be modified and intensified to become the blocking highs of the previous section, mainly in the region of South Georgia and the Scotia Sea. It is believed that these high cells are the origin of almost all quasi-stationary blocking situations. This would account for the winter maximum of blocks. The preference for anticyclonic outbreaks in winter is probably due to the increased ice-cap area with the much more extensive frozen sea surface; moreover, the preferred track of these highs from the Grahamland Peninsula provides access to the warm air of the subtropical highs within a reasonably short distance.

## THE ANTARCTIC FRONT

Here it is desired to indicate, briefly, examples of structures involving the polar front and the antarctic front together with waves on the antarctic front. In some examination of charts in this connexion modification of the antarctic air mass has been noted and this is described below.

The situation described in detail on page 25 shows all three basic fronts within the area. This, being a summer sequence, shows the activity of the antarctic front confined to near the coastline of Antarctica proper with the polar front well south in the area.

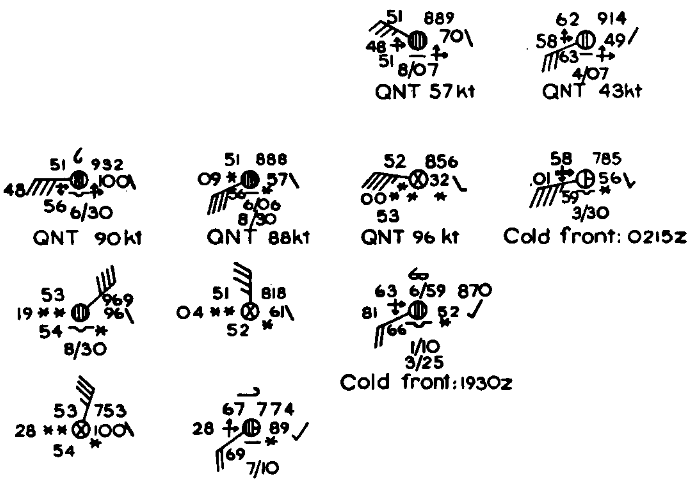
Irregular waves may readily form along the antarctic front but unless they are well marked and continue to develop they are difficult to trace and observe in their movement because of the few observations available east of Grahamland. Occasionally one is fortunate enough to observe a situation in which the observation hours coincide with the movement of waves past the reporting stations, thus permitting accurate detailed analyses on routine charts.

Following a cold air outbreak across the Falkland Islands Dependencies area, a cold anticyclone developed between the Falkland Islands and South Georgia with a marked ridge over south Patagonia (Figure 5(*a*)). In the strong south-westerly airstream over Grahamland waves developed along the antarctic front. The first readily discernible wave (Figure 5(*a*)), in common unstable wave formation but scarcely developed, moved rapidly from south-west to north-east towards the north Weddell Sea. Falls of pressure of near ten millibars in three hours were recorded together with a rapid gradient wind increase to about 75 to 90 knots and storm-force winds in many places. The second wave appeared within 450 nautical miles of the first (Figures 5(*a*) and (*b*)). This was more fully developed and again pressure falls of ten millibars in three hours were recorded at some stations and tight gradients were maintained. The speed of movement of the second wave was 32·5 knots taken over the 24-hour period 1200 GMT, 29 July 1957 to 1200 GMT, 30 July 1957, on a track of 070 degrees. During this period it deepened by six millibars. Following the second wave, the cold front broke through in the strong southerly to the Falkland Islands. The observations (Figure 5(*a*) and Table IV) show the gale- and storm-force winds experienced with these waves. The fronts of the second wave are well defined at Hope Bay, Argentine Islands and Horseshoe Island (Table IV). The final clearance of the cold front at Deception Island is also clearly marked (Table IV).

