The Physical Conditions of the Weddell Sea

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alarming. Goral (wild goat) are seen in quite extraordinary numbers in these gorges, especially in the evenings, clambering about the precipitous cliffs. The stretch from Lan-chou Fu to Chung-wei Hsien takes about five days, night travel not being possible.

At Chung-wei Hsien, a considerable city, where the Huang Ho emerges from its mountain gorges on to a broad alluvial plain, we abandoned our rafts for boats, since the river is here much obstructed by sandbanks, and the unwieldy rafts are constantly running aground. Passing through the famous Ning-hsia plain, a region of great agricultural wealth due to a complicated system of irrigation from the Huang Ho, the city of Ning-hsia is reached, and two days further on the Kansu border is crossed and the dreary wastes of the Ordos are entered, where for days one sees no signs of life save for the desert antelope and an occasional Mongol with his camels. In the neighbourhood of the San-ta-ho-tzu (where there is a Roman Catholic Mission) the country on the north bank improves, and a considerable Chinese population is found engaged in agriculture round the old branches of the Huang Ho; to the south the country remains desert. Millions of geese frequent this portion of the Huang Ho in September. The length of time taken over the journey through the Ordos depends very much on the wind, as with an adverse wind, or indeed any wind at all, the clumsy scows are constantly blown ashore. Strong winds are naturally frequent in these regions by day, but night travelling is often possible. Twenty-four hours (floating time) above Pao-t'ou the Wulashan Mountains are reached, a rocky range stretching along the north bank, and a prominent landmark from afar. From this point on the population increases until Pao-tou is reached, where the country is one vast cornfield.

From Pao-t'ou to Kuei-hua-ch'eng is four days by a good cart road across undulating grain-growing prairies just south of the Ta-ching Shan, a continuation of the Wu-la Shan. From Kuei-hua-ch'eng to Feng-chen, the present railhead of the Peking Kalgan Extension Railway, is also four long days' march by a good cart road through low mountains.

THE PHYSICAL CONDITIONS OF THE WEDDELL SEA.

R. G. Mossman, F.R.S.E.

Read at the Afternoon Meeting, 15 *June* 1916.

This paper was prepared originally for the guidance of the Committee appointed by the Admiralty to conduct the search for and relief of the Shackleton Expedition. overdue from the Weddell Sea. Before it was delivered Sir Ernest Shackleton reached the Falkland Islands, and the questions of immediate interest to the meeting were the hope of survival and

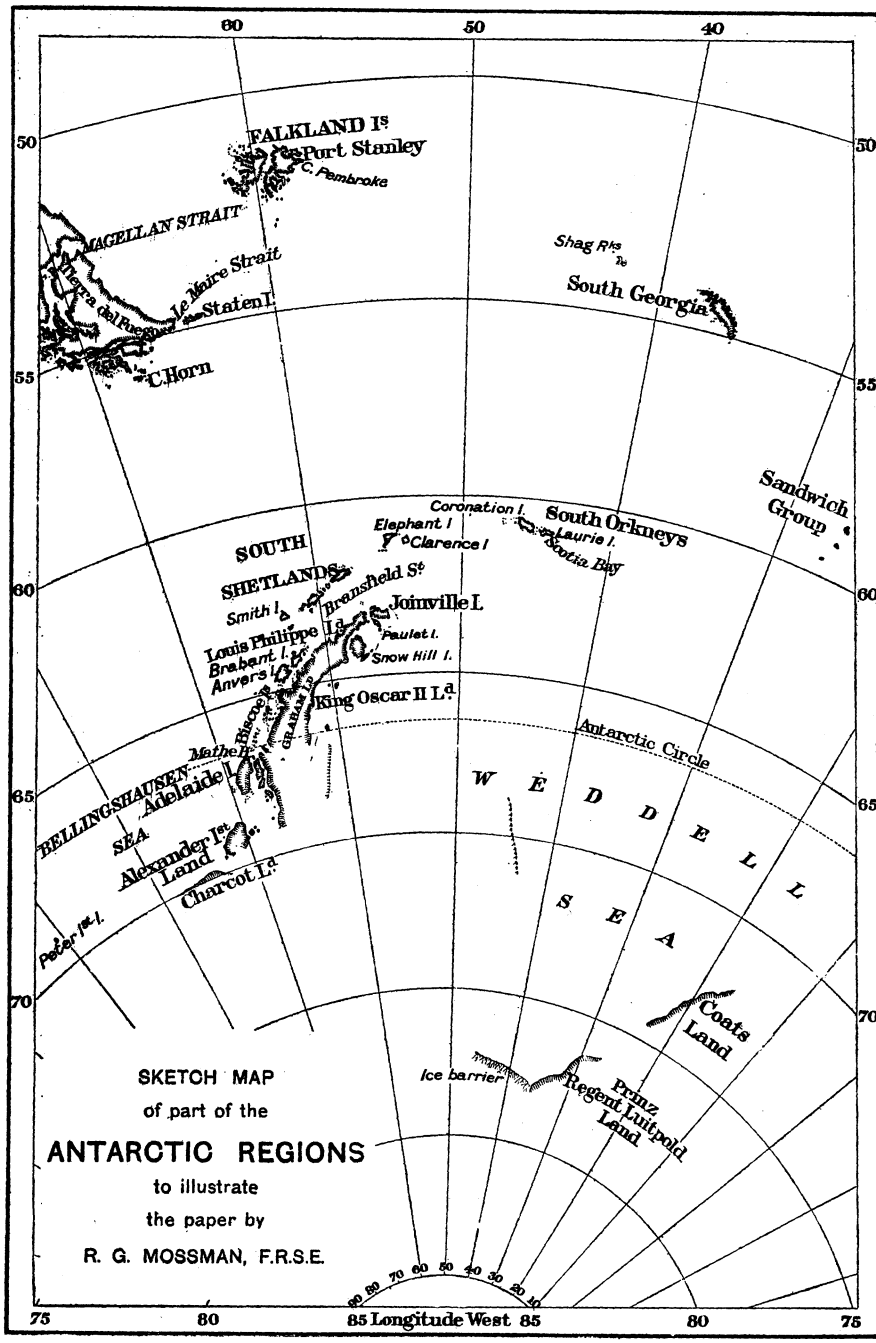
possibilities of rescue for the company on Elephant Island. Favourable speculations on these questions having been justified in the result, and with the prospect of an early authoritative account of the voyage, the author has eliminated those parts of this paper which were only of temporary interest; the remainder stands as a summary of our knowledge of the Weddell Sea up to the date of the latest expedition.

Ed. G. J.

THE Weddell Sea, which the discoverer himself named "King George IV. Sea" in honour of his reigning Sovereign, was successfully explored in February 1823, when, profiting by fair winds and (in the light of modern experience) a phenomenally open season, Weddell attained the latitude of 74° 15′ S. in the longitude of 34° W. Here on February 20 there was no ice in sight save three small bergs; but owing to a fresh southerly breeze and the lateness of the season, further progress towards the Pole was hazardous, and Weddell was compelled to return, having attained the then "farthest south," 214 nautical miles nearer the Pole than Captain Cook. This was a remarkable voyage, especially when we consider that it was made in a small brig, the *Jane*, a sealer of 160 tons, accompanied by a cutter, the *Beaufoy*, of 65 tons, ill adapted to withstand the perils of ice-encumbered seas.

