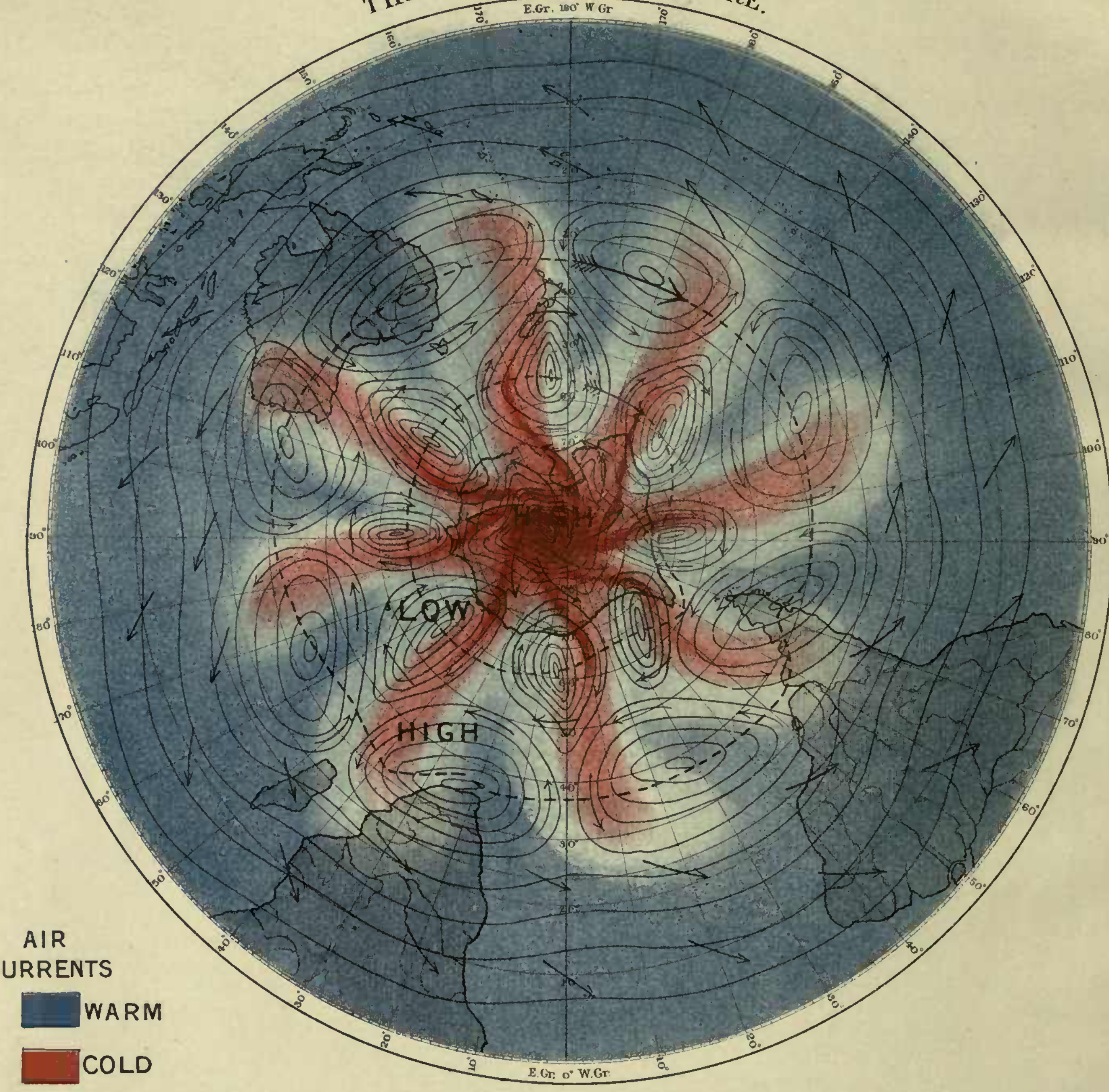
THE SOUTHERN HEMISPHERE.



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SOLAR PHYSICS COMMITTEE.

SOUTHERN HEMISPHERE SURFACE-AIR CIRCULATION:

Being a Study of the Mean Monthly Pressure Amplitudes, the Tracks of the Anticyclones and Cyclones, and the Meteorological Records of Several Antarctic Expeditions.

BY

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UNDER THE DIRECTION OF

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	Year of Publication.
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Second Report by the Committee on Solar Physics	(1889)
Positions and Areas of Sun Spots and Faculæ, 1887 and 1888	(1889)
" " " " " 1889	(1891)
" " " " " 1878–1882 (inclusive) and 1890 ...	(1892)
" " " " " 1891	(1894)
" " " " " 1892	(1895)
" " " " " 1893	(1896)
" " " " " 1894, 1895, 1896, and 1897 ...	(1899)
Spectra of Sun Spots, 1879–1897 (inclusive)	(1900)
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Researches on the Chemical Origin of various lines in Solar and Stellar Spectra ...	(1910)

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PREFACE.

In a previous memoir, entitled "A discussion of Australian Meteorology," which was a continuation of the researches undertaken in connection with solar and terrestrial changes, Doctor W. J. S. Lockyer pointed out the apparent similarity of the air movements over Australia, South Africa, and South America, and suggested that anticyclones which crossed Australia were indications of a continuous state of things occurring in a belt encircling the earth. The present memoir is an attempt by him to show that there is such a belt in which the anticyclones are moving from west to east and that these systems individually wax and wane during their passage.

Dr. Lockyer uses the values of the mean winter pressure-amplitudes to aid him in locating the paths of the anticyclones over the continents, islands, and oceans.

The investigation has been carried further south into the Antarctic regions, and the speed and direction of movement of the pressure (low) waves there studied have enabled him to indicate a scheme for the general surface-air circulation for the whole of the Southern Hemisphere.

It is hoped that the results of this extensive survey will greatly assist in attempts to associate solar activity with the air movements in the Southern Hemisphere; they suggest also that greater importance, from this point of view, must be attached to the meteorology of the polar regions than has hitherto been the case.

The research has entailed a great amount of labour and the collection and collation of data many of which were difficult of access.

May 25, 1910.
Solar Physics Observatory,
South Kensington.

NORMAN LOCKYER.

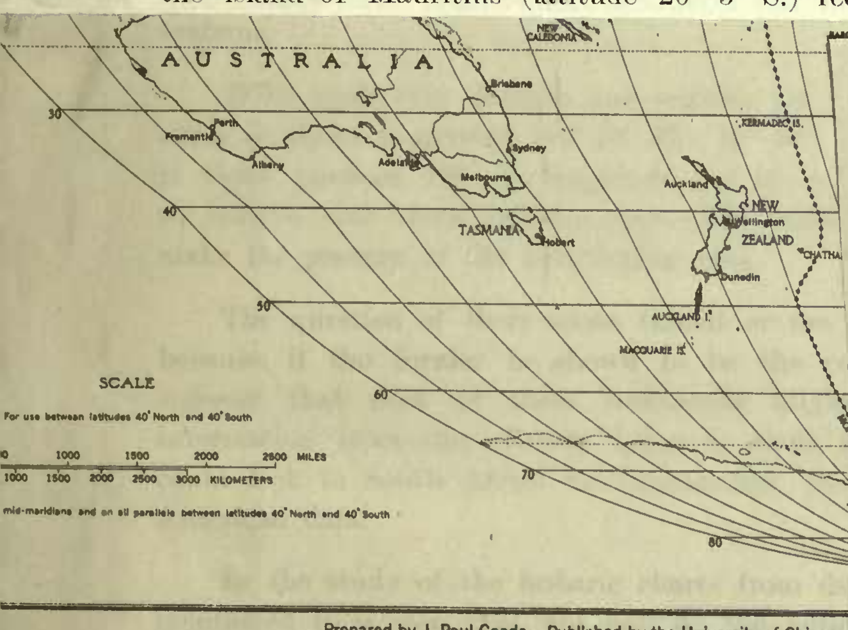
INTRODUCTION.

A question which has long been discussed by meteorologists is whether the anticyclonic systems which pass over the Australian continent from west to east are formed as the continent is reached, or whether they are systems which have crossed the South Indian Ocean. The latter view was strongly advocated by the late Mr. H. C. Russell.

Another point about which there seems to be a considerable difference of opinion is whether the high-pressure systems — lying to the west of the three southern continents, namely, South Africa, Australia, and South America—which are recorded on mean isobaric charts are permanent systems or not.

In a recent memoir published by the Solar Physics Committee and entitled "A discussion of Australian Meteorology," I brought together some evidence to show that in the Southern Hemisphere, between latitudes about 20° S. and 40° S., anticyclonic systems moved rapidly round that part of the earth included in the Australian area.

I stated further that the parts of South America and South Africa in about the same belts of latitude were also swept by a consecutive series of anticyclones which travelled approximately from west to east. It was indicated there also that the island of Mauritius (latitude 20° 5′ S.) recorded also the passages of those



Prepared by J. Paul Goode, Published by the University of Chicago

It may be concluded therefore that the stretch in longitude, namely 130°, which is known to be occupied by travelling anticyclones would be considerably extended if one were to include areas to the west and east of each of the countries equal in size to that of a normal anticyclone. Thus if the extent in longitude of a normal anticyclone be taken as about 25°, then 6 × 25° should be added to the length of the known belt. Thus the length of the belt becomes 280° instead of 130°, so that only 80° of longitude remains to be accounted for.

When this memoir was commenced it was proposed only to make a detailed investigation of the pressure changes from day to day at as many stations as possible distributed in the belt of latitude in which the anticyclones move. The inquiry, however, soon became more extensive as the work progressed, and nearly the whole of the Southern Hemisphere was finally included. This research was undertaken because it seemed useless to try to determine the effect of the solar changes on the Southern Hemisphere until something more was known about the mechanism of the atmospheric circulation taking place there.

Throughout the investigation so many interesting points have been raised that the memoir has exceeded its originally extended scope. It is hoped, however, that the matters touched on will be found of sufficient importance to justify their inclusion here.

It is to be specially noted that the pressure conditions have for the main part been considered only for the period of the year included in the six months April to September, the winter season in the Southern Hemisphere. The reason why this season was chosen was because the anticyclones at this time move in more northern latitudes and therefore transit more land surfaces where their effect on the barometer is recorded.

It seems very desirable that the summer season should be treated in the same manner, for the pressure-amplitudes of the two seasons are not the same and the rate of movement of the pressure waves may also be different.

Towards the end of the memoir an attempt is made to deal with the atmospheric circulation over the intervening oceans and to carry the inquiry as far south as possible into the Antarctic regions. Finally a suggested scheme of surface-air circulation over the Southern Hemisphere is put forward and a new interpretation of mean seasonal isobaric charts.

In the case of the present memoir a considerable time has been spent in collecting the necessary data for discussion, mean daily values of pressure for periods of six months for many very far distant stations being required.

Among those to whom I wish to express my indebtedness for help are the following:—

Dr. W. N. Shaw, F.R.S., the Director of the British Meteorological Office, for facilities for copying data.

Mr. A. Mosely, for data regarding St. Helena.

Monsieur Angot, the Director of the Bureau Central Météorologique, for information with respect to Rikitea.

Mr. H. A. Hunt, the Commonwealth Meteorologist for Australia, for the pressures of Sydney and Hobart.

Mr. R. G. K. Lempfert, of the British Meteorological Office, for information regarding the time-reckoning used at some of the South Pacific islands.

The High Commissioner for New Zealand for data regarding Wellington.

Mr. D. C. Bates, Director of the Government Meteorological Office, Wellington, New Zealand, for data regarding daily pressure values at Dunedin.

Dr. Hough, the Royal Astronomer at the Cape of Good Hope, for barometric readings taken at the Royal Observatory, Cape Town.

Dr. von Drygalski, the meteorologist of the German South Polar Expedition of 1901–3, for permitting the copying of data made on the "Gauss" and at Kerguelen. The published volumes of this expedition were finally obtained and utilized.

Dr. W. S. Bruce, who, on application for data, kindly presented me with the handsome volume containing the meteorological records of the Scottish National Antarctic Expedition, 1902–4.

Herr Gösta Bodman, for sending me the recently published volumes of the Swedish South Pole Expedition, 1901–3.

And finally to Sir E. H. Shackleton, for allowing Mr. James Murray to forward to me a copy of the pressures at Cape Royds, made during the recent British Antarctic Expedition, 1907–9.

Valuable aid in the abstractions of the data, reductions and the drawing of the multitude of curves has been rendered chiefly by Mr. W. Moss, and in part by Mr. T. F. Connolly, computers in the observatory; and the former has very materially assisted in the preparation of the diagrams and plates. Mr. J. P. Wilkie, who is employed in photographic work for the observatory, made the necessary photographic reductions from the original diagrams and curves for the memoir.

CHAPTER I.

THE MOVING ANTICYCLONES OF THE SOUTHERN HEMISPHERE.

If one examines the daily readings of the barometer from day to day for several weeks for stations south of the equator it is found that changes are indicated which are separate from the daily and annual periodic variations. The nearer the equator is approached the less apparent become these changes. They seem to form a consecutive series of waves of high pressure following one another more or less regularly and lasting for a few days. They are recorded on the islands in the mid-oceans as well as on the continents.

Dr. Julius Hann* draws attention to these pressure waves in the following terms :—

"In the tropical zones, especially in the equatorial region, the barograph writes regularly day by day two complete waves with 2–3 mm. distance between wave trough and crest. About the border of the tropical zone deep crater-form troughs in the pressure curves (amounting to 20–40 mm. and over) become noticeable occasionally in different parts of the earth, but not once every year, due to the passage of a cyclone. The pressure records of higher latitudes permit only, still seldom in summer, a regular pressure variation to be recognised, which is composed much more out of quite irregular entrances and departures of pressure waves of partly very large amplitudes and different lengths of period. They so suggest the appearance as if pressure waves, something analogous to ocean waves, proceed over a place in continuous succession, but with constantly changing wave-length and height, and for the most part in a direction from west to east, as results from the records of different stations."

On the continents in the Southern Hemisphere between certain restricted latitudes the cause of these waves is well known. They are due to the successive passage of high-pressure systems which pass over the land, and the configuration of these anticyclones has been determined by means of daily isobaric charts.

In the case of islands situated some distance from the mainland, the waves of high pressure do not seem to have been associated, so far as I can find out, with anticyclonic systems, probably because isobaric charts cannot be made in consequence of the small area over which daily data can be obtained.

There seems reason to believe, and grounds for this will be stated later, that the high-pressure waves on both the continents and the islands are caused by anticyclones travelling approximately from west to east, and, if the islands were sufficiently numerous and in the track of the anticyclones, they would be able to be traced passing eastward from one island to the other as their path is determined over the land.

* Lehrbuch der Meteorologie, 2nd Edition, p. 153.

In tracing the movements of anticyclones there is little doubt that special attention must be paid to the amplitudes of the pressure waves, for the amplitudes will be larger at places where the centres of the systems pass over than at those stations where only the fringes make their transit.

An examination of the accompanying figure will perhaps render this statement more clear.

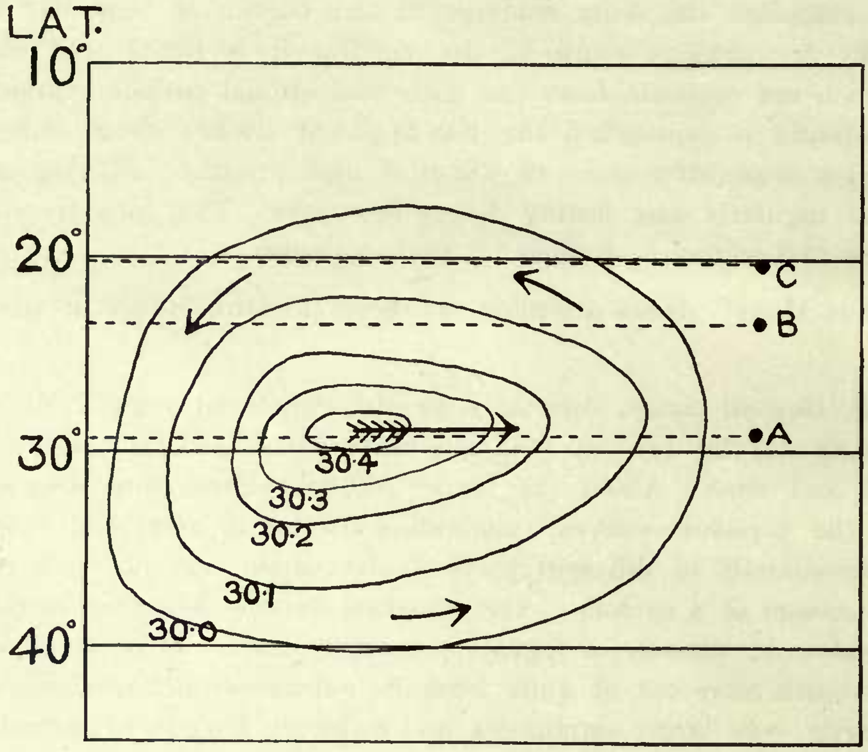


Fig. 1.

Let A, B, and C be three stations with decreasing southern latitudes respectively. Let an anticyclone pass over them from left to right, *i.e.* from west to east, the centre of the system passing over A. The barometer at A will have to rise through the readings 30·0, 30·1, 30·2, 30·3, and 30·4 inches, and fall in the reverse order. During the same period of time the anticyclone will only cause the pressure at C to rise to 30·0, and maintain this pressure for some time since the station only intersects one of the isobars. The amplitude of the pressure wave at C will thus be *small*, while that of the wave at A will be *large*. At B the amplitude will have an intermediate value.

The close relationship between anticyclones and the pressure-amplitudes at the stations over which they transit suggested at once that a systematic study of the latter, for a great number of stations well distributed in the Southern Hemisphere, was most desirable. It was thought that this study might give an important clue to the determination of their actual track round the earth, and thus render great assistance in pointing out the latitudes in which they should be sought after.

An attempt was therefore made to undertake this inquiry, and the method adopted and the results obtained form the subject-matter of the following chapter.

CHAPTER II.

A STUDY OF THE WINTER (APRIL—SEPTEMBER) AMPLITUDES OF THE ATMOSPHERIC PRESSURE WAVES.

(*a*)—METHOD OF AMPLITUDE DETERMINATION.

When the inquiry into the magnitudes of the pressure-amplitudes was first undertaken an attempt was made to determine their values from the curves originally drawn for following the movements of the anticyclones. As this work proceeded the results proved so suggestive that a more detailed examination over a very much more extended area was made, and this involved the inclusion of a large number of stations and consequently the drawing of a considerable number of curves. In fact, the amplitudes of no less than 57 stations were determined, these stations being situated in many different longitudes and extending from the Equator to the Antarctic regions. In a great number of cases the amplitude derived for any one station was the mean of several winter seasons. For most stations, therefore, many curves were drawn, and the total number examined for this investigation was 164.

In the first instance the amplitudes of the various stations were obtained by determining the differences between the readings of the several prominent maxima and their following minima. As a first approximation this procedure was satisfactory, as it served to differentiate between the large and small values of the amplitudes of the stations employed. Nevertheless, a second method was tried in which account was taken of all the maxima and minima of the curves, and by this means a finer discrimination between the different stations was obtained.

It was, however, finally decided not to include every small variation in the curves, but only those above a certain value, according to the general nature of the curves. Such a procedure was adopted because many very small changes, small when compared with the normal changes, reduced the final values of the amplitudes of the pressure curves and did not represent the typical variations the amplitudes of which it was desired to determine.

The method actually adopted was as follows:—

A curve for the barometric changes at any station during the six months April to September was taken, and the three largest amplitudes were selected. The mean amplitude of these three was then formed. Any variation *less than one-fifth of this mean amplitude was then disregarded*, and all the other variations of greater magnitude were utilised to form the final value of the amplitude.

For every station, where possible, the same season in different years was examined and a mean value for the station finally obtained.

Thus, to take the case of Adelaide as an example. It was found that a variation of 5 mm. could be safely disregarded after the examination of 13 winter seasons.

The different determinations of the amplitudes for each winter season for this station were as follows:—11·2, 12·7, 12·7, 11·5, 12·7, 12·5, 10·9, 11·7, 11·7, 13·5, 12·2, 13·2, 13·5 mm., and the value finally adopted was 12·3 mm.

In the case of another station, in this case one of small amplitude, namely, St. Helena, any variation smaller than 0·5 mm. was taken no notice of, and for seven winter seasons the values determined were 1·5, 1·8, 1·8, 1·3, 1·3, 0·8, and 2·0 mm., the mean of which, namely, 1·5 mm., was adopted as the final value.

(*b*)—THE SOURCES OF THE DATA.

The following table gives a complete account of the sources from which the data employed in this inquiry were obtained. The information is arranged as far as possible in the order of longitude of the stations used commencing with the West Coast of Africa and proceeding eastwards. The data regarding the Antarctic regions are placed at the end of the table.

Plate I. shows at a glance the names and positions of all the stations employed. It may be mentioned that the outline of the Antarctic continent has been revised after recent maps and indicates either land or the positions of the ice-barrier.

Kibokolo	Meteorological Notebook by the Rev. Thomas Lewis, missionary, at the Meteorological Office.
Walfish Bay	Deutsche Ueberseeische Meteorologische Beobachtungen. Vols. I and VI.
Cape Town	Magnetic and Meteorological Observations, Cape Town, Vol. II. and MSS. sent by Dr. Hough, His Majesty's Astronomer at the Cape.
Kimberley	Reports of the Meteorological Commission of Cape Colony.
Johannesburg Pretoria	Annual Reports of the Transvaal Meteorological Department.
Durban	Annual Reports of the Government Astronomer of Natal.
Zomba	British Central Africa Gazette.
Daressalam	Deutsche Ueberseeische Meteorologische Beobachtungen. Vol. XIV.
Antananarivo	Magnetic and Meteorological Observations made at Tananarive and Annales du Bureau Central Météorologique de France.
Mauritius	Magnetic and Meteorological Observations made at the Royal Alfred Observatory and Monthly Bulletins (MSS.).
Kerguelen Island	MSS. sent to the Meteorological Office by Prof. E. von Drygalski.
Batavia	Magnetic and Meteorological Observations made at the Royal Observatory at Batavia.
Perth	Meteorological Observations made at Perth Observatory.
Adelaide Alice Springs Port Darwin	Meteorological Observations made at Adelaide Observatory and other places in South Australia and the Northern Territory.

Daly Waters Wilson's Promontory	Meteorological Observations made at Adelaide Observatory and other places in South Australia and the Northern Territory, but read from curves.
Hobart	MSS. sent by H. A. Hunt, Esq., Commonwealth Meteorologist.
Sydney	Meteorological Observations made in New South Wales, and MSS. sent by H. A. Hunt, Esq., Commonwealth Meteorologist.
Port Moresby	Supplements to the British New Guinea Government Gazette.
Dunedin	MSS. sent by Mr. D. C. Bates, Director of New Zealand Meteorological Department.
Wellington	Extract from the "New Zealand Gazette" (Meteorological Returns) and MSS. sent by Mr. D. C. Bates, Director of New Zealand Meteorological Department.
Nauru Apia (Samoa) Raratonga	Deutsche Ueberseeische Meteorologische Beobachtungen, Vols. IX. and XII.
Suva (Fiji) Malden Island	MSS. Monthly Reports to the Meteorological Office.
Papeiti	Annales du Bureau Central Météorologique de France.
Rikitea	MSS. supplied by M. A. Angot, Director of the Bureau Central Metétéorologique de France.
Juan Fernandez Arica Caldera Punta Anjeles Ancud Punta Dungeness Punta Arenas	Anuario del Servicio Meteorolojica, Chile.
Santiago	Observaciones Meteorolojicas, 1885–7. Santiago Observatory.
Cordoba Chubut Rosario San Juan (B.A.)	Anales de la Oficina Meteorolojica Argentina, and Daily Weather Reports.
Buenos Ayres	Argentine Daily Weather Reports.
Itaqui Cuyabá Rio de Janeiro Aracaju Fortaleza Quixada	Boletim das Observacões Meteorologicas at 0^h G.M.T., Brazil.
Cape Pembroke	Lighthouse Log at the Meteorological Office and Scientific Results of the Voyage of the S.Y. "Scotia."
St. Helena	MSS. Monthly Reports to the Meteorological Office.
"Gauss"	MSS. sent to the Meteorological Office by Prof. E. von Drygalski.
Cape Adare	Magnetic and Meteorological Observations made by the "Southern Cross," Antarctic Expedition (Royal Society, 1903).
Ross Island	National Antarctic Expedition, 1901–1904. Meteorology, Part I. (Royal Society, 1908).
Cape Royds	MSS. supplied by permission of Sir E. H. Shackleton.

"Belgica" - - - Résultats du Voyage du S.Y. "Belgica" en 1897–1898–1899. Rapport sur les Observations Météorologiques Horaires par Henryk Arctowski.

Snow Hill - - - MSS. sent to the Meteorological Office by Dr. G. Bodman.

Laurie Island - - Scientific Results of the Voyage of the S.Y. "Scotia," 1902–1903–1904. Vol. II. (Scottish Oceanographical Laboratory, Edinburgh, 1907.)

(*c*)—THE VALUES OF THE AMPLITUDES.

When the investigation of the determination of the amplitudes of the pressure curves was commenced, it was considered desirable to examine the amplitude of any station, if possible, for more than one year, for it was not known whether the amplitude was the same for consecutive winter seasons. In fact, it was considered rather improbable to expect such a condition, for, in the case of Australia, I had already drawn attention to the passage of the anticyclones over that country, and showed that high-pressure years, in that continent, were associated with a greater size of anticyclonic systems* and a smaller number of low-pressure systems. This, in itself, suggested that the amplitudes would probably not have the same value in different years.

It was, therefore, desirable to employ more than one winter season in case large differences might be met with, and this procedure, as will be seen in the table, was found very imperative. In some cases this was not found possible, on account of the lack or inaccessibility of the necessary data.

With the above precautions, and by the method described in the last chapter, the values of the amplitudes were determined, and these are given in the following table. The stations are arranged in order of latitude, and the individual values for each winter season, April to September, for each station are included. The last three columns show:—

(1) the number of winter seasons from which the mean values have been deduced;

(2) the minimum values of the amplitudes which have been taken into account; and

(3) the mean values of the amplitudes of each station which have been adopted.

* "A discussion of Australian Meteorology," p. 19.

COMPARISON OF AMPLITUDES (APRIL—SEPTEMBER)

(in millimetres).

Latitude.	Station.	1845.	1878.	1881.	1883.	1885.	1886.	1887.	1891.	1892.	1895.	1896.	1897.	1898.	1899.	1902.	1903.	1904.	1905.	1906.	1908.	No. of Years.	Minimum Amplitude adopted. mm.	Mean Amplitude. mm.
° ′																								
0 26	Nauru - -										1·6		2·0		2·1							3	0·5	1·9
3 43	Fortaleza - -																1·6	1·7				2	0·5	1·6
4 0	Malden Island -								2·3		1·8							1·8				3	0·8	2·0
4 57	Quixada - -																	1·6				1	0·5	1·6
6 11	Batavia - -		1·3								1·4								1·6			3	0·4	1·4
6 17	Kibokolo - -																1·2	1·0				2	0·4	1·1
6 49	Daressalam -																1·5	1·5				2	0·5	1·5
9 25	Port Moresby -										1·6											1	0·75	1·6
10 55	Aracaju - -																1·6	1·7				2	0·5	1·6
12 28	Port Darwin -			2·5	1·6																	2	0·75	2·0
14 0	Apia (Samoa) -								2·2		1·8	2·2	2·2		2·1							5	0·75	2·1
15 20	Zomba - -																2·6	2·6				2	1·0	2·6
15 35	Cuyabá - -																3·8	4·3				2	1·5	4·0
15 56	St. Helena -						1·8			2·0			1·8				1·3	1·3	0·8			6	0·5	1·5
16 16	Daly Waters -			2·9	2·5																	2	1·0	2·7
17 32	Papeita - -																	3·2				1	1·0	3·2
18 5	Suva (Fiji) -						2·9		3·8		3·7	3·0					3·1	3·2		3·3		7	1·0	3·3
18 28	Arica - -																	2·4				1	1·0	2·4
18 53	Antananarivo -								2·1								2·1	2·4				3	1·0	2·2
20 5	Mauritius - -		3·2				3·1		2·9				3·0				2·4	3·0	2·9			7	1·0	2·9
21 12	Raratonga - -														4·2							1	1·5	4·2
22 56	Walfish Bay -						3·2		3·3	3·6												3	1·0	3·3
22 57	Rio de Janeiro -																5·8	5·8				2	2·0	5·8

COMPARISON OF AMPLITUDES (APRIL—SEPTEMBER)

(in millimetres)—*continued.*

Latitude.	Station.	1845.	1878	1881	1883.	1885.	1886.	1887	1891	1892.	1895.	1896.	1897.	1898.	1899.	1902	1903	1904.	1905.	1906.	1908.	No. of years.	Minimum Amplitude adopted. mm.	Mean Amplitude. mm.
° ′																								
23 7	Rikitea - -																5·0	4·7				2	1·5	4·8
23 38	Alice Springs -			5·9	7·1																	2	2·5	6·5
25 46	Pretoria - -																	4·3	4·6			2		4·4
26 11	Johannesburg -																	4·3	4·6			2		4·4
27 3	Caldera - -																3·0	2·8				2	1·0	2·9
28 42	Kimberley -														4·6		6·1					2	2·0	5·3
29 6	Itaqui - -																7·0	7·1				2	2·5	7·0
29 41	Durban - -						8·4		8·2				8·3			9·7	8·9	7·7	9·0			7	3·8	8·6
31 24	Cordoba - -						7·5		8·0				8·6					8·4				4	3·0	8·1
31 57	Perth - -				12·7				10·2				10·4			10·2	11·5	11·7	11·7	10·2		8	5·0	11·1
33 6	Punta Anjeles (Valparaiso).														4·6		4·7	5·0				3	1·5	4·8
33 26	Santiago - -						4·6	3·8														2	1·5	4·2
33 42	Juan Fernandez																7·0	7·7				2	3·0	7·3
33 52	Sydney - -			10·2	11·7		12·0		12·5		10·7		9·8		11·2		11·7					8	5·0	11·2
33 56	Cape Town -								9·9								9·2	8·9	8·2			4	3·6	9·0
34 36	Buenos Ayres -																	9·0				1	3·0	9·0
34 49	San Juan (B.A.)						9·4															1	3·0	9·4
34 57	Adelaide - -		11·2	13·2	13·5		12·7		12·7		11·5	12·7	12·5		10·9	11·7	11·7	13·5	12·2			13	5·0	12·3
41 16	Wellington (N.Z.)																		12·6	12·6	15·3	3	5·0	13·5
41 51	Ancud - -																9·9	10·9				2	2·0	10·4
42 50	Hobart - -																				15·6	1	5·5	15·6
43 18	Chubut - -					11·0																1	4·0	11·0
49 25	Kerguelen Island															16·5						1	6·3	16·5

51	41	Cape Pembroke -												16·0			14·3	17·8					3	5·0	16·0
52	24	Punta Dungeness														17·4	16·4	17·6	17·0				4	6·0	17·1
53	10	Punta Arenas -																	17·0				1	6·0	17·0
60	44	Laurie Island ("Scotia").															18·8						1	6·3	18·8
64	30	Snow Hill ("Antarctic").														15·6	18·0						2	6·3	16·8
66	2	"Gauss" - -														17·0							1	6·3	17·0
71	-	"Belgica" -												16·0									1	6·0	16·0
71	18	Cape Adare ("Southern Cross").													14·0								1	6·3	14·0
77	50	Ross Island ("Discovery").														15·0	15·5						2	6·3	15·2

Since the above table was completed and curves subsequently drawn the following additional amplitudes have been determined :—

Latitude.	Station.	1891.	1895.	1904.	1908.	No. of Years.	Minimum amplitude adopted.	Mean amplitude.
							mm.	mm.
29° 41′	Durban - - -				8·0	1	3·8	8·0
33° 52′	Sydney - - -				10·2	1	5·0	10·2
41° 16′	Wellington - - -	14·5	12·9	15·3	15·3	4	5·0	14·5
45° 51′	Dunedin - -	14·4	14·0	14·5		3	5·0	14·3
77° 33′	Cape Royds - - -				10·7	1	4·1	10·7

(*d*)—DISCUSSION OF THE DISTRIBUTION OF THE AMPLITUDES.

If the stations which have been employed be arranged in the order of latitude it is at once obvious that increase of southern latitude means generally a considerable rise in the values of the amplitudes. To illustrate this in a clear manner, the values of the amplitudes were plotted on squared paper, with latitudes as ordinates and amplitudes in millimetres as mantissæ, and a line drawn to satisfy as far as possible all the points. The curve thus obtained is illustrated on the right-hand side of Plate II. (curve 6).

The main features of this curve are as follows :—

1. The amplitudes of all stations from about 0° to 12° S. latitude are alike, having a value of about 1 to 2 mm.

2. From latitude 12° S. the amplitudes increase rapidly until about latitude 60° S. is reached, when they attain a maximum value of about 18 mm.

3. After this maximum the amplitudes definitely *decrease*, this decrease occurring up to the highest southern latitude at which records are available, namely 77° 50′ S.

There is little doubt that this amplitude curve suggests the existence of some law regarding the relationship between amplitude and latitude, nevertheless this mean curve in some of its portions (*see* latitude 34° about) departs considerably from the amplitude values of several stations. Those anomalies are not due to the errors in their determination, but to real variations from the mean amplitude as shown by the curve.

In order to analyse and explain, if possible, the existence of these anomalies, the values of the amplitudes of all the stations were plotted on a map of the Southern Hemisphere. Such a map is reproduced on Plate III. and the amplitudes are placed against the positions of each station.

In the same way as lines are drawn on a map to indicate stations undergoing at any epoch equal barometric pressure, and termed isobars, so an attempt was here made to draw lines to show *equal pressure-amplitudes*. As such lines will be subsequently often referred to, it seemed desirable that a suitable word should be coined to express them. For this purpose I consulted Dr. W. N. Shaw, and after several names had been proposed, the one finally suggested by him and adopted here is "isanakatabars," which being literally translated means "*equal ups-and-downs of pressure*."

If one had been dealing with temperature and not pressure curves, the lines of equal thermic amplitude would have been called "isanakatatherms."

Returning now to the map shown in Plate III. the lines of equal pressure, amplitude, or isanakatabars, have been drawn for every 3 mm., commencing with the isanakatabar of 4 mm.

The first feature which attracts the eye in looking over this system of isanakatabars is that, while in the main they take the form of small circles, there are two regions where the circle form is considerably departed from, namely about the American and African continents. In the former the isanakatabars on the west coast dip towards higher southern latitudes and recurve sharply over the Argentine Republic and Brazil to the north and north-east.

In the region of South Africa the isanakatabars again dip southwards as the west coast is reached and then take a north-easterly trend in South Africa itself, recurving again slightly as the South Indian Ocean is reached.

In the longitudes of Australia and the South Pacific islands the isanakatabars do not deviate much from small circles, thus running practically from west to east.