TABLE IV. *Plotted observations for hours between charts*, 29–30 *July* 1957

/ = rising-pressure characteristic; \ = falling-pressure characteristic.

| | 1200 GMT 29 July | 1800 GMT 29 July | 2100 GMT 29 July | 0300 GMT 30 July |
|---|---|---|---|---|
| Deception Island | | | | |
| Hope Bay | | | | |
| Argentine Islands | | | | |
| Horseshoe Island | | | | |




This example shows the sequence of cold air (maritime antarctic) reaching the Falkland Islands followed by the much colder air behind the antarctic front. This air, originating as continental antarctic or 'ice-cap' air, is necessarily much modified by the time it reaches South America and the Falklands, but its effects are unmistakable.

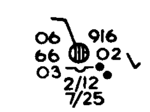
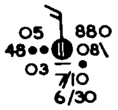
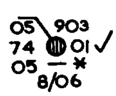
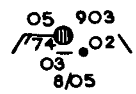
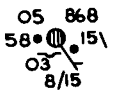
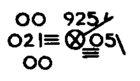
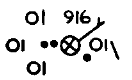
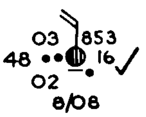
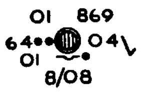
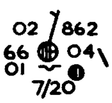
In studying the charts in the above connexion marked surface temperature differences were noted. Following the outbreak of continental antarctic air as described above, there appeared to be no discontinuity in type from the south Weddell Sea to the Falkland Islands. On Figure 5(*b*) are marked areas *A*, *B* and *C*. In area *A*, temperatures were −31·5°C (mean for four stations at 1200 GMT). In area *B*, temperatures were −26·7°C (mean for three stations at 1200 GMT) and in area *C*, −14·7°C (mean for three stations at 1200 GMT). The warming from area *A* to area *B* of less than 5°C, as against 12°C from area *B* to area *C*, over track distances of approximately 1200 nautical miles and 300 nautical miles, respectively, is particularly interesting and suggests oceanic influence. From *A* to *B* the track is over ice and snow-covered land while from *B* to *C* much of the track is over sea-ice. The further warming from the Grahamland Peninsula (area *C*) to the Falkland Islands was about 12°C and this fits well with the formula $T = T_o + 0{\cdot}6\ (T_s - T_o)$, where $T$ is the temperature after crossing the sea, $T_o$ is the temperature before crossing the sea, and $T_s$ is the sea temperature (Frost[11]).

### REJUVENATION OF AN OLD FRONT AND COMPLEX STRUCTURES

It will be readily seen that complex situations can be caused by the rejuvenation of an old front. The influence of these situations is much more localized than that of a main disturbance, and they are studied more for their effect on local weather than for use in broad-scale analysis. Usually they bring about variations of wind, precipitation, cloud, visibility and temperature which otherwise might be overlooked. The principal features are the effects of a 'preliminary' warm front and a 'secondary' cold front.

In the average situation one would expect to find the basic front being swept into the circulation of another depression giving a preliminary warm front, usually weak, and a secondary cold front, often well defined in a narrow belt. The situation shown in Figures 6(*a*) and (*b*) is the basic polar front around the occluded subtropical depression with the complex of new waves forming on the antarctic front (Figure 6(*c*)). With the approach of the subtropical depression from the west towards the Falklands, the old diffuse polar front which was lying across the area became a preliminary warm front as was shown by the observations at north Grahamland stations (Figure 6(*a*) and Table V). At Admiralty Bay the front can be accurately timed by the additional report of the time of cessation of continuous precipitation (Table V). At Hope Bay the main change is in temperature and weather, which changed