Tempted by Weddell's success other explorers were not slow to try the "open sea" route to the Pole, but no good fortune attended their efforts. When the French explorer Dumont d'Urville, in January 1840, attempted to follow Weddell's route, impenetrable pack-ice stopped him in 64° S., 615 nautical miles to the north of the record latitude. Ross, three years later, had no better fortune, encountering a continuous line of pack-ice from Louis Philippe Land eastward, while an agglomeration of ice-floes presented through hundreds of miles an effectual barrier to his southern progress. He crossed Weddell's track in 65° 13′ S., and a few days later found the pack-edge turning towards the south. On March 5, when in lat. 71° S., long. 16° W., at a short distance from the pack-edge, he was surprised by a hurricane from the north-east, the heavy seas rolling in on the ice presenting the appearance of a foaming line of breakers. Fortunately, after two days' incessant labour, the *Erebus* and *Terror* were able to beat off, and the danger of being cast on something worse than a lee shore was over.

These early voyages, although of considerable interest, provided few scientific data beyond meteorological observations taken during summer and early autumn in positions that were constantly varying. It is however worthy of remark that Weddell noted (Weddell, 'A Voyage Towards the South Pole' (London, 1827), p. 33) that the direction of the surface currents showed a strong set to the north-west to the south of the Antarctic circle, but that in the lower latitudes of 64° to 65° S. on the meridian of 40° W. the drift changed to the east. This is quite in harmony with the results obtained from recent expeditions.



After the voyage of Ross no expedition entered the Weddell Sea for half a century. In the summer of 1892–3 a number of Dundee whalers visited Louis Philippe Land in quest of the southern right whale. Scientific observations were made by Dr. Bruce on board the *Balæna*, and by Dr. Donald on board the *Active*. Ten years later the Swedish expedition under Nordenskjöld set up a winter station on the east coast of Graham Land at Snow Hill I., 64° 22′ S., where meteorological and magnetic work was carried on until November 1903, Nordenskjöld making sledge journeys to the south.

Early in 1903 the Scottish National Antarctic Expedition under Dr. W. S. Bruce entered the Weddell Sea, and on February 22 the *Scotia* was beset in 70° 25′ S. and 17° 12′ W. Subsequently the ship got free and returned to the South Orkney Islands, situated in 61° S., where winter quarters were occupied from March to November. A house and magnetic observatory were built and observations maintained, while the *Scotia* proceeded to Buenos Aires to refit. Dr. Bruce in the late summer returned to the South Orkneys, having on board an Argentine party of observers to continue the meteorological and magnetic observations.*

On 22 February 1904 the *Scotia* left the Orkneys, making a rapid advance until March 3, when a new land named Coats Land was discovered in 71½° S. and 18° W. This land was mostly bounded by an ice-barrier, which was followed to the south-west for 150 miles, where the ship was frozen in on March 7. During a blizzard in lat. 74° 1′ S., long. 22° W., the farthest south was attained. Close heavy pack prevented a nearer approach to the land than 2 miles; there was no open water in sight, and the temperature was down to zero Fahr., while the *Scotia*, owing to heavy ice pressure, had been heaved up bodily some 4 feet out of the water. On March 13 the ice opened, and the ship worked her way north, continuing her important oceanographical and other investigations.

The principal object of the German Antarctic Expedition, the next to visit Weddell Sea, was to test whether Penck's theory of the division of the Antarctic continent into two masses with a frozen strait between was correct.

Under Dr. Filchner, after a preliminary cruise to the South Sandwich group, they finally left South Georgia on 8 December 1911, and a week later the *Deutschland* entered the pack in the low latitude of 59° S. During the twenty-six days from 15 December 1911 to 10 January 1912 very slow progress was made, the average being less than half a knot; but from the 11th to the 14th the ice was open, and a rapid advance was effected. Another period of anxiety followed, the vessel being almost immovable in tight pack for nearly a fortnight; but on January 29, in lat. 75°, the mariners were agreeably surprised to see the ship's head

* Dr. Bruce's effort to place the South Orkney station on a permanent basis was rendered successful through the support obtained from Dr. Escalante, then Argentine Minister of Agriculture, Mr. W. Davis, Director of the Argentine Meteorological Service, and Dr. Francisco P. Moreno.

bowing to the swell, the "land water" characteristic of the lee side of Antarctic continental areas being in sight. The ship then worked south to lat. 77° 45′, long. 34° 40′, and found barrier ice much broken up. Attempts to establish a station were frustrated by the breaking away of the ice, and a retreat was inevitable.

On March 8, in lat. 74° S., the *Deutschland* was frozen in and drifted all the winter, a plaything of the wind and currents. Urged by the east winds prevailing in high altitudes the drift was first to the west-south-west; then followed four months of a drift almost due north on the meridian of 44° W. In September the prevailing south-south-west winds gave place to westerly winds, and the current drove the *Deutschland* east. After pursuing an erratic northerly drift for two months the ship worked free on 26 November 1912, in lat. 63° S., having been frozen in 263 days. At the end of June Dr. Filchner and two companions had made a sledge excursion from the ship to the west to see if any trace could be found of the debated Morrell Land, which the American sealer of that name said he had discovered in 1823, but which had never been seen since. This sledge party were away eight days, and came back without having seen land.

Dr. Filchner's expedition returned with an important series of meteorological, oceanographical, and biological investigations. Apart from the discovery of new land the drift of the ship demonstrated the general circulation of the air and ocean currents of the Weddell Sea area, which entirely corroborated the scheme of atmospheric and oceanic circulation deduced from the observations taken on the *Scotia* some years previously, while the new land forming the southern boundary of the Weddell Sea was found exactly in the position calculated.* It will be some time yet before the important scientific results of Sir Ernest Shackleton's Expedition are available. Their co-ordination with data already discussed will probably modify in some directions the synopsis of the physical conditions now under consideration.

Our knowledge of the various physical factors operating in the Weddell Sea area is very unequal, as was to be expected. Meteorology bulks large, while a good deal of hydrographic work has also been accomplished, particularly by the *Scotia* and the *Deutschland* expeditions. On the other hand, apart from the very complete land observations taken at Laurie Island and Snow Hill I., comparatively little magnetic work has been accomplished, and there is here a profitable field for the employment of a research ship like the *Carnegie* operating in high southern latitudes. In our attempt to summarize the existing information we begin with the Meteorology.†

* "Meteorology in the Weddell Quadrant during 1909." By R. C. Mossman. *Scott. Geo. Mag.*, vol. 26, 1910, p. 417.

† A full description of the meteorology of the area under consideration is given in my memoir on "The Meteorology of the Weddell Quadrant and Adjacent Areas" (*Trans. Roy. Soc. Edin.*, vol. 47, pp. 103–136) the essentials of which have been but slightly modified in the light of later observations.

Isobars and Prevailing Winds.

The general atmospheric circulation is shown in the annexed diagram (Fig. 1), which gives isobars and prevailing winds for February and March representative of the late summer, and of June and July the winter months.