The second feature which should be noted is that the isanakatabars represent increasing values of amplitude up to 19 mm., the isanakatabar of 19 mm. being a *maximum* and occurring approximately between latitudes 53° and 60° S. In order to satisfy the amplitutes in those latitudes this line cannot be drawn quite concentric with the South Pole, but has to reach to about latitude 53° in about the longitude of Australia and to about latitude 60° in longitude 50° W.

From the maximum isanakatabar the amplitudes begin to decrease towards the South Pole, but owing to the natural paucity of observations in these very southern latitudes, the position of the isanakatabar of 16 mm. can only be very approximately indicated. There seems, however, to be a general tendency for the line to take the shape of the land and ice barrier.

It is from the study of this map that the anomalies, referred to above and indicated in the curve representing the mean change of amplitude with latitude, will be seen to be restricted to two very definite regions. If the mean amplitude curve, indicated on Plate II. (curve 6) represented a general law between amplitude and latitude applicable to the whole of the Southern Hemisphere, then the isanakatabars should be small circles concentric with the South Pole. It is seen, however, from the map (Plate III.) that the isanakatabars are not small circles in their entirety, and that they are not all concentric with the South Pole, so that the law cannot be considered to hold good for all longitudes.

In order to investigate more closely the relation between amplitude and latitude, stations situated between the South Pole and the Equator and between certain longitudes have been grouped together and treated separately. In other words sections across the isanakatabars have been made for particular longitudes. The longitudes which were selected are as follows:—

30° E. to 90° E.
150° E. to 160° W.
70° W. to 90° W.
30° W. to 60° W.

These stretches in longitude are marked on Plate III. by thick lines on the circumference of the map.

For each of these sections curves have been drawn and these are all reproduced in Plate II. (curves 1–4). The first (longitude 30° to 90° E.) represents the amplitude change in latitude for the region about East Africa and the Southern Indian Ocean. The large extent in longitude was used so as to include the amplitudes of the island of Kerguelen and that of the "Gauss" Antarctic expedition's station. This curve indicates an amplitude of about 1·5 mm. for stations from 0° to 10° S. latitude. At latitude 20° S. the amplitudes begin to make a rapid increase in magnitude, a maximum of 18 mm. being reached in about latitude 58° S. From there the amplitude decreases so far as a smooth curve through the amplitude from the "Gauss" observations indicates.

The second curve (longitude 150° E. to 160° W.) represents the condition of things for Eastern Australia and the Pacific islands. There the isanakatabars run practically from west to east, so one is here dealing with a more or less simple or normal change of amplitude. From 0° to 14° of south latitude the amplitudes are of about 2 mm. in magnitude. They then increase about the same rate as they did in the Southern Indian Ocean area, reaching a maximum of about 17·5 mm. in south latitude of 58°. Again a decrease in amplitude towards the South Pole is indicated, as shown by the observations made at Cape Adare and Ross Island by the "Southern Cross" and "Discovery" Antarctic expeditions.

The third curve (longitude 70° to 90° W.) represents the amplitude change in the region to the west of the Andes in South America. Here it will be noticed that the increase in the amplitudes is very much less rapid to commence with, the more abrupt rise taking place in latitude 30° S. The curve, as before, then shows a continued increase of amplitude to a maximum of 18·5 mm. in latitude 60°, after which it decreases towards the South Pole, as suggested by the observations made by the Antarctic expedition's ship S.Y. "Belgica."

The fourth and last region here illustrated is that situated between the Equator and the South Pole between longitudes 30° to 60° W. This includes practically the whole of the East Coast of South America. The curve representing the change of amplitude with latitude is the fourth curve on Plate II. Here also the amplitude of the equatorial regions amounts to about 1 to 2 mm. up to about latitude 10° S., after which a steady increase takes place until a maximum of about 18 mm. is reached in latitude 60°. The observations made on the occasion of another Antarctic expedition in the ship "Antarctic" indicate, as in the case of the other curves, again a decrease in amplitude towards the South Pole if a smoothed curve be drawn through the deduced values of the amplitudes.

By combining now these four curves, and forming a mean curve, that numbered 5 in Plate II. illustrates its form. This curve, it may be remarked, does not necessarily represent the mean curve through the individual points (also indicated), but the mean of the four curves, giving them all the same weight. This curve can now be compared with that first mentioned, number 6, which represents the mean curve indicating the mean change of amplitude as shown by utilizing all the stations which have been analysed.

It will be noticed that there is not very much difference between them. While curve 5 is somewhat flat up to latitude 14°, curve 6 is less so and seems to indicate a small increase of amplitude from latitude 6° up to the Equator. Both curves show an increase in amplitude up to about 58° to 60°, where a maximum of 18 mm. is reached. After latitude 60° is passed the curves suggest that the magnitudes of the amplitudes do not decrease so rapidly as they increased. If the extrapolation of curve 6 could be trusted it would seem that the amplitude at the South Pole would be about 13 mm. It is quite possible, as will be seen further on, that the amplitudes in that region are considerably less than this value.

The general form of the isanakatabars and the anomalies in the regions of South Africa and South America lead one to believe that in them lies a useful key which may materially assist in the study of the surface atmospheric circulation.

After the completion of this chart and the rather laborious work involved in the determination of the mean values of the amplitudes, I thought that the barometric data had been handled and employed in a novel way. I have since found, however, through a reference in Dr. Hann's "Lehrbuch der Meteorologie" (2nd edition) that a similar kind of chart has previously been prepared, including one also for the Northern Hemisphere.

I may, however, add that, while I have employed the means of several oscillations of pressure during any one month, the investigation to which reference is made above only deals with the maximum and minimum readings in any one month; for this reason I therefore consider the method of procedure adopted in this memoir of a less approximate character than that just mentioned, because the difference between the maximum and minimum in any one month does not represent at all the value of the mean or typical amplitude of the pressure variations during that period.

Nevertheless the investigation is of very considerable importance, for it certainly differentiates between stations of large and small pressure-amplitudes, and moreover it was completed more than a quarter of a century ago (1882), when data were less numerous than they are now, and with data for years many of which have not been employed in the present memoir.

The article in question appeared in the "Annalen der Hydrographie" (Vol. X., page 275, 1882) and was entitled "Die monatlichen Barometerschwankungen deren geographische Verbreitung, Veränderlichkeit und Beziehung zu anderen Phänomenen," and was written by Dr. W. Köppen.

It was based chiefly on the work of Herr Felberg, who made tables for 316 stations (274 in the Northern Hemisphere and 42 in the Southern Hemisphere) giving the mean magnitudes of the pressure variations for single months and for the mean of three winter and three summer months; for each month the maximum and minimum readings alone were employed.

Köppen in his communication has added several new stations in the Southern Hemisphere, thus extending the area of inquiry. Further he has plotted all the winter and summer values on two maps of the world separately, and joined together by continuous lines stations exhibiting the same values. Thus he has made maps which may be considered nearly equivalent to the isanakatabar chart of the present volume.

It is therefore of great interest to compare Köppen's map of the June to August conditions with that given in the present memoir (April to September conditions). To make the comparison more easy, Köppen's lines have been redrawn on a skeleton map similar to that used in this memoir, and the stations that he has employed in their determination are represented by round dots. [Plate IV.]

Köppen's amplitudes must necessarily be on a very much larger scale than those determined by my method, because he has only employed the difference between the actual maximum and minimum readings in any one month, while I have utilized the mean of the differences between *several* maxima and minima for the same period.

Making now the comparison between the two charts (Plates III. and IV.) it will be seen in the first instance that the amplitudes increase from the Equator up to latitude 55° S. in both cases, and this applies to all longitudes.

Commencing with the region of South Africa Köppen's lines have a west-to-east direction, while those on my chart conform approximately to the curvature of the south coast. If we include Mauritius and St. Helena, it will be seen, however, that Köppen's result is only based on 4 stations, while that given by me includes the deductions from 10 stations, 7 of which are on the continent and well distributed towards the southern portion of it. That Köppen himself was rather doubtful of his result for this region is indicated by the fact that his lines are for the most part broken, the only continuous portion being that lying to the south just off the coast.

In the Australian region the data he has used are obtained from a greater number of stations than those employed in this investigation. This, however, does not add any extra value to the resulting positions of the lines, for the stations he employed are too near together; thus they are mostly situated in Victoria and New Zealand. Lack of data at other stations was probably the reason for his choice.

Nevertheless we are both in fair agreement as to the direction of the lines, both series taking a more southward course as the east coast of the continent is transited. There is, however, a great divergence between Köppen's 10-mm. line and that of 4 mm. on my chart.

Dealing now with the South American continent, here we have both evidently been driven to employ the data of many stations owing to the diversity of the amplitudes obtained. The difference between Köppen's lines and those drawn by me are due in the main to the fact that I have been able to utilize observations on islands east and west of the continent, while he had to restrict his deductions to the stations on the mainland, probably from lack of the island data.

The most interesting point brought out by the comparison of the two charts is that on the continent itself the lines are in both cases shown as having a decided north-easterly trend and not a direct west-to-east direction. Since this similar result is obtained by the employment of data for altogether different years, the reality of these positions for the lines is clearly brought out.

It may be concluded, therefore, that my discussion of the pressure-amplitudes corroborates in the main that published so long ago by Dr. Köppen, and that by the employment of more stations I have been fortunate enough to extend the inquiry not only to additional longitudes but further southward into the Antarctic regions, past the latitude of greatest pressure-amplitude, which he did not reach in his investigation.

(*e*) PRELIMINARY EXPLANATION OF THE AMPLITUDE-LATITUDE CURVES.

The curves from which the amplitudes of the several stations have been determined were made up by employing the daily readings of the barometer at some fixed hour for each station. In the method of determining the amplitudes themselves the daily and yearly variations of the barometer are practically eliminated. Thus the magnitudes of the amplitudes represent the values of the waves of pressure which may be considered independent of known periodic changes.

The amplitude-latitude curves thus afford a means by which it can at once be seen at what stations in the Southern Hemisphere the daily and annual variations are most prominent and where they are masked by the presence of large aperiodic variations.

Thus from latitude 0° to about latitude 20° S., the amplitude varies from 1 to 3 mm., so that stations lying in this belt have conspicuous daily and annual variations, while the aperiodic changes take quite a subsidiary place.

So conspicuous and regular are the periodic changes that a fairly accurate measure of them can be obtained by the study of the observations of a single day or year for the diurnal or annual variations respectively.

In the belt of latitude above specified the aperiodic changes lasting for several days each indicate the presence of waves of pressure which seem to pass from west to east over every station. Occasionally a circular tropical storm is indicated on the daily pressure curve by a sudden and considerable fall and rise, but in the main the chief features are long waves of small amplitude.

The increase of amplitude after latitude 20° S. is reached is due to the fact that, in these higher latitudes, the belt in which the anticyclones move is approached.

Thus, to take the case of Australia, anticyclones are known to be sweeping that continent from west to east, the centre of their tracks lying in about latitudes 30° to 35° S. The amplitudes of those systems are of the magnitude of about 10 to 12 mms. at the centre of their tracks. Thus the daily variation of the barometer becomes more or less masked as one proceeds southward, while the annual change is not so constant either in form or magnitude as exhibited by curves.

It is only possible, therefore, to obtain accurate mean values for the daily and annual variations by employing the observations extending over several days and years respectively. The aperiodic variations are the most prominent features of the daily curves, and this statement holds good for all latitudes up to the farthest south latitude yet reached.

The great increase of amplitude as shown by the amplitude-latitude curves further south than latitude 35° (about) was considered very probable, because, south of the anticyclonic track, the Antarctic low depressions or cyclones were known to occur. These cyclones or Λ-shaped depressions, as they are experienced for the most part on the land of South Australia and New Zealand, are very deep, and they influence more especially the weather in the latter country and more particularly that of the South Island.

It was expected that the greatest amplitude would be found to lie in the track of the *centres* of the low-pressure systems, which are known to be sweeping those southern latitudes in a west to east direction, for it was thought that there the greatest oscillations of the barometer would be experienced.

So far as I can find out the latitude of the mean path of these depressions is not known, and this deficiency in our knowledge is due probably to the fact that there are no stations south of New Zealand where observations are regularly made.*

* The most southern part of South America does not extend quite far enough south to show the paths of the centres of the Antarctic low depressions.

The fact that the *maximum* amplitude (of about 19 mm.) occurs about latitude 60° S. very forcibly suggests that this represents the mean position of the track of the centres of these depressions.

The decrease in amplitude towards the South Pole naturally results from an increase of distance from the track of the centres of the cyclones, and it is quite possible that, when the southern extremities of the lows are reached, an anti-cyclonic region at the South Pole is in existence.

This question of high southern latitudes will, however, be considered in more detail in a later part of this memoir.

The above preliminary explanation of the probable causes which produce the changes in the amplitudes of the pressure waves at different latitudes is of particular interest for the purposes of the present investigation, because it throws light on the sequence of anticyclonic and cyclonic conditions at the earth's surface from the Equator to the South Pole.

(*f*)—ISANAKATABARS AND THE PATHS OF THE ANTICYCLONIC SYSTEMS.

Having now discussed the distribution of the relationship between amplitude and latitude for the various stations employed in this inquiry and formed lines of equal pressure-amplitudes which have been termed "isanakatabars," an attempt is made in this portion of the memoir to associate an isanakatabar of a particular value with the track of the centres of the anticyclonic systems themselves.

It has previously (page 2) been suggested that the magnitudes of the amplitudes are closely associated with the proximity of the stations to the latitudes of the paths of the anticyclones, and one is led to suggest the view that the form of the isanakatabars gives a representation of the directions in which the air systems move round the earth from west to east.

This association between the geographical distribution of pressure-amplitudes and pressure systems is not pointed out for the first time. Köppen,* in 1882, wrote:—

"While the variations of the pressure, as we have seen above, become conditional in much higher latitudes on account of the extreme depths of the barometric minima, as on account of the extreme heights of the maxima, so one must expect that a relationship must exist between the geographical distribution of the pressure variations and the paths of the minima."

While the above extract relates to conditions in the Northern Hemisphere, it should apply equally well to the air movements south of the Equator.

It is proposed now to examine each of the southern continents separately, and find out whether the forms of the isanakatabars are corroborated by the existing knowledge regarding the passages of the atmospheric systems over the several countries.

The country where such movements have been most minutely studied is that of Australia, and this will be referred to first of all.

* Annalen der Hydrographie, Vol. X., p. 286, 1882.

If Plate III. be examined, it will be seen that for this region the isanakatabars run practically from west to east, and four of these lines cut the continent, namely, the isanakatabars of 4, 7, 10, and 13 mm.

Now it is known, and Russell* has often pointed it out, that the Australian weather is the product of a series of rapidly moving anticyclones travelling from *west to east* and which follow one another with remarkable regularity. A close study of the positions of the paths of these systems as they crossed the country led him to state the latitudes of the tracks for the different seasons of the year. Thus he wrote that "the latitude of anticyclone tracks varies with the season, being in latitude 37° to 38° in summer, and 29° to 32° in winter."

The above deductions were made from an analysis of monthly values extending from the year 1888 to 1892. More recently I have been able to determine† those values from a larger series of years, the monthly values being forwarded by Russell. Thus, for the period 1888 to 1901 the mean value for the latitude is 36° 45′ in summer and 32° 4′ in winter. As the present memoir only deals with the winter (or April to September) conditions, the value that is here required is that for the winter, namely 32° 4′, or approximately 32°.

Commander Hepworth has also made a detailed study of the paths of the anticyclonic and cyclonic systems which traverse the Australian area. He has shown that during both the winter and summer seasons the tracks of both systems are from west to east, but their latitudes vary slightly from one season to the other. In one of his publications‡ he has inserted a very instructive chart showing the tracks of all the systems which passed the region of Australia between November 1, 1890, and September 5, 1891. For the purposes of this memoir it is only the winter conditions which are of particular import, and with his permission I am able to reproduce the results of his work as exhibited in two charts for the period May 4 to September 5, 1891. These charts are shown in the accompanying figure (Fig. 2). The charts themselves are sufficiently self-

CENTRES OF HIGH ATMOSPHERIC PRESSURE.

From May 4th to Septr 5th 1891.

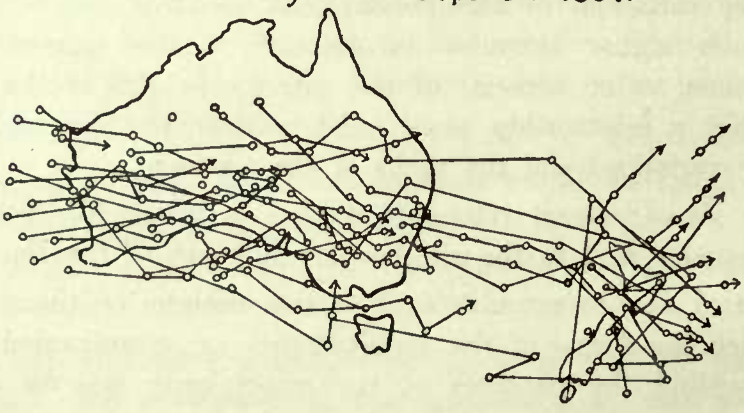


FIG. 2.

* Quart. Journ. Roy. Met. Soc., Vol. XIX., Jan. 1893, p. 24.
† A discussion of Australian Meteorology, 1909, p. 113. Addendum.
‡ Notes on Maritime Meteorology, p. 68, by M. W. Campbell Hepworth, C.B., Commander R.N.R. (Retired).

CENTRES OF LOW ATMOSPHERIC PRESSURE.

From May 4th to Septr 5th 1891.

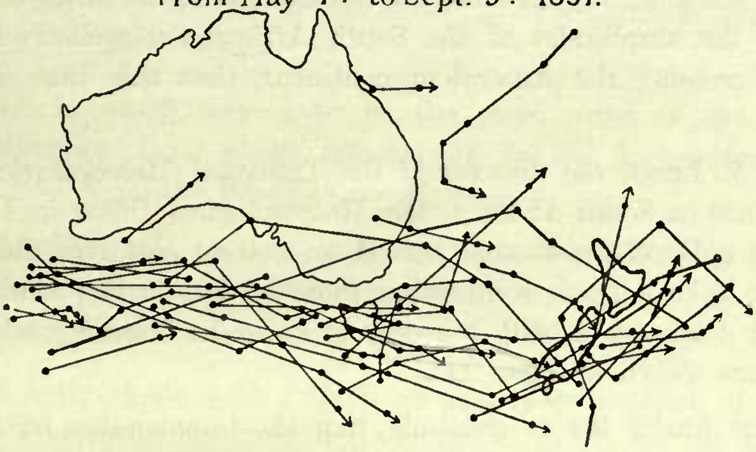


Fig. 2.

explanatory, and they demonstrate well the *west to east* progress of the centres of both the high and low atmospheric pressure systems.

It may be concluded, then, that, for the Australian continent, the anticyclones travel from west to east and the paths of their centres across the continent lie in latitude 32° S.

Since the isanakatabars are in a west-to-east direction the above observed conditions corroborate the form of the isanakatabars. Further, as the centres of the anticylones move during the winter season in latitude 32°, and the isanakatabar of 10 mm. is very close to this latitude, 10 mm. may be assumed to be approximately the mean amplitude of an Australian winter anticyclone. Thus, the isanakatabar of 10 mm. may be taken as representing the mean path and amplitude value of winter anticyclones passing over this continent.

With regard to the other two Southern Hemisphere continents, namely South America and South Africa, perhaps more is known about the air movements over the former than over the latter, although, so far as I am aware, nothing very definite has been published about either with respect to the paths of the travelling air systems.

Dealing with the South African region first, a survey of Plate III. shows that only two isanakatabars cut the continent, namely those of 4 and 7 mm., the isanakatabars of 10 and 13 mm. lying over the sea to the south, and approximately taking the form of the configuration of the country.

Now, a study of the South African conditions shows that during the winter season the centres of the anticyclones practically skirt the coast of this continent, and their more northern portions envelop the southern part of this continent. Such a position of the anticyclonic track is corroborated by the small number of low depressions which are able to reach the coast from the southward, their presence in this region being barred by the sequence of high-pressure systems.

Again, a study of the rainfall map of South Africa for the summer season shows clearly that this continent south of latitude 10° S. receives its rain from low-pressure areas to the north of the track of the anticyclones. As this rainfall extends practically to the south of the continent, the low latitude of the anticyclonic track becomes very marked.

It is very evident that the position of the isanakatabar of 10 mm., indicated on Plate III., cannot be very far from the track of the winter anticyclones, and, if the mean value of the amplitudes of the South African anticyclones is of the same order as those crossing the Australian continent, then this line should represent their path.

Mr. R. T. A. Innes, the director of the Transvaal Meteorological Department, during a discourse on South Africa at the Meteorological Office in London, in 1908, stated that the anticyclones do not pass from west to east over the land, but that they seemed to take a track conforming more or less to the configuration of the country. Such a course, it will be seen, is quite in harmony with the form of the isanakatabars shown in Plate III.

One is thus finally led to conclude that the isanakatabar of 10 mm. in this part of the world represents approximately the path, and most probably the amplitude, of the South African anticyclones.

Turning now, finally, to the third continent, namely, South America, it will be seen, from Plate III., that all the isanakatabars from 4 up to 16 cut this country. As described before, the lines take a south-easterly direction as the west coast is reached, after which they recurve sharply after the Andes are passed, pursuing a north to north-easterly direction over Argentine and the western portion of Brazil, and leaving the continent in an approximately easterly direction. The isanakatabar of 10 mm., which coincided with the track of the centres of the winter anticyclones over Australia, strikes the west coast of South America in about latitude 42° S., leaving the east coast in about latitude 37° S.

An examination of the mean isobaric charts for the seasons of the Argentine Republic* indicates that during the quarter June to August (the isobars are only drawn for every three months and the whole year) the isobars north of latitude 40° S. have a distinct north-easterly trend.

This suggests, therefore, that the paths of the anticyclones and cyclones which cross this country do not pass directly from west to east, but pursue an oblique course over the land north-eastwards.

During this season the latitude of the mean path of the anticyclones that strike the west coast is as determined from this chart, approximately 35° S., while on the east coast it is nearer the Equator about latitude 27°.

This chart corroborates in the main the peculiar course of the isanakatabars in this region: no evidence is, however, forthcoming regarding the curved path to the west of the mainland, as the mean isobars in the chart to which reference has been made terminate on the sea coast.

To gain a further insight into the air movements over this region an examination of the Argentine daily weather reports and charts was undertaken. Only the winter months (April to September) were dealt with and these were for the winters of 1902 to 1905, both years inclusive.

* "Climate of the Argentine Republic," by Walter G. Davis, 1902, Plate XIII.

The result of the analysis of these daily maps led one to conclude that the anticyclones seemed to take one or the other of two paths as they passed from the Pacific to the Atlantic Ocean.

The first track, which seemed to be the more usual of the two, lay in a north-easterly direction from about latitude 30° to 35° S. on the Chilian coast to latitude 25° to 30° S. on the Brazilian coast.

It is possible that this track may be extended further north along the coast of Brazil. It was noticed also that occasionally anticyclones reach this part of Brazil from a more southern portion of the Argentine coast.

The second anticyclonic path (which seemed more marked in 1902 than the following years examined) lay from latitude 22° to 27° S. on the Chilian coast to latitude 35° to 40° S. on the Argentine coast. It was further noticed that occasionally anticyclones moving along this path took a northward turn and travelled along the first-mentioned track along the coast.

While, therefore, all the evidence points to the fact that the anticyclones do not travel in a direct west-to-east direction, at the same time it suggests a north-easterly trend for the path over the Argentine Republic.

It is not without interest to remark that, if the track of the anticyclones has a north-easterly course over this part of the country, the depressions which hug their southern boundaries would pursue a parallel course further south. That this actually is the case can be gathered from Mr. Davis's remarks in his description accompanying his excellent series of charts, for he says:—*

"South of latitude 43° the height of the Andes is not sufficient to intercept the winds from the Pacific, which in this latitude blow directly from the west, and after crossing the Andes are probably attracted by the low-pressure region to the north and diverted to the north-east, depositing in their path the moisture from the Pacific."

This quotation indicates clearly that the depressions which are responsible for the rainfall move towards the north-east.

An attempt was made to utilize the daily weather charts issued by the Meteorological Service of Brazil in order to trace day by day the changes in the positions of the isobars. Unfortunately these were of little assistance, for the isobars drawn are restricted for the most part to the coast and scarcely at all extend inland, and present nearly constant features which remind one of contour lines. When these charts are compared with those of Chili and the Argentine Republic, there seems reason to suspect that the Brazilian maps are constructed from data which have some inherent imperfections. This view seems to be corroborated by some statements published recently by Mr. Herbert L. Solyom in an article on "Argentine Weather."†

* "Climate of the Argentine Republic," by Walter G. Davis, 1902, p. 48.

† Monthly Weather Review: U.S. Department of Agriculture, Vol. XXXVII., No. 3, March 1909, p. 96.

In this article he publishes several charts made by himself from the daily observations of several Brazilian stations, and he states in the text (page 96):—

"In preparing these maps, the barometric readings at Cuyabá, Jonzeiro, Victoria, and Bagé have been subjected to a nearly constant correction. The necessity for this becomes apparent after a study of a large number of maps, and is thought to be due to either a large but unapplied instrumental error or, more probably, to the inaccurate determination of the sea-level altitudes of the stations."

Mr. Solyom refers also to the peculiar form of the Brazilian isobars to which I have referred, and he gives several reasons which he thinks "combine to give "the isobars of the map weird contours dissimilar to anything observed in other "countries, with barometric gradients out of all proportions to the observed wind "velocities."

The above extracts are sufficient to indicate that the Brazilian daily weather maps cannot be utilized here.

It is interesting to note that Mr. Solyom, in his article, gives daily maps for eight consecutive days (July 13 to July 20), and on them is recorded the passage of an anticyclone across South America. Approximate measures of the latitudes of its centre, as it approaches and transits the country eastwards, are stated below in a small table, and indicate that this July anticyclone conforms well to the path shown by the winter season isanakatabars over South America, and that it does not travel direct from west to east.

Approximate Positions of Centre of Anticyclone in South America, July 13 *to* 20, 1908.

—	Latitude, S.	Longitude, W.
	°	°
July 13 - - - - - - -	23 ?	70 ?
„ 14 - - - - - - -	30	70 ?
„ 15 - - - - - - -	30	67
„ 16 - - - - - - -	30	60
„ 17 - - - - - - -	31	60
„ 18 - - - - - - -	27	48
„ 19 - - - - -	27	48
„ 20 - - - - - - -	24	45

While this inquiry was in progress I was fortunate enough to have the opportunity of showing the isanakatabar chart, and my deductions therefrom, to Comandante A. Silvado, the director of the Brazilian Meteorological Service, who was in this country to attend the London meeting of the Solar Commission of the International Meteorological Committee.

Comandante Silvado expressed himself as being entirely in agreement with my suggestion of the northward trend of the pressure-waves to the southward of

Brazil. In fact, he told me that his experience had led him to look towards the south for the information he sought for the purposes of weather-forecasting, and not towards the west, as had been the usual procedure.

Such a valuable opinion, corroborating, as it does, the views here expressed, shows that the isanakatabar chart may be an important aid to the tracking of the movements of the air systems in South America.

One is thus led to the conclusion that the result of the discussion of the daily sequence of pressure changes over South America indicates sufficient evidence for the statement that the isanakatabars in this region conform to the directions of movement of the anticyclones and their attendant depressions to the south of them.

The analysis of the air movements over the three southern continents justifies one in assuming, I think, that the pressure-amplitudes are closely associated with the latitudes of the travelling anticyclones and cyclones and that the forms of the isanakatabars over these continents indicate the direction of motion eastward of these moving air-systems. Further the isanakatabar of 10 mm. may be looked upon as representing approximately the mean track of the centres of the anticyclonic systems as they cross these countries during the winter season.

If there were no islands in the oceans separating these three countries, it will be seen that the isanakatabars crossing the land could be quite easily and rationally connected up with each other. Since, however, there are some islands, and the pressure-amplitudes at several of them have been determined, the isanakatabars as above drawn require only slight alterations here and there to make them conform to the amplitude values recorded.

There seems, therefore, no reason why it should not be assumed that the anticyclones, with their attendant low-pressure systems, travel also across the oceans in conformity with the ocean isanakatabars. Undoubtedly the amplitudes at the islands justify this assumption and also the appearances of the pressure changes on these islands.

The two large regions where observations of amplitude are lacking are those situated in longitudes 80° to 130° West and 70° to 110° East, but these deficiencies are really not very serious, because both east and west of them the positions of the isanakatabars are moderately well determined.

It is unfortunate that many of the islands, the pressure observations of which have been employed, have not a more southern latitude, for then they would have been more in the track of the anticyclones and therefore possessed larger pressure-amplitudes. This statement applies more generally to the islands in the South Pacific.

In spite of these and other drawbacks, which render the research less convincing than it might have been, an attempt has been made to find out whether these air systems do complete the whole circuit of the earth. The isanakatabar of 10 mm. has been adopted as representing the amplitude and latitude of the anticyclonic systems, and, failing stations on this line, those situated on either side of it have been utilized.

CHAPTER III.

METHOD EMPLOYED IN TRACING THE BAROMETRIC WAVES EASTWARD.

The present study of the question as to whether these waves of pressure were caused by travelling anticyclones resolved itself in trying to trace, from one station to another more eastward, the same wave or series of waves, and so determine the time interval in days between the arrival of the same waves at different stations.

Throughout the inquiry either the mean readings for every 24 hours, or readings for some particular hour each day, have been employed. The unit of time thus adopted being one day, a comparison between any two stations, to determine the interval of time between the passage of a barometric wave, could not be made closer than 24 hours.

Between distant stations this unit is sufficiently small, but in these cases the waves alter so in form that they are difficult to identify. For short distances the waves are easy enough to follow, but, then, for accurate timing the unit of one day is too large.

This unit had, however, to be adopted, for in most cases hourly readings during the 24 hours or even three hourly readings were not available.

Coming now to the method of procedure in tracing the waves actually adopted, the following example will perhaps be the best means of explaining it.

The mean daily readings of the barometer at, say, Perth (Australia), were plotted on a long strip of squared paper for the six months of any year. Similar data for Adelaide were treated in the same way on another strip, the data covering exactly the same period of time, *i.e.*, for the same season and same year. It was seen at a glance that both curves showed series of waves of pressure, following each other closely and fairly regularly. By placing the Adelaide curve just below that for Perth it was found that the similarity and coincidence of the waves became at once apparent if the time scale of the Adelaide curve was moved back (to the left) two days.

From this comparison it was easy to see that, within the limits of the unit adopted, each wave of high pressure or anticyclone took two days to travel from Perth to Adelaide. The object of using a strip covering data for six months is obvious, because by this means several points of coincidence can be utilized. Such a comparison, made for several years, gave independent values for the intervals of time deduced. Thus three separate determinations for the years 1897, 1902, and 1904 gave in each case two days for the anticyclones to travel from Perth to Adelaide.

In like manner the data for Adelaide and Sydney were compared, and the time of travel between them from three determinations was one day.

Thus it was deduced that on the average an anticyclone takes two days to pass from Perth to Adelaide, and one day more to reach Sydney.

By comparing next curves for Perth directly with those for Sydney it was easy to identify the same waves in each. The Sydney curve was placed under that of Perth and the same waves, when placed vertically under each other, indicated a shift in the time scale of three days.

In the case of these three stations the comparisons gave the following intervals in days between Perth and Sydney:—

Perth to Adelaide + Adelaide to Sydney = 2 + 1 = 3 days.
Perth to Sydney (direct) = 3 days.

Thus two quite independent determinations gave the same interval of time.

It is to be understood that it is not supposed, or even expected, that individual anticyclones in these southern latitudes do not change their intensity and other characteristics. As a matter of fact the curves examined show that considerable changes are always occurring. Between stations even so close as Adelaide and Perth some distinct variations have been noted.

Again, in the winter months the anticyclones are much larger than they are in summer.

Fortunately most of the stations which are available for bridging the distances between the three continents lie on the equatorial side of the anticyclonic centres. Thus it was possible to use the most favourable season of the year, namely winter, when the anticyclones were large and in less southern latitudes.

In the tracking of these anticyclones round the earth there are two important features concerning them which render the investigation less difficult than it might have been. The first is that the anticyclones are of considerable size, so that their influence, as regards pressure changes, is felt to a great stretch of latitude north and south of the centres of their paths. Thus it is not an uncommon size of an Australian anticyclone for it to be as large as the whole of that continent. This spread in latitude thus enables the observations at stations situated some distance from the centres of their tracks to be utilized, but the amplitudes at these stations will be small.

The second feature relating to them is that during the course of a year their tracks over South America, South Africa, and Australia vary in latitude according to the seasons. In the summer months in these countries, namely October to March, the mean latitude of the tracks lies in higher latitudes, about 36° S., while in the winter months, April to September, the latitude is not so high, but about 32° S.

CHAPTER IV.

DETERMINATION OF THE TIME OF TRAVEL OF THE BAROMETRIC WAVES EASTWARD, FROM ONE STATION TO ANOTHER, OVER THE CONTINENTS AND THE OCEANS.

(*a*)—GENERAL REMARKS.

The inquiry would have been facilitated and rendered probably more complete if it had been possible to deal with observations of a few years common to all the stations. This, however, from the beginning was found to be impossible, as the required data were not available.

An attempt was, therefore, made to use those years in which data could be obtained for the majority of the stations employed. In this way a kind of triangulation round the earth was eventually made, and stations were coupled up with each other in many different ways.

In spite, however, of the many difficulties which had to be contended with, the results obtained seemed, on the whole, to be fairly consistent.

In the study of the movements of the pressure-waves eastward it is proposed in the first instance to deal with each of the southern continents with their neighbouring islands separately, beginning first with South Africa.

After that an attempt will be made to bring together evidence to show that the pressure-waves make the transit of the oceans between the continents. In this case also the oceans, namely, the South Indian, South Pacific, and South Atlantic, will be treated separately and in the above order.

(*b*)—THE REGION OF SOUTH AFRICA.

For the purpose of identifying and tracing the passage of waves of high pressure over the African region the available information is not only somewhat meagre but difficult of access. It has been possible, however, by employing the data for several different years to determine the passage of the waves in this way. Twelve stations in all have been utilized, and they cover an extent of about 63° in longitude, St. Helena (longitude 5° 40′ W.) being the most westerly point and Mauritius (longitude 57° 33′ E.) lying furthest to the east. With regard to extent in latitude, the observations at Kibokolo (latitude 6° 17′ S.) and Daressalam (latitude 6° 49′ S.) on the west and east coasts respectively are the most northerly stations used, while those at Cape Town (latitude 33° 56′ S.) represent the most southerly conditions.

It may be stated in the beginning that the African region does not lend itself very well to the study of the passage of the anticyclones, because the normal path of these systems lies for the main part to the south of the land area.

One is therefore forced to trace the pressure-waves by the records left by the passage of their northern portions, and this is somewhat unsatisfactory, because the amplitudes of the waves are considerably reduced in magnitude, and the observations of pressure utilized require to be very accurately made.

Unfortunately the island of St. Helena lies too far north to assist materially in the tracing of the waves, but, nevertheless, the observations made there have been utilised, as this is the only available station to the west of the mainland.