TABLE V. *Plotted observations,* 28 *February*–1 *March* 1956

| | | | |
|---|---|---|---|
| | 1800 GMT 28 Feb. | 1500 GMT 29 Feb. | 0600 GMT 1 March |
| Admiralty Bay |  Cont. ppn. ceased 1715Z |  Cont. ppn. ceased 1430Z |  |
| | 1500 GMT 28 Feb. | 0600 GMT 29 Feb. | 0300 GMT 1 March |
| Deception Island |  |  |  |
| | 2100 GMT 28 Feb. | 2100 GMT 29 Feb. | 0600 GMT 1 March |
| Hope Bay |  |  |  |
| | 0300 GMT 29 Feb. | 1500 GMT 29 Feb. | 2300 GMT 29 Feb. |
| Argentine Islands |  |  |  |

from cloudy with occasional precipitation to fog (Figure 6(*a*) and Table V). Later the occlusion of the main feature went through these stations (Figure 6(*b*) and Table V) to be followed by the polar front (Figure 6(*c*) and Table V) recurving behind the subtropical system as a cold front. The characteristics in this case are less well defined in Grahamland than at Stanley. The occlusion is shown mainly by a period of precipitation at the Grahamland stations and temporary fluctuations of the wind. At most places the barometer tendency steadied a little and then fell again. Similarly the cold front is rather diffuse but cloud-breaks and some precipitation indicate its eastward passage as is also shown by Ship *Protector* at 61°S, 59·7°W at 1200 GMT on 29 February 1956 (Figure 6(*b*)). The polar front then took over, with a new-formed system developing to the west of South America and moving east (Figure 6(*c*)). Simultaneously with this development new waves on the antarctic front formed in the south of the Bellingshausen Sea producing vigorous wave lows which moved rapidly eastwards into the Weddell Sea. These depressions are, perhaps, not unusual but are often difficult to locate. On this occasion observations from whaling factory ships in the extreme south of the Bellingshausen Sea gave clear indication of the approach and passage of the fronts and lows (Figure 6(*c*)).

## TRINITY PENINSULA EDDY

A local effect of isobaric disturbance with consequent wind variation has been frequently noted in and around the northern tip of Grahamland, known as the Trinity Peninsula. This effect, called here the Trinity Peninsula eddy, may cause forecasters some initial difficulty in analysis owing to the apparently contrary wind directions reported at some stations. It occurs in the wake of a travelling depression usually with a strong gradient. An example is shown in Figures 7(*a*) and (*b*). Some pilot-balloon soundings have been made in the region of this eddy and the depth seems to be generally about one kilometre but occasionally as much as two kilometres. Of the occasions with available soundings it has been found to have a depth of never less than 500 metres and it is thought that it could extend to three kilometres. There appears to be no major dynamical effect but the resulting wind shear may produce cloud formations and turbulence sufficient to impede aircraft operation. In the scale of helicopters used for whaling or those and other aircraft for aerial survey this feature can be important.

## CLOUD STRUCTURES

It has always been said that frontal cloud structures in high latitudes are greatly diminished and the evidence of observations continues to uphold the belief. Nonetheless the normal frontal cloud sequence is still observed in the far south and unstable cloud to great heights can occur.

Orographic stratus is a common feature in maritime polar air at the northern reporting stations in Grahamland and frequently may obscure the approach of frontal cloud. The stratus is usually low, base below 300 metres, and seldom more than 500 metres in depth. It can be associated with a temperature inversion which may be either pre- or post-frontal depending on the situation.

Wave-cloud formations are a feature of most of the stations in this area. Fine examples of wave-cloud altostratus have been observed at Stanley while 'whalebacks' and other lee-wave formations have been frequently reported, particularly from Signy Island and South Georgia. Comments on cirrus and other cloud observed at South Georgia are given by Mansfield and Glassey.[1] It will be noted that lee-wave cirrus cloud is included at South Georgia and this has been observed elsewhere in the area at heights of up to 8000 metres. Observations have been made of many-layered wave clouds at about 6000 metres at Signy Island. On these occasions the lowest layer is about 200 to 300 metres with the next layer at 600 to 1000 metres followed by many-layered stratiform cloud merging into chaotic altocumulus with cirrus above. Each wave layer appears directly above the one below and the distance between successive (wave-form) clouds along the direction of the flow is about 30 to 40 kilometres, as far as can be seen.