It will be seen that in the region to the west and east of Cape Horn two "centres of action" are indicated. The one to the west over the Bellingshausen Sea is centred just about in the latitude of the Antarctic

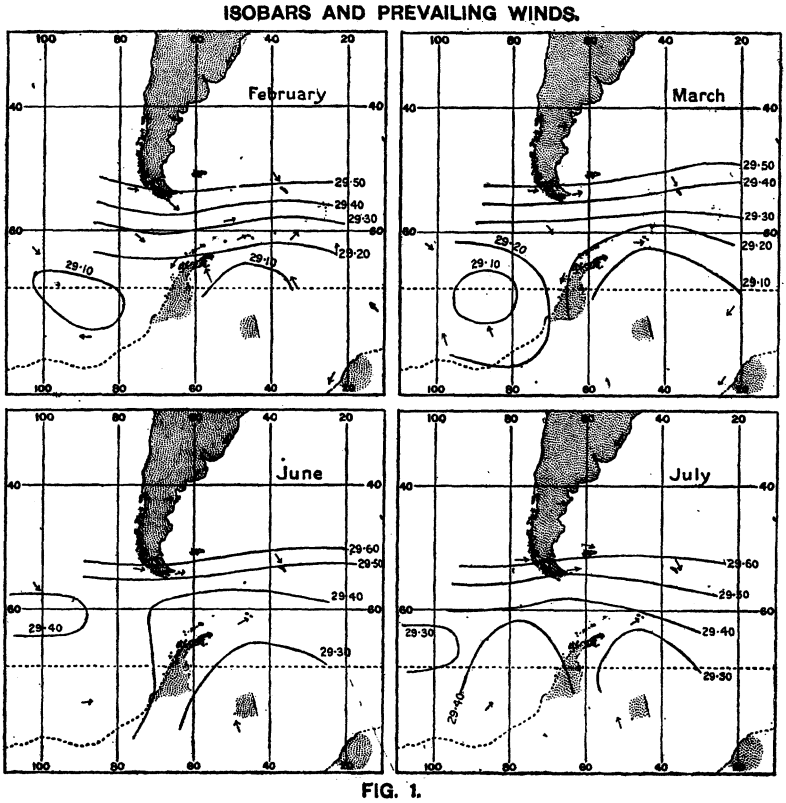


FIG. 1.

Circle; that over the Weddell Sea, which largely controls the conditions at the South Orkney group, is located a little further south. Over the South of Graham Land an area of relatively high pressure is shown. There is thus a wind divide which places the region east of Graham Land under the control of Atlantic influences, while to the west of Graham Land the circulation is dominated by the cyclonic centre located about 100° W. The boundary-line is approximately the 60th meridian of west longitude from lat. 68° to 60° S. or down the centre of Graham Land. On reaching the southern extremity of the South American continent the boundary-line has changed to 70° W., so that places to the west of this line up to about

lat. 30° S. are strongly dominated by Pacific influences, the Andean chain forming a natural division between the Atlantic and Pacific air circulations. On the Pacific side of Graham Land strong north-east winds prevail south of lat. 62° S., and further to the west in about lat. 70° S., long. 82° to 99° W., as shown by the *Belgica* observations, the winds are monsoonal, easterly in summer and westerly in winter. On the west side of Graham Land, as shown by various explorers, away from land in a mean position 64° S. long., 55° W. winds in summer are evenly distributed round the compass. At Paulet Island and Snow Hill I. in the same area the prevailing wind is south-west, at the South Orkneys west-south-west, at South Georgia west-north-west; while further east and south-east about the meridian of Greenwich, south of lat. 60° S., strong easterly or north-easterly winds are met with

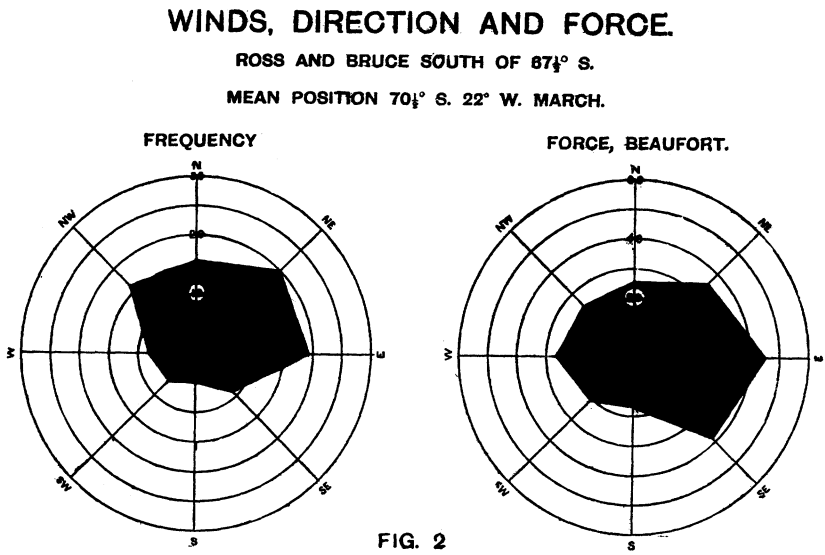


FIG. 2

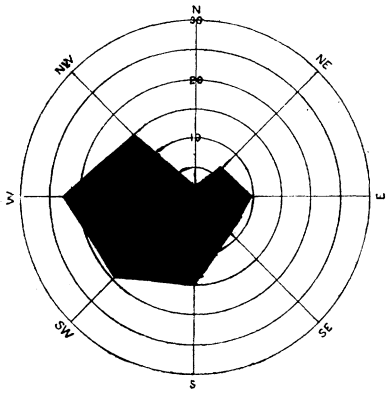
(see Fig. 2), which in summer and early autumn on the meridian of 35° W. prevail up to lat. 78° S., as shown by Filchner's observations and those made on the *Endurance*.

On the western side of the low-pressure area the mean wind is about south-south-west, the combined mass of observations indicating a general circulation round the Weddell Sea. This circulation is also confirmed by the drift of the *Endurance* (see Fig. 3).

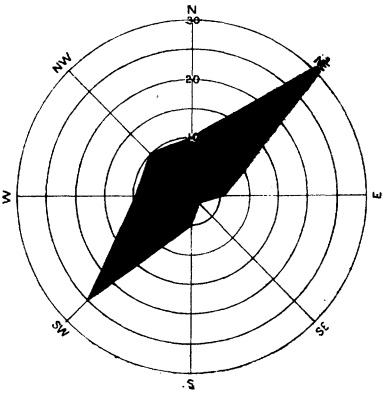
In Fig. 4 the effect of this circulation on the isotherms is shown for the months of February and March, for which months the greatest amount of information is available, and for June and July, the coldest months. The lines of equal temperature are drawn for intervals of 5° Fahr. for the two former; but for the two later months the lines represent intervals of 10° Fahr.

WIND FREQUENCY "DEUTSCHLAND 1911-1912."

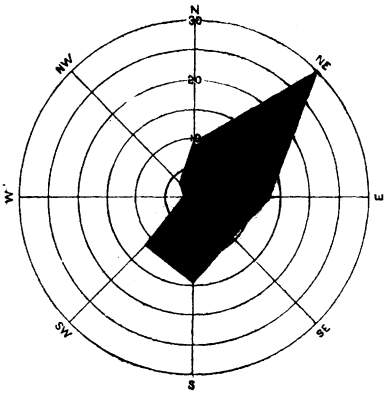
DEC. 17th, 1911 TO JAN. 10th, 1912.
62° S. 31° W.