The following table gives a complete list of the stations, the observations at which have been examined for this region, together with their latitudes and longitudes. They are given in the order of longitude from west to east, and the mean pressure-amplitudes in millimetres have been added in the last column.

Station.	Longitude.		Latitude.		Amplitude.
					mm.
St. Helena - - - - -	5°	40′ W.	15°	57′ S.	1·5
Walfish Bay - - - - - -	14	26 E.	22	56	3·3
Kibokolo - - - - - -	15	17	6	17	1·1
Cape Town - - - - - -	18	39	33	56	9·0
Kimberley - - - - - -	24	27	28	42	5·3
Johannesburg - - - - -	28	2	26	12	4·4
Pretoria - - - - - -	28	11	25	45	4·4
Durban - - - - - -	30	30	29	51	8·6
Zomba - - - - - - -	35	18	15	22	2·6
Daressalam - - - - - -	39	18	6	49	1·5
Antananarivo - - - - -	45	16	18	55	2·2
Mauritius - - - - - -	57	33	20	6	2·9

It has been previously mentioned that the curves employed throughout for tracing the pressure-waves were constructed from the daily readings of the barometer at some fixed hour and extended over the period for the six months April to September, the winter season for the Southern Hemisphere: the unit of time employed is one day.

Having explained the principle adopted in comparing the curves one with another in a former section, one may pass at once to the actual results of the direct comparisons of the curves for the different stations employed. These are given in the following table and the order of the stations is from St. Helena eastwards.

The several columns with years at their head denote the years for which the winter season curves have been drawn for many of the stations.

The figures in each of these columns denote the number of days of travel of the pressure-waves from one station to another, as stated, on the same horizon, in the first column. Thus the time of travel from Cape Town to Johannesburg was determined from curves of these two places made from observations in the years 1904 and 1905 and was one day in each case.

In the last column the mean time of travel from one place to another from the several comparisons is given.

SOUTH AFRICAN REGION.

Times of Travel of the Pressure-Waves in Days.

Names of Stations.	1891.	1897.	1903.	1904.	1905.	—	——	Means,
Saint Helena—Kibokolo -				1 ?	?			1 ?
—Cape Town -			?	2 ?	3 ?			2·5?
—Kimberley -			3 ?					3 ?
—Johannesburg				3 ?				3 ?
—Durban -		3 ?	3 ?	3	3 ?			3
—Zomba - -			?	3				3
—Antananarivo			3 ?					3 ?
—Mauritius -		?	3 ?	3				3 ?
Walfish Bay—Cape Town -	2							2
—Durban - -	2							2
—Mauritius -	?							?
—Antananarivo	?							?
Cape Town—Kimberley -			1					1
—Johannesburg -				1	1			1
—Pretoria - -				1				1
—Durban - -	0		1	1	1			1
—Zomba - -			2	2				2
—Daressalam -			3 ?	4 ?				3·5 ?
—Antananarivo -	3 ?		?	4				4
—Mauritius - -	3 ?		?	5	?			5
Kimberley—Durban - -	0							0
—Zomba - -			1					1
—Daressalam -			1					1
—Antananarivo -			1					1
—Mauritius - -			1					1
Johannesburg—Pretoria -				0				0
—Zomba -				0				0
—Daressalam -				0				0
—Mauritius -				0	3			1·5

Names of Stations.	1891.	1897.	1903.	1904.	1905.	—	——	Means.
Durban—Johannesburg -				1	0–1			1
—Pretoria - -				1	0–1			1
—Zomba - - -			1	1				1
—Daressalam - -			1	1				1
—Antananarivo -	3 ?		1	1				1
—Mauritius - -	3 ?	3	1	1	3			2
Zomba—Daressalam - -			0	0				0
—Antananarivo - -			0	0				0
—Mauritius - -			0	0				0
Daressalam—Antananarivo -			0	0				0
—Mauritius -			0	0				0
Antananarivo—Mauritius -	0		0	0				0

While it is difficult to determine the direction of movement of the pressure-waves as they approach South Africa from the westward, in consequence of the absence of any observing stations, with the exception of St. Helena already mentioned, the land data are capable of indicating their directions of movement after the continent has been reached.

A close examination of the preceding table shows in the first instance how difficult it is to trace the pressure-waves accurately from St. Helena to the mainland, in consequence, no doubt, of the small pressure-amplitude (1·5 mm.) at this station and its great distance from the path of the anticyclones. It seems, nevertheless, to be suggested that the pressure-waves take about two days to reach Cape Town or three days to reach Durban.

From Cape Town the waves can be traced, taking a day or thereabouts to travel to Johannesburg, Pretoria, or Durban, and another day to reach Zomba. From Durban direct measures indicate a day's run to Zomba, Antananarivo, and Mauritius, and a day, or less than a day, to Johannesburg or Pretoria. The direct comparison between the curves for Zomba, Daressalam, Antananarivo, and Mauritius shows no difference of time phase.

These last four stations do not show any difference of time between the epochs of the passage of the same waves in spite of the fact that, with the exception of Daressalam, they are all well distributed in longitude. If the pressure-waves moved from west to east, then in passing Durban they should be nearly simultaneous with those passing over Zomba (a difference of longitude of only 5°). Since, however, there is a distinct difference of one day, it must be concluded that the pressure-waves or anticyclones take a more northerly course, and occupy about a day to travel over the 14° which is the difference of *latitude* between these two stations. This direction of movement would then account for the nearly simultaneous arrival of the pressure-waves at Antananarivo and Mauritius, for the effect of the anticyclones moving in this direction, *i.e.*, advancing towards them end-on, would be to alter their barometric similarly and at the same time.

It must not be inferred, however, that the anticyclonic systems proceed far enough north for their centres to pass over these stations, for they evidently do not, because the small amplitudes determined there show that only the fringes of these systems affect them. They most probably, after this curvature in their track, pursue an easterly course and travel towards the Australian continent.

It is of interest here to note that the path of the pressure-waves above determined from the curves of the daily observations conforms in a very close manner with the forms of the isanakatabars over South Africa. These latter take a very decided north-easterly trend and are oriented in a direction which is nearly at right angles to the line joining the three stations, namely, Zomba, Antananarivo, and Mauritius. If the centres of the anticyclones be supposed to be moving along the isanakatabar of 10 mm., then the forward isobars of the systems should affect the three stations almost simultaneously.

There is thus good evidence here to show that the forms of the isanakatabars represent the direction of movement of the anticyclones over South Africa.

The movements of pressure-waves over South Africa have been studied by Mr. R. T. A. Innes.*

The method he adopts is the same as that employed in this memoir, but he only makes use of the three stations Cape Town, Johannesburg, and Durban, and deals only with two or three months of two years.

In summing up his conclusions he says: "Collectively these diagrams show " that the movements of the barometer at the Cape precede by 24 to 48 hours " similar movements at Johannesburg and Durban. This is a fact of fundamental " importance, because, as just stated, it will permit us to forecast the weather."

There is, however, a very important point which seems to have escaped the notice of Mr. Innes. If the pressure-waves move from west to east, then they should affect first Cape Town, then Johannesburg, and lastly Durban, since this is the order of the stations in longitude. In this memoir it is shown that the pressure-waves reach the stations in the order Cape Town, Durban, and Johannesburg, there being an interval of about one day's travel between each station. It was from this fact that the conclusion was drawn that the anticyclones take a north-easterly course and that their front portions reach Durban prior to Johannesburg.

While the comparison of the curves for the different stations shows that the pressure-waves pass over South Africa in a somewhat curved track, it is difficult to determine a correct value for the mean rate of travel.

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* "The Barometer in South Africa." Report of the South African Association for the Advancement of Science, 1906, p. 77.

If, however, the run from the longitude of St. Helena (longitude 5° 40′ W.) to that of Durban (30° 30′ E.) be taken, namely three days, this indicates a velocity of about 12° per day. As the anticyclones move in a little more southern latitude here than they do in Australia, one may take latitude 35° S. as the mean position of their track between these two stations. Reckoning 57 miles as equivalent to 1° of longitude, the daily rate of movement works out at about 680 miles. Again, if the run from Cape Town to Durban be taken as about one day, as the curves indicate, the difference of longitude between these stations, namely 11° 51′ or, say, 12°, is traversed in one day. Assuming the same mileage per degree of longitude as before, the distance travelled per day is also about 680 miles.

One is thus led to conclude, therefore, that the daily rate of movement of the anticyclones about the region of South Africa is 12° or about 680 miles, or, say, between 600 and 700 miles per day.

In order to show examples of some of the pressure curves for the South African region and their movement towards the east, the set of curves reproduced in Plate V. has been given. These curves are constructed from the observations made during the winter season, but only three months of the whole six months are here given in order not to reduce the time scale too much in magnitude.

All the curves are placed underneath one another, in the order of longitude eastwards, in such a way that the same pressure-waves are vertically below each other: to do this the time scale had to be moved horizontally, and the amount that was necessary in each case is shown by the vertical thick line on the right-hand side of the curves. Thus it will be seen that the waves take two days to reach Cape Town from St. Helena,* another day's travel to arrive at Durban, and lastly one more day to reach all the four stations, Zomba, Daressalam, Antananarivo, and Mauritius, simultaneously.

An idea of the magnitudes of the pressure-amplitudes can be gathered from the curves themselves, because they are all drawn to the same scale. Thus the curve with the smallest mean amplitude is that of St. Helena (1·5 mm.), and that with the largest is Cape Town (9·0 mm.), followed closely by Durban with 8·6 mm. amplitude.

Attention should be drawn to the fact that the pressure-waves or anticyclones during their transit are always undergoing changes, *i.e.*, diminishing or increasing their intensity. Thus changes in the curves, even between stations quite close to one another, become apparent, and it was for this reason that curves extending over six months were utilized to determine a mean value for the time-phase difference between any two stations.

A statement has previously been made (page 20), that Innes has remarked that the path of the anticyclones conforms more or less to the configuration of the land in South Africa, and the isanakatabars in their form have indicated the probability of such a course.

* Owing to the small amplitude of St. Helena this determination is not satisfactory.

It seems quite possible therefore that the origin of the temporary southing of the travelling anticyclones as South Africa is reached, and their recovery to their usual path, may be attributed to the presence of the high land in the interior of that continent. Such land might act as a slight barrier to the northern front portions of the anticyclones in their eastward movement and thus change the path of the centres of the systems by pushing them a little towards the south, where their onward progress would be no longer impeded. Recovery of their normal path would take place as soon as the effect of the land was no longer felt.

To give some idea of the physical configuration of South Africa one cannot do better than quote a brief extract from the excellent article entitled "The Meteorology of South Africa," by Charles M. Stewart, secretary of the Meteorological Commission, Cape Colony, which appeared on page 21 in "Science in South Africa" (1905).

"Taken as a whole, South Africa may be regarded as consisting of a series of four elevated plains or plateaux, separated from each other by steep escarpments which rise to a considerable elevation above the plains themselves, and appear, when viewed from the coast sides, as a series of high mountain ranges running roughly parallel with the coast. This division into plateaux is most distinctly marked on the southern side of the sub-continent, but is not so well defined in the west, where the slopes are more gradual, or in the east, where the plateaux partake more of the character of mere terraces; these plateaux have been named as follows:—

"1. The Coast Plateau, or Coast Flats, having an average elevation of 500–600 feet, and varying considerably in width, from about thirty miles in German South-West Africa to three or four miles, or even less in the south-east of the Cape Colony.

"2. The Southern or Little Karoo, a narrow tableland about fifteen miles in width, and of an average elevation of 1,500 feet; it is separated from the low coast area of the south by the Langebergen and Outeniqua mountain ranges.

"3. The Central and Great Karoo, having an average elevation of between 2,000 and 3,000 feet, bounded on the west by the Cedarberg and Bokkeveld, and on the south by the Witteberg, Zwartberg, and Zuurberg ranges.

"4. The Northern Karoo or High Veld is the innermost plateau, comprising the remainder of the Cape Colony, the Orange River Colony, and the Transvaal. It is bounded on the south by the Klein Roggeveld, Nieuweveld, Winterberg, Stormberg, and Drakensberg ranges. This plain has an average elevation of about 4,000 feet, rising in the eastern portions to 6,000 feet, and forms the main watershed of the country. From the Drakensberg the land slopes northwards and westwards towards the Orange River and the Limpopo, decreasing gradually to an elevation of less than 3,000 feet, but rising again to over 4,000 feet in the Damara-Namaqua Plateau of German South-West Africa and the Mashona-Matebele Plateau of Rhodesia.

"It will thus be seen that by far the greater portion of South Africa has an elevation of over 3,000 feet, whilst the area below 1,500 feet forms merely a narrow fringe around the coast."

(*c*)—THE REGION OF AUSTRALIA.

In my previous memoir entitled "A discussion of Australian Meteorology"* I described (page 13 *et seq.*) the general features of Australian meteorology according to the views of the late Mr. H. C. Russell. It was there mentioned that Australian weather was the product of a series of rapidly moving anticyclones or high-pressure areas, which followed one another with remarkable regularity and which were the great controlling force in determining local weather. These anticyclones moved from west to east at an average rate of about 400 miles a day. About forty-two passed over the continent in the course of a year, the average transit over any place being in summer 7 and in winter 9 days, the average time of passage over any place being about 8·7 days.

In their passage across the continent the centres of the anticyclones are not always in the same latitudes, but vary according to the time of the year. Thus Russell has shown that in the Australian summer months, *i.e.*, from October to March, the mean latitude of their paths is about 37° to 38° S., while during the winter months, April to September, they lie about latitudes 29° to 32° S. These values I have altered to 36° 45′ and 32° respectively (*see* page 18).

In form the anticyclones are generally elliptical, their axes being in the relation of about 2 to 1, with the longer axis directed east and west. So long as the anticyclones pass over the flat lands, this shape is generally maintained, but as soon as the east coast range of mountains is reached the major axis becomes shortened and turned more in a north and south direction.

The above general features indicate that the Australian continent is particularly favourable for the study of the passages of the anticyclones, first because their centres pass over the land surface, and second because they travel in a west-to-east direction straight across the continent.

This latter fact, based on the observation of individual anticyclones from daily isobaric charts, is of great interest here, because from the study of the amplitudes of the Australian stations this west-to-east direction is indicated by an independent method. We are therefore justified, as was the case in the South African region, in assuming that the isanakatabars over Australia represent the direction of motion of the anticyclones, and these are in a west-to-east direction, as can be seen from a glance at Plate III.

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* Solar Physics Committee. Wyman and Sons. London, 1909.

Further, as in this investigation only the winter (or April to September) months are considered, and as the mean track of the anticyclones for this season lies in about latitude 32° S., the isanakatabar of 10 mm. may be approximately said to represent the track of the centres of the systems in their movement eastward.

One is now in a position to turn attention towards tracing the anticyclones across this continent by the same method as was adopted for the South African region.

Although daily pressure values for the stations are not very numerous, yet sufficient is available to clearly indicate the speed of the travelling anticyclones.

The following table gives the names of the stations employed, and accompanying them are their latitudes and longitudes together with their amplitudes. They are arranged in order of longitude, commencing with the most western station, namely, Perth.

Station.	Longitude.		Latitude.		Amplitude.
					mm.
Perth - - - - -	115°	52′ E.	31°	57′ S.	11·1
Port Darwin - - - -	130	51	12	28	2·0
Daly Waters - - - -	133	23	16	16	2·7
Alice Springs - - - -	133	37	23	38	6·5
Adelaide - - - -	138	35	34	56	12·3
Sydney - - - - -	151	11	33	52	11·3

By drawing curves representing the changes of pressure from day to day for the winter season, and using different years for the purpose of coupling up the stations (owing to lack of available data for some years), the transit of the pressure-waves over the land has been determined.

As before, the curves for the same years were compared and the time scales adjusted to make the curves fit each other.

The following table shows the results obtained, and the various determinations for each winter season analysed are given.

It may be remarked that Port Darwin lies too far from the track of the anticyclones to render the recognition of the more southern waves certain, and this explains the ambiguity of the results for that station. As this station has only an amplitude of 2 mm. this result was not unexpected. The last column indicates the mean time of travel of the waves from one station to those more east expressed in days.

AUSTRALIAN REGION.

Times of Travel of the Pressure-Waves in Days.

———	1881.	1883.	1886.	1891.	1895.	1897.	1899.	1902.	1903.	1904.	1905.	Means.
Perth—Adelaide - -				2		2		2	2	2	2	2
—Sydney - - -				3		3			3			3
Port Darwin—Alice Springs	?	0 ?										0 ?
—Sydney -		0 ?										0 ?
Alice Springs—Adelaide -	0	0										0
—Sydney -		2										2
Adelaide—Sydney - -		1	1	1	1	1	1		1			1

The main results derived from the comparison of the curves are as follows:—The first is that the anticyclones travel directly from west to east. This is indicated in the first instance by the arrangement, as regards latitude, of the amplitudes, and secondly by the pressure-waves affecting Alice Springs a fraction of a day before Adelaide. The fact that there is an interval of one day between Adelaide and Sydney, and two days between Alice Springs and Sydney, suggests that probably, if hourly barometric readings were examined, the time of travel from Adelaide to Sydney would be a little more than one day but much less than two. It is a pity that data are not available to couple Perth directly up with Alice Springs.

The measures between Perth and Adelaide and between Perth and Sydney are very consistent, indicating a time of travel of two days in the first and three days in the second case. It may be concluded therefore that on the average in the winter months the anticyclones take three days to move from the west to the east coast of Australia.

As the difference of longitude between Perth and Sydney is 35° 19′ and this distance is traversed in three days, the anticyclones travel at the rate of 11° 46′ per day. Taking 60 miles as equivalent to 1 degree of longitude in latitude 30° S., then the rate of travel is approximately 705 miles per day.

Russell has stated* that "the daily rate of translation derived from all the available records is, over Australia, four hundred miles." This value is, I think, distinctly too low, for if such a rate be the case then the time of passage from Perth to Sydney would be more than four days. The above comparisons of the curves for several different winter seasons indicate that the interval of even four days is not compatible with the data here analysed.

* Three Essays on Australian Weather, by Hon. Ralph Abercromby, 1896, p. 3.

The time of transit from Perth to Sydney, as above stated, is of the order of three days, and the fact that the time of travel from Perth to Adelaide is two days confirms the higher rate of speed. Thus the difference of longitude between these two latter stations is 22° 43′, and as this is traversed in two days, the rate per day is 11° 22′ or 680 miles approximately.

Hunt,* in his paper on "Types of Australian Weather," shows that anticyclones moving quicker than 400 miles per day are quite a common occurrence. Thus he says, "as a general rule weather is set fine when anticyclones move rapidly " . . . *i.e.*, at a rate exceeding five hundred miles per day." In another instance he refers to a winter anticyclone as "an unusually rapid one." This travelled 900 miles in one day and 750 miles in the succeeding 24 hours, thus averaging 825 per day.

These statements suggest, therefore, that the velocity of a little under 700 miles per day is well within the range of anticyclonic movements as recorded by authorities in Australia.

One is thus led to the final conclusion that the anticyclones in Australia travel from west to east at the rate of about 11·5° a day or about 690 miles per day. The previous value of 680 miles per day which was deduced from the movements of the pressure-waves over South Africa approximate therefore very closely to the value found for the Australian region.

Attention may be drawn here to the fact that Australia may be considered as a flat country, the mountainous region being confined to the south-east part. The anticyclones find, therefore, no obstruction in their path, so that they can pursue a direct west-to-east route as they have been shown to do. It is only when they are approaching the east coast that the mountains begin to be approached, and then, as mentioned in the beginning of this section, their major axes become shortened and turned more in a north and south direction.

It will be noticed also that the isanakatabars near the east coast take a slight southern trend, and this may be in consequence of the mountains endeavouring to push the anticyclones a little towards the south. It is interesting to note that both in South Africa and in Australia the high land effect is to make the anticyclones pursue a more southern track, and, as will be seen further on, it is the same in South America with the Andes, only in a very much more pronounced manner.

To illustrate the Australian pressure-waves, both as regards movement and amplitude, Plate VI. is given.

Here one can see the gradual progression of the pressure-waves eastward from Perth on the west coast, over Alice Springs, Adelaide, and to Sydney on the east coast. As before, similar pressure-waves are placed vertically under each other, and the necessary movement of the time scales is indicated by the vertical thick line on the right-hand side of the curves. The curves here given are for the three months May to July as before, but belong to the year 1883. It will be seen that the waves take two days to travel from Perth to Alice Springs or Adelaide, and another day to reach Sydney.

* Three Essays on Australian Weather, p. 64.

(*d*)—THE REGION OF SOUTH AMERICA.

The South American region is about the best of the three southern continents for studying the atmospheric movements in the Southern Hemisphere, because the land stretches from about latitude 55° S. to the Equator and beyond. For the study of the passage of the anticyclones this region is most important, because both their northern and southern sides transit the land surface. The three islands, Juan Fernandez on the west coast and the Falkland and Laurie Islands on the east coast, add material assistance also to the study of the pressure-waves. The investigation of the amplitudes of the pressure-waves of this region has already been dealt with on page 11, and it was shown that the isanakatabars are not lines stretching from west to east, but that, as the west coast is approached, they take a decided southern dip and recurve again as soon as a portion of the land surface has been transited.

The present chapter is devoted to the investigation of the direction and rate of travel of the anticyclones over this continent, and the procedure adopted is the same as that employed in the case of South Africa and Australia. Fortunately there is a considerable amount of data available for the three countries, Chili, Argentine and Brazil, and these allow one to follow very closely the pressure-waves across the country.

The accompanying table gives a list of the names of the stations the observations at which have been utilized. They are arranged in order of longitude, commencing with the most western station. Their latitudes and also their mean pressure-amplitudes as previously determined are added in subsequent columns.

———	Longitude.		Latitude.		Amplitudes.
					mm.
Juan Fernandez	78°	45′ W.	33°	42′ S.	7·3
Ancud	73	50	41	51	10·4
Punta Anjeles	71	38	33	1	4·8
Caldera	70	52	27	3	2·9
Santiago	70	41	33	26	4·2
Arica	70	20	18	28	2·4
Punta Dungeness	68	25	52	24	17·1
Chubut	65	5	43	18	11·0
Cordoba	64	12	31	25	8·4
Rosario	60	38	32	57	9·0
Buenos Ayres	58	22	34	35	9·0
San Juan (B.A.)	58	3	34	49	9·4
Cape Pembroke	57	42	51	41	16·0

——	Longitude.		Latitude.		Amplitudes.
					mm.
Itaqui	56°	33′ W.	29°	7′ S.	7·0
Cuyabá	55	45	15	35	4·0
Rio de Janeiro	43	10	22	54	5·8
Quixada	39	32	4	57	1·6
Fortaleza	38	30	3	43	1·6
Aracaju	37	4	10	55	1·6

In order to couple the stations up with one another three different years have been used, namely, 1886, 1903, and 1904. More could have been employed if it had been necessary, but it was found a comparatively easy matter to follow the pressure-waves from one station to another. As was the case with the other two continents dealt with, the waves were easiest to follow in those parts of the country where the amplitudes were large. When curves of large amplitude are directly compared with those of small amplitude, the resulting durations of transits are less trustworthy.

In the following table the measurements, deduced from this comparison of the curves among each other for the several stations, are all brought together. The stations are taken in the order from west to east as before, and the mean values of the times of transit in days are given in the last column.

SOUTH AMERICAN REGION.

Times of Travel of the Pressure-Waves in Days.

Names of Stations.	1886.	1903.	1904.	Means.
Juan Fernandez—Ancud		0	0	0
—Punta Anjeles		0	0	0
—Punta Dungeness		0	0 ?	0
—Buenos Ayres			2	2
—Itaqui		2		2
—Cuyabá		3	3	3
—Rio de Janeiro			3 ?	3 ?
Ancud—Punta Anjeles		0	0	0
—Punta Dungeness		0	0	0
—Cordoba			1	1
—Buenos Ayres			1	1

Names of Stations.	1886.	1903.	1904.	Means.
Ancud—Itaqui - - - - - - - -		1	1	1
—Cuyabá - - - - - - -		3	2 ?	3
—Aracaju - - - - - - -		3	3	3
Punta Anjeles—Caldera - - - - - -			0	0
—Cordoba - - - - - -			1	1
—Buenos Ayres - - - - -			1	1
—Cape Pembroke - - - -		0 ?	1	1
—Itaqui - - - - - - -		1	1–2	1
—Cuyabá - - - - - -		?	2 ?	2 ?
—Rio de Janeiro - - - - -		?	3	3
Caldera—Arica - - - - - - -			0	0
—Cordoba - - - - - - -			1 ?	1 ?
—Cuyabá - - - - - - -			?	?
Santiago—Chubut - - - - - - -	1 ?			1 ?
—Cordoba - - - - - - -	1			1
—San Juan (B.A.) - - - - -	1			1
Punta Dungeness—Cape Pembroke - - - -		1	1	1
—Itaqui - - - - - -		1	1 ?	1
Chubut—Cordoba - - - - - - -	1			1
—San Juan (B.A.) - - - - - -	1			1
Cordoba—Buenos Ayres - - - - - -			0	0
—San Juan (B.A.) - - - - - -	0			0
—Itaqui - - - - - - -			0–1	0–1
—Cuyabá - - - - - - -			1	1
—Rio de Janeiro - - - - - -			2	2
Buenos Ayres—Itaqui - - - - - -			0	0
—Cuyabá - - - - - -			0–1	0–1
—Rio de Janeiro - - - - -			2	2
Cape Pembroke—Buenos Ayres - - - - -			0	0
—Cuyabá - - - - - -		0	0	0

Names of Stations.	1886.	1903.	1904.	Means.
Itaqui—Cuyabá - - - - - - - -		0	0	0
—Rio de Janeiro - - - - - -		1	1	1
—Aracaju - - - - - - -		?	2 ?	2 ?
Cuyabá—Rio de Janeiro - - - - - -		1	1	1
—Quixada - - - - - - -			?	?
—Fortaleza - - - - - - -		1	2 ?	1
—Aracaju - - - - - - -		1	2	1·5
Rio de Janeiro—Fortaleza - - - - - -		0	1	0·5
—Aracaju - - - - - -		0	1	0·5
Quixada—Fortaleza - - - - - - -			0	0
Fortaleza—Aracaju - - - - - - -		0	0	0

An analysis of the above table demonstrates in the first instance that the pressure-waves are in existence, and that, generally speaking, they move over the country from west to east.

Dealing first with the movement on the west coast, it is found that the time of travel from Juan Fernandez to the mainland of Chili is of the order of less than one day, because a comparison of the coast stations with that island does not indicate any difference of time. Thus all the curves for Caldera, Punta Anjeles, Santiago, Ancud, and Punta Dungeness show similar waves occurring at the same epochs of time. This fact indicates in the first instance that the anticyclones meet the west coast from the west nearly square on, and that they pass over the longitudes between Juan Fernandez and the above stations sufficiently fast that the unit of a day is not small enough for a determination of their speed over this course.

The pressure-waves after transiting the west coast stations now suffer either a diminution in their speed or a change in the direction of their movement. This deduction is made on the strength of the comparison of several curves. Thus it is found that the Cordoba curve has to be moved back one day to make it agree with that of Santiago, while the difference of longitude between these stations is only 6°·5 about. Again, the waves take one day to reach Cordoba from Ancud, a distance of 9° 38° in longitude, and one day from Punta Anjeles to Cordoba, a distance in longitude of 7° 26′. Since no interval in time can be found between Juan Fernandez and Santiago, the difference of longitude between these stations being 8° 4′, some alteration in the rate or direction of motion becomes evident.

Again, some other significant facts come out from the above table. For instance, while there is a difference of one day between Punta Anjeles and

Cordoba with a longitude difference of 7° 26′, there is no interval of time between Cordoba and San Juan, although the difference of longitude between these stations is 6° 9′. This suggests that the waves reach Cordoba and San Juan about the same time. Further, the run from Punta Anjeles to Buenos Ayres (a station close to San Juan) is also one day, and the difference of longitude in this case is 13° 10′! This fact again suggests that the pressure-wave strikes Cordoba and Buenos Ayres or San Juan nearly simultaneously.

Another important piece of evidence to indicate the direction of movement of the pressure-waves in this part of South America is that gained from the curves of the stations Chubut, Cordoba, and San Juan. While the first two of these stations differ only by about 53′ in longitude but by 11° 53′ in latitude, the waves take one day to pass from Chubut to Cordoba. From Chubut they take also one day to reach San Juan, these stations having a difference of longitude of 7° 2′ and latitude 8° 29′.

There is, therefore, reason to believe that the pressure-waves or anticyclones, after they have passed the west coast stations, suffer some alteration in their course, and, instead of continuing in an easterly course, they pursue over the Argentine a north-easterly or northerly path. This change of direction of their movement seems to be a simple and rational explanation of the time differences found in comparing the curves of the several stations.

It seems most probable that this alteration in the path of the anticyclones is due to the presence of the Andes, which they must either transit or pass to the south of.

It might be thought that the anticyclones when they met the very high barrier of the Andes had either to pursue a prolonged northern or southern track to get round this obstruction or become annihilated in the attempt to cross it. The curves here examined seem to show fairly conclusively that, although the systems suffer considerable modification, they do actually transit these mountains, but their course is somewhat deflected southwards.

Thus a comparison of the pressure-waves at Santiago to the west and Cordoba to the east of the Andes shows that they reach the latter station after about a day's journey, but the waves are very much more altered in this short stretch of longitude than they are between Cordoba and San Juan (Buenos Ayres), the latter station being more to the eastward and at a very much greater distance.

Following the movements of the pressure-waves over Argentina and Brazil, the comparison of the curves indicates that they again take an easterly course.

Thus it is found that the waves occupy one day in passing from Cordoba (longitude 64° 12′ W.) to Itaqui (longitude 56° 33′ W.) or Cuyabá (longitude 55° 45′ W.), these last two stations being well separated in latitude, being 13° 32′ apart.

From Itaqui or Cuyabá another day is taken before the pressure-waves are felt at Rio de Janeiro, the difference of longitude between Itaqui and Rio de Janeiro being 13° 23′.

All the curves for Quixada, Fortaleza, and Aracaju show no difference of time between the pressure-waves they record, but they follow a day or less after those at Rio de Janeiro. The fact that the pressure-amplitudes at these stations is very small renders the identification of the waves with those of more southern stations somewhat difficult.

The study of the South American pressure observations has thus led one to conclude that—

(*a*) Anticyclones cross the country.

(*b*) Their path is not due east, but easterly when they strike the west coast, north-easterly or northerly after the Andes have been passed, and again easterly just before the east coast is reached.

With regard to the mean rate of motion of the pressure-waves their curved path renders this rather difficult of determination.

As there is no difference of time indicated between the curves for Juan Fernandez and Santiago, possibly in consequence of the unit of one day being too large, it may reasonably be assumed that the waves occupy 0·5 days to traverse this distance.

By taking into consideration the measures between the several stations, and commencing with Juan Fernandez and terminating with Aracaju, the following table shows the various times taken for the waves to travel over this distance:—

Table showing the Intervals in Days of Travel between one Station and another.

Juan Fernandez - -	0	0	0	0	0	0	0	0
Ancud - - - -					0·5		0·5	
Punta Anjeles - -	0·5			0·5				
Santiago - - -	1·0				0	0·5		
Cordoba - - - -						1·0		
Buenos Ayres - - -				1·0				
Itaqui - - - -		2·0			1·0			
Cuyabá - - - -			3·0					3·0
Rio de Janeiro - - -	2·0	1·0		2·0	1·0	2·0		
Aracaju - - - -	0·5	0·5	1·5	0·5	0·5	0·5	3·0	1·5
Totals - - -	4·0	3·5	4·5	4·0	3·0	4·0	3·5	4·5

Mean - 3·75 days.

Thus it is seen that the pressure-waves take 3·75 days to travel from the longitude of Juan Fernandez to that of Aracaju. Since the difference of longitude between these stations is 41° 41′, a speed of 11°·11 per day is indicated. The actual track of the anticyclones is, however, not direct from west to east, so that the speed may be a little greater than this. Utilizing this value as an approximate speed for this region, it is interesting to compare it with those already obtained for the other two southern continents. This comparison is made below:—

	°	′	
South Africa - - - - - -	11	51	per day.
Australia - - - - - -	11	46	,, ,,
South America - - - - -	11	6	,, ,,
Mean - -	11	34	,, ,,

It will thus be seen that the speed of the anticyclones over all three continents is approximately of the same order of magnitude, and this fact suggests very pointedly that they transit the intervening oceans.

The above inquiry into the successive pressure changes of the different South American stations has shown that the anticyclones meet the west coast nearly square on from the west, then probably south a little and take a north-easterly course after the Andes have been passed, and eventually recurve again to their original direction, namely, easterly.

If now the chart (Plate III.) be examined, which shows the isanakatabars for this region, it will be seen that practically the same course is pursued by the lines themselves. These isanakatabars recurve slightly southwards as the west coast is approached from the west, then sharply recurve, taking a north-easterly trend until eventually they leave the east coast having an easterly direction.

If the isanakatabar of 10 mm. be assumed to be the track of the centres of the anticyclones, as was shown to be the case in Australia and probably in South Africa also, then this line in the South American region may be looked upon as the path of the anticyclones for the winter season.

There is now very good evidence for assuming that the isanakatabars do really indicate the tracks of the pressure-waves, for in each of the three continents they have conformed to the directions of motions of the atmospheric high-pressure systems as they crossed or skirted the countries.

The forms of the isanakatabars over South America seem to suggest that as the anticyclones reach the Andes the systems become compressed and pushed southwards, while after they have crossed or practically rounded those mountains they recurve northwards and suffer considerable expansion. It is possibly this expansion which gives rise to the large northerly air movement after the longitude of the Andes has been passed.

To illustrate the pressure-amplitudes and the direction of travel of the waves over South America (Plate VII.) has been constructed. The curves represent the daily pressure values for the year 1904, and extend over the three months May, June, and July. The stations are given in order of longitude beginning with the most westward station. As before, the same pressure-waves are placed vertically under one another, and the amounts the time scales have had to be moved are indicated by the vertical thick line on the right-hand side.

Thus it will be seen that the pressure-waves reach Juan Fernandez, Ancud, and Punta Anjeles at the same time. A day is occupied before the same waves arrive at Cordoba, Buenos Ayres, and Itaqui. They then take another day to reach Rio de Janeiro, and one day more to arrive at Aracaju.

The curves are all drawn to the same scale and the largest and smallest amplitudes are shown by the curves of Ancud (10·4 mm.) and Aracaju (1·6 mm.) respectively.

(*e*)—THE REGIONS OF THE SOUTHERN OCEANS.

The tracking of the waves of pressure over the land surfaces has shown that, while the actual operation is not difficult, provided the stations are not too far distant from each other, the waves themselves suffer sometimes a considerable change in quite short distances or short intervals of time. In other words, a travelling anticyclone sometimes becomes, so to speak, cut in two or three parts, and, instead of having one region of high pressure, it is resolved into a system with two or three such centres.

It has been suggested in a previous part of this memoir that high land plays a considerable rôle in altering the direction of movement of the anticyclones and also in affecting their intensities during their transit over the land.

It might be expected, therefore, that when the anticyclones cross the oceans the absence of such obstructions would render them less liable to be so disturbed, and consequently fewer stations should be necessary to trace them across.