Many occasions are reported of nacreous (mother-of-pearl) cloud from the Grahamland stations. Some clearly defined and extensive nacreous cloud has been reported at 'a considerable height' above thin cirrus and cirrostratus which was about six to seven kilometres high. Reports of this cloud in the area have been confined to Grahamland, so far. Much of the Peninsula is over one kilometre high with peaks to near three kilometres. From 400 to 500 miles to the south of Horseshoe Island there is extensive high ground between two and three kilometres above sea level with peaks to four kilometres.

At Loubet Coast station, E. M. P. Salmon, meteorologist-in-charge, had opportunity in 1956 to study the cloud extensively on several occasions. In a private communication he has said that always the clouds have been stationary in characteristic wave form (that is, arched appearance) with thinning transverse edges and slight shadowing. He has given the following description:

'The clouds before sunrise have drawn attention to themselves as a bright white patch in the sky. At about half an hour before dawn they started colouring, following the outline of the cloud with the green band outermost. The intensity of colour reached its peak shortly after sunrise and the last colour, a delicate orange–pink, covered the whole cloud by twenty minutes or so later. The coloured stage lasted a relatively short time. The cloud then took on the white pearl texture and it also became less bright. Whether this was actually due to the lightening sky cutting the contrast is not known.'

Development of cumulus cloud in the area is somewhat restricted and cumulonimbus with anvil ($C_L9$) is usually noted to have a vertical extent of about three kilometres in most types of air mass. At Stanley, in particular, some occasions of deeper cumulonimbus may be observed in maritime polar air or maritime antarctic air but rarely in true antarctic air. In true antarctic air, cumulus clouds seldom extend above two or three kilometres, even as far north as Stanley, and frequently may have a depth of one to $1\frac{1}{2}$ kilometres while still producing shower-type precipitation. In this connexion shallow antarctic air may produce what are known locally as 'showers of drizzle' at Stanley. Small but extensive cumulus clouds, seven to eight oktas cover, with base about 100 to 200 metres and tops one kilometre give intervals of drizzle-type precipitation, that is, with drops too small to be properly classified as rain. Accompanying these 'showers' is a very low visibility, sometimes into fog limits.

In the context of cloud structures it seems hardly reasonable to mention occasions of little or no cloud, but since these are associated with frontal discontinuities they call for special note. At Stanley—and this does not occur at any of the other stations in the area except those of the Republic of Argentina in Patagonia—it has been noted that fronts may cross the Falkland Islands with little or no cloud in the spring and early summer. These situations have clearly defined warm and cold fronts at the surface except for the absence of cloud. Later in their passage eastwards cloud will develop as sufficient moisture is gathered from the sea and at South Georgia they may produce prolonged precipitation. It is interesting that the drying effect of the uplift over the Andean chain can be maintained for some 300 nautical miles of sea track to the Falklands.

Föhn bank cloud is frequently observed at many of the reporting stations particularly in maritime polar air, but can occur in almost any air mass.

## FÖHN AND LOCAL WINDS

Föhn winds are comparatively common in the area, due largely to the mountainous nature of the topography near the reporting stations. The South American föhn from the Andes may occasionally reach the Falklands, bringing warm dry weather with strong winds and, usually, cloud cover. It has been seen, at Stanley, that this cloud at medium level is sometimes discoloured, presumably by dust picked up from Patagonia. One instance in the writer's experience was of altocumulus of a vivid yellow–orange shade.

Föhn winds have been recorded with gusts to 135 knots and the temperature range can be very high. Instances at South Georgia have already been shown with a temperature range of over 12°C (Mansfield and Glassey[1]), while at Hope Bay, with surrounding high ground less than one kilometre high, ranges of up to 14°C have been observed. In one recorded instance on 12 June 1952 (that is, in mid-winter), the temperature rose from −2°C at 0800 LMT to +10°C at 1000 LMT, and finally reached +11°C at 1200 LMT. The humidity on this occasion fell to five per cent. During föhn winds at Hope Bay temperatures in excess of +10°C have been recorded in mid-winter; the highest winter maximum was +13·0°C in July 1952, and this figure was also recorded in October 1952.