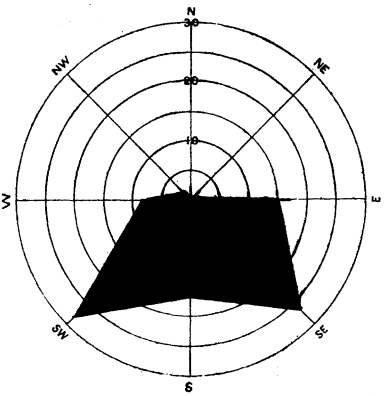
JAN. 13th TO 29th, 1912.
72° S. 28½° W.



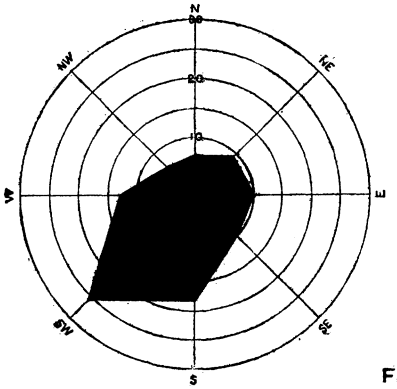
JAN. 30th to MAR. 4th, 1912.
77¼° S. 34° W.



MAR. 6th TO MAR. 31st, 1912.
73° S. 34° W.



APRIL TO AUG. 1912.
70° S. 42½° W.



SEPT. TO DEC. 16th, 1912.
64° S. 38° W.

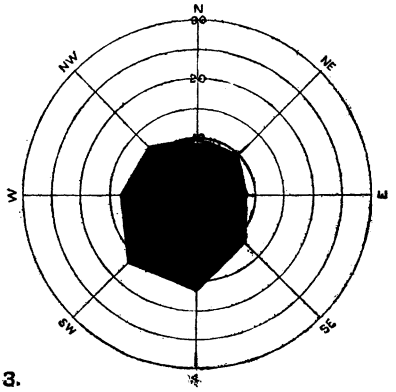


FIG. 3.

It will be seen that a cold area lies in the vicinity and to the south and west of Snow Hill I., Nordenskjöld's station. The relatively milder climate that prevails on the west as compared with the east side of Graham Land is due to the prevalence of the relatively warm north-east winds just referred to. The cold Antarctic current which sweeps down the east side of Graham Land appears to pass to the east of, but sometimes surrounding, Elephant Island, causing the isotherms to bend to the north in harmony with the northern limit of the ice-stream. The oscillations of the northern

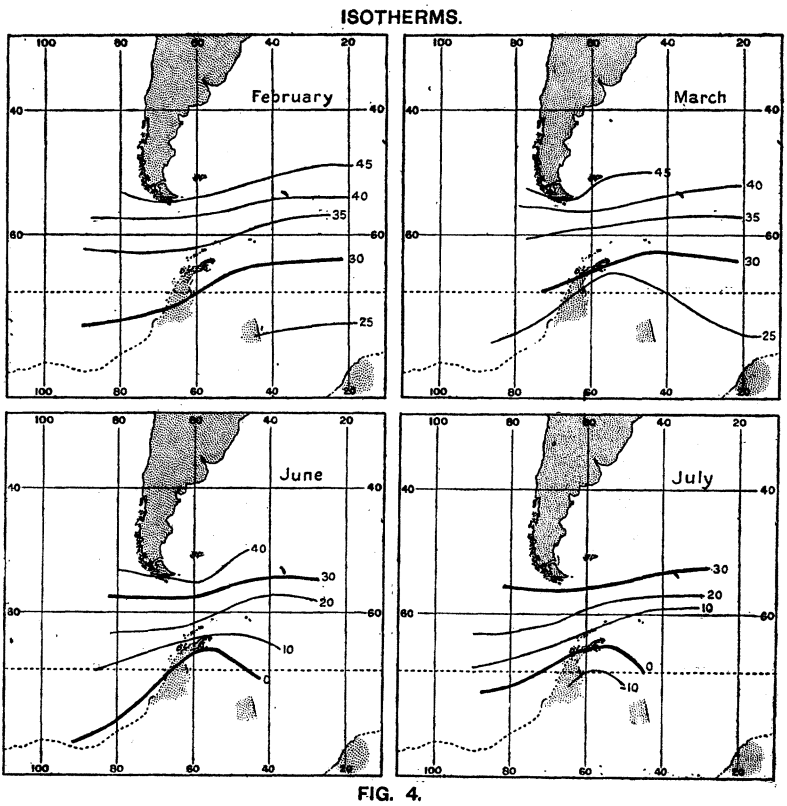


FIG. 4.

limit of the pack ice from season to season are very wide in the Weddell Sea area, and these profoundly influence the climatic conditions.

The annual temperature variation in most temperate and tropical regions is covered by well-defined factors which are more or less constant from one year to another; but at the South Orkneys the presence or absence of pack-ice around or in close proximity to these islands causes great variations in the mean monthly, seasonal, and even annual temperatures. The striking difference that prevails between the mean annual temperature of the South Orkneys and of South Georgia, some 380 miles

to the north-east, is shown by the circumstance that, during the six years 1905 to 1910, while the mean annual values at the South Orkneys varied from 23°·1 to 26°·6 a range of 3°·5; at South Georgia the difference was only 0°·5, and at Cape Pembroke, Falkland Islands, 1°·1. These pronounced differences are almost wholly occasioned by the greater variability of temperature at the South Orkneys during the autumn and winter months, since from November to March there is little change from one year to the next in the mean temperature, owing to the comparatively open ice conditions.

As showing the range in the mean temperature of the months we give the values corresponding to the mean of the warmest and coldest months, with the departure from the mean, and the range. The difference between the summer and the winter months is very striking, the climate being insular from November to March, and continental during the remainder of the year.

	Highest temp.	*Year.*	*Diff. from mean.*	*Lowest temp.*	*Year.*	*Diff. from mean.*	*Range.*	*Mean 1903–1914.*
Jan.	33°·9	1906	+1°·9	30°·2	1913	−1°·8	3°·7	32°·0
Feb.	34°·5	1907	+1°·8	30°·6	1905	−2°·1	3°·9	32°·7
Mar.	32°·7	1910	+1°·6	28°·5	1913	−2°·6	4°·2	31°·1
April	31°·1	1914	+4°·7	20°·6	1903	−5°·8	10°·5	26°·4
May	26°·8	1910	+6°·7	10°·5	1904	−9°·6	16°·3	20°·1
June	22°·7	1910	+8°·3	6°·1	1913	−8°·3	16°·6	14°·4
July	17°·5	1910	+6°·4	2°·3	1905	−8°·8	15°·2	11°·1
Aug.	22°·5	1905	+6°·5	−0°·4	1915	−16°·4	22°·9	16°·0
Sept.	26°·8	1908	+5°·7	13°·4	1903	−7°·7	13°·4	21°·1
Oct.	27°·6	1905	+3°·0	18°·4	1904	−6°·2	9°·2	24°·6
Nov.	31°·1	1904	+3°·3	23°·2	1913	−4°·6	7°·9	27°·8
Dec.	32°·4	1913	+1°·8	28°·8	1904	−1°·8	3°·6	30°·6
Year	26°·6	1908	+2°·6	20°·6	1915	−3°·4	6°·0	24°·0

In some years the climatic features are in general those that pertain to a continental situation, while in others oceanic conditions prevail, except for a brief period after the winter solstice, when even in open seasons there is a pronounced tendency towards continental conditions, owing to the freezing of the ocean at no great distance to the south. At all times, however, the climatic conditions are essentially polar, since the islands are situated in the direct track of an Antarctic current, which even when no ice is present brings a constant supply of ice-cold water past the South Orkney group. This cold current extends in a north-east or east-north-east direction (see effect on isotherms, Fig. 4), and its indirect influence has been found by Captain Hepworth to extend as far north as lat. 40° S. on the Greenwich meridian. Bouvet Island in lat. 54° 25′ S., long. 3° 24′ E., is virtually a mass of ice down to sea-level, without any vegetation whatsoever, while at South Georgia, in approximately the same latitude but further to the west, there are no less than 214 species of plants, of which nineteen are flowering. Further to the west in Tierra del Fuego the climatic conditions are those normal to extensive land areas in the south

temperate zone, a result largely due to the Föhn-like effect that accompanies the excessive precipitation on the western coasts. The distribution of temperature through the months of the year at various places from 51° to 61° S. is shown in Fig. 5.