Unfortunately for this inquiry the islands which lie in the track of the travelling anticyclones are very few. One is thus driven to make use of the pressure data of islands which lie either to the north or south of the centre of the anticyclonic track or compare the data belonging to the east coast of one continent with those obtained from the west coast of the continent which lies to the eastward of the first.

Both of those procedures are very unsatisfactory, because, in the case of the islands, the mean monthly amplitudes are small and therefore the pressure-waves sought after are somewhat untrustworthy,* and in the cases of the continents the distances between them are so great that the identification of the waves, after the oceans have been crossed, becomes very difficult and sometimes well nigh impossible.

Nevertheless, in spite of these drawbacks the attempt has been made, and the results obtained for the three oceans are given in the following paragraphs.

* At stations where the amplitudes are small it requires very accurate daily readings of the barometer in order to determine the aperiodic variations. These aperiodic variations are minute compared with the daily and annual periodic variations. Whether such extreme accuracy is specially attempted in the cases of such remote islands which lie in the South Pacific Ocean I do not know, but it is quite possible that more accurate readings would render the results deduced from the comparison of the curves here discussed more satisfactory.

THE SOUTH INDIAN OCEAN.

Over this ocean the pressure-waves have already been traced as far as Mauritius from South Africa (*see* page 26), so that it is necessary here to inquire whether the waves reach the Australian continent.

For this purpose a number of comparisons of pressure-curves has been made between Cape Town and Durban (in South Africa) and Perth (in Australia). The observations made at the island of Kerguelen in the year 1902 by the German Antarctic Expedition, 1901–3, have also been utilized, and these act as a stepping-stone between Cape Town and Perth. It is unfortunate that Kerguelen lies so far south of the isanakatabar of 10 mm., the probable track of the anticyclones, for otherwise it would have formed a very valuable station for the purpose of this inquiry.

The following table sums up the results of the various comparisons that have been made to which reference above is given:—

Times of Travel of Pressure-Waves in Days.

——	1891.	1902.	1903.	1904.	1905.	Means.
Durban to Perth - - -	8	10	10	9	10	9·4
Durban to Kerguelen - -	—	5	—	—	—	5
Kerguelen to Perth - - -	—	4	—	—	—	4

The above comparisons were made for the winter months (April to September) of the Southern Hemisphere. In order to utilize a series of summer observations made at Kerguelen, a comparison was made between these and Cape Town and Perth for the summer of 1902–3. In this case the time of travel of the pressure-waves amounted to 5 days between Cape Town and Kerguelen, and 4 days between Kerguelen and Perth; thus about 9 days is the time interval between Cape Town and Perth, or 8 days between Durban and Perth.

Summarizing all the above values, the following brief table shows the results:—

	Days.
Durban to Perth (direct) for all years - - -	9·4
„ „ *viâ* Kerguelen, 1902 - - -	9·0
„ „ „ 1902–3 - - -	8·0
Mean - - - - -	8·8

While emphasising the fact that very little weight can be given to the result, the time of travel of the pressure-waves from Durban to Perth may be taken as about nine days. This interval of time represents a speed of 9° 32′ per day, a velocity much below that obtained for the mean rate of movement over the continents, namely, 11° 34′.

With such a limited number of stations it is, of course, impossible to state whether the anticyclones follow the course of the isanakatabars as previously suggested.

In Plate VIII. will be found, for the three months May to July and for the year 1903, the pressure-curves for Cape Town, Durban, Perth, and Adelaide. The stations are arranged downwards in order of longitude eastwards, and similar waves of pressure have been placed under one another.

The thick black line on the right-hand side as before denotes the amounts the time scales have been moved. This line thus indicates that the waves take 1 day to pass from Cape Town to Durban, 10 days to reach Perth from Durban, and another 2 days to travel from Perth to Adelaide.

THE SOUTH PACIFIC OCEAN.

In dealing with the transit of the pressure-waves from Australia to South America the available stations are, again, not very suitably placed to satisfactorily trace their eastward movement. Wellington (New Zealand), for which data are available, lies a little too far south of the latitude of the anticyclonic track, while the majority of the available islands are situated in the Western Pacific, and are too far north. From Rikitea, in the island of Mangarewa (longitude 137° 18′ W.), no other station is available eastward until the island of Juan Fernandez (longitude 78° 45′ W.) is reached; thus there is a break of 58° 33′ in longitude where the waves cannot be followed at all.

It must not be forgotten that in tracing the waves in the *eastern* direction over this ocean the line is crossed where the change of day occurs. This line is called the "date line," and its exact position does not seem to have been finally determined.

The positions for this line have been assigned by Wharton, Smith, and Davidson. and Stieler's hand atlas, Map No. 5 (1892), gives another position. In the case of the last-mentioned the line differs very considerably from the others. The positions of all the lines mentioned above are given on Plate I., and they have been taken from a diagram in "The Journal of the British Astronomical Association" (Vol. X., page 176), which accompanies an article written by Dr. A. W. M. Downing, F.R.S.

On this map the positions of the islands used in the present investigation are marked, and the importance of knowing the position of the date line becomes sufficiently obvious. If Wharton's, Smith's, or Davidson's lines be accepted, then Suva is the only island on the west of the line. If, however, Stieler's Atlas be taken as the authority, then Papiete and Rikitea are the only islands which lie on the east side.

Wharton's and Davidson's lines are coincident in the Southern Hemisphere, so in the map the latter is marked only with Wharton's name.

Failing any definite information as to the actual date line adopted when the observations on the islands here discussed were made, it is proposed here to assume that Suva (Fiji) was the only one of the islands here dealt with that lay to the west of this line. In other words Stieler's line was disregarded. From those who have recently travelled in the South Pacific I have learnt that the island of Raratonga does not keep the same date as New Zealand, but I am doubtful about Apia (Samoa). In tracking the pressure-waves eastward, however, there seems good reason for believing that, while Suva (Fiji) keeps the Eastern (Australian) date, Apia (Samoa) adopts the Western (American) date.*

In the tracing of the pressure-waves to the eastward of Australia the great difficulty in this region was to obtain pressure data for all the places for the same year or years. Several different years have, therefore, to be employed in order to show that the waves passing one station reach another. This difficulty will be understood when it be mentioned that in dealing with New Zealand no data were available for that country and Sydney for the same year, except 1908. One had, therefore, chiefly to fall back on Adelaide for the last record of the pressure-waves leaving Australia.

The investigation of the pressure-waves shows with very little doubt that they travel eastward, but the only uncertainty is the accurate determination of their speed.

Dealing first with Wellington (New Zealand), curves for the years 1904 and 1905 indicate that 4 days are occupied by the waves travelling between the longitudes of Adelaide and Wellington. The comparison of the Perth curves for 1905 and 1906 with those of Wellington gives a 6 days' run between the longitudes of those places. It has been shown previously (page 35) that the waves take 2 days to reach Adelaide from Perth.

Curves for the year 1908 indicate that, while no differences of time can be detected between the passages of the waves from Hobart to Sydney, there is a difference of three days between their transit over Hobart and their arrival at Wellington.

The mean rate of travel from Perth (longitude 115° 52′ E.) to Wellington (longitude 174° 48′ E.) is thus about 9° 50′ per day.

Commander R. A. Edwin, R.N.,† in an interesting paper, entitled "Meteorology "of New Zealand: On the routes of High and Low Pressures, and the changes "of pressure and wind-movement resulting from them," refers to the direction of motion and speed of the depressions which hug the southern borders of the

* Although Malden Island, which is indicated on Plate I., lies too near the Equator to assist in tracing the pressure-waves, the information I have been able to gather with regard to the time reckoning used there may be of interest. Mr. Lempfert kindly secured the information for me by communicating with Mr. H. A. Hunt, the Commonwealth Meteorologist of Australia. The latter writes—

"Regarding the practice adopted as regards the time at Malden Island, we have to state that the time reckoning of western longitude has always been used. This is found to be convenient for vessels visiting the island, also as most of the natives employed there are from the Cook Islands, which keep western longitude time, it avoids changing their day of the week. They can thus keep the same days as Sunday at Malden as they do at their own islands, this being an important matter to the native mind."

See also *Monthly Weather Review*, Vol. XXX., No. 7, 1902, p. 363.

† Transactions and Proceedings of the New Zealand Institute, 1904, Vol. XXXVII., p. 555.

anticyclones. He points out that anticyclonic pressures (page 557) are usually followed by low pressures from the west, and that (page 560) "These low-pressure " waves occupy on an average six days from the date of their passing the " meridian of Cape Leeuwin to the meridian of the South Cape of New Zealand." As the longitudes of those two stations are 115° E. and 167° 30′ E. respectively, this represents a mean eastward movement of 8° 45′ per day.

Another statement as to the course and speed of these low-pressure systems has recently been published* and is as follows:—

> "The rate at which the disturbance travelled is indicated by the difference in time between the passage of the lowest pressure at Bluff and at Wellington. The distance is measured on the latitude of Bluff. The rate at which these storms progress is generally about 300 nautical miles per day on a west-to-east route. . . ."

Taking the latitude of Bluff as 46° 33′, and 300 nautical miles as equivalent to 345 statute miles, it is found that the rate of motion is 7° 12′ per day.

The evidence thus brought together shows that, while there is a consensus of opinion as to the pressure-waves travelling from west to east and passing the longitude of New Zealand, there is a doubt as to their mean velocity. The daily rates of motion mentioned above were 9°50′, 8° 45′, and 7° 12′: if the mean of these be adopted, namely 8° 35′ or about 8°·5, then this is a little less than the speed determined for their movement over the Indian Ocean, which was 9°·1.

Turning attention now to the South Pacific Islands, these, it must first be remarked, have all fairly small amplitudes and lie on the northern side of the anticyclones the centres of which are assumed to be following the isanakatabar of 10 mm. From the first available station, namely Suva (Fiji) it is found that the waves passing over Sydney reach the longitude of Suva in three and three or four days in the years 1891 and 1895 respectively, thus indicating a rate of travel of 7°·8 a day. In 1896 the waves reach Suva five days after they have been recorded at Adelaide, the deduced velocity being 8° per day.

A comparison of the pressure-curves of Suva and Apia (Samoa) for the years 1891 and 1896 shows that similar waves occur at both islands on the same recorded day. Since the change of date takes place at the longitude between these islands, there is really an interval of 24 hours between the times of the recorded observations. For this reason the pressure-waves take about one day to travel from Suva to Apia.

For the year 1899 the pressure at Apia can be compared with that of Raratonga. The curves show that the waves of pressure at the latter island pass always one day later than the recorded date at Apia. In this case also the eastward travel of the pressure-waves is shown.

* Meteorological Journal of the Marine Department, New Zealand, January 1909, p. 3.

Progressing still further away from the Australian continent, a few observations are available at the islands of Papiete and Rikitea.

In the year 1904 it is found that the pressure-waves travel from the west towards the east to the latter island and reach it one day after they were recorded at Papiete.

As one has only been able to obtain the daily observations of pressure for Papiete for a single year, namely 1904, the nearest station to the westward of it, with which it can be compared, is Suva. Since all these stations have small pressure-amplitudes, it is hardly to be expected that the same pressure-waves could be traced over that distance. Curves for the two stations were nevertheless drawn and compared, but the waves could not be identified with certainty.

The following table brings together all the measures between the various stations mentioned above.

Times of Travel of Pressure-Waves in Days.

——	1891.	1895.	1896.	1899.	1904.	1905.	1906.	1908.	Means.
Perth to Wellington - - -						6	6		6
Adelaide to Wellington - - -					4	4			4
„ „ Suva - - - -			5						5
Hobart to Sydney - - - -								0	0
„ „ Wellington - - -								3	3
Sydney to Suva - - - -	3	3–4							3·5
Suva to Apia - - - -	1		1						1
„ „ Papiete - - - -					?				?
Apia to Raratonga - - -				1					1
Papiete to Rikitea - - -					1				1

From the above table the time occupied for the waves to travel from Adelaide to Rikitea can be deduced if an assumption for the time of travel between Raratonga and Papiete be made. As the difference of longitude between these two stations is 10° 11′, a fair value for the time occupied would be one day. Adopting this value and forming the following table the result is given below :—

Adelaide to Suva - - - - - - -	5 days
Suva to Apia - - - - - - -	1 day
Apia to Raratonga - - - - - -	1 „
Raratonga to Papiete - - - - -	1 „
Papiete to Rikitea - - - - - -	1 „
Adelaide to Rikitea - - - - - -	9 days

Since the difference of longitude between Adelaide (138° 35′ E.) and Rikitea (137° 18′ W.) is 84° 7′, and the time occupied by the waves in travelling over this distance is 9 days, the velocity deduced is 9° 20′, or 9°·34 per day.

Comparing this velocity with that obtained for the transit of the pressure waves over the South Indian Ocean, which was stated previously to be 9° 6′ per day, it will be seen that both values are about the same order of magnitude and both below that determined for the continents, namely, 11° 34′ per day.

Lack of data prevents one from following the pressure-waves as far as the west coast of America, so attention will next be drawn to an attempt to trace them across the South Atlantic Ocean.

In Plate IX. are given three sets of curves to illustrate the pressure-waves in the Western Pacific. The curves have been drawn in the same manner as those previously described, but here each series has its own pressure scale, as the pressure-amplitudes of the curves here illustrated have such extreme values.

In the case of the three uppermost curves for 1908 it will be seen that the waves which transit Hobart and Sydney nearly simultaneously, their difference of longitude amounting only to 3° 51′, pass by the longitude of Wellington three days later.

The thick vertical line to the right of the curves for Suva and Apia in 1896 indicates no difference of time between the arrival of similar waves at these stations. The change-of-date line, as previously mentioned, being situated between these two stations, there is really a difference of 24 hours between the two, the waves reaching Apia after they have passed Suva.

Although the curves for Apia and Raratonga for the year 1899 are not as convincing as they might be, they yet indicate similar kinds of waves with an interval of a day between them as shown by the thick line on the right of the curves.

The South Atlantic Ocean.

Owing to the lack of islands in the South Atlantic Ocean this region is not a very favourable one for tracing the pressure-waves across it. Further, the anticyclonic systems, which transit the longitude of South Africa, only skirt for the most the southern coast. Thus there is only a small portion of land surface which can be used most effectively for determining the arrival of the pressure-waves from South America.

In the present inquiry three South African stations have been chiefly employed, namely, Cape Town, Kimberley, and Durban, and the pressure observations made there have been compared directly with those made in South America at stations which lie in those latitudes in which the centres of the moving anticyclones are known to be travelling eastwards over that country.

The comparison, however, has led to no definite conclusion, in spite of the fact that a considerable number of curves have been drawn both for several years and different places in each of the two countries.

While a tantalizing likeness exists between the pressure-curves drawn for both South America and South Africa, the similiarly is not sufficiently satisfactory to warrant a correct identification of the waves.

Nevertheless the impression is forced on one that the anticyclones, which produce the pressure-waves, do cross the ocean in approximately a west-to-east direction, but the changes which they individually undergo during transit render the systems unrecognizable when they reach the African coast for want of intermediate stations.

While many comparisons of the curves indicate a time of travel across the ocean amounting to about four days, others equally suggest eight or nine days.

Such differences behove one, therefore, to consider this region as indeterminable at present, but it is well to mention that it is most probably due to the lack of stations for observation that proof of their actual transit cannot be given.

Bringing together the results deduced in this chapter concerning the mean eastward velocity of the pressure-waves or anticyclonic systems over the oceans, the values found are as follows:—

	Velocity per Day.
	°
South Indian Ocean - - - -	9·5
„ Pacific „ - - - -	9·3
„ Atlantic „ - - - -	(9·2 ?)
Mean - - -	9·4

CHAPTER V.

TIME TAKEN BY THE BAROMETRIC WAVES TO MAKE A COMPLETE CIRCUIT OF THE EARTH.

In the previous chapter an attempt has been made to determine the velocity of travel eastward of the pressure-waves over both the continents and oceans.

Over the former it has been shown that the waves deviate from a true west-to-east direction owing probably to the presence of high land, which renders the determination of their velocity somewhat difficult. In the case of the latter the absence or unsuitability of position of islands is a great drawback to the accurate following of the waves as they move from continent to continent.

The determination, therefore, of their mean velocity round the earth cannot be given with any great degree of accuracy, but a rough value may be gathered which may be considered as a first approximation.

Summarizing in the first instance the results obtained in the last chapter the following table can be formed :—

Eastward Movement of Pressure-Waves over	Velocity in Longitude per day.	
	Continent.	Ocean.
South Africa - - - -	12°·0	—
Indian Ocean - - - -	—	9·5
Australia - - - - -	11·5	—
South Pacific Ocean - - -	—	9·3
South America - - - -	11·1	—
South Atlantic Ocean - - -	—	?
Means - - - -	11·5	9·4

It will be seen from the above table that, while each of the series of values in their respective columns harmonize well with one another, they display a difference between continent and ocean. In fact the speed over the continent exceeds that over the ocean by about 2° per day. This result was rather surprising, for it was thought that the pressure-waves would travel more easily and therefore at a greater velocity over the oceans in consequence of the absence of such obstructions as high mountains.

It must not be forgotten, however, that the degree of accuracy of the value for the velocities is greater in the case of the continents than the oceans, so that the value for the latter may approach more to that of the continents than is exhibited in the table.

Considering the nature of the data handled, it seems permissible to adopt a mean velocity for both the transcontinental and transoceanic passages, by giving a weight of two to the former velocity and one to the latter. The mean velocity thus deduced would be $10^\circ \cdot 7$ per day.

It is a pity that the speed over the oceans cannot be more correctly determined, for, during the passage of the pressure-waves round the earth in about latitude 30° S., the relation of ocean to continent traversed is in the proportion of about 3 to 1. The velocity over the oceans should, therefore, have a predominating value in the determination of the length of the interval of time taken in making a complete circuit of the earth.

If, therefore, the mean value above mentioned, namely $10^\circ \cdot 7$, be considered as only a first approximation for the velocity of the general surface-air movement in a west-to-east direction, it results that a complete circuit round the South Pole occupies about 33·6 days.

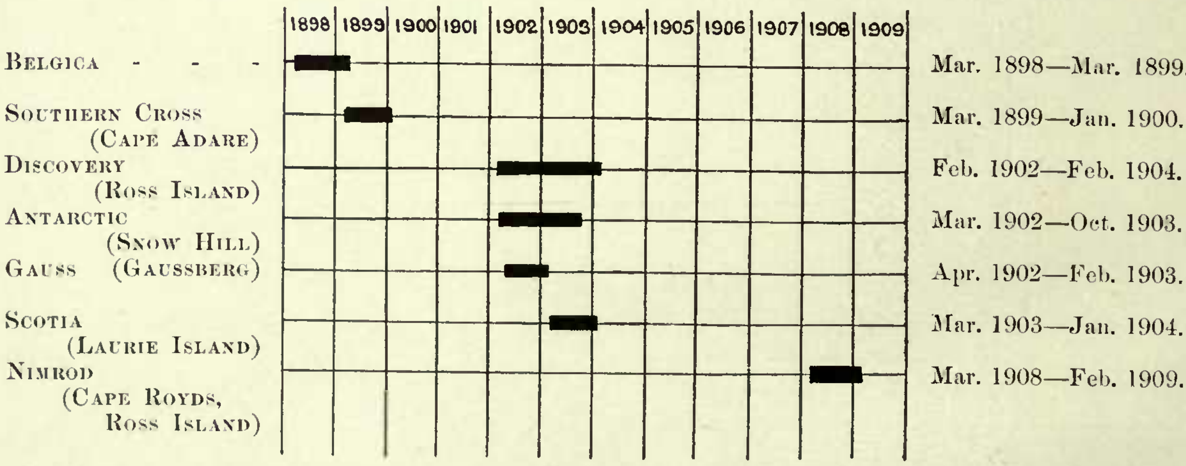
CHAPTER VI.

THE MOVEMENT OF THE BAROMETRIC WAVES IN THE ANTARCTIC REGIONS.

Having shown that the general surface-air circulations south of about latitude 10° S. as far as about 50° S. consists of an easterly drift moving at the rate of about 10·7° a day, it is important to carry the inquiry further south into the Antarctic regions.

The data which can be used are necessarily those which have been obtained by expeditions to those regions and consequently they are neither numerous nor very continuous. So long, however, as simultaneous daily pressure observations are recorded at stations not too far distant from each other, a means is offered of comparing the curves made up of the plotted daily values, as was done in the cases of places in lower southern latitudes.

The following diagram shows the various expeditions the observations of which have been considered, and the form in which it is given serves to show at a glance where the observations overlap. Thus it will be seen that while the "Discovery" was in winter quarters at Ross Land from February 1902 to February 1904, the "Antarctic" was at Snow Hill from March 1902 to October 1903, the "Gauss" at another position from April 1902 to February 1903, and the "Scotia" at the Laurie Islands from March 1903 to January 1904.



The positions of all the Antarctic stations are indicated on Plate I.

To make the survey as complete as possible, and to associate the air movements noted in high southern latitudes with those occurring further to the north, the observations have so far as possible been compared with simultaneous records at southern Australian and American stations. The data will be dealt with in the order of time, beginning with the year 1898.

During the year 1898 the S.Y. "Belgica," of the Belgian Antarctic Expedition, was the first ship to spend a night in the Antarctic regions, and a valuable series of meteorological observations was made extending from March 1898 to March 1999, During this time the ship moved with the ice and its position varied from time to time. Thus the ship wandered between 70° and 71°·5 in latitude, while its movement in longitude varied from 82° W. to 92° W. For the purpose of this inquiry the observations may be considered as made from a fixed station.

Fortunately the position of the "Belgica" was such that simultaneous pressure observations could be compared with a land station not very far distant. Thus it has been found possible to utilize the observations made at Cape Pembroke in the Falkland Islands.

Curves, therefore, of the daily-pressure values from both the "Belgica" and Cape Pembroke observations were plotted for the six months April to September in each case, and these were compared in the manner adopted previously in this memoir.

It was found that the curves bore a strong resemblance to each other if the time scale of the latter station be moved three days back in relation to that of the "Belgica." In other words the waves of pressure took three days to pass from the longitude of the "Belgica" to that of Cape Pembroke. The difference of longitude between these stations being 29° 42′, assuming the "Belgica's" position as 87° W. The velocity of the pressure-waves amounts to about 9°·7 per day.

Thus in these very southern latitudes the surface-air circulation is from west to east, and the velocity of movement is comparable with that derived for the oceans in more northern latitudes.

During the year 1902 these expeditions were in the Antarctic regions. The "Discovery" was at Ross Island, the "Antarctic" at Snow Hill, and the "Gauss" at a position in latitude 65° S. and longitude 89°·5 E.

Dealing first with the winter six months (April to September), the "Gauss" observations have been compared with those made simultaneously at the island of Kerguelen. While the curves suspiciously suggest a west-to-east movement of the pressure-waves, the curves are not sufficiently similar to deduce this direction of movement conclusively. An attempt was also made to see if the pressure-waves recorded by the "Discovery" at Ross Island could be associated with those at the "Gauss" position, but no definite conclusion could be arrived at: this result was, however, rather expected, as the distance between these two stations was about 80° in longitude. The absence of any available data for a New Zealand station prevented any comparison being made with the "Discovery's" Antarctic station.

Coming now to the position of the ship "Antarctic" at Snow Hill, one is able to compare the daily pressures observed there with those recorded simultaneously at Punta Dungeness in South America. An inspection of the curves for these stations, drawn for the six months April to September shows clearly that similar waves of pressure affect both stations. The curves fit each other best when their time scales are made coincident, but there is a distinct tendency in parts of the curves for the waves to indicate their presence at Punta Dungeness before Snow Hill. Thus there is a suggestion of a west-to-east motion of the air waves, while the difference of longitude between the two stations is 11° 29′, it might be expected that about a day's run would be shown by the pressure-curves: it is quite possible, however, that the anomalies previously referred to, which occur in the region of South America, may extend into the Antarctic regions and so effect the direction of motion of the pressure-waves in these very southern latitudes.

The scarcity of observations during the winter months in the Antarctic suggests that an attempt should be made when possible to try and find out the direction of movement of the pressure-waves during the summer months, since such observations exist for some of these periods. In the case of the winter of 1902–3 this has been done, because there were three expeditions in those regions for that period, namely the "Discovery," the "Antarctic," and the "Gauss."

Commencing with the "Gauss" observations, these have been compared with those made at Kerguelen and Ross Island. In the first case the pressure-waves reach the "Gauss" two days after they have passed Kerguelen thus indicating a velocity of nearly 10° a day. While Ross Island is considerably remote from the "Gauss" position, the best similarity of the curves is obtained when the time scale of the former is moved back 9 days. This indication of a west-to-east motion results in a daily velocity of the waves of about 8°·5. Again, a comparison between the curves for Ross Island and Snow Hill leads one to the conclusion that the curves are best matched when the time scale of Snow Hill is set back 15 days. Such a difference in time corresponds to a west-to-east velocity of a little over 9° a day. As before the curves for Punta Dungeness and Snow Hill are very similar and do not show any difference between the times of occurrence of the waves.

During the winter months (April to September) of the year 1903 the "Discovery" was at Ross Island, the "Antarctic" at Snow Hill, and the "Scotia" at the Laurie Islands. An attempt was first made to compare the "Discovery's" pressure observations with those recorded simultaneously at Sydney in Australia and Punta Dungeness in South America, but no definite result could be arrived at. In the case of the observations at the two other Antarctic stations, namely at Snow Hill and the Laurie Islands, a very satisfactory conclusion could be drawn. The curves for Snow Hill and Punta Dungeness were found to be very similar and agreed well without any alteration of the time scale of the curves. This result agrees with the two former determinations in the winter of 1902 and the summer 1902–3. When the observations made at Snow Hill were compared with those at the Laurie Islands, there was a distinct day's difference between the time of arrival of the pressure-waves at the two stations, the waves passing over Snow Hill first. Between Cape Pembroke and the Laurie Islands, while a difference of one day is not clearly shown by the curves, there is a considerable tendency for the curves to show that the waves reach the Laurie Islands subsequent to Cape Pembroke. It is in such a case as this that hourly readings at the two places should be compared, for the unit adopted in this memoir, namely, one day, is too large.

More evidence for the west-to-east direction of movement of the pressure-waves can be obtained from the comparison of curves of Punta Dungeness and Cape Pembroke for the winter of 1904. For both stations the pressure-waves are very similar, but the time scale of Cape Pembroke has to be placed one day back to make them correspond to those of Punta Dungeness.

The difference of longitude between these stations being 10° 43′, this value represents the daily speed of the waves in a west-to-east direction.

Owing to the kindness of Sir E. H. Shackleton, I have been able to obtain a copy of the mean daily barometric readings made at the winter quarters, Cape Royds, during the recent British Antarctic Expedition (1907–1909). These were forwarded to me by Mr. James Murray. The curves for the six months April to September for the year 1908 have been compared with those for the same year and period for Sydney, Hobart, and Wellington. While the pressure-waves can be traced passing over Sydney and Hobart simultaneously and reaching Wellington three days later, they are not able to be associated with those indicated by the Cape Royds curve. The great difference of latitude between the Cape Royds stations and the other three more northern stations accounts, no doubt, for this apparent lack of association. Nevertheless, although the comparison has failed, the attempt was well worth trying.

In the accompanying figure (Plate X.) is given a series of typical curves which have been used in this inquiry to trace the Antarctic pressure-waves from one station to another. In plotting the curves the same procedure as before has been adopted, namely, by indicating the movement of the time scale by thick vertical lines on the right-hand side.

The first two curves show the pressure-curves of the "Belgica" and Cape Pembroke for the months of May, June, and July of the year 1898.

The latter curve has been moved three days to the left so that similar waves fall vertically under one another.

The next three curves illustrate the waves transiting Punta Dungeness, Snow Hill, and the Laurie Islands. The time scales of the first two curves are placed coincident with each other, but that of the Laurie Islands put back one day. These curves are for the months of May, June, and July of 1903.

Next follow two curves for the same months, but for the year 1904, to illustrate the passage of the pressure-waves from the longitude of Punta Dungeness to that of Cape Pembroke. In this case the latter curve has been moved one day to the left in consequence of this interval being the time taken for the waves to travel between the stations.

The conclusion that has been arrived at, after a study of the pressure observations in high southern latitudes, is that there is evidence to show that the general surface-air circulation is in a west-to-east direction. The rate of travel seems to be of the order of about 9 to 10 degrees of longitude a day, a value harmonizing with that obtained for more northern latitudes.

It can be concluded, therefore, that the pressure-waves in the Antarctic are closely associated with those occurring more to the north, and this suggests that there is one general scheme of circulation applicable to the whole of the Southern Hemisphere.

Such a scheme will be presented in the next chapter.

CHAPTER VII.

SUGGESTED EXPLANATION OF THE CHANGE OF PRESSURE-AMPLITUDE WITH LATITUDE.

In the preceding chapters it has been shown that the pressure-waves travelling from west to east over the three southern continents and intervening oceans represent the fluctuations of pressure due to the easterly movement of anticyclones.

Further south, the existence of larger amplitudes of the waves and their west-to-east motion suggest that in those latitudes anticyclones are replaced by moving cyclones of considerable pressure gradients.

In the Antarctic regions, up to about latitude 80°, pressure-waves of reduced magnitude are still prominent, and there seems to be evidence, as has been indicated, of their west-to-east direction of motion.

With this general idea it is possible to suggest an explanation regarding the relationship, with respect to latitude, between these air systems and the pressure-amplitudes.

Such an attempt forms the subject of the present chapter. For a clearer exposition of the case it was found best to exhibit the explanation in diagram form, and for this purpose the accompanying illustration (Plate XI.) was drawn, which should be consulted with the text.

On the extreme left (curve 1) is again reproduced the pressure-amplitude curve, and in the middle a diagrammatic representation of a typical anticyclone is drawn indicating the monsoonal tongues of low pressure to the north and the cyclones or deep low-pressure systems to the south, these latter lying below the junctions of consecutive anticyclones.

The positions of these systems on the diagram as regards latitude have been determined from the following considerations.

In the first place it has been previously mentioned that the mean amplitude of a winter anticyclone is about 10 mm.

The latitude of the 10 mm. reading on the amplitude-curve (curve 1) was then read off, and the centre of the anticyclone placed on about the same horizon. The reading found was 35° S. and this may be looked upon as the *mean latitude* of the path of the anticyclones in their circuit of the earth.

A typical anticyclonic set of isobars was then drawn, and extended to the Equator to represent the monsoonal region. If now this system be supposed to travel from west to east, *i.e.*, from left to right, the pressure-waves of the places passed over in different latitudes will have amplitudes of the order shown in the amplitude-curve (curve 1) on the left-hand side. Thus there will be a gradual, and afterwards a less gradual, fall in amplitude towards the Equator as the distance from the anticyclonic track (latitude 35° S.) is increased.

The increase in the values of amplitude further south than latitude 35° is, no doubt, caused by the presence of the Λ-shaped depressions which travel with the anticyclones eastward. Unfortunately nothing or very little is known about the latitudes of the tracks of the centres of these low-pressure systems, of which the Λ-depressions form part.

The position of such a track should be indicated by the latitude of the greatest pressure-amplitude.

The fact that the amplitude-curve (curve 1) has a distinct maximum at about latitude 60° S. is very suggestive, and practically demonstrates that this is the mean position of the track of the centres of the "lows" as they make the circuit of the earth.

In the diagram the centre of the track of this low-depression system has been placed in latitude 60° and typical isobars drawn to represent it.

Proceeding southward from latitude 60° S., the amplitude-curve shows a decided decrease in the values of the amplitudes. What is the latitude of the southern extremities of these deep depressions is, so far as I know, unknown, but I have, however, examined carefully many of the Antarctic records, and they suggest that the depressions extend much further southward than the coast line or ice barrier.

The amplitude-curve up to this point is thus easily explained by increase of distance southward from the track of the low depressions.

In the Antarctic regions data for the determination of the amplitudes are not abundant, so that the amplitude-curve south of latitude 70° is uncertain. If the curve be simply extrapolated the amplitude value at the Pole would be about 13 mm. It is exceedingly probable, however, that this extrapolation will not suit the facts when they become known.

It seems more likely that after latitude 70° the amplitude decreases very rapidly and that at the Pole itself it has a zero or nearly zero value. Both these ideas are represented by dotted lines in the diagram (curve 1, Plate XI.).

As there seems reason to believe that, at some distance a little further south than the coast line or ice barrier, the southern limit of the extent of the low depressions is reached, then the continual decrease in the value of the amplitudes would indicate the existence of a permanent single anticyclonic system.

The air movement in the neighbourhood of the South Pole must be in the nature of an intense but comparatively small (in area) anticyclone, because this system has to feed singly the southern portions of all the deep depressions which circulate round it.

Thus in this stationary anticyclone the air must be descending at a great speed and rushing out nearly radially at a great velocity in every direction. This may explain the very strong southerly winds which were continually met with by Sir Ernest Shackleton in his dash to the South Pole in 1909.

It is quite possible, therefore, that the pressure-amplitudes at and near the Pole may be small and that they may increase rapidly northwards.

To represent this condition in the diagram (middle part) isobars have been drawn to indicate the Antarctic anticyclone, and the southern extremities of the depressions have been shown as terminating in about latitude 80° S.

Attention should be drawn to the fact that the increase of amplitude from the Equator to latitude 60° S., and the subsequent decrease to the South Pole, has its counterpart in the *Northern* Hemisphere. Thus Köppen,* in discussing the irregular monthly pressure variations for different latitudes, has published the following values for the Northern Hemisphere.

Mean Monthly Barometric Variation (*mm.*).

N. latitude.	80°	70°	60°	50°	40°	30°	20°	10°	0°
				Winter.					
Ocean -	34	40	*45*	38	29	16	8	4	3
Continent -	—	29	*31*	25	18	13	9	6	4
				Summer.					
Ocean -	18	25	*28*	25	16	9	6	4	3
Continent -	—	18	*19*	14	12	10	7	5	4

This table shows clearly that the pressure-amplitudes increase steadily up to latitude 60° N., after which they decrease towards the Pole.

Dr. Hann, with respect to this change of amplitude with latitude, wrote:—

"The dependence of the magnitudes of the irregular pressure variations on the geographical latitude is a most remarkable occurrence, the explanation of which must be left to the so-called dynamic meteorology."

The fact that the relationship between the pressure-amplitudes and latitude may be considered to be approximately identical for *both* hemispheres is of considerable importance.

It suggests that the general atmospheric movements in the Northern Hemisphere, which give rise to the various values of amplitudes, are most probably closely similar to those occurring in the Southern Hemisphere, due allowance being made for the modifications brought about by the distribution and greater proportion of land to water surface in the Northern Hemisphere.

The general relationship between the amplitudes and the anticyclonic and cyclonic systems suggested in this memoir receives further corroboration from a

* Annalen der Hydrographie, Vol. X., 1882.

† Lehrbuch der Meteorologie, 2nd Ed., 1906, p. 155.

study of the *mean* annual pressures for different latitudes, for it should be expected that the highest mean pressure should be in the latitude corresponding to the track of the centres of the anticyclones and the lowest to the track of the centres of the cyclones.

Hann* gives the values for the mean barometric readings for different degrees of latitude in the Southern Hemisphere. These are as follows: —

700 mm. + (gravity correction).