A feature of föhn winds at Hope Bay is the readily observed line of demarcation between the air masses involved. This is shown in Figure 8. In the western part of the area winds of gale force are common in the föhn with temperatures much above normal while to the east light variable winds and low temperatures are experienced. About the line of demarcation local features called 'whirlies' are often present. These miniature whirlwinds lift snow up to a height of near 100 metres at times, although more frequently to about 50 metres.

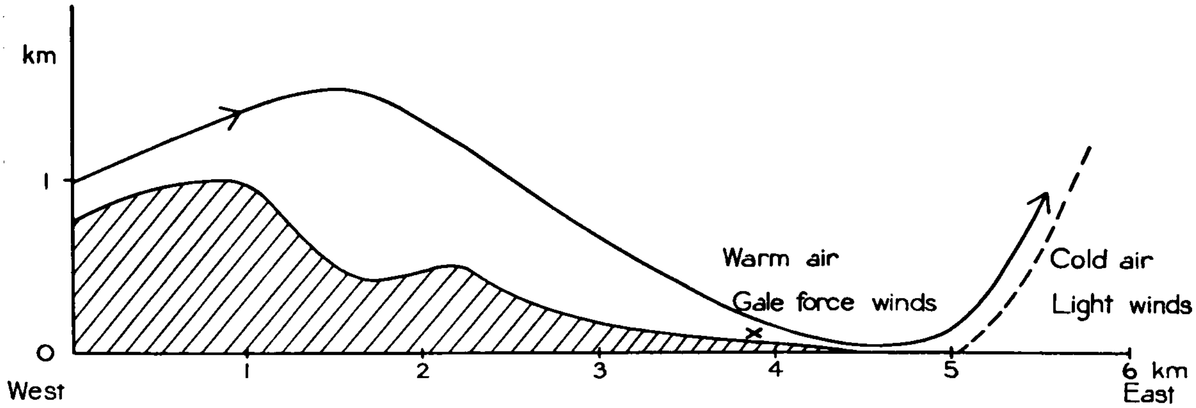



FIGURE 8. Diagram of approximate profile adjacent to Hope Bay and suggested streamline of föhn wind The broken line shows the demarcation zone and × marks the site of the anemometer.

The rotation is anti-clockwise which is anticyclonic in this hemisphere. The vigorous effect of the 'whirlies' extends along the surface for 10 to 20 metres within which a man can easily be bowled over. It seems curious that these should maintain an anticyclonic rotation when they are due to violent wind-shear which one might expect to originate movement in either direction.

Horseshoe Island and Loubet Coast base are two other stations subject to local winds which give a bias to climatological summary and cause difficulty in synoptic analysis. Both these places are subject to funnelling effects down glacial valleys and wind speeds in excess of the gradient wind are not uncommon. The directions, too, are often several points different from what one would expect, easterly or south-easterly directions being strongly preferred. At Loubet Coast there is also a tendency for winds to be deflected to north to north-north-west.

Regularly in the spring and summer, sea-breezes are recorded at Stanley. Geostrophic westerlies of up to 20 knots can be turned to east to south-east sea-breezes of up to 15 knots. Normal spring-to-summer sea temperature is between +7° and +10°C and usually an air temperature at least five degrees in excess of the sea temperature is required before the onset of the breeze. With the stronger gradients, temperature differences of 6° to 8°C have been noted with the surface westerly wind decreasing as the morning progresses; the wind then becomes light and variable and finally light to moderate east to south-east by midday (zone time). In light gradients of any direction or in a calm situation a 15-knot sea-breeze may result. The harbour at Stanley (some nine kilometres long) often shows a clear break on the water surface from the easterly sea-breeze to the westerly true wind.

## SUMMARY

The basis for weather map analysis in the area is given as fundamentally a three-front model—the subtropical, the polar, and the antarctic fronts. Five main features are propounded: travelling depressions, warm anticyclones, cold anticyclones, cold depressions and mixed situations, presented in that order of importance.