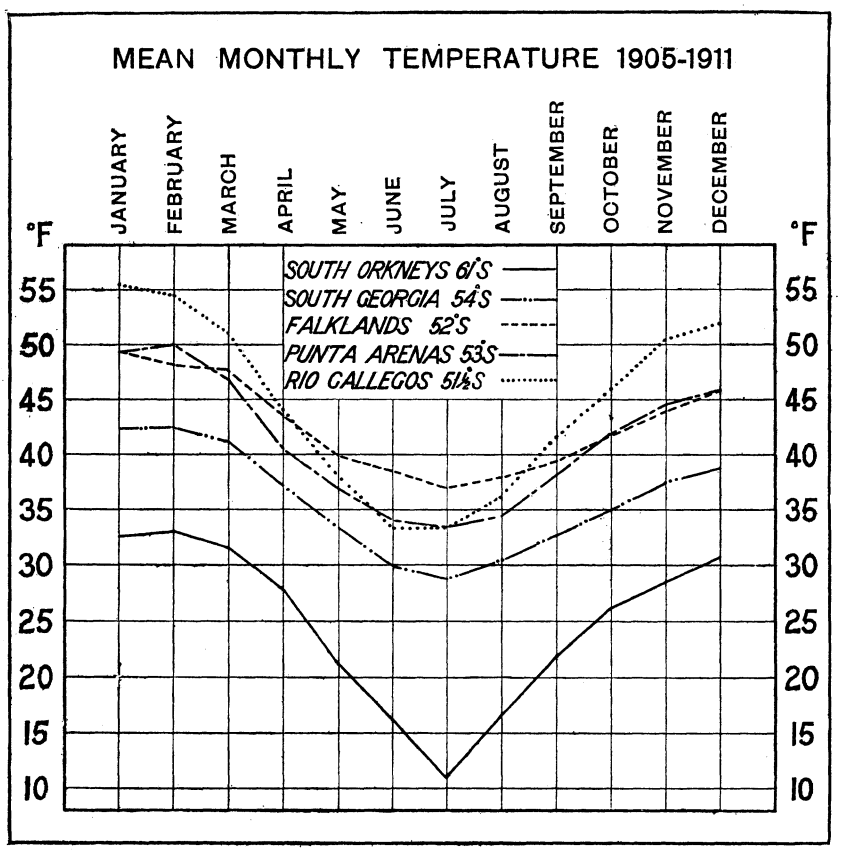


FIG 5.

At Laurie Island, South Orkneys, a careful note has been kept of the period during which Scotia Bay has remained frozen, the results being shown graphically in Fig. 6.

Thus Scotia Bay is closed with compact ice on the average 177 days in the year, the periods varying from 272 days in the season 1904–1905 to only 52 days in 1908. The earliest date of freezing was March 30 in 1903, and the latest July 25 in 1910. In 1908 the bay opened on August 27, while in 1905 it was not until February 6 that the ice broke.

An even later date may be assigned to 1903, as the Scottish Expedition found Scotia Bay still frozen at the beginning of February, when the islands were first visited. The bay was probably clear of ice only for a few days

in March, as when winter quarters were found there on March 27 it was quite obvious from the appearance of the icefoot that the bay had only very recently been ice free. In most cases pack ice drifts into the bay with a south wind, and then becomes consolidated; but occasionally, as in 1908, the seas are free of pack, a level plain of young ice forming as the temperature falls. Pack is often seen in summer, when from time to time

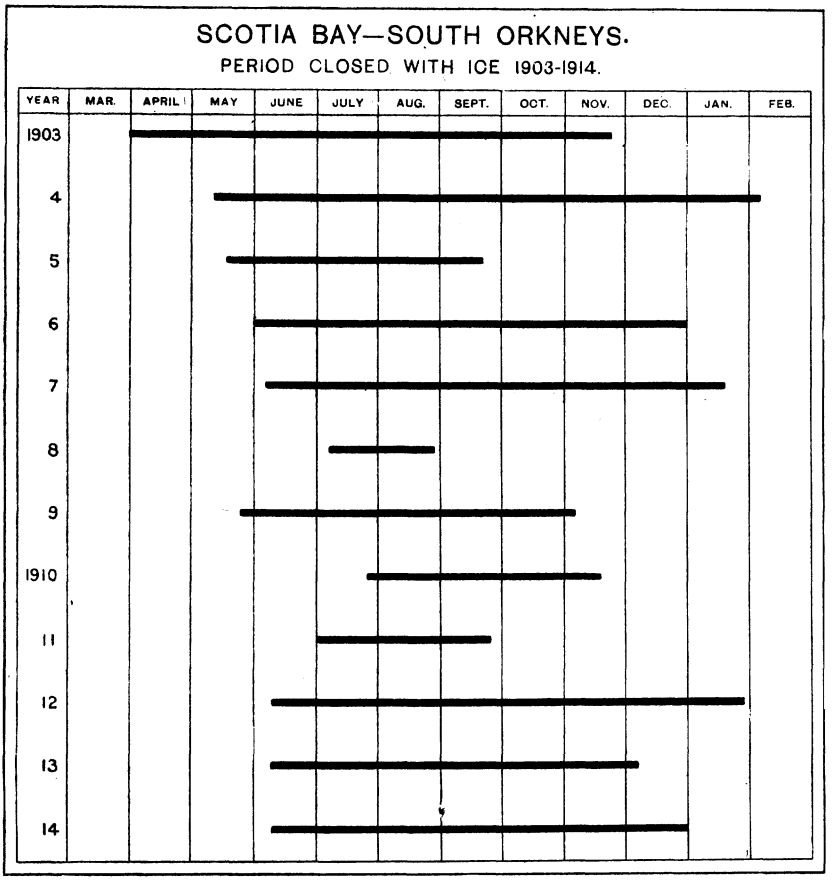


FIG. 6.

the islands are for perhaps several days enveloped in a broad stream of ice. In the very open season of 1908 Captain Larsen met with much pack in the middle of November when in lat. 59° S., long. 26° W., eleven weeks after the ice cleared away from the Orkney group. The effect of these variations in the amount of ice on the air temperature is shown in Fig. 7, which gives the mean monthly temperature of the mildest year 1908, and the coldest year 1915, with the normals for the period 1903–1914.