Latitude	Eq.	5°	10°	15°	20°	25°	30°	35°	40°	45°	50°
January	58·0	57·9	57·8	57·8	58·5	59·7	61·0	62·0	61·9	58·2	52·7
July	59·1	60·0	60·9	62·0	63·5	64·7?	65·1	63·9	60·6	57·1	52·8
Year	58·0	58·3	59·1	60·2	61·7	63·2	63·5	62·4	60·5	57·3	53·2

Regarding the mean pressures in the Southern Hemisphere, he states that the pressure rises in the Southern Hemisphere up to 30° and then begins to fall towards the Pole quicker in the Southern than in the Northern Hemisphere.

In the Southern Hemisphere about latitude 60° to 70° the pressure again rises, as is shown by the observations of Antarctic expeditions.

The above mean annual pressure values have been plotted on the extreme right in Plate XI. (curve 2), and a smooth curve drawn through them. The more southern portion has been dotted, as its position is based on insufficient data.

It may be here mentioned that for any one place, especially when it is situated far away from the Equator, while two or three years' observations are sufficient to determine the value of the monthly pressure-*amplitude* with fair accuracy, it requires many years' observations before even an approximate value of the *mean annual pressure* can be secured. Hence, not too great a weight must be attached to the exact position of the dotted portion of the curve to which reference has just been made.

Comparing this curve directly with the latitudes of the air systems (April to September) indicated in the middle of the figure, it will be seen that the highest pressure approximates favourably with the position of the centre of the anticyclonic track. The position of lowest pressure falls further southward than that of the track of the low depressions but, as stated above, the pressure-curve is very uncertain about these latitudes.

The final increase of pressure towards the South Pole indicated by the curve corroborates the pressure of the Antarctic anticyclone indicated in the figure.

While the values of the isobars given in the middle diagram (Plate XI.) for the anticyclone and cyclones have been taken to represent actual conditions,

* Lehrbuch der Meteorologie, 2nd Ed., 1906, p. 136.

as suggested by daily isobaric charts in the Australian region, those further south are purely hypothetical.

If such a system represents actually a mean condition of affairs then it is possible not only to determine the amplitude per latitude, as the system moves from west to east, but also the mean pressure per latitude as well.

The former can be obtained by taking the difference between the highest and lowest isobaric reading cut by a horizontal line, while the latter is secured by forming the mean of the two readings.

The curves thus obtained have been placed to the left and right of the central diagram and are designated by the numbers 3 and 4.

It will be seen that the amplitude-curve (curve 3) reproduces the main features of curve 1, and suggests very forcibly the rapid decrease of amplitude in the Antarctic regions previously pointed out. The mean pressure curve (curve 4) in its main features is not very unlike that drawn (curve 2) to represent the actual mean pressures as obtained by observation. It is very probable that, when more observations become available, curve 2 south of latitude 50° may take the form of curve 4 more closely.

In his treatise on meteorology, Hann writes: "the extraordinary low mean "pressure at sea level in the higher southern latitudes has, since they were "known, continually raised astonishment, and courted different hypotheses as to "its cause."

The view put forward in this memoir is that it is due to the series of rapidly eastward-moving cyclones or deep depressions which revolve round the Antarctic anticyclone, their centres following a track which lies approximately in about latitude 60° S.

CHAPTER VIII.

SUGGESTED SCHEME OF SURFACE-AIR CIRCULATION.

The general discussion of the daily pressure data for the numerous stations dealt with in this investigation has led one to form the following conclusions:—

1. The isanakatabars are approximately small circles with the South Pole as centre and indicate a relationship between latitude and amplitude common to the whole Southern Hemisphere.

2. Where the actual atmospheric movements are known, *i.e.*, in the regions of the three southern continents, the isanakatabars are intimately associated with the anticyclones and cyclones which take part in these movements.

3. The order of the atmospheric movements as one proceeds from the Equator to the South Pole is as follows:—

    First, a belt of anticyclones, the centre of which lies in latitude 32° S. about.

    Second, a belt of cyclones, the centre of which is situated in about latitude 60° S.

    And third and last, a stationary anticyclone at the South Pole.

4. In all longitudes the general air movement is approximately in a west-to-east direction, and this applies to those stations situated in the Antarctic regions which have been examined as well as to those in more northern latitudes.

5. The mean daily velocity may be considered, as a first approximation only, as amounting to about 10° of longitude, so that the actual velocity in miles per day increases as the Equator is approached.

The above considerations lead one to put forward a general scheme of surface-air circulation for the Southern Hemisphere which, besides satisfying the above-mentioned conclusions, falls in with the most well-determined facts of surface wind directions.

The circulation here suggested is embodied for the most part in Plate XII. which in the first instance is a stereographical projection of the Southern Hemisphere on the plane of the Equator. Attention is first called to the two broken-line and nearly concentric circles which are situated in approximately latitudes 32° S. and 60° S. These circles represent the tracks of the centres of the anticyclones and cyclones which pursue their course round this part of the earth in the directions indicated by the two large arrows, *i.e.* from west to east. In the diagram a series of these two sets of air motions has been diagramatically inserted, and the impression to be gathered from them is that one is supposed to be viewing them all at one moment of time : in other words the diagram represents a synchronous barometric chart for those latitudes.

It must, however, be borne in mind that the anticyclones in their journey break up and reform individually, this breaking-up being due to the occasional southward or northward passage of the cyclones which appear on their equatorial or southern sides respectively: these low depressions force their way between, and in some cases through, the anticyclones themselves.

An individual anticyclone cannot, therefore, be followed very far along its track owing to this rapid transformation during transit. It is only by means of a chain of fairly close stations, such as land areas afford, that the same anticyclone can be recognized by its ever-changing barometric record. In fact six or even a less number of days is approaching the limit of duration of any such system. This comparatively short life-history of an anticyclone, and the same may be said of a cyclone, is probably the reason why no successful attempts have so far been made to trace them across the oceans directly from one continent to another in the Southern Ocean.

In the diagram, therefore, it must not be supposed that these systems, whether anticyclones or cyclones, as drawn, make the whole circuit of the earth individually, like spokes in a revolving wheel. Both systems in their respective belts of latitude are being continually formed and dissipated. Nevertheless the latitudes of the centres of the tracks will always be one of relatively high pressure in the case of the anticyclones, and relatively low in that of the cyclones.

Coming now to the Antarctic region bordering the southern sides of the series of cyclones, here an intense anticyclonic area is situated and is indicated by a set of closed isobars in the diagram. The outer isobars of this permanently fixed anticyclone should probably present the appearance of a cog wheel, the cogs forming northern extensions of the anticyclone to fill up the spaces between the southern ends of the cyclones.

On the equatorial side of the series of anticyclones which transit the continents isobars have been drawn to represent the low-pressure conditions prevailing there. In these regions the normal conditions consist generally of tongues of low pressure between individual anticyclones. Occasionally, however, tropical circular storms appear, which, as before mentioned, strive to force themselves southward between the anticyclones.

The system of surface-air circulation as shown in the diagram illustrates the mean winter conditions for the Southern Hemisphere. That for the summer season will not differ very much from it. The series of anticyclones which transit the continents will move in a track a few degrees nearer the South Pole. The track of the cyclones will likewise be a little more south, while the Antarctic anticyclone will cover a smaller area.

Before an attempt is made to find out whether this scheme of surface-air circulation is capable of explaining the most accurately known directions of the surface air currents, it is as well to draw attention to the internal mechanisms of the fundamental air swirls as designated by the names anticyclone and cyclone.

It is here considered that an anticyclone,* or area of high pressure, is a spiral movement of air downwards or from very elevated regions to the earth's surface, and the direction of motion of the air forming this system is anti-clockwise in the Southern Hemisphere. In such a system the directions of the wind may be taken to be parallel to the isobars.

A cyclone, or area of low depression, on the other hand, is a spiral movement of air upwards and the direction of movement of this air is clockwise. The wind directions in this system may also be considered as parallel to the isobars.

While, therefore, an anticyclone is fed, so to speak, with air at high altitude, the cyclone is nourished with air moving on the earth's surface.

Considering the above remarks in connection with the diagram (Plate XII.), it will be noted that, commencing at the Equator, there are belts of rising, falling, and rising air consecutively, while at the Antarctic there is a region of descending air.

Restricting oneself now to the air movement on the earth's surface, it will be seen that the outpouring of the air in a north-westerly direction from the northern fringes of the anticyclones (descending air) gives rise to the well-known south-east trade winds. The northern portions of the cyclones or Antarctic low depressions (ascending air) and the southern portions of the anticyclones maintain a nearly constant stream of air moving eastwards giving rise to the strong westerlies of the Southern Hemisphere. The intermediate region in which the anticyclones themselves travel must be and is a region of variable winds, because many wind directions must be experienced there.

In about latitude 60° S. (the exact latitude depends to some extent on the particular longitude in question) another zone of variable winds should be encountered, because here is the track of the centres of the cyclones and therefore the most favourable condition for winds from all points of the compass.

It will be noticed in the diagram that the southern extremities of the Antarctic cyclones are shown as touching or overlapping the ice barrier. One was led to draw them like this, because this extreme south position was suggested by the amplitude-curve (curve,) illustrated in Plate XI., and seemed a simple way of accounting for the decrease of amplitude and an increase in the values of the mean pressures per latitude in those regions.

In the neighbourhood of the ice barrier, and to some distance inside the Antarctic continent, the southern extremities of the cyclones should therefore give rise to winds the chief component of which should be easterly and not westerly. The passage of those portions of the cyclones should give rise on their approach first to strong north-easterly and easterly and comparatively warm winds, and subsequently to intensely cold south-easterly and southerly winds.

* These definitions of anticyclones and cyclones are more minutely dealt with in Chapter X., p. 90

Possibly during the interval between the passages of these portions of the cyclones a short calm might reign and allow the phenomena of land breezes to exist due to the large temperature difference between the water and the ice barrier. Such a calm might be possible when a tongue from the Antarctic anticyclone extends northward into the space between two cyclones. At this time very low temperatures would probably be experienced owing to air flowing out from the Antarctic anticyclone.

It should be borne in mind, however, that the weather experienced at an Antarctic station will depend to a great extent on whether the station is situated just inside the zone of these travelling cyclones or outside, and therefore immersed, in the Antarctic anticyclone. The question of the latitude of the observing station may, therefore, be of very great importance, and a small change of position in latitude might mean a large difference in the kind of weather experienced.

Now, while the suggested scheme of surface-air circulation meets the requirements laid down by observed facts up to about latitude 50°–55° S., it becomes necessary to examine the records of Antarctic expeditions to find out whether the scheme is borne out in those regions. This inquiry forms the subject of the next chapter.

CHAPTER IX.

ANTARCTIC RECORDS IN RELATION TO THE PROPOSED SCHEME OF SURFACE-AIR CIRCULATION.

It is not proposed to enter here into a very minute discussion of the weather experienced by all the Antarctic expeditions, but to summarize as briefly as possible some of the conclusions which have been drawn by the authors who have discussed the original observations from the point of view of the general atmospheric motions.

It may, however, in the first instance be mentioned that in this memoir a considerable number of curves representing the daily changes of barometric pressure at the Antarctic stations has been employed, firstly to determine the pressure-amplitudes and secondly to trace the movements of the pressure-waves. All of those suggest that the pressure changes thus exhibited might easily be explained by the transits of portions of cyclones over the observing stations.

Coming now to the conclusions derived from the several expeditions, these will be dealt with, so far as possible, in the order in which they set out for the Antarctic.

BELGIAN ANTARCTIC EXPEDITION. 1897–1899.*

While the "Belgica" did not occupy the same position during the time that it was caught in the ice, from the point of view of the present inquiry its location may be considered as fixed. The limiting positions of the ship were actually 69° 38′ and 71° 36′ S. in latitude and 80° 30′ and 96° 40′ W. in longitude.

The first point to which particular attention should be drawn is M. Arctowski's reference to the waves of pressure which passed over the ship. In his examination of the barograph records he noted these oscillations of pressure and counted their number. To restrict his counts to typical waves of pressure, he omitted those of small amplitude in a nearly similar way to the method employed previously in this memoir.

The conclusion to which he arrived was as follows:—

From 1st March 1898 to 2nd March 1899, 70 such oscillations of pressure occurred, the mean amounts of their rises and falls of pressure being 15·9 and 16·0 mm. respectively. The duration of these rises and falls lasted on the average 63 hours in each case. Thus the mean duration of one oscillation was 5 days 6 hours.

*Résultat du Voyage du S. Y. Belgica en 1897–1898–1899, Météorologique ; par Henryk Arctowski, 1904.

When one presents the idea that the falls of pressure were caused by the passage of the southern portions of a series of cyclones over the ship's position, the alternate rise and fall of the barometer and the duration of each pressure oscillation harmonize well with the idea suggested in the scheme of surface-air circulation here put forward. Thus it has been stated that the mean velocity of travel of the pressure-waves from west to east amounted to about 10°·7 a day, so that a complete circuit would be travelled in 33·4 days. In the diagram (Plate XII.) eight cyclones have been represented as filling up the space in this cyclone belt. If this number be reduced by one, then each cyclone would occupy about 4·9 or 5 days in passing over a station. M. Arctowski's time duration for the waves passing over the "Belgica" being 5·2 days, the proposed scheme meets with considerable support. Turning attention now to the frequency of winds, M. Arctowski makes a very complete discussion of the "Belgica's" record.

Whilst acknowledging the fact that the meteorological observations extend only over a year, M. Arctowski is of the opinion that some deductions can be drawn from them which may be taken as an approximation to the normal conditions occurring in that region.

Thus one conclusion of great importance which he derived was that there exists "a real characteristic contrast between the winds of the Antarctic winter and summer" (page 42). Dividing the frequency of the wind directions up into the two groups of months May to October (winter) and November to April (summer), he finds that during the former period the winds from E.N.E. to S.S.W. are less frequent, while those from the W. (or from W. to N.W.) are predominant. On the other hand during the summer months (November to April) the winds from E.N.E. to E.S.E. are the most frequent. The following table gives the totals for the different wind directions during those two seasons of the year:—

	N.	N.N.E.	N.E.	E.N.E.	E.	E.S.E.	S.E.	S.S.E.	S.	S.S.W.	S.W.	W.S.W.	W.	W.N.W.	N.W.	N.N.W.
May-Oct.	249	226	260	131	181	181	142	123	198	94	284	254	621	389	323	211
Nov.-Apr.	132	147	380	504	502	408	334	228	177	132	200	262	215	133	105	84

Attention should be drawn to the fact that, while he refers chiefly to the *predominant* winds, throughout both seasons winds occur from all quarters.

Now, the large amplitudes of the pressure-waves, their movement approximately from west to east, and the duration of each wave over the station being in the mean 5·25 days, all suggest that the atmospheric conditions in this region are brought about by the passage of a series of low depressions. Assuming for a moment that such is the case, then the wind directions stated above seem to corroborate this view. In order to make the most frequent winds during the winter months W. or N.W., the centres of the cyclones should pass a little south of the observing station. In this way the westerly components of the winds should predominate. Fig. 3, No. 1, (page 70) shows diagrammatically the passage of such a cyclone, and the shaded area in the north-eastern part of it indicates the segment in which the winds will be westerly to north-westerly.

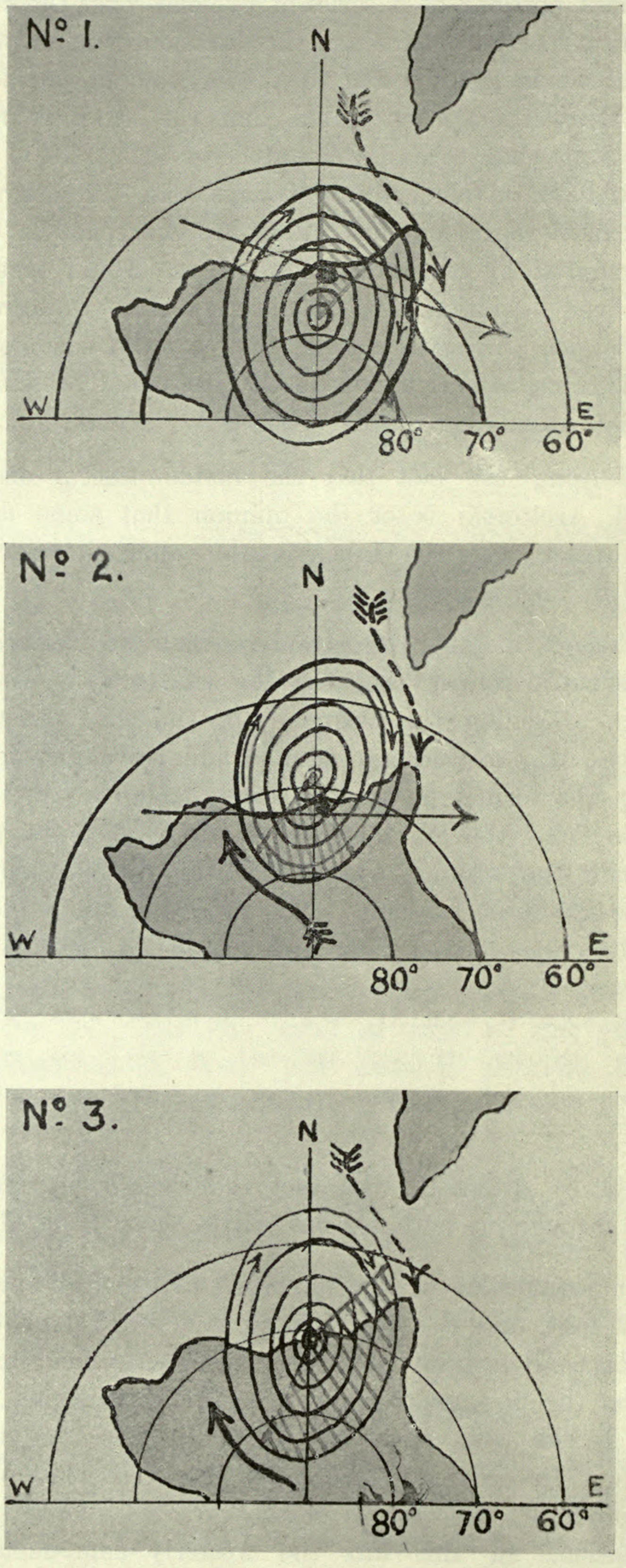


Fig. 3.

In the case of the summer conditions (November to April) it is necessary for the centres of the cyclones to pass north of the station, so that the latter may come under the influence of the southern portions of the cyclones. In this case the easterly component of the winds will predominate, and in No. 2 of Fig. 3 the shaded area indicates that portion of a cyclone which contains the predominating winds noted by Arctowski, namely, E.N.E. to E.S.E.

If the above be the existing state of affairs, then it becomes of great interest to examine the temperature observations in relation to wind direction. Since the wind direction in the case of a cyclone is in the same direction as the movements of the hands of a watch, the air in the northern part of the cyclone passes over a comparatively warm surface (ocean) and that in the southern part over a comparatively cold surface (ice barrier and snow-covered mountains). It should be expected, therefore, that the winds on the forward part of the cyclone reaching the ice barrier should be comparatively warm, because they have traversed the greatest amount of water surface. Further, as they have been reinforced by air from the southern sides of the anticyclones to the north (*see* large broken arrows in Fig. 3, Nos. 1, 2, 3), their temperature should be higher still. Thus the warmest winds which should have been experienced by the "Belgica" should be those from the north-west, north, north-east, and east.

On the other hand the coldest winds would be those that have passed over the greatest amount of land or ice surface. They should, therefore, be the winds which are situated in the following part of the cyclonic system. Where those systems are fed by the Antarctic anticyclone, namely in their south-western quadrants (*see* large continuous arrows in Fig. 3, Nos. 2, 3), their low temperature should be considerably accentuated. Thus the S.E., S., and S.W. winds should be cold winds.

M. Arctowski sums up the discussion of the observations of wind and temperature in the following words (page 45) :—

> "des écarts positifs s'observent par vents de N.W. à E.S.E., et les vents de N.E. sont les plus chauds, tandis que les vents du S. et du S.W. sont les plus froids et les écarts négatifs des vents W. et W.N.W. sont plus élevés que ceux des vents S.E. et S.S.E."

In Fig. 3, No. 3, the shaded area in the cyclone represents the winds from N.W. to E.S.E., which are stated by M. Arctowski to be on the average warm, while the unshaded portion represents the area of cold winds. It will be seen, therefore, that M. Arctowski's deductions agree perfectly with the above-mentioned expected conditions. In the diagram the reader is supposed to imagine the cyclone moving approximately from left to right, *i.e.* from west to east; thus the front of the cyclone is very much warmer than the rear portion.

The general conclusion that can be drawn from the "Belgica's" observations is that the position in which the ship lay was such that it was passed over by a series of moving cyclones travelling approximately eastward. Attention must, however, be drawn to the fact that the centres of these cyclones lie in a very much more southern latitude than is indicated by the isanakatabar of 19 mm. (*see* Plate III.), which was taken as the track of the cyclones. It is quite possible, however, that, as the anticyclones to the north have been shown to make an exceptional amount of southing in order to obviate the obstruction to their motion due to the presence of the Andes, so the cyclones to the south of these high-pressure systems are compelled to make a similar detour.

While the isanakatabars of 19 mm. and 16 mm. in these longitudes do not indicate* such a southern trend, this may possibly be due to the few number of stations on which they are based.

BRITISH ANTARCTIC EXPEDITION.

1898–1900†.

During the period extending from 3rd March 1899 to 28th January 1900 the scientific members of the "Southern Cross" made their camp at Cape Adare in longitude 170° 9′·5 E. and latitude 71° 18′·S. and secured a valuable set of meteorological observations. These were reduced at the British Meteorological Office, under the direction of Dr. W. N. Shaw, F.R.S., and the discussion of them was published in the above-mentioned volume.

One of the chief results derived from the examination of the records was the direction of the prevailing winds. Thus it is stated that 41·1 per cent. of the winds were S. and S.E., 41 per cent. were calms, while the remaining 17·9 per cent. belonged to other directions: these facts were based on 2,570 observations taken during 11 months.

The predominating wind directions, as above stated, suggest, that the extreme southern portions of the low depressions pass on the average over this station, because in these parts of the cyclones the winds will be chiefly easterly and southerly. In comparing the changes of temperature with the direction of wind the fact is brought out that the strongest and most frequent winds are accompanied by a rise of temperature, while the south-west winds are associated with the coldest weather. The reason for this seems to be that the south-east winds are winds in the cyclonic systems which have previously passed over the ocean and therefore become comparatively warm. On the other hand the south-westerly winds are those winds of the cyclones which not only have previously passed over a portion of the Antarctic ice surface but which have been reinforced by the winds from the inner part of the Antarctic continent, and therefore extremely cold.

Again, the general behaviour of changes of pressure with wind direction point to the passage of low-pressure systems passing to the north of the observing station.

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* *See* Chapter X. for further remarks on these isanakatabars.

† Magnetic and Meteorological Observations made by the "Southern Cross" Antarctic Expedition, 1898–1900.—Royal Society, 1903.

Rearranging slightly the facts published in the volume of the Cape Adare observations, the following table shows the relation of pressure to wind direction for the whole eleven months of observation:—

Wind Direction.	Mean Pressure (inches).
N.E. and E.N.E.	29·167
E.	·155
E.S.E. and S.E.	·020
S.S.E. and S.	·084
S.S.W. and S.W.	·134

If the station at Cape Adare be assumed to be immersed successively in the southern extremities of the cyclones travelling easterly, then pressure should fall with winds from the N.E. to S.E. and rise when the wind veers to S. and S.W. That this actually occurs is shown in the above table, in spite of the fact that the observations are not very numerous and only cover less than a year.

The meteorological conditions noted at this station favour, then, the suggestion that a series of low depressions travel in higher latitude eastwards, their lowest portions only traversing the Cape Adare quarters.

Thus the Antarctic anticyclone seems to have had a greater extension north in those longitudes than in those occupied by the "Belgica" and this probably would help to further explain the predominating and strong south-east winds. A general summary of the wind features at Cape Adare is given by Mr. Bernacchi in an appendix (page 305) to the book entitled "First on the Antarctic Continent." *

As Mr. Bernacchi was in charge of the meteorological work, this account is of great value and may be quoted here:—

"The prevailing E.S.E. and S.E. winds at Cape Adare, which is within the area of abnormally low pressure, tend to prove the existence of a great anticyclone stretching over the polar area, which in its turn implies the existence of upper currents from the northward towards and in upon the polar regions to make good the drain caused by the surface outflowing S.E. winds."

"The frequency and force of these gales, and the persistency with which they blew—always from the same direction, E.S.E.—the invariably high rise in the temperature, and the sudden fall and rise of the barometer, the dryness of the winds—the relative humidity generally between 40° and 50°—and the motion of the upper clouds from the N.W., point to the fact that the South Pole is covered by what may be regarded practically as a great permanent anticyclone, more extensive in the winter months than in the summer."

* By C. E. Borchgrevink. George Newnes, Ltd., 1901.

BRITISH NATIONAL ANTARCTIC EXPEDITION.

1901–1904.*

In the observations made at the winter quarters of the "Discovery" at McMurdo Sound, Ross Island, latitude 77° 50′ 30″ S., longitude 166° 44′ 45″ E., a most valuable meteorological record will be found. The discussion of them was undertaken at the British Meteorological Office, under the direction of Dr. W. N. Shaw, and issued in a large volume, which was published by the Royal Society in 1908.

Dealing first with the directions of the wind, the fact which stood out above all others was the great frequency of the east wind. This will be seen from the following table, which gives the percentage of observations under each of the eight points, including calms:—

N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.	Calms.
8	15	34	12	5	1	—	2	23

Now, the predominance of the easterly component of the wind and the almost entire absence of the westerly component again show that the wind conditions are such as to make one believe that they are due to the passage of the southern extremities of cyclones passing over the station.

A further indication of the eastward movement of these cyclones is the statement made that (page 482): "A quickly falling barometer was frequently, but "not invariably, associated with relatively high temperature, and conversely an "increase of pressure commonly brought with it an increase of cold."

Thus the higher temperature would be produced by the air flowing from the ocean in the forward portion of the cyclone, while the lower temperature would be due to the flow of air in the rear part of it, reinforced most probably by the outflow from the Antarctic anticyclone.

It has previously been stated that, after the passage of a "low" and before the advent of the next following one, a short period of calm would probably occur. Thus the sequence of weather changes should be as follows:—

A calm, then N. to N.E. winds increasing in strength with rise of temperature and fall of barometer. The wind should then become more easterly, with temperature still rising and barometer falling. After this E.S.E. to S.E. winds should follow with rising barometer and temperature falling slightly. As the cyclone passes away the wind would diminish considerably in strength and low temperatures be recorded. The following extract from a summary referring to the changes of temperature and of the wind indicates that these conditions were experienced by the "Discovery's" party at winter quarters (page 505):—

"When the change of temperature coincided with the springing up of a wind after a calm, the temperature nearly always rose, and, indeed, the only exceptions to this rule occurred when the temperature change between the two observations amounted to less than ten degrees; in no case when the rise in

* National Antarctic Expedition, 1901–1904. Meteorology, Part I. Royal Society, 1908.

temperature exceeded that amount did it accompany a falling away of the wind force to a calm. On the other hand, the large and sudden decrease of temperature almost as generally coincided with the dying away of the wind force to calm."

Now, while the predominance of an easterly component of the wind at the "Discovery's" winter quarters conforms with expectations from the point of view of the scheme here suggested, the question has been raised as to whether this was not simply a local wind due to the configuration of the surrounding country. This subject is discussed fully in the volume containing the observations, and the result, as Dr. Shaw states in the preface, is as follows (page xii.):—

"It is curious that endeavours to reach, by two separate crucial tests, a definite conclusion upon this interesting point, as to whether the easterly wind at winter quarters is a local wind or a true general wind implying a high pressure to the south, fail through very slight omissions in the observations or the records."

This question of a "local" or "general" wind seems to be settled by the observations made by the recent British Antarctic Expedition, 1907–9, which took up its winter quarters not far from that of the "Discovery's" party. Reference to this is made in a subsequent part of this chapter (page 87), but it may be stated here that the "general" wind is considerably favoured.

GERMAN ANTARCTIC EXPEDITION.
1901–1903.*

On the 22nd of February 1902 the German Antarctic ship "Gauss" was frozen in the ice in latitude 66° 2′ S. and longitude 89° 38′ E., and it was not until February 8, 1903, that the ship was free to move again. During this time a valuable series of meteorological records was secured, and these, with the deductions therefrom, have recently been published in the volumes referred to below.

Before the issue of these volumes, Dr. Hans Gazert, the meteorologist to the expedition, published some preliminary statements, which are referred to at some length in the volume on "Meteorology" of the British Antarctic Expedition, 1901–1904. Many of these statements will be referred to in this section, and these, together with those given in the volumes before me, indicate, I think, with little doubt that this observing station was enveloped in the southern extremities of a series of low-pressure areas or cyclones which followed each other successively eastwards.

The first point to which attention should be called is Dr. Meinardus' statements relative to the non-periodic waves of pressure exhibited on the barograph records.

* Deutsche Südpolar-Expedition, 1901–1903. III. Band: Meteorologie I. Bände I. II. [Georg. Reimer, Berlin, 1909.]

In order to discuss the main features of these waves he eliminated those of a less magnitude than 5 mm. of amplitude. During the 362 days, from 20th February 1902 to 17th February 1903, he deduced that 71 pressure-waves were recorded, thus giving a mean duration for each wave of 5 days 2·4 hours.

The following values are taken from a table which he gives in his investigation (page 34) :—

Season.	No. of Waves.	Mean Duration of a Wave.		Mean Amplitude.
		d.	h.	
Autumn - - - - - -	12	7	11	17·4 mm.
Winter - - - - - -	21	4	14	18·3
Spring - - - - - -	21	4	9	15·9
Summer - - - - - -	17	4	23	13·7
Year - - - - - - -	71	5	2	16·3

It will be recalled that the duration of these pressure-waves is practically the same as that deduced from the observations of the "Belgica." There it was shown that, from March 1898 to March 1899, 70 oscillations of pressure occurred, the mean duration of each amounting to 5 days 6 hours.

Now, while these two observing stations, the "Gauss" and the "Belgica" were situated about 180° of longitude apart, the above results show very clearly that similar kinds of pressure-waves at both stations were experienced. This view is also put forward by Dr. Meinardus, for he writes (page 35) :—

"Dies darf wohl als Beweis dafür angesehen werden, dass die beiden, auf entgegengesetzten Seiten des Südpolgebiets gelegenen Ortlichkeiten, von gleichartigen atmosphärischen Storüngen beherrscht werden."

It is interesting to note that the mean pressure-amplitudes obtained by Meinardus for the "Gauss" and by Arctowski for the "Belgica" are closely in accord with those determined previously for this memoir, as will be seen below :—

Mean Pressure-Amplitudes (mm.).

	Meinardus.	Arctowski.	Lockyer.
"Gauss" -	16·3	—	17·0
"Belgica" -	—	16·0	16·0

There is, therefore, good ground for assuming that these pressure-waves are caused by a series of low-pressure areas sweeping past both these stations in an easterly direction.

Dealing now with the recorded directions of wind, the following table brings together the results in percentage (page 10) :—

E. by N.	E.	E. by S.	E.S.E.
23·7	18·3	10·6	6·5

In the case of any of the other wind directions the percentage was below 4.

These values show conclusively that the "Gauss" position was situated in a latitude which was considerably to the south of the centres of the depressions which swept these longitudes. Thus the approach of a depression would be heralded by the wind being north of east, at middle transit the wind would be east, while as it was passing away eastwards the wind would veer to the south of east.

The very small percentage of the other winds shows that the "Gauss" was situated very near the southern extremities of these depressions.

Unfortunately in this publication of the German expedition, while the different meteorological elements are discussed in detail separately, there are no statements made as regards the relationship between changes of pressure, temperature, and direction of wind.

It would be expected that the characteristics pertaining to the passage of the depressions would be, first, increase of temperature with falling barometer and increase of easterly (with northerly component) wind velocity and snow. After the centre of the depression had passed that longitude, then the temperature would begin to decrease, wind become south of east and reduced in velocity, and finally a calm with very low temperature and small wind velocity. It is fortunate, however, that such general statements are available, and these can be found in the volume containing the discussion of the meteorological observations of the British National Antarctic Expedition, 1901–1904 (Meteorology, Part 1).

Thus in describing the general behaviour of the weather during the passages of the depressions Dr. Gazert writes (page 430):—

"With a falling barometer and a wind springing up or freshening up from east, we noticed in that direction a bank of dark clouds, from which fragments were given off, which soon covered the whole sky. The sun disappeared . . . . The barometer fell slowly at first, then more rapidly, frequently with a sharp curve. Thus we observed, from the beginning to the climax of a gale, on the 30th July to the 1st August a fall of 35 millimetres (1·378 inches) in 52 hours, when the minimum reading . . . . was reached. The mercury fell almost as much in 30 hours on August 9th to 10th. . . . .

"As the storm progressed the wind increased more and more; driving snow filled the air . . . . The gale reached its climax occasionally in a few hours, but usually in from 24 to 48 hours, and remained at its height for 12 to 24 hours, being of a squally character . . . .

"It was at this stage, as a rule, that the air pressure reached its minimum. With a decreasing squally wind the barometer began to rise. A slow rise was a good sign, a quick rise a bad sign, as it usually meant an equally quick fall and another gale. With the decrease of the wind the driving snow lessened and we frequently could see the sun or stars faintly shining.

volumes containing some of the scientific results obtained,* and (2) Commander Hepworth's references to this expedition in the volume, Meteorology, Part I., containing the discussion of the British National Antarctic Expedition, 1901–1904.

Before dealing with the observations of the directions of the winds, attention may first be drawn to the question of the suitability of the station for recording accurate wind directions. The wind vane was set up on a staff on the roof of the winter quarters hut, this house being situated on a small hillock close to the sea shore. This observing station was located on the north extremity of Snow Hill Island, but on the western shore: this shore trended in a nearly N.E. and S.W. direction, and, while it was exposed to all winds from the S.W. through W. to the N.E., it was sheltered from all the other winds by high neighbouring hills.

With these preliminary remarks the following table shows the percentage frequency of the winds from the 16 points for the period March 1902 to November 1903:—

N.	N.N.E.	N.E.	E.N.E.	E.	E.S.E.	S.E.	S.S.E.	S.	S.S.W.
0·9	4·0	8·2	3·8	2·2	0·6	0·9	0·6	4·7	20·7

S.W.	W.S.W.	W.	W.N.W.	N.W.	N.N.W.
22·1	10·9	0·3	0·4	0·3	0·2

Calms, 16·6. Variable, 2·2.

The above figures show that the most predominant winds, as recorded at the station, were from the S.S.W., S.W., and W.S.W., amounting to about 54 per cent. in all, while the next most frequent winds were the N.N.E., N.E., and E.N.E., giving 16 per cent. The apparent absence of the N.W. wind is explained by Dr. Bodman in his discussion of the observations. He shows that, owing to the configuration of the coast and neighbouring hills, the N.W. wind is deflected along the coast and affects the wind vane as if the wind were blowing from the N.E. Observations on the spot showed that, while a N.W. wind was blowing at places in the open and free from local obstructions, the wind vane at the winter quarters station was indicating a N.E. wind.