A short summary of upper air information is made. It is concluded that 'tropopause disappearance' in this area is more a feature of the polar front jet than of antarctic air, although much more work is required on this subject. It has been found that independent work in the northern and southern hemispheres has produced much agreement in many synoptic features.

Analyses are given in the sections dealing with depressions and anticyclones and it is thought that warm anticyclones are less infrequent than has been believed before. Cold anticyclones are shown to have a high rate of transfer and are considered a feature in the maintenance of the subtropical, semi-permanent anticyclones of the Pacific and Atlantic Oceans. Notes are given on cloud observations in and around Grahamland, together with some details of local wind peculiarities, to assist others in studies of the region and in synoptic chart analysis.

The whole is presented as a guide to the practice and findings of forecasting in the area in an effort to expand the limited knowledge of the atmospheric circulation of the higher latitudes of the southern hemisphere.

Acknowledgement is made to His Excellency the Governor of the Falkland Islands and Dependencies and to the Director-General of the Meteorological Office for kind permission to publish this paper. The author wishes to thank Mr. H. H. Lamb and Mr. P. A. Canning of the Meteorological Office for helpful criticism and advice.

## Bibliography


1. MANSFIELD, A. W. and GLASSEY, S. D.; Notes on weather analysis in the Falkland Islands Dependencies, Antarctica. *F.I.D.S. Sci. Rep., London*, No. 16, 1957.
2. SUTCLIFFE, R. C.; Reviews of modern meteorology—6; Principles of synoptic weather forecasting. *Quart. J.R. met. Soc., London*, **78**, 1952, p. 291.
3. SERRA, A. B. and RATISBONNA, L. R.; As massas de ar da América do Sul. Ministério da Agricultura, serviço de Meteorologia, Rio de Janeiro, 1942. (Washington, USAAF Weather Information Branch, Report No. 403, 1943—Translation).
4. ANDERSON, R., BOVILLE, B. W. and MCCLELLAN, D. E.; An operational frontal contour-analysis model. *Quart. J.R. met. Soc., London*, **81**, 1955, p. 588.
5. GIBBS, W. J., GOTLEY, A. V. and MARTIN, A. R.; Meteorology; Vol. 1, Heard and Macquarie Islands, 1948. ANARE Reports, Series D, Part 1(*c*), Antarctic Div., Melbourne, 1952.
6. BRITTON, G. P. and LAMB, H. H.; A study of the general circulation of the atmosphere over the far south. *Weather, London*, **11**, 1956, pp. 281 and 339.
7. LAMB, H. H.; Two-way relationship between the snow or ice limit and the 1,000–500 mb thickness in the overlying atmosphere. *Quart. J.R. met. Soc., London*, **81**, 1955, p. 172.
8. LAMB, H. H.; The southern circumpolar westerlies: broad characteristics and apparent associations. *Met. Res. Pap., London*, No. 1065, 1957.
9. DEFANT, F. and TABA, H.; The threefold structure of the atmosphere and the characteristics of the tropopause. *Tellus, Stockholm*, **9**, 1957, p. 259.
10. VAN LOON, H.; Blocking action in the southern hemisphere. *Notos, Pretoria*, **5**, 1956, p. 171.
11. FROST, R.; A note on polar air-mass modification. *Proc. roy. Soc., London*, **198**, Series A, 1949, p. 27.



Printed in England under the authority of Her Majesty's Stationery Office
by James Townsend & Sons Ltd.





Wt. 2364—BM414 3K8 3/61

Published by
HER MAJESTY'S STATIONERY OFFICE

To be purchased from
York House, Kingsway, London W.C.2
423 Oxford Street, London W.1
13A Castle Street, Edinburgh 2
109 St. Mary Street, Cardiff
39 King Street, Manchester 2
50 Fairfax Street, Bristol 1
2 Edmund Street, Birmingham 3
80 Chichester Street, Belfast 1
or through any bookseller

*Printed in England*

S.O. Code No. 40-146-7