As it is only ocean swell that causes the disruption of the ice on the south coast of Laurie Island, the break up of the ice is an index that the

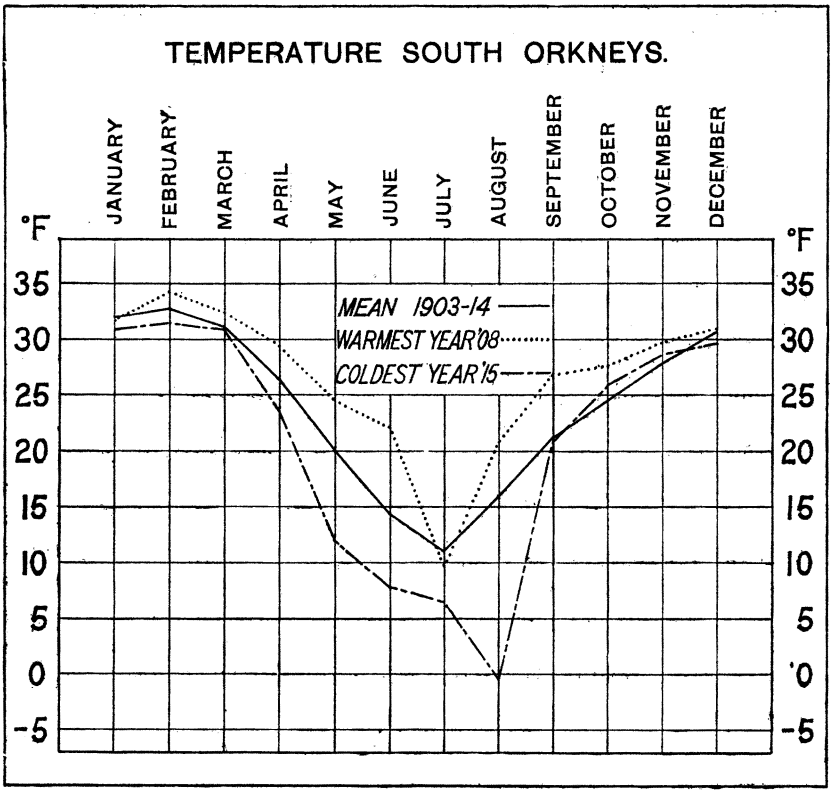


FIG. 7.

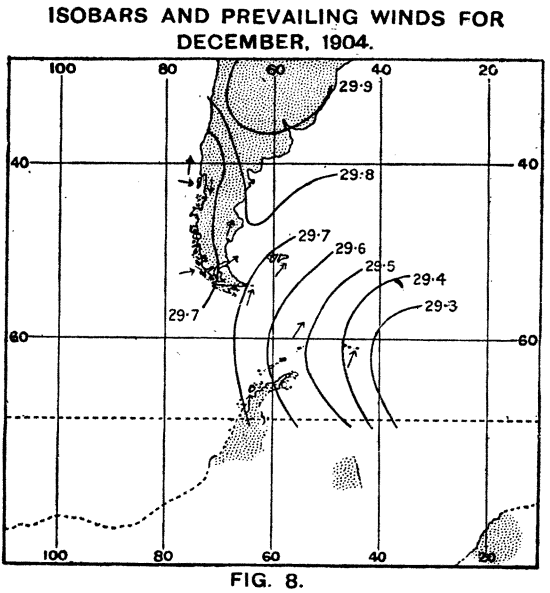


FIG. 8.

seas are clear to the west. The quantity of ice flowing past the South Orkney group must largely depend on variations in the barometric gradient between the high pressure over Graham Land and the low pressure in Weddell Sea. In November, for example, the seas in low latitudes are often clearer of ice than in December, as there is in the latter month a marked tendency for south-west winds, due to the intensification of the gradient between these two "action centres of the atmosphere." Such summer months as February 1903, December 1904, and February 1905, when the pack was met to the north of the South Orkneys, are always associated with strong southerly and south-westerly winds, which bring the ice-belt normally located on these meridians in about 64° S., some 300 miles or more to the north. The distribution of barometric pressure and prevailing winds is shown in Fig. 8 for December, 1904.

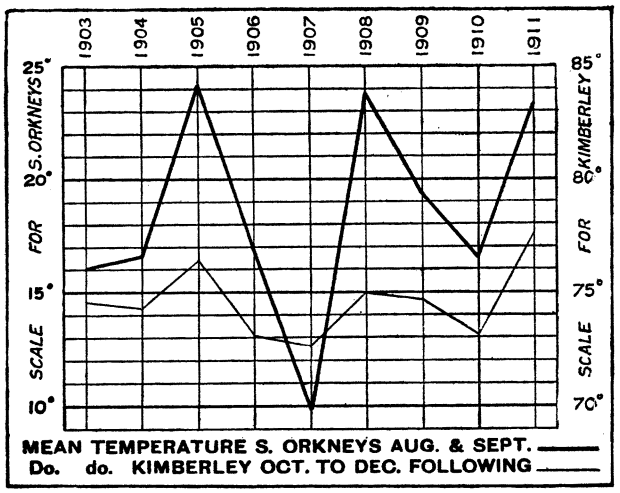
*Correlations.**

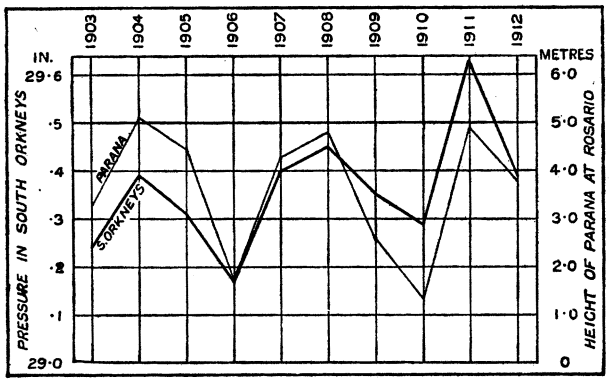
Since the South Orkney observatory was established in 1903 the August and September temperature there has been a direct index of the temperature at Kimberley, South Africa, during the three months following. The temperature during August and September at the South Orkneys is largely dependent on the ice conditions of the surrounding ocean, and as the ice is moving east-north-east it is feasible to suppose that the temperature prevailing over the South African plateau is related in some way to the antecedent conditions in the great southern ocean.

In the month of December the height of the River Parana at Rosario (lat. 33° S., long. 61° W.) and the mean barometric pressure at Laurie Island, South Orkneys, are intimately related. When the barometric pressure in the sub-Antarctic is high the height of the Parana is also high, and when pressure is low in the far south the Parana is also low. The explanation is that the height of the Parana, as measured at Rosario, really depends on the rainfall over the south of Brazil and adjacent areas, and this is related to the barometric pressure. There is at this time of the year a marked tendency for high pressure to the south and south-east of Cape Horn, and it is not unreasonable to suppose that when the Graham Land lobe of the Antarctic anti-cyclone is intensified the pressure over the interior of Brazil will be correspondingly diminished, and *vice versâ*.