Fortunately one has at one's disposal a means of checking this deduction, for during the months April to November in 1903 the wind directions were being observed at Paulet Island not very far off (latitude 63° 35′ S., longitude 55° 50′ W). The following table shows a summary of the wind directions reduced to 8 points and converted into percentages at that station:—

N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.
2·4	2·1	3·9	6·3	13·8	21·4	22·6	5·4

Calms, 21·9

* Wissenschaftliche Ergebnisse der Schwedischen Südpolar-Expedition, 1901–1903, unter Leitung von Dr. Otto Nordenskjöld, Band II., Lieferung 2. Meteorologische Ergebnisse der Schwedischen Südpolar-Expedition. I., Stündliche Beobachtungen bei Snow Hill, bearbeitet von Gösta Bodman (1908); II., Tägliche Beobachtungen an bord der "Antarctic" und auf der Paulet-Insel, bearbeitet von Gösta Bodman (1909).

A glance at this table shows the high percentage of the W. and N.W. winds, namely 28·0 per cent., and the low percentage of the N. and N.E. winds, namely 4·5 per cent. As before, the S.W. wind frequency is high.

Thus Dr. Bodman sums up the wind directions at the two stations as follows (page 13):—

"On Paulet Island we obtain consequently not the two kinds of winds S.W. and N.E. as at Snow Hill, but S.W. and as its counterpart N.W."

Since the N.E. wind at Snow Hill is to be considered as the deflection of the N.W. wind at that station, it is to be concluded that at both stations the prevailing winds were S.W. and N.W.

It has been shown in a previous part of this memoir (page 57) that the curves showing the changes of pressure from day to day suggest an approximate eastward movement of the pressure-waves when comparisons are made with the pressures at neighbouring stations.

Assuming, therefore, that these pressure-waves are due to a successive series of low-pressure areas travelling eastwards, then the prevailing winds at Snow Hill Island indicate that the mean track of the centres of those areas lies a little to the south of Snow Hill Island. Thus the fronts of these low-pressure areas will give rise to the N.W. winds and the rear portions to the S.W. winds. In the chart showing the path of this track round the South Pole (*see* Plate III.) the portion of the track about Snow Hill Island requires to be placed a little further south to meet the above conditions of winds.

With such systems transiting Snow Hill Island it would be expected that the N.W. wind, which has traversed a large ocean area, should be warm, while the S.W. wind, which flows from the Antarctic area, should have a comparatively low temperature.

While no mention is made, so far as I am aware, of the warmth of the N.W. winds—except the single statement that "Dr. Nordenskjöld mentions that a strong warm wind from north-west set in about the middle of March 1902 and lasted for a few days, and that it drove the ice from the land . . .—yet it is distinctly noted that the cold comes with the wind from the south. Thus Dr. Bodman writes (page 11): "with south winds comes the cold."

Again, Commander Hepworth, in referring to the results of the Snow Hill Island observations,* quotes the statements of Dr. Otto Nordenskjöld, spoken before the Royal Geographical Society on March 21, 1904, with reference to the severe storms and great cold the expedition was exposed to in far southern latitudes:—

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* National Antarctic Expedition, 1901–4. Meteorology, Part I., p. 427.

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N.	N.N.E.	N.E.	E.N.E.	E.	E.S.E.	S.E.	S.S.E.	S.	S.S.W.
0·9	4·0	8·2	3·8	2·2	0·6	0·9	0·6	4·7	20·7

S.W.	W.S.W.	W.	W.N.W.	N.W.	N.N.W.
22·1	10·9	0·3	0·4	0·3	0·2

Calms, 16·6. Variable, 2·2.

The above figures show that the most predominant winds, as recorded at the station, were from the S.S.W., S.W., and W.S.W., amounting to about 54 per cent. in all, while the next most frequent winds were the N.N.E., N.E., and E.N.E., giving 16 per cent. The apparent absence of the N.W. wind is explained by Dr. Bodman in his discussion of the observations. He shows that, owing to the configuration of the coast and neighbouring hills, the N.W. wind is deflected along the coast and affects the wind vane as if the wind were blowing from the N.E. Observations on the spot showed that, while a N.W. wind was blowing at places in the open and free from local obstructions, the wind vane at the winter quarters station was indicating a N.E. wind.

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N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.
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* National Antarctic Expedition, 1901–4. Meteorology, Part I., p. 427.

The words of Dr. Otto Nordenskjöld endorse further the view here put forward for a succession of low-pressure areas and the proximity of the Snow Hill Island to the centre of their tracks. Thus, to use the words quoted by Commander Hepworth:—

He commented on "the frequent occurrence and protracted duration of the storms" at Snow Hill, which sometimes attained a velocity of 70 to 90 miles an hour. "The average velocity of the wind," he continued, "for the 8 months (March to October) in 1902 was 31 feet per second, which is probably a record for so cold a climate."

The result of the Swedish expedition, so far as can be gathered from the information as yet published, conform to the view here put forward, namely that a series of low-pressure areas are travelling round the Antarctic anticyclone in an easterly direction, and that the mean position of the track of their centres in the longitude of Snow Hill Island is in about latitude 65°–70° S.

THE SCOTTISH NATIONAL ANTARCTIC EXPEDITION.

1902–1904.*

The observations made during this expedition are extremely important for the purposes of the present memoir, because they deal with the atmospheric conditions at three southern regions, namely, Cape Pembroke, latitude 51° 41′ S.; Laurie Island, South Orkneys, latitude 60° 44′ S.; and the Weddell Sea (approximate latitude of "Scotia"), latitude 66° 6′ S. These regions all lie between longitudes 29° W. and 58° W.

In the volume mentioned in the footnote the observations have been fully discussed, and they form a most valuable record of Antarctic meteorology, while the volume is a worthy monument to the Scottish expedition.

In the following brief summary the three regions will be dealt with in their order of latitude, commencing with the most northern station.

The observations at Cape Pembroke (latitude 51° 41′ S., longitude 57° 42′ W.) were made at the lighthouse, and exhibit the chief features of the meteorology for the years 1903 and 1904.

Dealing first with the wind observations, these show a predominating westerly component, as is displayed by the following table of percentages as given by Mr. Mossman, in his discussion of the observations (page 290):—

S.	S.W.	W.	N.W.	N.	N.E.	E.	S.E.
4·9	12·8	22·6	25·1	19·3	9·9	2·8	2·3

Now, if it be assumed, as is suggested in the present memoir, that in these southern latitudes there is a series of rapidly moving cyclones of large dimensions travelling approximately from west to east, then these wind percentages

* Report on the Scientific Results of the Voyage of the S.Y. "Scotia." Vol. II., Physics. Part I., Meteorology.

indicate clearly that this station lies well to the north of their centres as they pass by. The mean track of these centres was represented in Plate XII., and was indicated by the isanakatabar of 19 mm. in about latitude 60°. Thus the wind directions here recorded corroborate the position of this isanakatabar and further the view of the travelling cyclones.

Thus in these latitudes gales should be south-westerly and not south-easterly, and Mr. Mossman states (page 293):—

> "the most frequent gales are recorded from the south-west, while at no hour of observation during the two years was force 8 reached with winds from the S.S.E., S.E., or E.N.E."

Again, if a series of low depressions pass by from west to east, the barometric pressures should show a close connection with wind direction. Thus the directions of the wind at the front and at the rear of the cyclones should exhibit the highest pressure, while the lowest pressure should be recorded when the wind was west. The following table shows that this is actually the case, the N. wind representing the forward and the S. wind the behind side of the low-pressure systems, the wind backing through the west:—

	N.	N.W.	W.	S.W.	S.
Wind percentage - -	19·3	25·1	22·6	12·8	4·9
Mean pressure, inches 29 +	0·681	0·634	0·574	0·586	0·662

Another test for the existence of these large moving cyclones should be the changes of temperature with different wind directions. The clockwise motion of the air composing these systems, coupled with the cold indraught from the Antarctic anticyclone, *i.e.* from the south, and the warm indraught from the anticyclones in lower latitudes, *i.e.* from the north, should render the fronts of these systems warm and their rear portions cold. These views also receive corroboration, for Mr. Mossman writes (page 295):—

"On the mean for the year the warmest wind is N., with an average temperature of 43°·9 F. and the coldest S. with a mean of 40° F., the range being 3°·9." A portion of the table which he gives is as follows:—

N.	N.W.	W.	S.W.	S.
°	°	°	°	°
43·9	42·9	40·7	41·0	40·0

The comparatively small range between the cold and warm winds is due, no doubt, to the low southern latitude of Cape Pembroke, for the cold air from the Antarctic anticyclone had previously passed over a considerable stretch of ocean.

Thus in the case of the Cape Pembroke station, the meteorological data favour the view of easterly-moving cyclones, their centres travelling in a track lying well to the south of this station.

Coming now to the observations made at Laurie Island (latitude 60° 43′ 42″ S., longitude 44° 38′ 33″ W.) in the South Orkneys, these were taken during the year ending 31st March 1904, the station being the winter quarters of the "Scotia" in Scotia Bay during the seven months April to October 1903, and after that at the land station at Omond House, some 600 yards north-west of the "Scotia's" position.

Dealing first with percentage frequency of the winds for the twelve months April 1903–March 1904, here again is found a predominating westerly component, as the following figures in percentage frequency given by Mr. Mossman indicate (page 267):—

	N.	N.W.	W.	S.W.	S.	S.E.	E.	N.E.
Wind percentage -	10·9	36·1	11·1	12·5	9·1	9·5	2·1	2·7

These values show that even this station is not sufficiently far south to be on the southern side of the centres of the cyclones, for the easterly component has only a very small percentage frequency. This view is taken also by Mr. Mossman, for he says (page 266):—

"At no season of the year do the South Orkneys come within the influence of the east wind system which is so conspicuous a feature of the atmospheric circulation at Snow Hill* (latitude 64° 22′ S., longitude 57° W.); Wandel Island (latitude 65° 03′ S., longitude 63° 26′ W.), and at the winter quarters of the "Gauss" (latitude 66° 02′ S., longitude 89° 38′ E.)."

While the prevailing winds at Cape Pembroke and Laurie Island are closely alike, so also is the relation between the pressure and the wind direction: this is even shown by the record of only seven months available in 1903 (page 278):—

	N.E.	N.	N.W.	W.	S.W.	S.	S.E.	E.
Wind percentage	2·7	10·9	36·1	11·1	12·5	9·1	9·5	2·1
Pressure 29 + -	0·170	0·313	0·282	0·177	0·280	0·177	0·196	0·212

Thus when the northern part of the cyclone commences to transit the station the northerly component of the wind is associated with falling pressures, the west wind with low pressure, and the southerly components with increasing pressure.

Again the winds with the northern component, as in the case of those at Cape Pembroke, are warm winds, while those from the south are cold. Thus Mr. Mossman states (page 277):—

"The warmest winds are N.W. and N. and the coldest S. and S.E., there being a difference of 21°·7 F. between the warmest and coldest directions."

He further remarks:—

"It is of interest to note the great difference between the temperature of west and south-west winds. On the mean of seven months the south-west is 16°·5 F. colder than the west, while in June the difference was as much as 22°.2 F."

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* *See* discussion of Snow Hill observations in a previous paragraph. According to Dr. Bodman, the N.E. wind at Snow Hill was a deflected N.W. wind.

The following table shows the means for the seven months:—

	N.E.	N.	N.W.	W.	S.W.	S.	S.E.	E.
Temp. F.	22·4	24·8	26·9	23·9	7·4	5·2	5·6	8·1

Here again is seen the effect of the incoming cold air from the Antarctic anticyclone and that the warm air from the anticyclones which lie in more northern latitudes. The greater contrast here experienced is, no doubt, due to the fact that the cold southerly winds have passed over very little water surface to raise their temperature, while the warm northerly winds have lost little of their heat in passing over the ocean.

It will be seen that in Plate XII. the track of the cyclones was placed in about the same latitude as Laurie Island. The above discussion of the observations suggests that this track as represented by the maximum isanakatabar of 19 mm. should be situated a little further south in order that the station should lie to the north of the track of the cyclonic centres.

It may be concluded, therefore, that the weather experienced at Laurie Island conforms with the view of a succession of cyclones travelling from west to east, their northern portions transiting the above-mentioned station.

Coming now to the last set of observations, which have been discussed in the Scottish volume to which reference has been made, these relate to the summer cruises of the "Scotia" in the Weddell Sea. The approximate mean position of the ship for February 1903 and March 1903 and 1904 was 66° 6′ S., longitude 29° 28′ W. For these three months Mr. Mossman makes the following statement about the winds experienced (page 250):—

"With regard to the winds, the most frequent direction was N.E. with 16 per cent. of the whole, closely followed by N. with 15 per cent. Taking the combined observations it cannot be said that there was any marked excess of one direction over another; but an examination of the values for short periods will show very clearly that easterly winds prevail in the Weddell Sea, south of the Antarctic circle while north of 62°—64° the north westerly-system is entered."

This statement is of great importance, for it clearly shows that in the Weddell Sea the region is reached where the *centres* of the low depressions pursue their easterly course.

Combining this result with that deduced from the wind observations at Laurie Island, it may be concluded that in longitude 40° W. (about) the centres of the cyclones reach as far south as latitude 65° S. This extreme southern position of the cyclonic track receives considerable support from the observations made by the "Belgica" previously referred to (page 71), and shows that between longitudes 30° W. and 90° W. both the cyclonic and anticyclonic systems are considerably further south than in other longitudes. It is to be deduced from this, therefore, that the Antarctic anticylone is less extensive in these longitudes and consequently the centre of this system lies more in the longitude of 130° E. than at the South Pole itself.

Referring now to the other climatic features of the Weddell Sea, for the most part applying to a region south of latitude 60° S., these are discussed by Mr. Mossman and are for the short periods 2nd February to 26th March 1903, and for 23rd February to 31st March 1904.

Mr. Mossman sums up the broad features deduced from these observations, and they bear out the view of easterly-travelling low-pressure systems.

Thus he says (page 251) :—

"The characteristic features of *northerly* winds are a pressure a little in excess of the normal, with a high temperature and humidity, cloudy skies and a wind force of normal strength."

This is the condition for the fronts of cyclones, the northerly wind bringing the comparatively warm moist wind from a latitude further to the north.

"*Easterly* winds are strong, with a low barometric pressure, much cloud, and the humidity in excess of the normal" (page 252).

With the centre of the depression passing just north of the locality these conditions are fulfilled. He makes no mention of temperature, but it should not be low.

"*Southerly* winds have a high pressure, and are light in force, have a very low temperature and humidity, and are accompanied by a relatively small amount of cloud" (page 252).

These conditions should be expected to occur when low depressions are leaving the locality in an easterly direction. The low temperature is due to the cold air from the Antarctic anticyclone entering and circulating in the wind system of the cyclone.

"*Westerly* winds have a pressure and temperature approximating to the average, with a low humidity, cloud less than the average, and wind force also in close agreement with the normal" (page 252).

All the above conditions, with the exception of average pressure, are fulfilled when the centre of the depression passes a little to the south of the observing position. In this case the pressure should be low. It is quite possible that, had the ship been moving more in the westerly than in the easterly wind system,—or in other words been situated to the north and not so much to the south of the centres of the low-pressure systems—westerly winds would have been associated with "low" and not with "average" pressure.

Summing up then the "Scotia's" meteorological records, they endorse the view of easterly-moving cyclones. They suggest, however, that the centres of those systems move in slightly higher southern latitudes (latitude 65° S. about) than is indicated in the isanakatabar chart (Plate XII.), which represented the track as lying in about latitude 60° S.

BRITISH ANTARCTIC EXPEDITION.

1907–1909.

While the meteorological observations made on this expedition at winter quarters have not yet been discussed in detail, some account of the general weather conditions experienced can be gathered from statements which have already been published. Thus in Sir E. H. Shackleton's book on "The Heart of the Antarctic" an appendix (No. V.) is given, in which Professor Edgeworth David, F.R.S., and Lieutenant Adams, R.N.R., summarize briefly the meteorological results generally.

The winter quarters of this expedition was situated at Cape Royds, latitude 77° 32′ S., longitude 166° 12′ E., in McMurdo Sound. This station, like that of the "Discovery's" at Hut Point, lay at the foot of Mount Erebus, and they were distant from one another by about 20 miles. In relation to Mount Erebus, Cape Royds lay nearly due west, while Hut Point was nearly due south, slightly inclined to the westward. Thus from a wind point of view the "Nimrod's" winter quarters party was apparently protected from the east and the "Discovery's" party from the north, both by Mount Erebus. These details are mentioned to show that, while both stations are fairly close to one another, they are differently exposed to winds.

It will be remembered that in the preceding discussion of the winds at the "Discovery's" winter quarters the winds were chiefly easterly, the larger percentage of winds being as follows:—

N. 8: N.E. 15: E. 34: S.E. 12: S. 5: Calms 23. Now the surface winds at Cape Royds are described (page 378) as:—

"Either gentle northerly winds whose speed seldom exceeded twelve miles an hour, or gentle winds from the south-south-east or south-east. If these latter winds became strongly developed they passed into a definite blizzard. One of the rarest winds at Cape Royds was a north-westerly."

This result agrees well with that obtained at the "Discovery's" winter quarters, with the exception of the high percentage of east winds at that station. Since, however, Cape Royds was shielded by Mount Erebus on the eastern side, while Hut Point was exposed on that side, it seems quite possible that the high frequency of the S.E. winds at Cape Royds might be the result of the deflection of the easterly winds due to Mount Erebus.

There is, therefore, reason to believe that the record obtained at the "Discovery's" winter quarters indicated a "general" and not "local" wind, and the recent expedition's record practically demonstrates that in these latitudes and longitudes the most frequent winds are contained in the quadrant N.E. through E. to S.E.

These facts are then in conformity with the assumption that the southern extremities of low-pressure areas pass over the stations, and the absence of westerly winds proves that the centres of these systems always lie to the northward of these stations.

With regard to wind and temperature it is stated (page 377): "The tempera-
"ture of the atmosphere invariably increased considerably from the beginning of
"a blizzard towards its end. This rise was very marked, for, whereas the initial
"temperature of a blizzard would be perhaps minus 30° F., at the end of a
"blizzard, after a lapse of possibly twenty-four to thirty hours, the temperature
"would have risen to plus 12° or plus 15° F.

This experience is in agreement with that of most of the other expeditions to which reference has been made, and convinces one that the air movements in those storms is only part of a series of very large systems travelling eastward.

Thus the rise of temperature, as before stated, is due to the air having previously passed over a large extent of ocean to the northward and probably been reinforced by the warmer air flowing out of the southern and western sides of the anticyclones moving in lower latitudes.

It is important here to draw attention to the direction of the prevailing winds as recorded in very high southern latitudes.

According to the scheme of air circulation suggested in this memoir they should be strong southerly to south-south-easterly, varying slightly according to the positions of the cyclones immediately to the north: the higher the latitude the more southerly should the wind become. That the prevailing winds are south-south-easterly to southerly was found by the party that attempted to reach the South Pole; indeed, it was a head wind that prevented them from reaching the Pole and it was the same wind that rendered their return to the winter quarters possible.

At the farthest point south attained by them, latitude 88° 23′, the sastrugi were large and high and trended from south-south-east to north-north-west. These snow furrows presented an excellent indication of the direction of the prevailing wind, and were visible proofs of its extreme constancy of direction.

GENERAL SUMMARY.

The discussion of the meteorological observations made by the various Antarctic expeditions and the general deductions made from them lead one to conclude that the assumption of a series of easterly-moving low-pressure area receives a considerable support. The observations made by the "Belgica" and "Scotia," and more especially the former, have shown that the low-pressure areas move in much higher southern latitudes than was indicated by the isanakatabar chart. This result is of considerable importance, because the only large anomaly that was found with regard to the movements of the anti-cyclones in much lower latitudes is shown to have its echo in the movements of the southern cyclones in about the same longitudes. Thus the southing of the anticyclones as they approach the west coast of South America corresponds to a southing of the southern cyclones.

The high southern latitude of the cyclones in those western longitudes and their positions in lower latitudes in other longitudes suggest that the Antarctic anticyclone may not have the South Pole at its centre. In fact, the observations seem to indicate that very possibly more than half of the area which the anticyclone covers may be situated in eastern longitudes and the "Gauss" observations considerably favour this view.

CHAPTER X.

FURTHER REMARKS ON THE SUGGESTED SCHEME OF SURFACE-AIR CIRCULATION.

The examination of the Antarctic records made in the previous chapter has endorsed the scheme of surface air circulation, brought forward in this memoir, in a very satisfactory manner. It has nevertheless suggested that the most probable track of the cyclones is not quite in accordance with that deduced from the study of the pressure-amplitudes and shown as the isanakatabar of 19 mm. in Plate III. The observations of the "Belgica" and "Scotia" pointed so decidedly to a more southern position of the track of these low-pressure systems in about longitudes 50° to 90° W. that it was considered desirable to modify this plate.

A new chart was, therefore, prepared and the isanakatabars were slightly altered to meet the new requirements. The changes inserted are confined mainly to the positions of the isanakatabars from 16 mm. in latitude 50° S. to the South Pole. It must be clearly understood that the new positions of these lines are made to accord as far as possible both with the Antarctic deductions of the foregoing chapter and the pressure-amplitudes previously determined. It will be seen, therefore, that in some instances the amplitudes are not in quite a satisfactory accord with the isanakatabars.

This new chart is given in Plate XIII. The chief points to be noted in it are, first the southern trend of the 19-mm. line in about longitude 120°–90° W. and second its northward trend to longitude 60° W. In consequence of this new position the isanakatabar of 16 mm. to the north has been brought down a little to a more southern latitude, but yet kept sufficiently near the continent of South America to satisfy the amplitudes of the three stations situated in that region.

The 16-mm. isanakatabar to the south of the 19-mm. line, which previously was made to follow the contour of the ice barrier in western longitudes, has here been placed further inland. Thus it will be seen that the Antarctic anticyclone which lies south of the 16-mm. line is now situated more in the eastern hemisphere than it was before. Comparing this chart now with that given on Plate III., it will be noticed that all the isanakatabars in the longitude of South America are in better accord with one another than was the case before.

Using as a groundwork the modified positions of the isanakatabars, and drawing as before an hypothetical synchronous system of isobars showing the series of cyclones and anticyclones in their respective belts of latitude, one can now obtain a clearer idea of the transference of air between the Equator and the South Pole. This will perhaps be more easily understood if reference be made to the accompanying coloured chart forming the frontispiece (Plate XIV.).

The large broken-line circle, as before, represents the track of the centre of the anticyclones and the smaller one that of the centre of the cyclones, the large arrows indicating their direction of movement.

The blue tints, becoming lighter polewards, indicate the reduction of the temperature of the warm surface-air currents as higher southern latitudes are reached, while the red tints fading out towards the Equator illustrate the cold polar surface currents becoming less cold as they reach lower latitudes.

In the discussion of the Antarctic records it was pointed out that the northerly and north-easterly winds brought warmer air into the Antarctic regions, while the southerly winds were associated with very low temperatures. In the chart it will be seen that the outflow of the cold air from the centre of the Antarctic continent passes into the *western* portions of the cyclones and is transferred into lower latitudes, eventually reaching the circulation in the eastern sides of the anticyclones. Such a transference of air from the Pole to the equatorial regions occurs at the passage of every low-pressure system, and, as several of such systems are in existence at any one moment, the total outflow in all longitudes must be considerable.

On the other hand the warm air in the circulation of the western portions of the anticyclones, which is reinforced by air from more equatorial regions, is transferred into the eastern parts of the cyclones to the south, and this air is carried down into the Antarctic regions, where it is eventually chilled.

A fact worthy of record may be referred to here. During a conversation with Commander Hepworth, at the British Meteorological Office, relating to the suggested explanation of the warm and cold winds at the Antarctic stations described above, he pointed out to me that he had prepared, though not published, a chart somewhat similar to that given here. In his chart he had placed a low depression just to the north of each of the stations occupied by the "Gauss," "Discovery" party, and the "Belgica," and had painted the eastern sides of the "lows" red to indicate warm air currents approaching the Antarctic continent, and the western sides blue to show cold air currents leaving that continent. The intermediate spaces between these lows he had left blank, but if, as I suggested, these spaces were filled up by depressions of about the same magnitude, it would require four more low-pressure areas to complete the series. In my chart eight such "lows" are represented, so that there is not a very great difference between the two suggested series of depressions. It is thus important for the purpose of the present memoir to have the positions of the low depressions here suggested as encircling the region about to South Pole corroborated in three well-separated longitudes by so high an authority.

This apparently systematic interchange of air between the equatorial and polar regions draws one to the consideration of what are the fundamental currents involved in the atmospheric circulation. Thus one is led to inquire whether the series of large air swirls, the anticyclones and cyclones, are really in the main made up of descending and ascending spiral air movements respectively and of fundamental or primary importance, or whether they are simply large eddies, set up by the warm and cool air currents moving polewards and equatorwards respectively, and thus of secondary consideration.

This subject has recently been considered in much detail, in an important publication written by Dr. Shaw and Mr. Lempfert.*

This investigation, as the authors state (page 25), "throws some light upon the " question from which the investigation started, viz., the relation of surface-air " currents to cyclonic depressions and anticyclonic areas."

They state the present generally accepted views in the following concise words (page 25):—

"It is sometimes supposed, and indeed it may be said without injustice, that the commonly accepted view with regard to surface-air currents is that they represent the passage of air from anticyclonic areas, where they are supposed to originate, to cyclonic depressions, where they become ascending currents. It is a natural consequence of this view that the currents should be regarded as due to the difference of pressure between the anticyclone from which they proceed and the cyclonic area towards which they tend. The energy of their motion should, therefore, be regarded as representing the exhaustion of the potential energy of the pressure difference, which must be supposed to have originated in some manner, although at present we do not understand precisely how it is produced or maintained."

With these views before one it is important to summarize the conclusions to which these authors have arrived in their inquiry. The main result is that the (page 26) "surface-air currents belong rather to the type of circular motion " controlled in direction by pressure difference than to the type of motion " derived from the exhaustion of the potential energy of pressure difference."

According to them well-marked anticyclonic areas are not conspicuous as the sources of surface-air currents, but are looked upon as "inert and " comparatively isolated masses of air, taking little part in the circulation that " goes on around them." Thus they are led to state that (page 26) "the moving " currents may be regarded as maintaining the anticyclone quite as truly as " being maintained by it."

Again, with regard to cyclonic depressions, they consider that the relation of moving air to these systems "is much less close than the idea of surface " currents, as air in direct transit from anticyclone to cyclone would lead us to " suppose." They are led to the conclusion therefore that "the flowing air " current is, on the whole, a more stable and persistent feature than the " depression."

* The Life-History of Surface-Air Currents: a study of the surface trajectories of moving air. M.O. 174. Wyman and Sons, London, 1906.

The view, therefore, expressed in the above researches is that the anticyclones and cyclones play quite a secondary *rôle*, while the air moving on their fringes forms the main currents in the surface-air circulation.

In considering the earth's atmosphere as a whole it is well to bear in mind the main origin of the circulation, namely the interchange of cold for warm air between the Poles and the Equator respectively. In the simplest of cases, the warmer air of the equatorial regions would rise and travel polewards, while the cold air from the poles would move equatorwards over the earth's surface to replace it. In this, the simplest case, the cold surface air would move equatorwards in one sheet and the warm upper returning air polewards in another sheet.

Now, instead of a homogeneous sheet of cold air moving towards the equator in the Southern Hemisphere, observations indicate that this sheet is broken up into streams: it is only natural, therefore, that between these cold streams there should be warm streams moving towards the Pole. There should thus be formed a series of "eddies," each "eddy" being made up of half warm and half cold air, and the direction of rotation of the "eddy" would be with the hands of a watch in the Southern Hemisphere. There should, therefore, be as many "eddies" as there are cold streams issuing from the Artarctic region. Observations seem to suggest that at any one moment there are seven or eight of such streams issuing from the Antarctic regions.

It must be remembered, further, that the issuing cold air streams move from latitudes of low velocity into latitudes of higher velocity: these streams should therefore gradually lag behind in longitude as they travel towards the Equator: thus they should drift more *towards* the west the lower the latitude. On the other hand the warm return surface-streams move from a region of high to a region of low velocity: their tendency should therefore be to move more towards the east. In mid-latitudes, therefore, another series of eddies should be formed of larger dimensions but less violent in action, than those just mentioned, and these should have a rotation in the opposite direction to the hands of a clock.

While in the case of the first-named eddies, their eastern sides will be relatively warm and their western sides cold, in the case of the lower latitudes air swirls their eastern sides will be cold and their western sides relatively warm.

It is important to point out here that the direction of rotation of the higher latitude eddies suggests a cyclonic movement and that of the lower latitude eddies an anticyclonic movement.

As it has been shown in this memoir that the anticyclonic and cyclonic systems have an easterly movement of approximately 10° a day, then to satisfy this condition the cold and warm air streams must be moving with this velocity round the South Pole like spokes in a revolving wheel.

Up to this point the suggestion that the anticyclonic and cyclonic swirls may be considered as eddies formed by the main currents of air flowing towards and away from the Equator meets with no great opposition. It is, however, when one tries to find an explanation for the origin of the low-pressure belt, the centre of which is situated about latitude 60° S., that a great difficulty may be met with.

If one again takes the simplest case of air circulation, it should be expected that the lowest mean pressure would be found nearest the Equator and the highest at the Pole: in the intermediate latitudes a gradual rise of pressure should take place from the Equator to the Pole. Now, the actual mean pressure curve for all latitudes in the southern hemisphere shows a steady rise up to about latitude 34° S. (*see* curve 2, Plate XI.), but then a rapid descent to about latitude 60°–70° takes place, after which an increase of pressure is indicated towards higher latitudes. It will be remembered that the centre of the tracks of the anticyclones is situated in latitude 34° S., while that of the cyclones lay in latitude 60°–70° S.

If, therefore, the anticyclonic and cyclonic systems are to be considered simply as eddies* set up by the in- and out-flowing warm and cold air streams respectively in the neighbourhood of the Pole, what then is the origin of the belt of extreme low pressure the centre of which is situated inlatitude 60°–70° S.? Is it explained by assuming that the greater part of the warm air surface current from the Equator ascends into the upper atmosphere? This seems very probable.

In this memoir it is not intended to pursue further inquiries into this subject. The whole question of terrestrial atmospheric circulation is so large and important, and has been considered by so many able investigators, that the matter cannot be dealt with either briefly or even superficially.

It is hoped that the deductions brought forward in these pages may form new material for consideration, and help, even if only in a small way, to advance our knowledge of this fascinating problem.

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* *Report on the International Cloud Observations*—May 1896 to July 1897. Report of the Chief of the Weather Bureau, 1898–99, Vol. II., p. 447. Washington 1900. F. H. Bigelow.

In this Volume, Professor Bigelow is led to adopt the same view in the case of the Northern Hemisphere. Thus he writes :—

"We are also led to the remark that the apparent anticyclonic movement at the ground has its source, to a large extent, in these northern and southern currents flowing past each other, the circular adjustment being natural in such fluid motions, ..."

Again, *Popular Science Monthly*, May 1910, page 448, Professor Bigelow writes :—

"The actual cyclone is warm on the one side and cold on the other side of the centre, and likewise the anticyclone is cold on one side of it and warm on the other side of it. The northerly cold current, therefore, has a cyclone on the east side of it, and an anticyclonic centre on the west side of it, while the southerly warm current has an anticyclonic centre on the east side of it, and a cyclonic centre on the west side of it. These differences are also fundamental."

CHAPTER XI.

TRAVELLING ANTICYCLONES AND CYCLONES AND THE INTERPRETATION OF MEAN SEASONAL ISOBARIC CHARTS.

An attempt has been made in this memoir to show that between about latitudes 20° to 40° S. there occurs a series of anticyclones following one another in succession, and that these pass over the continents and oceans in an approximately easterly direction, forming, dissipating, and reforming during their passage.

To the south of this another series of air systems is moving, also in an easterly direction: these systems are of the cyclonic type, and the belt in which they are contained extends from about latitude 40° S. to about latitude 70° S.

These two belts of atmospheric swirls have a seasonal movement in latitude, being in higher latitudes in summer than in winter.

In a previous memoir* I have indicated that, while the mean position of the belt in which the anticyclones move does not vary very much from one year to another, yet there is distinct evidence to show that the anticyclones alter their condition, and are individually of much greater intensity in high- than in low-pressure years. Thus the breadth of the belt is larger in some years than in others, and it was found that the north and south fringes of this belt indicated a cyclical variation of position as regards latitude, the cycle repeating itself about every four years.

During the progress of movement of an anticyclone its condition will depend on the temperature of the surface over which it moves, other things being equal. Thus, if an anticyclone passes over an area which is colder than that just previously transited, the cooling capacity of this area will tend to lower the temperature of the surface air in the anticyclone, and so make the anticyclone *more* anticyclonic.

On the other hand, if an anticyclone moves over an area which is warmer than that previously passed over, the heating tendency of the area will initiate air currents upwards, which will render the anticyclone *less* anticyclonic. Thus the *intensity* of an anticyclone will be increased or decreased according as it passes over cooler or warmer surfaces on the earth, and if a succession of travelling anticyclones be in question, then the greater the intensities over any area the greater the mean pressures at stations in that area.

To take an example in the case of Australia. During the summer season on this continent the land will be much warmer than it is during the winter time. It should be expected, therefore, that the anticyclones which pass over this surface

* A discussion of Australian Meteorology. 1909. p. 20.

should be recorded as being more intense or larger in winter than in summer. What actually occurs can be gathered from the very definite statement by Mr. H. A. Hunt in his description of types of Australian anticyclones,* who writes: —

"During the winter months the anticyclones are much larger than they are in summer, and their latitude about 30° S. Very commonly their area is equal to Australia, and their control of the weather more complete than it is in summer."

Again, in referring to years which are conspicuous by having the mean barometric pressure very much above normal, I have stated elsewhere† :—

"One may conclude, then, that such years as 1877, 1881, 1885, 1888, and 1891, which were years of very excessive pressure, were caused by the anticyclones having altered their *normal condition*, and become on the average *very much larger*."

In the case of low-pressure years I stated‡ :—

"It will be found that such large anticyclonic systems, as have been referred to above, are more the exception than the rule . . ."

With this definite view regarding the seasonal change and variation from year to year in intensity of the Australian anticyclones as they transit that country, it seems a fair assumption to make, failing any published statements, that similar changes occur as the anticyclones pass over or near the other two southern continents, namely, South America and South Africa.

Now, in the belt of latitude in which the anticyclones move, namely, about 20°–40° S., the ratio of land to ocean area is approximately 1 to 5. Again, the specific heat of water in relation to soil and rocks is as 4 to 1 according to Buchan.§

From the above it can be gathered, therefore, that the surfaces over which the anticyclones move are in the first place chiefly ocean and in the second place subject chiefly to only small and slow changes of temperature.

According to Buchan (page 108) the mean temperatures of the oceans south of the Equator are as follows:—

	° F.
South Atlantic - - - - -	66·7
South Pacific - - - - -	67·7
Indian Ocean - - - - -	69·3

and, if the tropics and northern oceans be included, the temperature of the sea in a few cases only is greater than 85° F. (page 89).

* Three Essays on Australian Weather. Hon. Ralph Abercromby. 1896. p. 96.

† A discussion of Australian Meteorology, p. 20.

‡ Idem., p. 20.

§ Handy Book of Meteorology, p. 86 (2nd edition).

In the case of the land very much higher temperatures are reached. Thus the surface temperature of sandy deserts in the tropics rises to 120°, 140°, and, more rarely, to 200° F., while the temperature of the air is known to have risen to 120° F. in the shade.

It is not, therefore, an unreasonable assumption to make, with regard to the belt of latitude under consideration, namely, 20°–40° S. latitude, that during the summer months the land areas are at a very much higher temperature than the intervening oceans, while during the winter months they approximate nearly to that of the oceans, being possibly a little cooler.

A study of mean isothermic charts for the Southern Hemisphere for the two seasons of the year, as represented by January (summer) and July (winter), corroborate in the main these conclusions.

Such charts are here reproduced in Plate XV. and are taken from Hann's "Lehrbuch der Meteorologie" (2nd edition).

Only the portions of the two charts placed above the horizontal dotted lines and marked 1 and 3 need here be referred to.

No. 1 shows the July isotherms. If attention be concentrated on the belt of latitude lying between latitudes 20° and 40° S., it will be seen that the isotherms dip slightly northward or equatorwards in the regions of the land areas. This shows that during the winter the mean temperature of the air over the land areas is a little colder than that over the oceans in the same latitudes.

No. 3 illustrates the January or summer isotherms: at this period of the year the land is very much hotter than the oceans on each side of it in the same latitudes. It will be seen that this is indicated by the deviation southward of the isotherms over all the three southern continents.

Attention may be here called to the form of the isotherms over Australia: this continent, in the belt under discussion, is spread most in longitude and is, therefore, most suitable for observing the greatest effect of heated land surface.

It is interesting also to notice the effect of the Andes in South America. Since the air systems approach from the westward, this range of mountains shields the land surface on its eastern side and allows this heated land to warm the air over it to a greater extent than would be the case if the mountain range were absent.

It has already been stated in the case of Australia, and this should apply to any other continent, that when travelling anticyclones are larger or more intense than usual the mean pressures at places passed over by them are higher than usual.

Thus the mean pressures at stations lying in the track of the anticyclones are criteria for the intensity of these air systems. If, therefore, over any belt of latitude anticyclones are always of greater intensity in one part of it than in any other, then that region will be indicated on a mean isobaric chart of the whole belt by an area of higher pressure than that of the remaining portion.

On the other hand a part of the belt in which for some reason or other the intensities of the anticyclones are very much reduced would be indicated on a mean isobaric chart of the belt by a region of low mean pressure.

Such being the case, one can apply this principle to the belt of latitude between 20° and 40° S., in which it has been shown in this memoir that anticyclones are continually moving eastward in rapid succession. The winter or July season will first be considered.

During this season the isotherms (*see* Plate XV., No. 1) make only slight bends to the northward, showing that the temperatures of the air over the land areas are not very different from those of the neighbouring oceans in the same latitudes. The travelling anticyclones in their circuit round the earth in this belt may be considered, therefore, as passing over a nearly homogeneously heated surface; thus varying surface-air temperatures, as a source of altering their intensities, are practically eliminated.

It should be expected, therefore, that an accurate mean isobaric chart for this season would show as a conspicuous feature a belt of nearly continuous high pressure encircling the globe, covering the land as well as the ocean areas.

Turning now to the summer or January season of the year (*see* Plate XV., No. 3), the isotherms show a very marked change in the neighbourhood of all the southern continents: during this period the land is very much hotter than the oceans in the same latitude. The anticyclones in their eastward movement have, therefore, to pass over alternately small highly heated areas and long stretches of ocean at a much lower and more even temperature.

As they approach and pass over the continents, they should become very much reduced in intensity, that is, become less anticyclonic. After the land transits are completed the cooler oceans should make them gradually more intense or more anticyclonic, and their intensities should continually increase until a maximum stage of development is reached, which should be in the ocean lying near to the west shore of the next land area.

Thus the loci of regions of highest pressure, *i.e.* where the anticyclones are most intense, should be situated on the oceans nearer to the west than the east coasts of the continents, while those of lowest pressure should be restricted to the land areas.

Thus a mean isobaric chart of the belt in which the anticyclones move should, for this season of the year, be conspicuous by exhibiting areas of high pressure off the west coasts of the three continents and regions of lowest pressure on the continents themselves.

The above suggested behaviour of the anticyclones at those two seasons of the year indicate that mean isobaric maps for each season should differ very considerably from one another.

It is well to bear in mind that in the belt in which the anticyclones move the intervening oceans are not of the same length and the continents present different areas.

Thus the South Pacific Ocean extends in the belt for about 140°, and since the temperature of this ocean varies little, if any, from one season to another, the anticyclones, when they reach the east side of this ocean, will display to the best extent, the maximum ocean effect on them, which will probably be the same for both seasons.

Again, the continent of Australia presents the largest land surface in the track of the anticyclones to be passed over, and therefore offers the most favourable condition to watch the greatest effect of a heated land surface on the anticyclones.

Over that continent, therefore, during the summer months, the regions of low pressure throughout the whole extent of the belt should have the lowest pressure area of all in the longitude of that continent.

Again, it must not be forgotten that the easterly movements of the cyclones to the south of the anticyclonic belt cause the cold Antarctic waters to have an easterly drift. These waters, tending naturally to flow towards the Equator, meet the *west* coasts of all the three southern continents and so give rise to the well known cold currents which flow along those coasts.

On the other hand warm return currents are found hugging the *eastern* shores of these continents eventually, being absorbed in higher latitudes.

Thus these sets of cold and warm ocean currents present further irregularities in the temperatures of the surfaces passed over by the anticyclones. They, therefore, afford an additional argument for expecting the regions of high pressure in the anticyclonic belt to be on the average nearer the west than the east coasts.

If, now, in the light of all the above remarks, an examination be made of mean isobaric charts of the Southern Hemisphere for the two seasons of the year, it will be found that the forms of the isobars approximate closely to the expectations previously stated.

These charts are illustrated in Plate XV., and No. 2 represents the July (winter) conditions, and No. 4 the January (summer) conditions. They are taken from Hann's "Lehrbuch der Meteorologie" (2nd edition).

Considering No. 2 first, here is exhibited a belt of high pressure between latitudes 10° and 40° S., almost continuous except for a break in the Western Pacific. In No. 4, on the other hand, the belt is no longer continuous but broken up into regions of maxima and minima: the former are situated closer to the west than the east coasts of the continents, while the latter are situated over the land areas.

Those charts can now be compared with the isothermic charts for the same months placed immediately above them. Thus it will be seen that the heated continents, in the summer time, break up the pressure belt into several maxima, while during the winter months this source of local disturbance is practically absent, and the belt is thus nearly continuous.

These isobaric charts thus endorse the views expressed above by exhibiting regions of highest pressure where it was expected that the anticyclones in their eastward movement would have their greatest intensity.

The conclusion to be drawn, therefore, is that *the regions of high pressure on mean isobaric charts are the loci of regions where the travelling anticyclones are most intense.*

It is not without interest to mention here the interpretation generally placed on these mean isobaric charts. The constancy of position of the three high-pressure areas in the summer months, and their apparent increase in size during the winter months, has led many to believe that these areas of high pressure are really permanent anticyclonic systems fixed in positions on the oceans varying in position and intensity slightly from one season to another.

It is the presence of these high-pressure areas on the oceans that has led most probably to the disbelief in the travelling over the oceans of the anticyclones which are known to pass over the land. These areas of high pressure have been looked upon as barriers through which these systems could not pass.

Indeed so strong has been and still is the belief in the reality of these regions of high pressure as being permanent anticyclonic systems that the known land anticyclones and cyclones are regarded as secondaries or offshoots from these the main systems.

A similar view has also been held with regard to the regions of high pressure in the Northern Hemisphere, especially in the case of that area situated in the North Atlantic. An investigation has recently been completed to find out whether the anticyclones, which traverse North America, cross the Atlantic Ocean and reach Europe. The author of this paper,* Colonel H. E. Rawson, C.B., is inclined, however, to give an individual anticyclone too long a life. In this memoir, it has been pointed out that, in the favourable conditions such as exist in the Southern Hemisphere, the anticyclones are continually being formed, changed, and dissipated, and that the life of a few days, five or six, is an exceptionally long one. In the Northern Hemisphere, where land areas predominate and where surface changes of temperature undergo more rapid variations, the anticyclonic systems cannot be so stable.

In spite however of this, Colonel Rawson has found that some of them travel across the Atlantic, for he says:—"It is very rare for an individual system, which "has traversed the American continent, to cross the ocean from land to land. The "few cases which occur are restricted to the months of October to February."

* The North Atlantic Anticyclone: Tracks of the Centres of High Areas. 1882–3. Quarterly Journal, Roy. Met. Soc., 1910.

A study of the mean seasonal isobaric charts of the Northern Hemisphere shows that, in about latitude 40°, the anticyclonic belt behaves, as regards regions of high and low pressure, just like the Southern one, the differences being due simply to the different relative amounts of land and ocean passed over.

During the northern winter the conditions are most favourable for the transits of the anticyclones from the North Atlantic Ocean to occur, and it is at this season that Colonel Rawson has recorded their passage across as stated above.

The northern high-pressure belt is nearly continuous during winter and is broken up in summer: in the latter season the areas of highest pressure are situated over the oceans, nearer the western than the eastern coasts of tbe continent. This behaviour of the belts is in exact accordance with the high-pressure belt of the Southern Hemisphere.

Thus one is led to the view that this pressure belt is the track of a succession of anticyclones, and that the high and low pressure areas are really the loci where the anticyclones are increased or decreased in intensity respectively in their eastward journey, as has been suggested to be the case in the Southern Hemisphere.

CHAPTER XII.

GENERAL CONCLUSIONS.

Note.

It was mentioned in the Introduction that the object of the investigation included in this memoir was to make a study of the mechanism of the atmospheric circulation in the Southern Hemisphere in order, if possible, to find out what were the primary factors in operation. This was done because it was desired to know what terrestrial meteorological factors in this circulation would be most likely to be primarily affected by any changes in the heat given out by the Sun, a body which is known to be undergoing variations of activity of considerable magnitude.

In the preceding chapters it has been shown that the general circulation of the Southern Hemisphere surface air is made up of a belt of rapidly moving anticyclones and to the south of this another belt of moving cyclones, both series moving from west to east, and in the South Polar area a permanent anticyclone is installed there. The question was raised as to whether these systems were of primary importance, or whether they were only of secondary consideration, or mere "eddies" set up by the main streams of warm and cold surface air-currents flowing from Equator to Pole and from Pole to Equator. The latter view seems to be the more natural one to hold, and it is strongly advocated by Dr. Shaw and Mr. Lempfert, and also by Professor Bigelow for the Northern Hemisphere, so there seems to be ground for directing special attention to the polar and equatorial regions for the first effect on the earth's atmosphere of any solar changes.

This conclusion seems to be the most general one that is arrived at after the discussion of the material employed in this memoir.

In the following paragraphs are summarized the conclusions which have been drawn from the various discussions of data dealt with in the preceding chapters. It should be remarked that the terms "anticyclones" and "cyclones" may be either considered to apply to the usual definitions of these air systems, or they may be looked upon as "anti-clockwise" or "clockwise" eddies respectively.

CONCLUSIONS.

1. Lines of equal-pressure amplitude, or isanakatabars, are (approximately) small circles with the South Pole as centre.

2. The regions where the small circle directions are conspicuously departed from are situated in South America and South Africa where high land exists.

3. The pressure amplitudes increase in value from a minimum near the Equator, rise to a maximum in about latitude 60° S., and decrease to the South Pole.

4. The increase in amplitude from the Equator to about latitude 34° S. is due to the approach towards the belt in which the anticyclones move: the further increase up to 60° S. is due to the proximity to the centre of the cyclonic belt, and the decrease is caused by the increased distance from the centre of this cyclonic belt.

5. The paths of the isanakatabars over the land surfaces correspond to the directions of movement eastward of the anticyclones over these lands.*

6. The mean daily rate of movement of the anticyclones in the region of South Africa is about 12° in longitude.

7. The mean daily rate of movement of the anticyclones over Australia is about 11°·5 in longitude.

8. The mean daily rate of movement of the anticyclones over South America is about 11°·1 in longitude.

9. The mean daily rate of the movements of the anticyclones over the three southern continents is about 11°·5 in longitude.

10. The mean daily rate of the movements of the anticyclones over the southern oceans is about 9°·2 in longitude.

11. The mean velocity of the anticyclones round the earth is approximately 10°·7 per day, so that a complete circuit is made in 33·6 days.

12. The pressure-waves in the Antarctic regions move from west to east with a mean velocity of about 9° to 10° of longitude per day.

13. The view of the existence of two belts, one in which the anticyclones move and the other in which the cyclones travel, is in harmony with the change of amplitude per latitude, and with the values of the mean pressure per latitude.

14. The systems of moving anticyclones and cyclones in their respective belts account for the well-known predominant wind directions.

* Since this memoir was completed, an important statement, regarding atmospheric movements and the presence of high mountains, has been made by Professor Bjerknes of Christiania. An account of his lecture appeared in *Symons's Meteorological Journal* (July 1910, p. 111), and the point in question, which harmonises well with the views expressed in this memoir (*see* p. 41), is referred to as follows :—

"This is the fact that, owing to the far greater velocity in a horizontal than in a vertical direction, the lines of wind flow prefer, when the obstacle presented by rising land is of considerable magnitude, to travel round rather than over the obstruction, provided, of course, there is a possibility of their doing so. This is a point which should prove of value in the study of problems of rainfall distribution, in connection with specific types of atmospheric circulation."

15. The Antarctic records endorse the view of quickly moving cyclones in high latitudes travelling easterly. They corroborate the suggested position for the track of those low-pressure systems; and finally they give evidence for the presence of a permanent anticyclone over the South Polar area.

16. No definite conclusion is drawn as to the origin of anticyclones or cyclones, *i.e.*, whether they are "eddies," set up by the interchange of hot and cold air between the Equator and Pole, or not, but the evidence seems to favour the former.

17. The areas of high pressure on mean seasonal isobaric charts represent the loci of regions where the travelling anticyclones are most intense. They are not regions of permanently situated anticyclonic systems.

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PLATE

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II. Curves showing changes of amplitude with latitude in various selected longitudes.

III. Map of the Southern Hemisphere showing lines of mean equal-pressure-amplitude, or isanakatabars, for the winter months April to September.

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VI. Curves illustrating the eastward movement of barometric waves over Australia.

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XIII. Revised isanakatabar chart in accordance with the deductions made from the discussion of the Antarctic expeditions' data.

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(2) July isobars,
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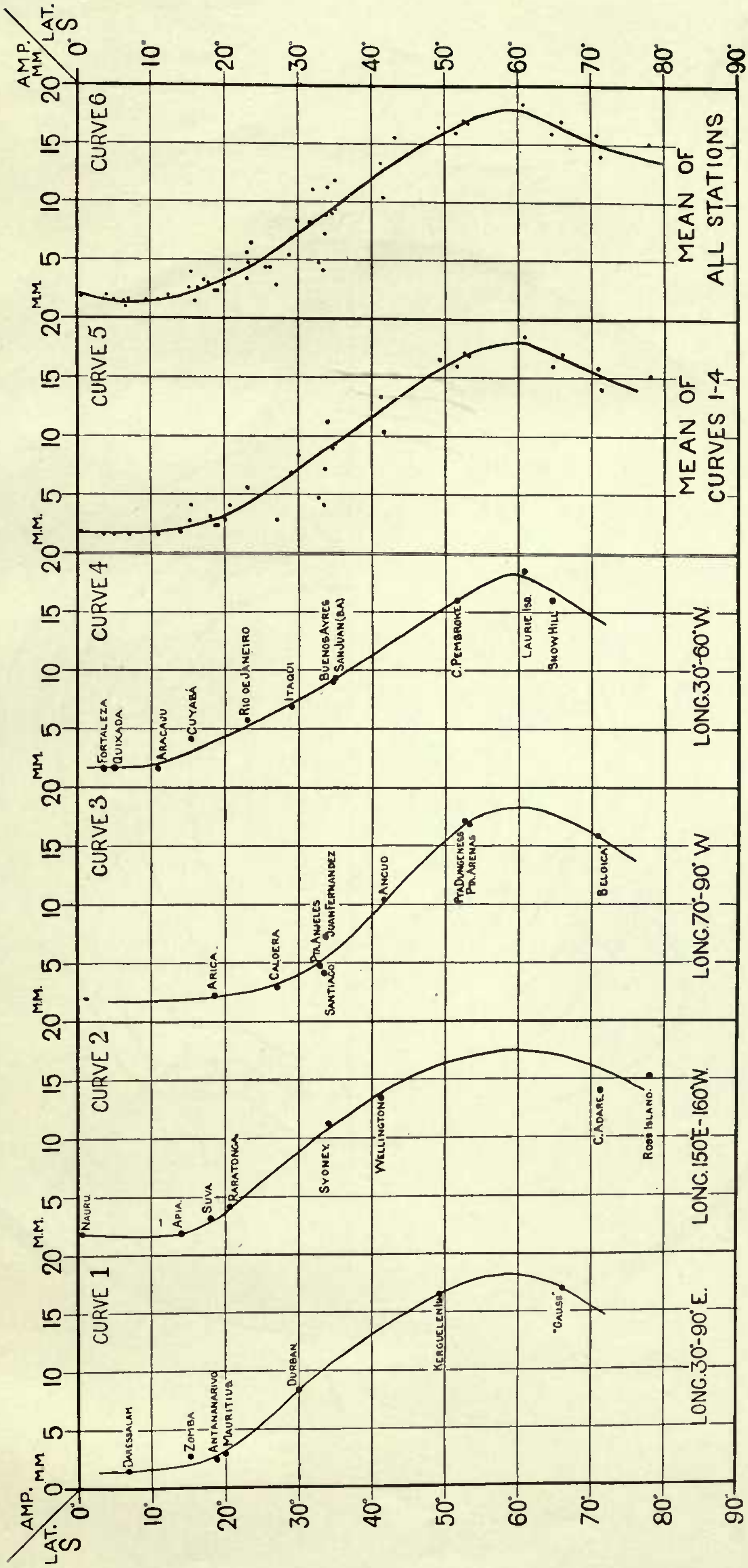
(4) January isobars,

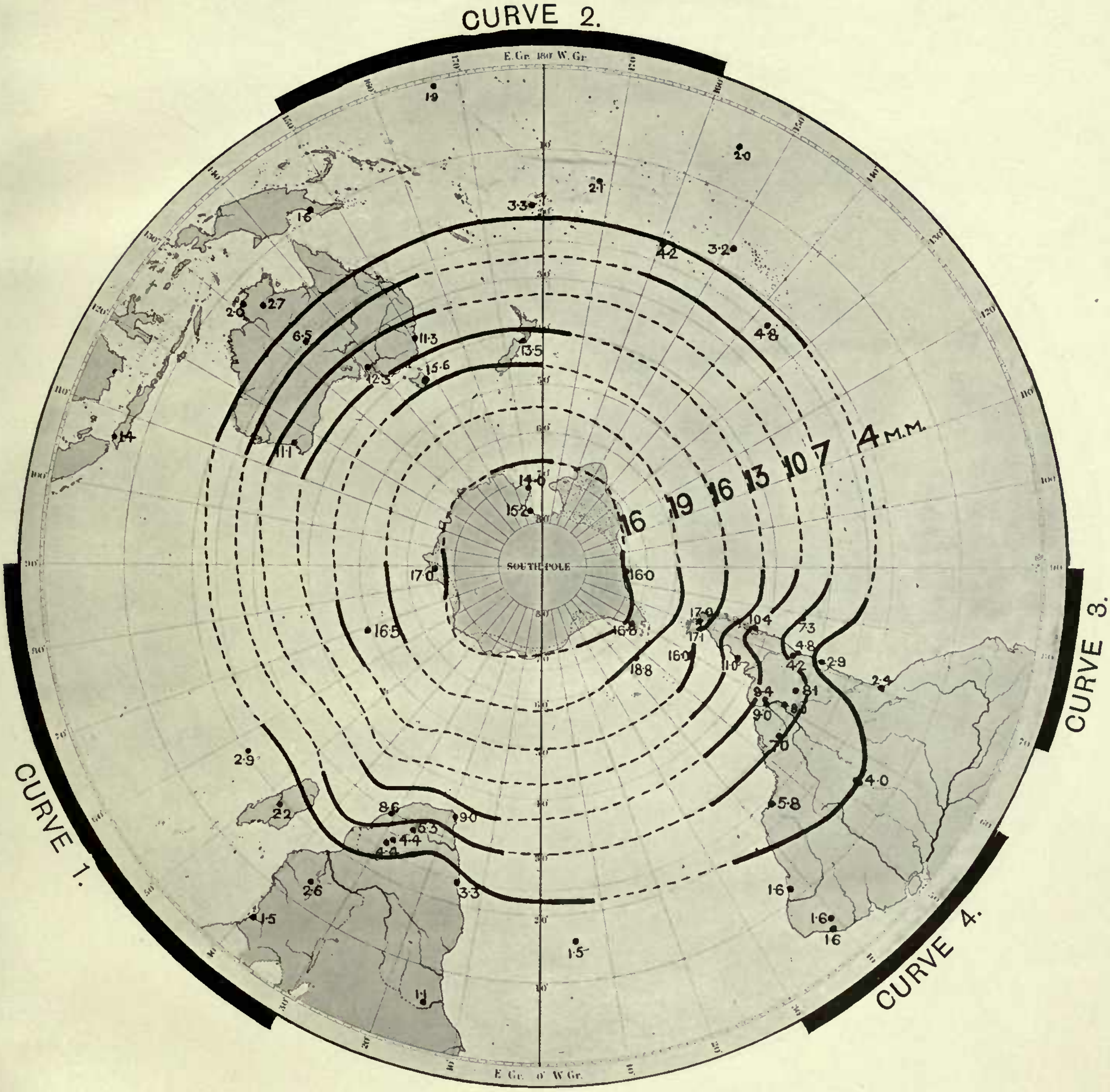
for the Southern Hemisphere (Hann).

THE SOUTHERN HEMISPHERE.

See pp. 4, 46.

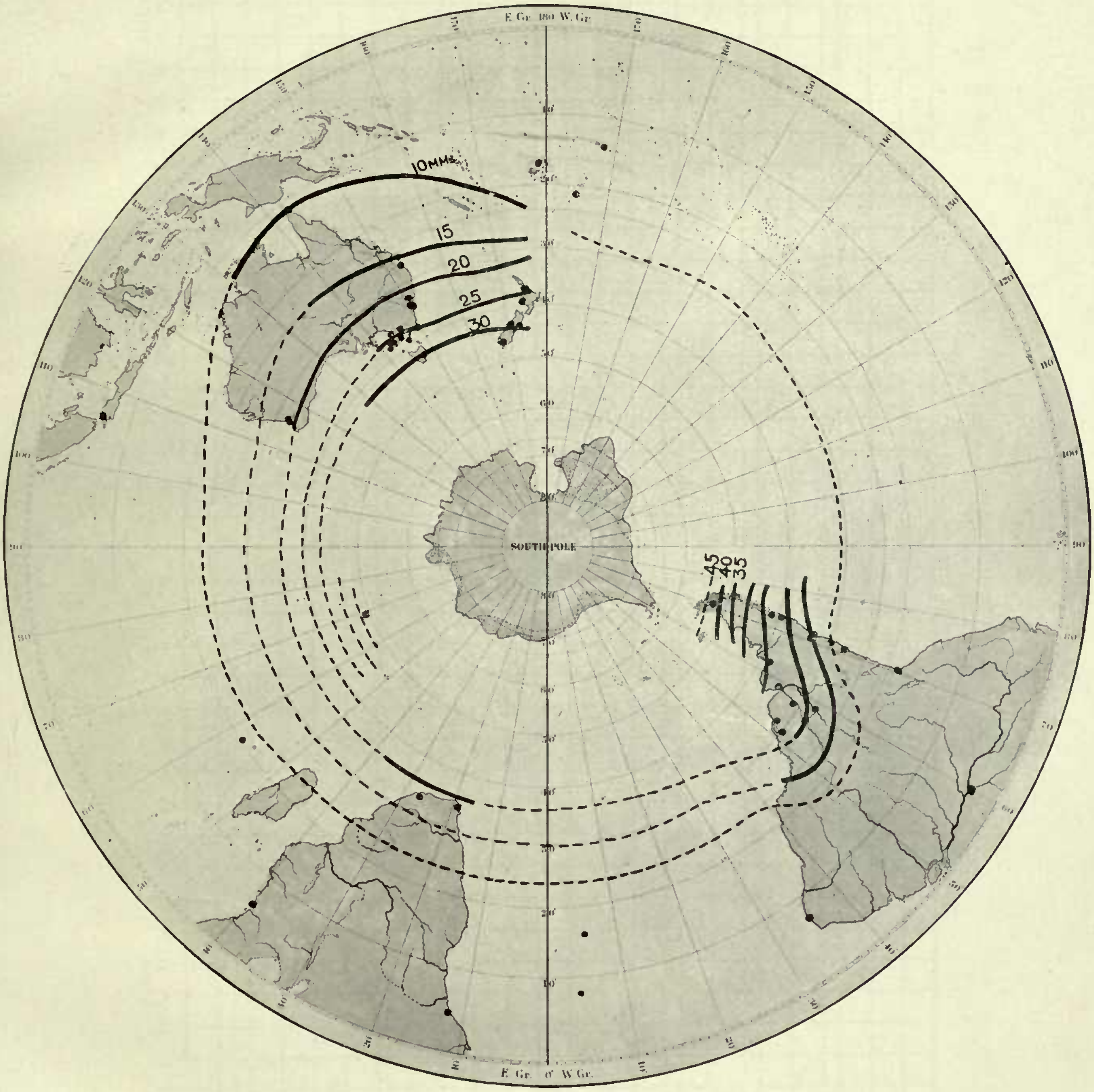

CURVE 1
LONG. 30°-90° E.
DARESSALAM
ZOMBA
ANTANANARIVO
MAURITIUS
DURBAN
KERGUELEN
GAUSS
CURVE 2
LONG. 150°E-160°W.
NAURU
APIA
SUVA
RARATONGA
SYDNEY
WELLINGTON
C. ADARE
ROSS ISLAND
CURVE 3
LONG. 70°-90° W
ARICA
CALDERA
SANTIAGO
PTA. ANJELES
JUAN FERNANDEZ
ANCUD
PTA. DUNGENESS
PTA. ARENAS
BELOICA
CURVE 4
LONG. 30°-60° W.
FORTALEZA
QUIXADA
ARACAJU
CUYABÁ
RIO DE JANEIRO
ITAQUI
BUENOS AYRES
SAN JUAN (B.A.)
C. PEMBROKE
LAURIE ISD.
SNOW HILL
CURVE 5
MEAN OF CURVES 1-4
CURVE 6
MEAN OF ALL STATIONS
AMP. MM
LAT. S

See p. 10.

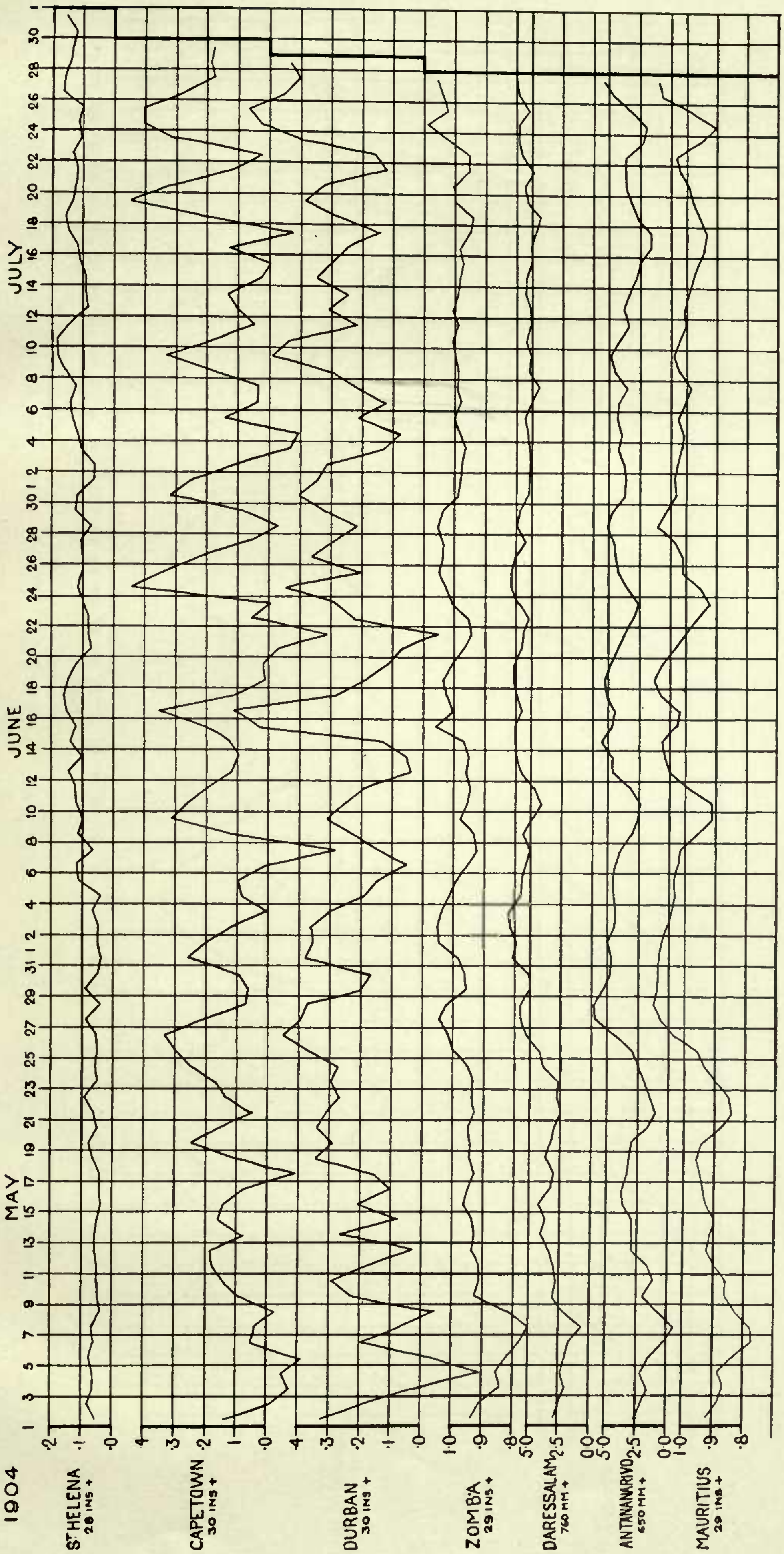

CURVE 2.
CURVE 1.
CURVE 3.
CURVE 4.
E. Gr. 180° W. Gr.
E. Gr. 0° W. Gr.
SOUTH POLE
4 M.M.
7
10
13
16
19
16

See p. 10.

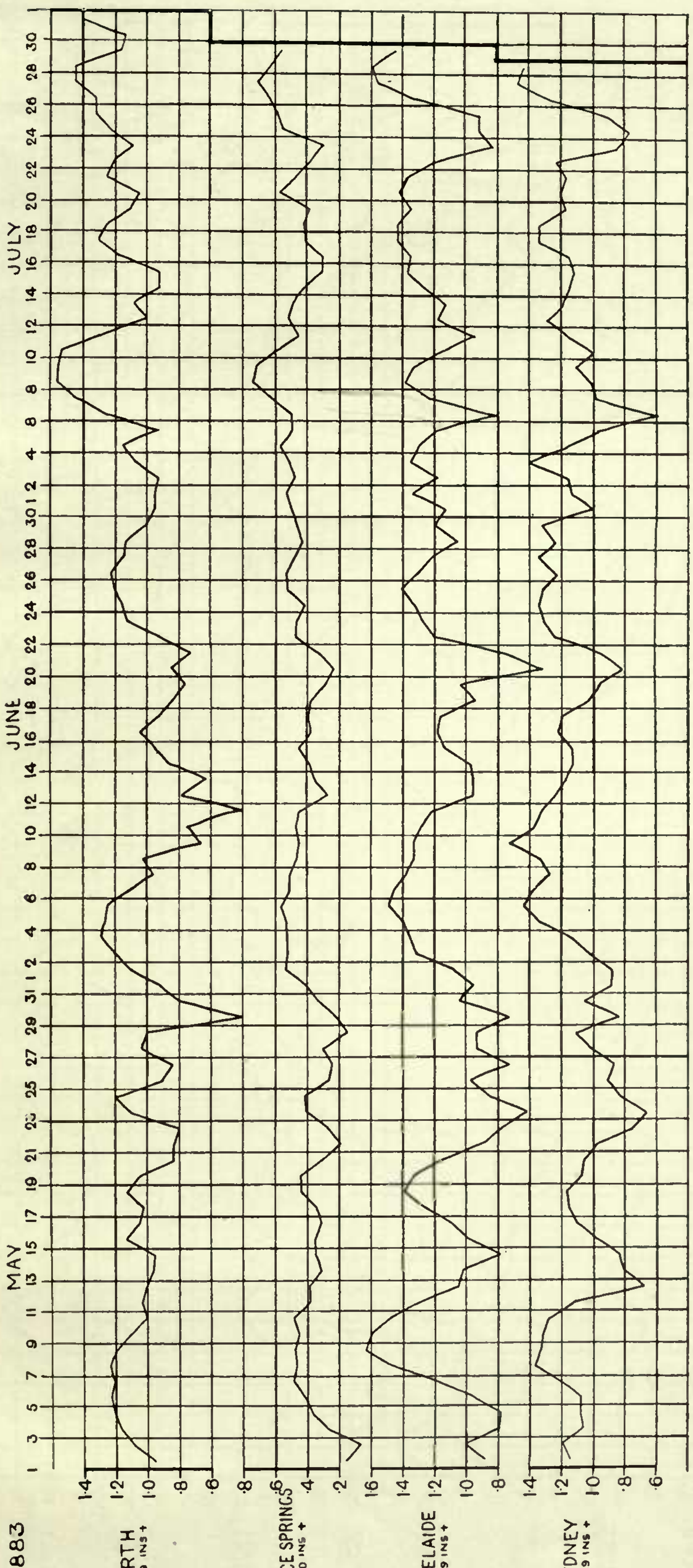
THE SOUTHERN HEMISPHERE.