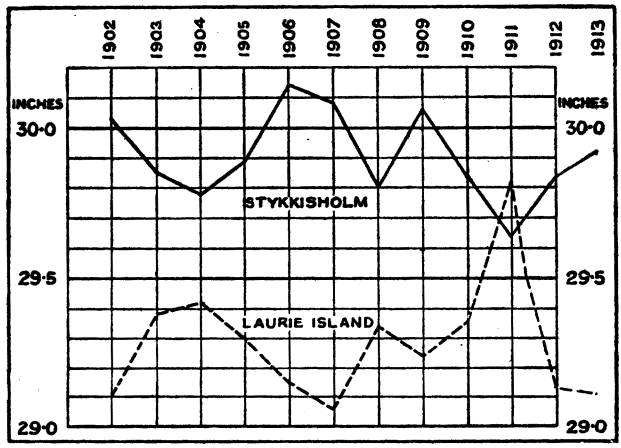
In the month of May a most pronounced opposition is shown between the barometric pressure at Stykkisholm, Iceland, lat. 65° N., and Laurie Island, South Orkneys, lat. 61° S. Stykkisholm, it is almost superfluous to remark, is situated in the vicinity of the great North Atlantic "centre of action," while the South Orkneys are located a little to the north-west of one of the most pronounced Antarctic "centres of action," viz. that in the Weddell Sea. Data from 1902 to 1914 show no break in the sequence (Fig. 9).

* "Southern Hemisphere Seasonal Correlations." By R. C. Mossman. *Symons' Meteorological Magazine*, 1913.





BAROMETRIC PRESSURE AT THE SOUTH ORKNEYS
AND HEIGHT OF THE PARANA IN DECEMBER.



BAROMETRIC PRESSURE IN MAY AT STYKKISHOLM,
ICELAND (LAT. 65° N.) AND LAURIE ISLAND,
SOUTH ORKNEYS (LAT. 61° S.)

FIG. 9.

Among the correlations may be noted a see-saw of weather conditions between the Weddell Sea and the Ross Sea (cf. *Geog. Journ.*, vol. 47, p. 67). The relation that has been established between the winter rainfall on the Chilian littoral and the southern rivers in Argentina on the one hand and the weather conditions prevailing in the Weddell quadrant on the other are also of interest (see *Scot. Geog. Mag.*, vol. 26, pp. 411–416). The track of the cyclonic storms from west to east across the southern portion of the South American continent appears to move in harmony with the northern limits of the ice-belt, so that when the ice is far north the cyclonic track is also north, but when the ice-belt retreats to the south the cyclones also pass to the south. In illustration of this we may refer to the very pronounced see-saw shown between the South Pacific high-pressure area and the corresponding low-pressure area in the Bellingshausen Sea, as when the barometer rises in the one region a fall takes place in the other, and *vice versâ*, this being especially marked in the winter months.

On the Atlantic side the relations between the Weddell Sea low and the coast stations in from 35° to 40° S. were much less marked than on the Pacific; but an investigation carried out some years ago (see *Symons' Meteorological Magazine*, vol. 45, p. 181) showed that the influence of Antarctic conditions affected the weather on the Argentine coast up to lat. 35°.

Temperature and Density of the Sea.

The data used in this connection have been extracted from the observations given *in extenso* in the memoir dealing with the results of the Scottish National Antarctic Expedition * and of the German Antarctic Expedition.† Dealing first with the results of the Scottish Expedition it may be remarked that the stations from which the data were obtained range in latitude from 61° 22′ S. to 73° 30′ S., and in longitude from 10° 52′ W. to 44° 26′ W. The mean position on the thirty-one days during which observations were made is lat. 67° 6′ S., long. 29° 22′ W. The data refer to the months of February and March of the years 1903 and 1904, four sets of observations being made late in February and twenty-seven in March. The density values are those of the water *in situ*, as explained on p. 77 of the publication given below. As it is understood that an elaborate discussion of the *Scotia* data is in course of preparation, only the broader aspects of the subject are here considered.

* The Temperatures, Specific Gravities, and Salinities of the Weddell Sea and of the North and South Atlantic Ocean. By William S. Bruce, LL.D., Andrew King, F.I.C., and David W. Wilton. *Trans. Roy. Soc. Edin.*, vol. 51, Part I. (No. 4). Edinburgh, 1915.

† Brennecke, Dr. W., "Ozeanographische Arbeiten der Deutschen Antarktischen Expedition (Die Eisfahrt)." *Annalen der Hydrographie*, 1913, pp. 134–144.

The results are given in the annexed table:—

Depth in fathoms.	*No. of observations.*	*Temperature. Degrees F.*	*Density* in situ.
0 ...	... 31 ...	... 29·7 ...	... 1·02720
53 * ...	... 10 ...	... 29·7 ...	... 767
100 ...	... 9 ...	... 30·1 ...	... 775
200 ...	... 6 ...	... 32·7 ...	... 787
300 ...	... 7 ...	... 32·5 ...	... 782
400 ...	... 6 ...	... 32·2 ...	... 782
500 ...	... 9 ...	... 32·7 ...	... 774
600 ...	... 2 ...	... 31·1 ...	... 776
700 ...	... 3 ...	... 32·5 ...	... 782
800 ...	... 1 ...	... 32·4 ...	... 780
1000 ...	... 9 ...	... 32·0 ...	... 774
1400 ...	... 4 ...	... 31·9 ...	... 782
1500 ...	... 7 ...	... 31·5 ...	... 791
2000 ...	... 8 ...	... 31·6 ...	... 799
2200 ...	... 1 ...	... 32·4 ...	... 776
2400 ...	... 4 ...	... 31·5 ...	... 777
2500 ...	... 6 ...	... 31·4 ...	... 784

Hence in the first 100 fathoms cold water of a relatively low specific gravity is met with. From 200 to about 1400 fathoms water of Atlantic origin is found, the warmest water and that of lowest specific gravity being encountered at a depth of 500 fathoms. Below 1400 fathoms the temperature with rare exceptions is constant about 31°·5 down to the bottom, the greatest density being at 2000 fathoms, below which water of somewhat lower density is found.

The bottom temperature at depths exceeding 2000 fathoms is remarkably uniform. Of thirteen observations at depths ranging from 2092 to 2680 fathoms eleven varied between 31° and 31°·9, eight of these being either 31°·4 or 31°·5. In two cases (27 and 28 February 1904, lat. 66° 14′, long. 31° 18′ W., and 66° 43′ S., long. 27° 55′ W. respectively) the bottom temperature was 29°·7 and 29°·0. In three cases in which bottom soundings were obtained in relatively shallow water of 1131 to 1400 fathoms the temperature was somewhat higher than in greater depths, being 31°·9. The following are the particulars of these two series of bottom temperatures and densities:—

No. of obsns.	*Mean depth. Fathoms.*	*Mean lat.* ° ′	*Mean long. W.* ° ′	*Temp.* °	*Density.*
3 ...	... 1250	71 44	17 16	31·9	1·02785
10 ...	... 2467	69 10	29 17	31·1	1·02777

In the more eastern parts of the Weddell Sea, close to the Antarctic continent, the bottom water is thus largely mixed with water of Atlantic origin, as shown by its higher temperature and specific gravity when compared with the water filling the greater depths of the western portion of this sea.

From the results of the German Antarctic Expedition the following condensed abstract dealing with the bottom temperatures in various parts of the Weddell Sea has been prepared:—

* Mean of ten observations between 30 and 90 fathoms.

Date.	Extreme positions. Lat. S.	Long. W.	Mean position. Lat.	Long.	No. of obsns.	Mean depth. Fath.	Bottom temp. °C.	°F.
	° °	°	° ′	° ′				
Dec. and Jan. 1911–12	61 –74½	27 –33½	68 45	29 28	8	1802	−0·33	31·5
Jan. and Feb. 1912 ...	75 –77¾	31½–41	76 46	35 03	7	308	−1·89	28·6
Mar. to Aug. ,, ...	72½–67	36 –45	71 28	43 37	11	2125	−0·62	30·9
December ,, ...	62½–60	36½–38	61 03	37 19	6	1618	−0·32	31·5

The bottom temperatures thus agree very closely with those of the *Scotia* over the areas traversed by both expeditions. In higher latitudes from 75° S. to Prinz Regent Luitpold Land the bottom temperature is very low in the shallow water lying over the continental shelf.

Surface Temperature and Density.

The mean sea surface temperature and density observed during the two cruises of the *Scotia* were as follows, 209 observations being utilized. The air temperature is appended for comparison:—

Month.	Mean lat. S.	Mean long. W.	Mean temp. of sea.	Mean of air.	Mean density.
	° ′	° ′			
Feb. 1903	64 0	29 45	30·0	27·8	1·02673
Mar. 1903	64 1	40 52	29·4	25·0	1·02705
Mar. 1904	70 18	17 47	29·7	25·0	1·02727

Hence in comparatively high latitudes the sea temperature in late summer and early autumn is considerably higher than that of the air.

A point of some little interest refers to the northern limit of water of Antarctic origin. To throw light on this question I have examined the sea temperature observations taken on the voyages of the *Scotia* and of the various relief expeditions to the Argentine station on Laurie Island. These relief observations were carried out on various dates from December to February, but confining the inquiry to those effected in the month of February (when the sea and air temperature are at their annual maximum) we obtain the following positions, in which the sea temperature fell to 2° C. (35·6° F.) or below. The reading on 30 January 1903 is also given. The temperatures and positions are those at noon on the dates specified.

Date.	Lat. S.	Long. W.	Sea temperature. °C.	°F.
	° ′	° ′		
1903 Jan. 30	57 2	47 15	1·7	35·1
1904 Feb. 12	58 53	50 40	1·7	35·1
1908 Feb. 16	59 0	49 16	1·8	35·2
1909 Feb. 6	60 7	45 10	2·0	35·6
1911 Feb. 9	58 41	48 43	1·8	35·2
1913 Feb. 10	58 37	47 44	1·9	35·4

Thus the region in which polar water is encountered has varied through three degrees of latitude in a mean position longitude 48° W. In the relief expedition of 1906 the sea surface temperature did not fall to 2° C. until a position 59° 11′ S., 46° 6′ W. was reached, and that as early as December 22. Reference to the diagram showing the period during which Scotia Bay was closed with ice indicates the close relation that obtains between the two classes of phenomena.

Surface Temperature of the Sea at the South Orkneys.

The mean monthly temperature of the sea and the corresponding air temperatures are shown in the annexed table. The data refer to the seven years 1904 to 1910.

	Sea temperature. °	*Air temperature.* °	*Difference of air from sea.* °
January	32·0	32·5	+0·5
February	32·2	33·1	+0·9
March	32·1	31·6	−0·5
April	30·7	27·5	−3·2
May	29·3	19·6	−9·7
June	28·8	15·3	−13·5
July	28·8	9·7	−19·1
August	28·6	15·2	−13·4
September	28·9	19·2	−9·7
October	29·4	25·1	−4·3
November	30·0	29·4	−0·6
December	31·5	30·6	−0·9
Mean	30·2	24·1	−6·1

The mean annual temperature of the sea surface is 30°·2, and shows a range between the months of 3°·6 Fahr. The sea temperature is highest 32°·2 in February and lowest 28°·6 in August. In January and February the surface temperature of the sea is slightly lower than that of the air. In all other months it is higher than that of the air, the excess being small in March and December and large in the winter months.

Depth of the Weddell Sea.

The general depth of the Weddell Sea except near the land is between 4500 and 5000 metres or 2500 fathoms. Shallow water is shown between the South Sandwich group and the South Orkneys, while close to Coats Land soundings of 161 and 159 fathoms were obtained 2 miles from the shore. Relatively shallow water was also found to the east, indicating an extension of the Antarctic continent in that direction, and shallow water was also found by the German expedition to the south of 75° S. (see general map).

Deep-sea Deposits.

In the Weddell Sea south of 60° S. the bottom deposit is either blue mud approximating to red clay, or blue mud and terrigenous deposits.

Further north we enter the area of diatom ooze which markedly contracts west of the 25th meridian. Within the area of blue mud most of the material carried off Antarctic lands is deposited through the gradual dissolution of the icebergs. The area of blue mud approximating to red clay extends furthest north not far from Bouvet Island, a little to the west of the meridian of Greenwich, on which longitude the greatest northern extension of the polar water occurs.

As showing the lowering effect on the sea temperature of this ice-drift,

it may be noted that the isotherm of 2° C. (35°·6 Fahr.) on the Greenwich meridian in summer lies in about 51° S., whereas in the vicinity of the South Shetland the same sea temperature is not reached until 62° S. on the meridian 60° W.

Magnetic Observations.

Absolute determinations of the magnetic elements were commenced by the writer in May 1903, and continued by him in this form until the end of 1904. A discussion of the 1903 data by Dr. Chree, F.R.S., appears in Vol. 2 of the *Scotia* results, while the results for the year following when the station was carried on under Argentine auspices are discussed by Mr. L. G. Schultz in Vol. 16 of the *Anales of the Oficina Meteorológica Argentina*. In January 1905 automatic methods of registration were introduced, and the data down to the end of 1912 are quoted in Part II., Vol. 17 of the above *Anales*, pp. 173–314. The following comparison from hourly records for the years 1905 to 1912 will be sufficient to indicate the annual march of the magnetic elements.

Year.	*Declination.*	*Horizontal force.*	*Dip.*	*Horizontal intensity.*	*Total force.*
	° ′		° ′		
1905	5 16·0 E.	0·25667	54 31·0	0·25558	0·02358
1912	4 44·6 E.	0·25334	54 26·0	0·25256	0·02110

Tides.

The tidal observations made at Laurie Island, while the *Scotia* was frozen in from March to November 1903, are discussed by the late Sir George H. Darwin, who remarks that the tide seems to be normal for a place in the Southern Ocean. "The semi-diurnal tides are considerable, but the solar tide is unusually large compared with the lunar tide, the ratio being 0·6 as compared with 0·465 of the equilibrium theory. The semi-diurnal tides are almost exactly 'inverted,' so that low water occurs very nearly when the moon is on the meridian" ('*Scotia* Reports,' vol. 2, 'Physics,' pp. 321–324).

Before the paper the PRESIDENT said: Mr. Mossman, who is to give us a paper on the Weddell Sea, has been in that inhospitable region with Dr. Bruce. He has lived for some time in the South Orkneys, and he has made a particular study of the meteorological conditions of that portion of the globe.

(*Mr. Mossman then read the paper printed above and a discussion followed.*)

Dr. H. R. MILL: It is a very great pleasure for me to be here. Mr. Mossman is one of my oldest friends and colleagues, and he is the only man at present in this country who has had experience of meteorological observations in those regions. It was he who as a member of the staff of the *Scotia* founded the meteorological station in the South Orkneys, and he remained there during the time when the *Scotia* was making her second trip in the Weddell Sea, so that he spoke from experience, which his modesty hardly let you perceive, when he referred to the extremely unpleasant conditions of the winter there. I am