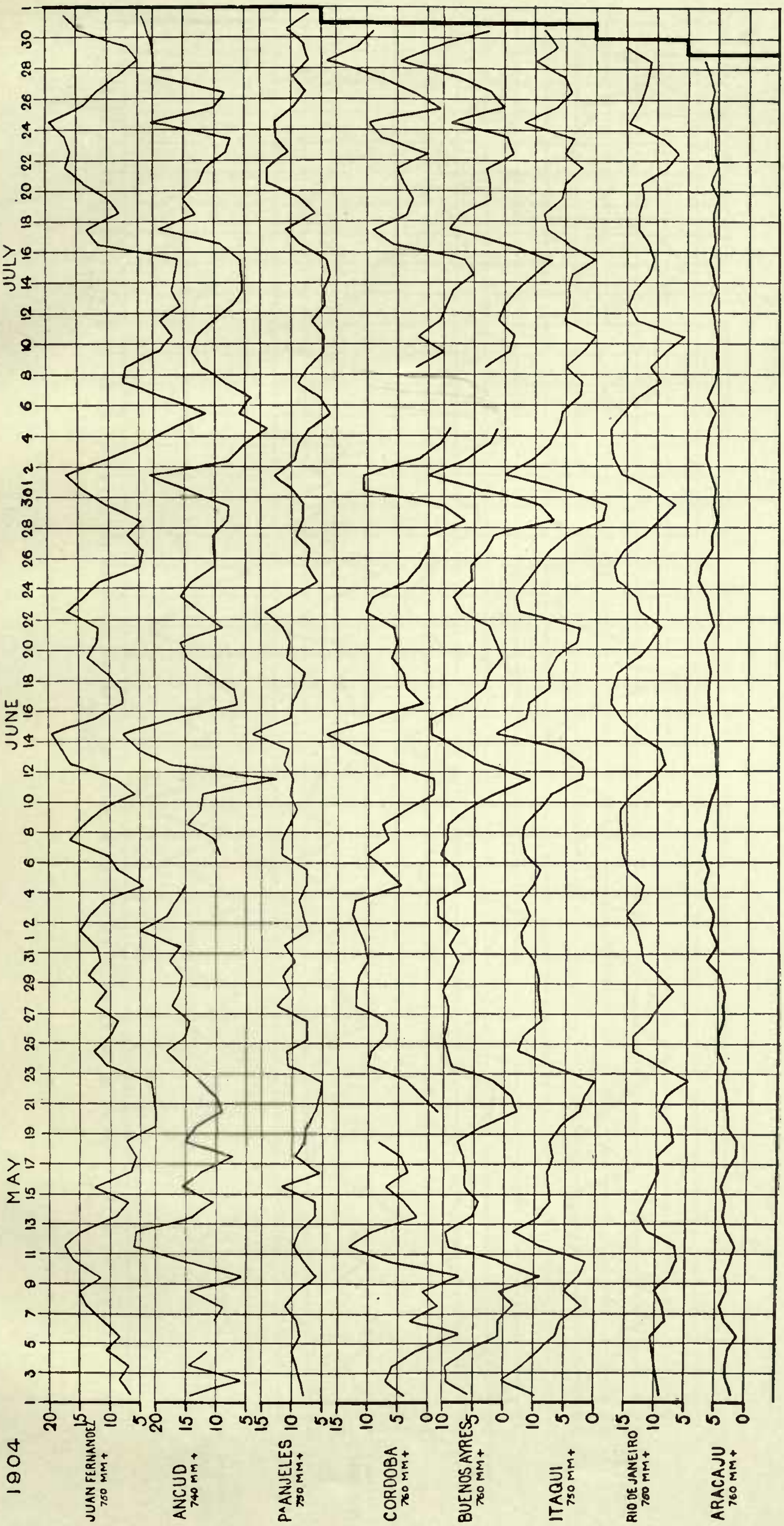
See p. 14.


1904
ST HELENA 28 INS +
CAPETOWN 30 INS +
DURBAN 30 INS +
ZOMBA 29 INS +
DARESSALAM 760 MM +
ANTANANARIVO 650 MM +
MAURITIUS 29 INS +
MAY
JUNE
JULY

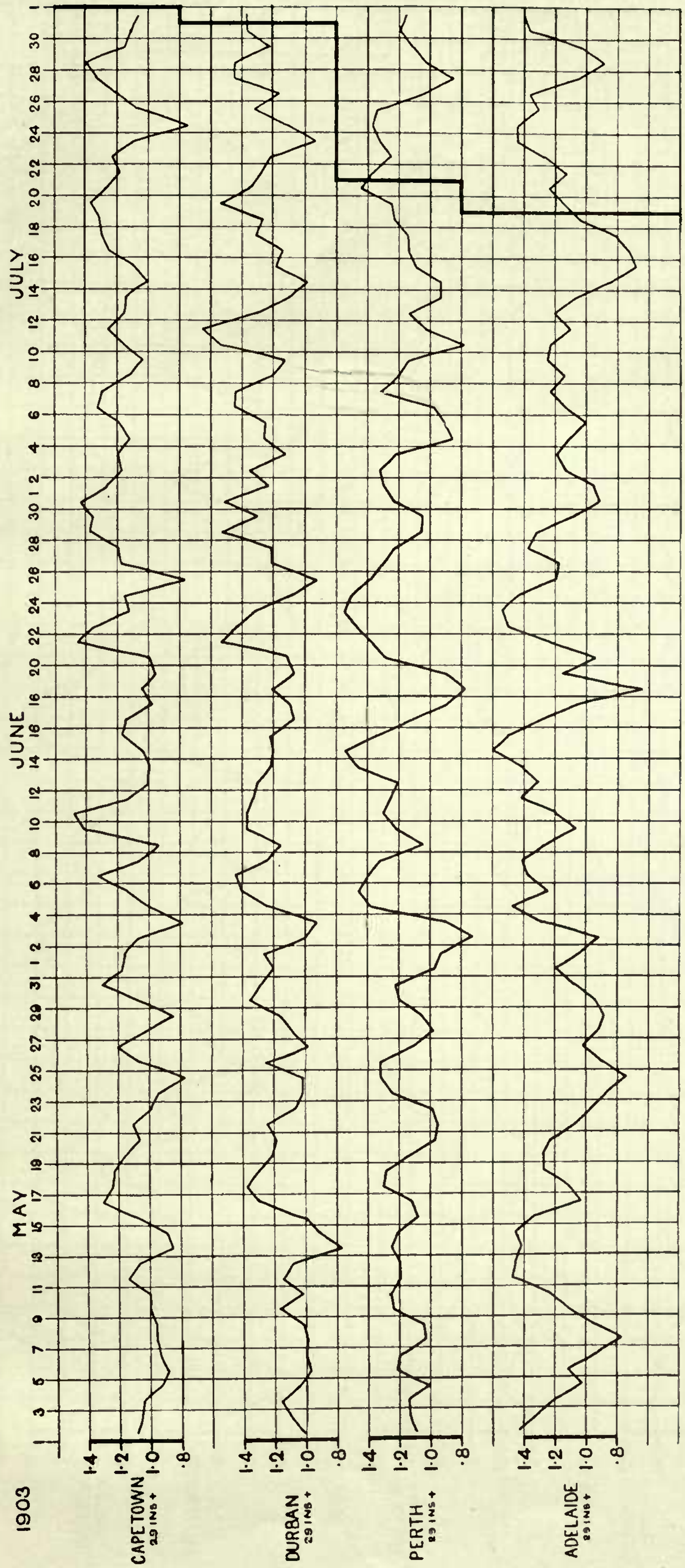
See p. 31.


1883
PERTH 29 INS +
ALICE SPRINGS 30 INS +
ADELAIDE 29 INS +
SYDNEY 29 INS +
MAY
JUNE
JULY

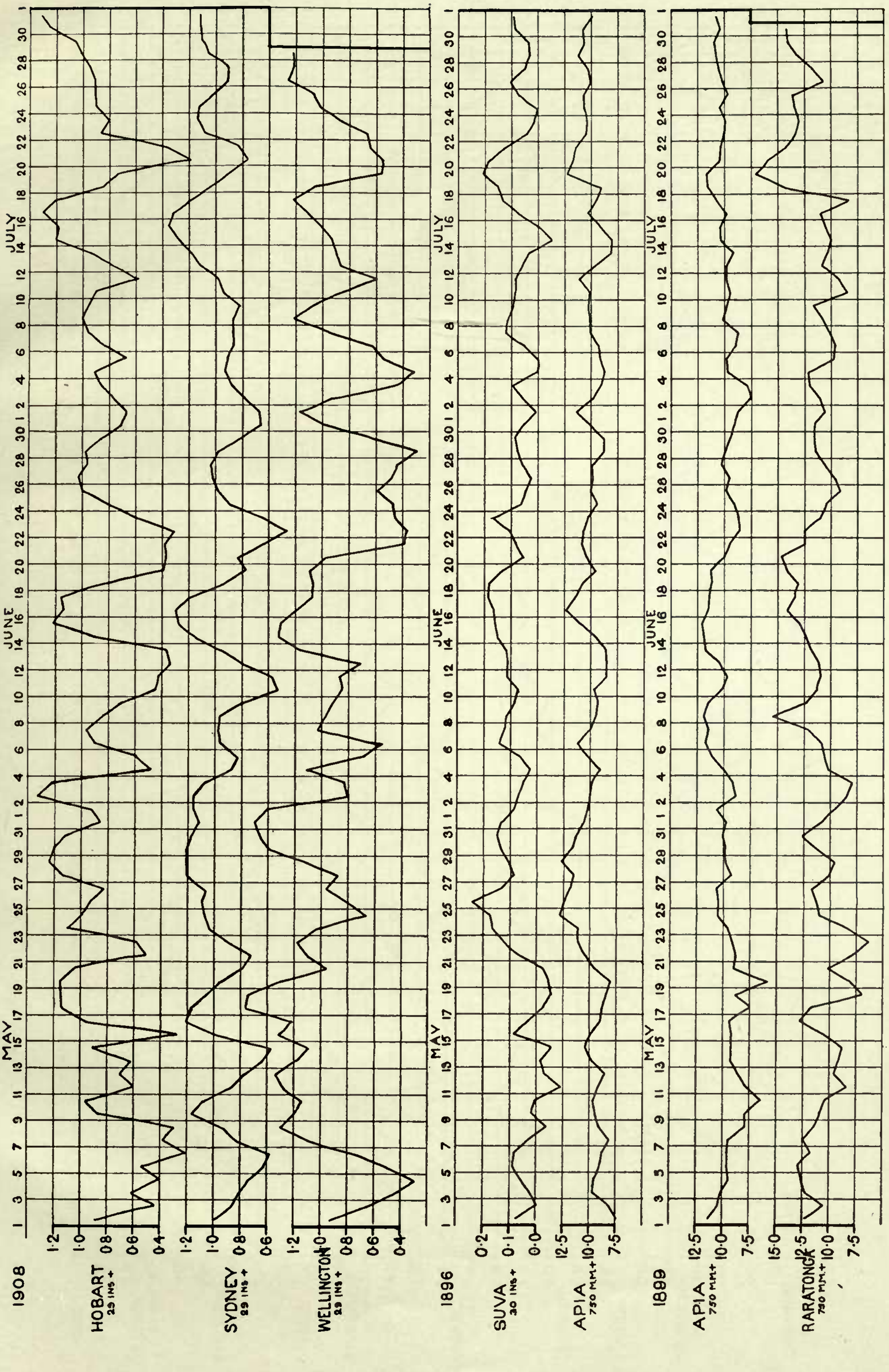
See p. 36.


1904
MAY
JUNE
JULY
JUAN FERNANDEZ 750 MM +
ANCUD 740 MM +
Pta ANJELES 750 MM +
CORDOBA 760 MM +
BUENOS AYRES 760 MM +
ITAQUI 750 MM +
RIO DE JANEIRO 760 MM +
ARACAJU 760 MM +

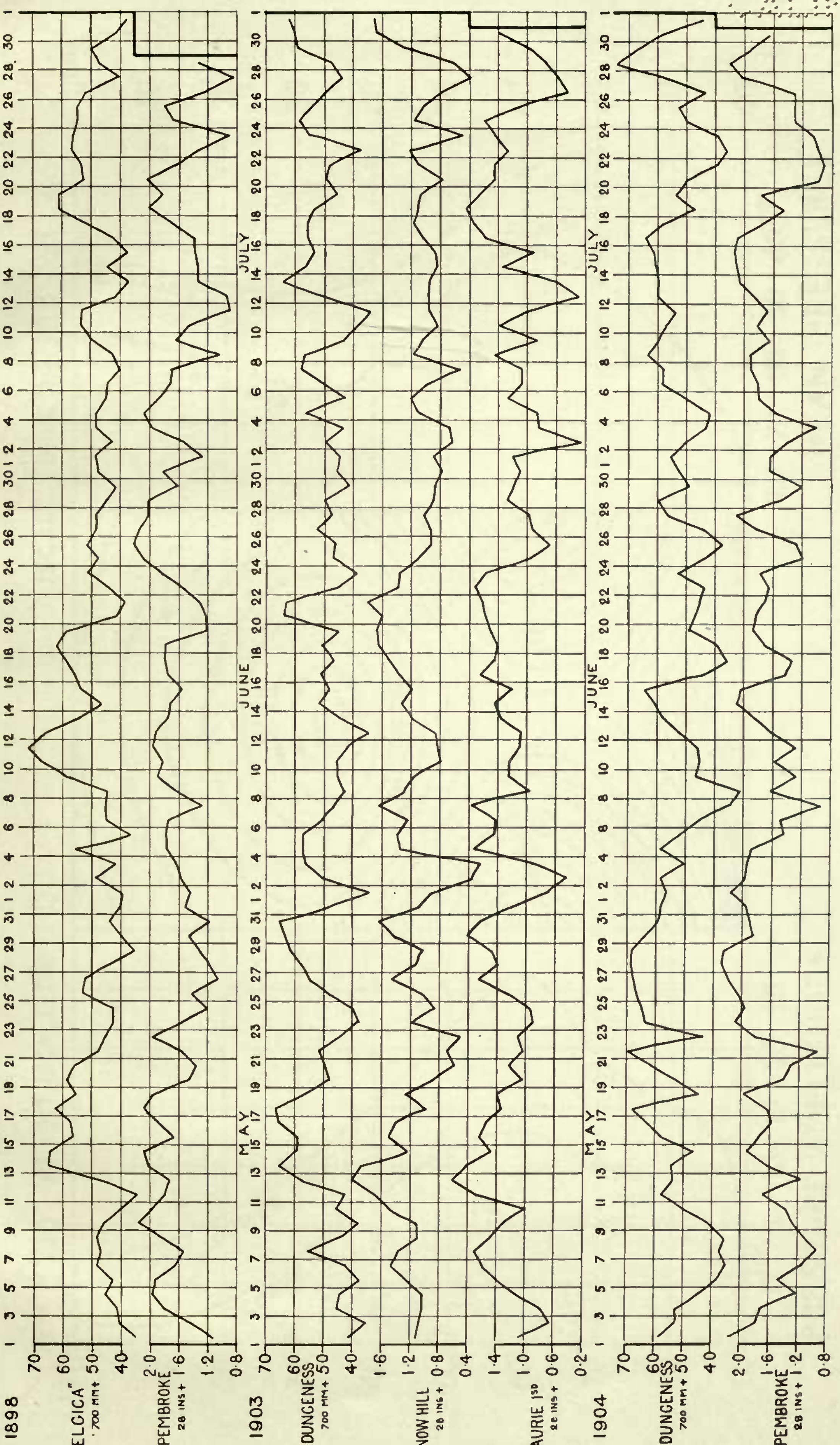
See p. 43.


1903
MAY
JUNE
JULY
CAPETOWN 29 INS +
DURBAN 29 INS +
PERTH 29 INS +
ADELAIDE 29 INS +
1·4 1·2 1·0 ·8

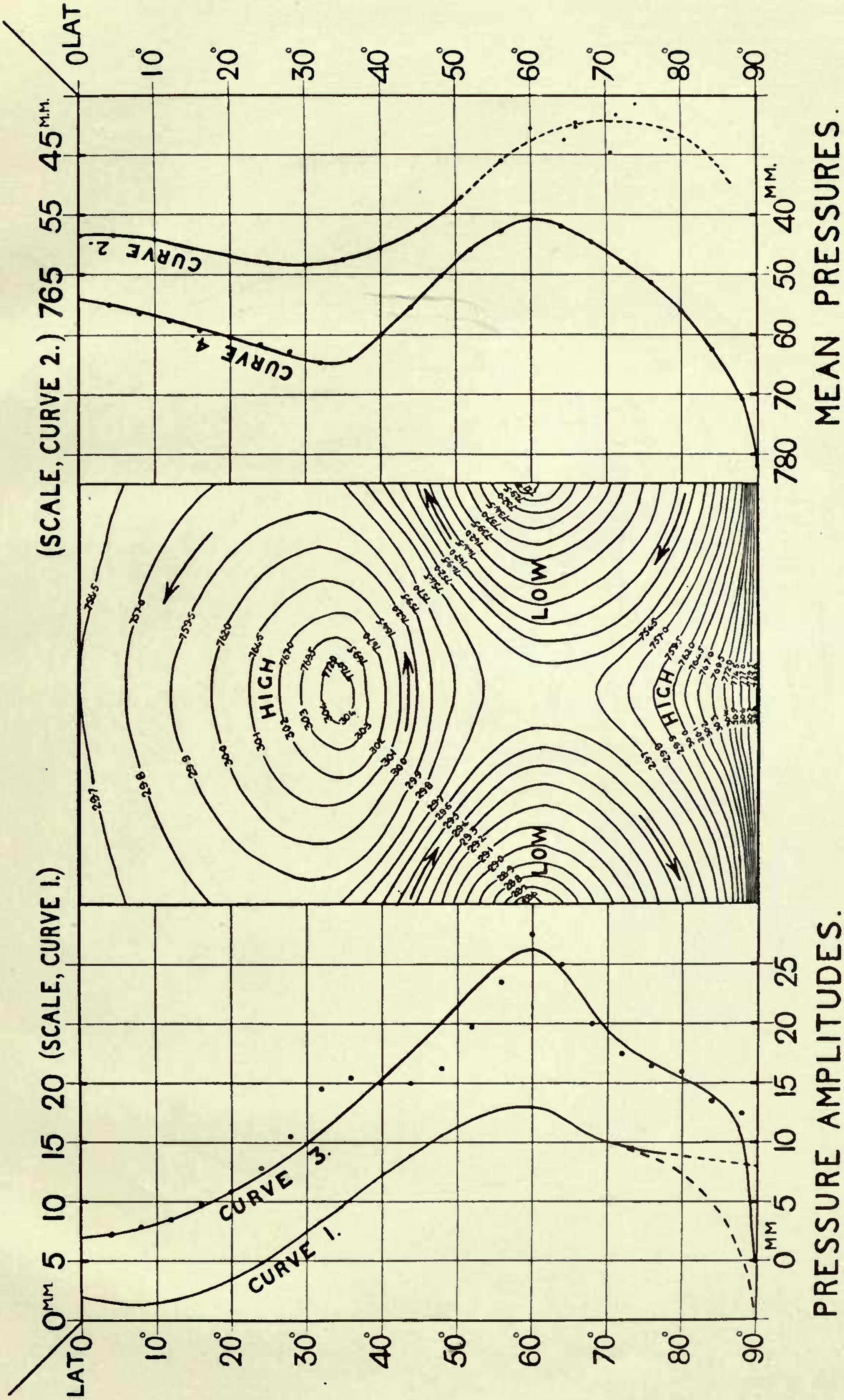
See p. 46.


1908
HOBART 29 INS +
SYDNEY 29 INS +
WELLINGTON 29 INS +
1896
SUVA 30 INS +
APIA 750 M.M. +
1899
APIA 750 M.M. +
RARATONGA 750 M.M. +
MAY
JUNE
JULY

See p. 51.

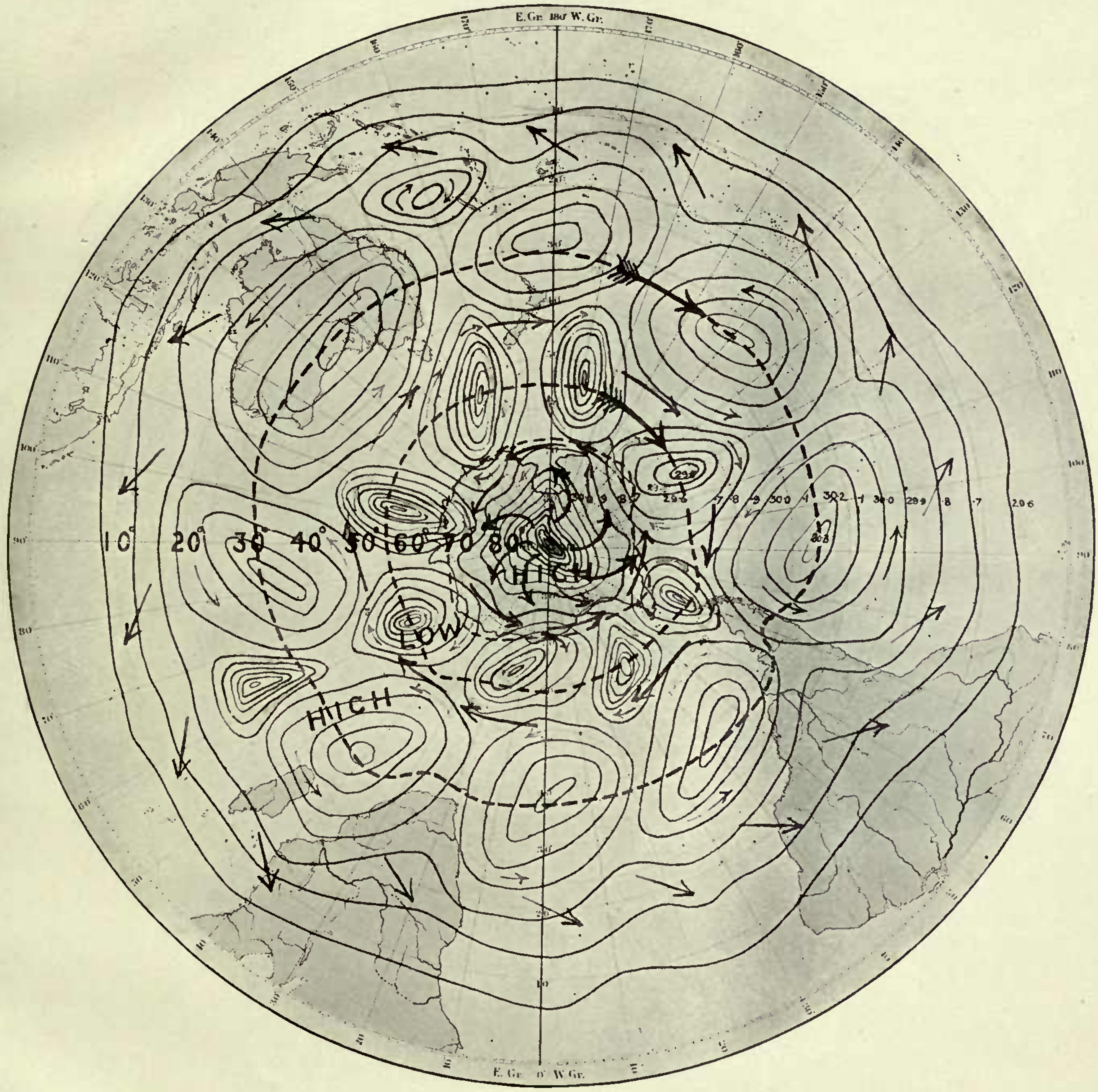

1898
"BELGICA" 700 MM+
C PEMBROKE 28 INS+
1903
P DUNGENESS 700 MM+
SNOW HILL 28 INS+
LAURIE I^SD 28 INS+
1904
P DUNGENESS 700 MM+
C.PEMBROKE 28 INS+
MAY
JUNE
JULY
70 60 50 40
2·0 1·6 1·2 0·8
1·6 1·2 0·8 0·4
1·4 1·0 0·6 0·2

See p. 57.


(SCALE, CURVE 2.)
(SCALE, CURVE 1.)
CURVE 1.
CURVE 2.
CURVE 3.
CURVE 4.
HIGH
LOW
MEAN PRESSURES.
PRESSURE AMPLITUDES.
LAT

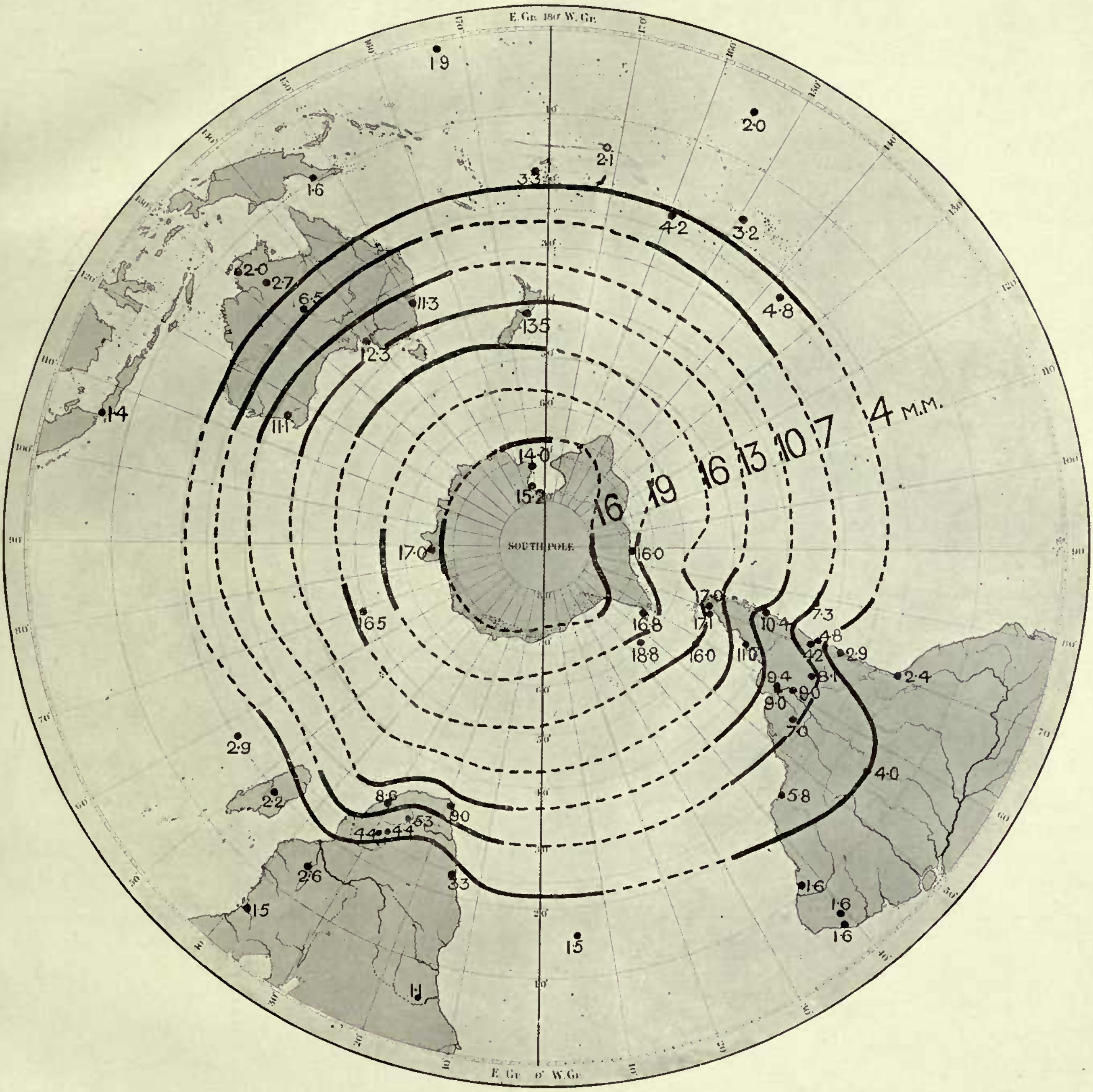
See p. 59.

THE SOUTHERN HEMISPHERE.

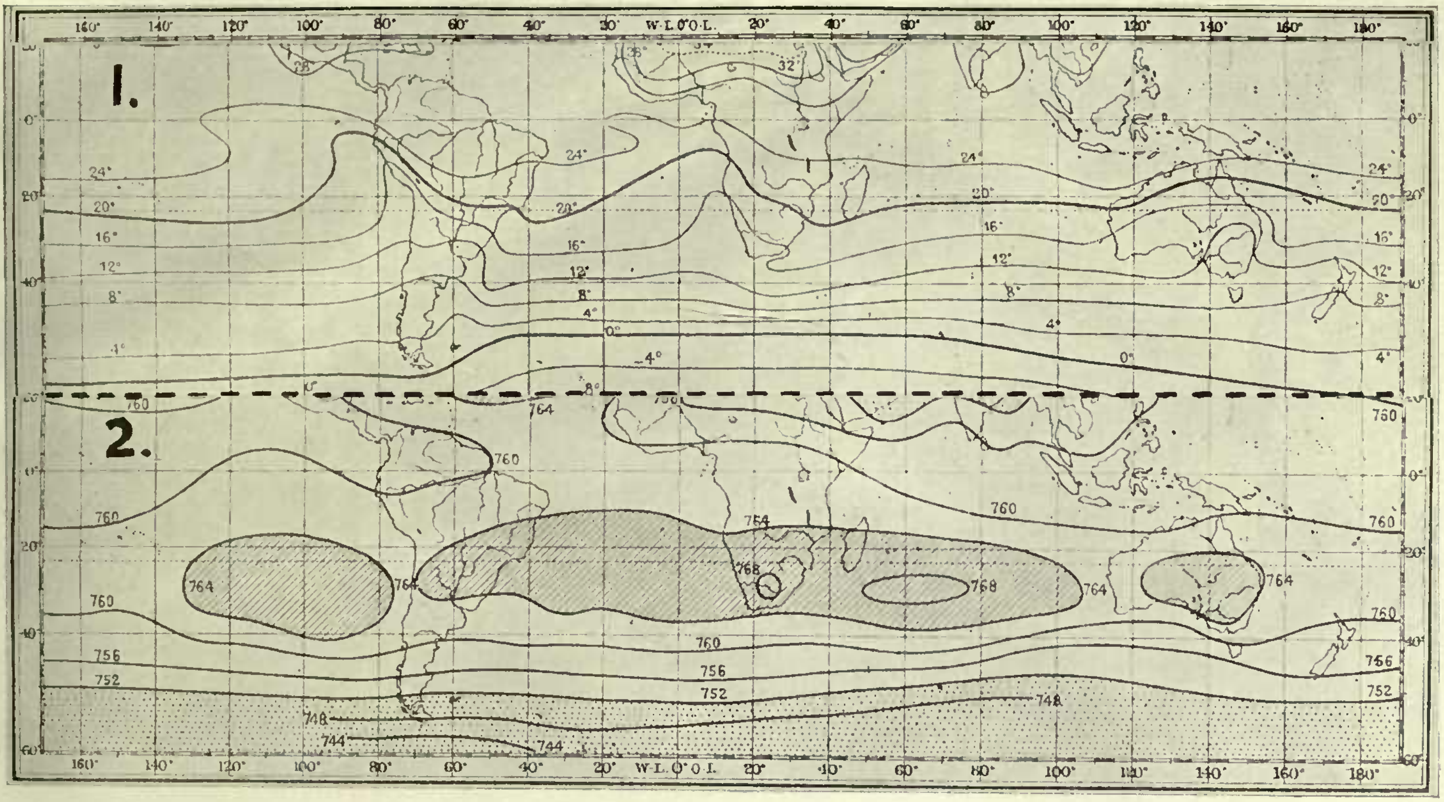


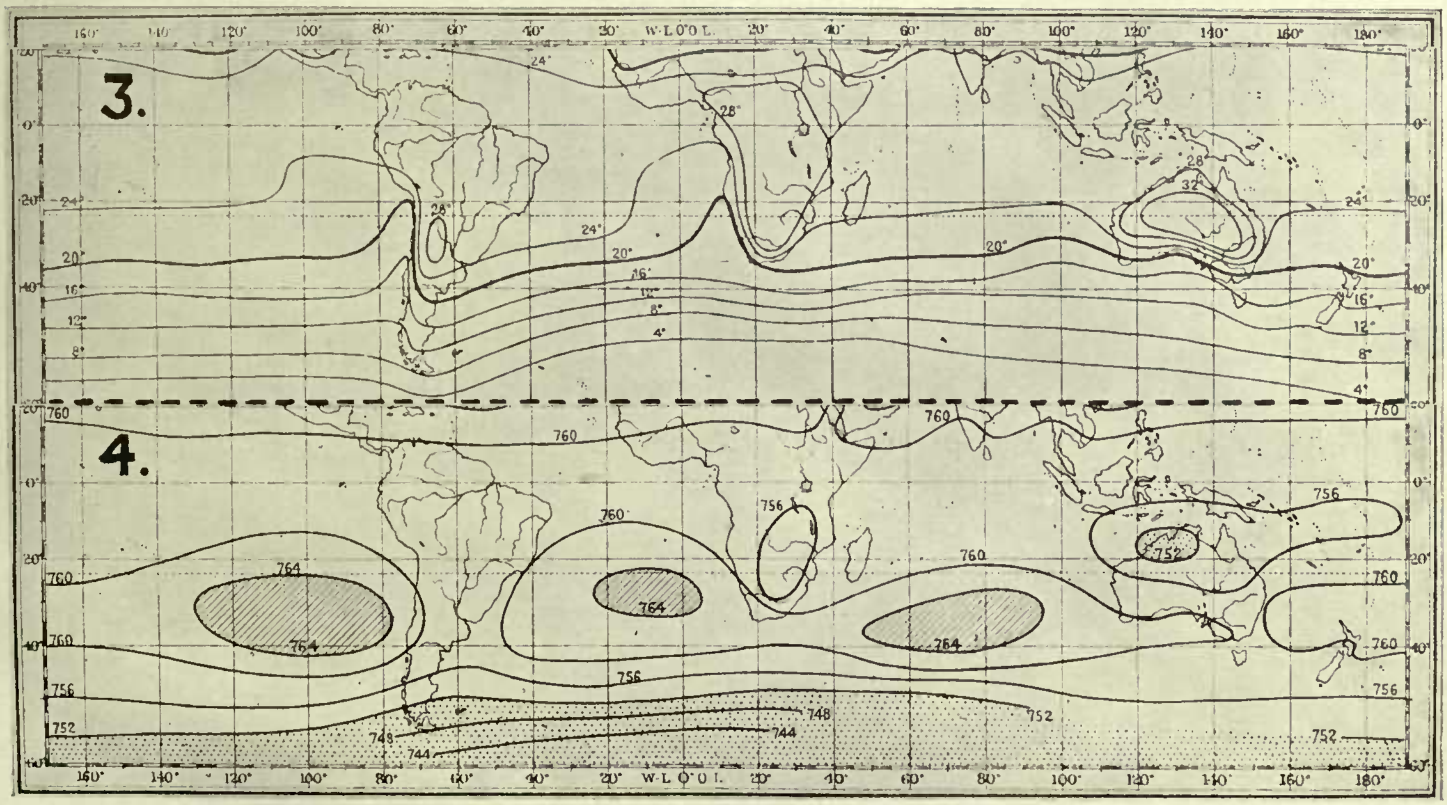
See p. 64.

THE SOUTHERN HEMISPHERE.



See p. 90.





1. Mean July isotherms.
2. Mean July isobars.
3. Mean January isotherms.
4. Mean January isobars.

See p. 97.