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A

BAROMETER MANUAL

FOR THE USE OF SEAMEN;

WITH AN APPENDIX

ON

THE THERMOMETER, HYGROMETER, AND HYDROMETER.

Issued by the Authority of the Meteorological Council.

THIRD EDITION.

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A

BAROMETER MANUAL

FOR THE USE OF SEAMEN.

THE BAROMETER.

Description of the Instrument and Instructions for its Management.

The barometer is an instrument with which to measure the variations in the weight or pressure of the atmosphere. It consists of a glass tube closed at one end, which is filled with mercury, all air being carefully excluded; the tube is then inverted, and its open end immersed in a small cistern, also containing mercury, so as to prevent air entering the tube. Great care is taken to exclude the air, as its presence even in minute quantity will vitiate the readings of the instrument. The pressure of the atmosphere on the surface of the mercury in the cistern maintains the mercury in the tube at a height which corresponds to that pressure, and measurements with the instrument are made by reading the height of the column in the tube above the surface of the mercury in the cistern. English instruments are graduated in inches and decimals of an inch, the average height at the sea level being rather less than 30 inches, though the mercury sometimes rises to nearly 31 inches and falls below 28 inches.

In handling barometers it should be remembered that they are delicate and expensive instruments. The result of rough treatment is breakage; and for scientific purposes, observations with an instrument repaired, and not verified by comparison with an instrument whose error is known, are almost useless.

The barometer should hang where it can swing freely, so as always to take up a truly vertical position; it should be carefully protected from injury, out of the reach of persons passing near it, and fixed in a convenient place for observing, if possible, with the light coming from behind the observer, and where it is not liable to considerable changes of temperature, and therefore away from the influence of sunshine or the direct heat of fires or lamps.

A bracket and screws for suspending the barometer are supplied with it. The bracket having been screwed up, the instrument

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should be carefully lifted out of its box, the hinged part of the suspension arm bent back, and the barometer slipped into the bracket. The mercury will then fall gradually, and the instrument will usually be ready for observation in about an hour; but as local temperature affects the instrument slowly, it may be well not to record observations from it for some hours after first fixing. Sometimes in a new tube the mercury does not readily quit the top of the tube. If, after an hour or so, the mercury has not descended, tap the cistern end rather sharply, or make the instrument swing a little in its gymbals, which should cause the mercury to rise and fall in the tube. If this method does not succeed, the force of the tap must be slightly increased, but violence must never be used.

Whenever it may be necessary to take down a barometer and place it in its box, first lift the instrument out of the bracket, and bring it gradually into an inclined position, to allow the mercury to flow very gently up to the top of the glass tube, avoiding any sudden movement which would cause the mercury to strike the top of the tube with violence, the absence of air making the force of the blow little different from that of a solid rod of metal, so that it might break the tube. The barometer should then be taken lengthwise and laid in its box. To be carried with safety it should be held with the cistern end upwards or lying flat, and it must not, on any account, be subjected to jars or concussions.

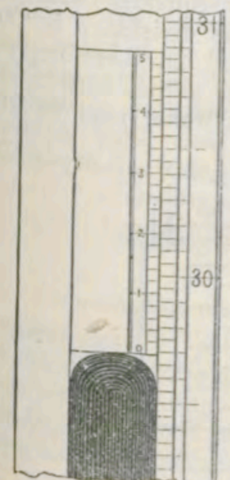
Experience shows that it is advisable to give some directions as to packing barometers. If the instrument is to be sent by rail or other conveyance, and is thus liable to be handled by persons unacquainted with its delicate and peculiar construction, it should, after having been placed in its box as directed, be enclosed in a packing case with two or three inches of soft elastic packing all round it, such as hay, straw, shavings, tow, or paper-cuttings. To avoid concussion, the lid of the case should not be nailed down, but always fastened with screws. The address label should be pasted or nailed on before the lid is screwed down, and at the end of the case which is next the cistern of the barometer, and it should be marked "Glass and "fragile instruments. Keep this box lying flat, or carry it this "end upwards." If two or more barometers be packed together, the cisterns should all be placed at this marked end of the case. Barometers should be sent by passenger train, or by whatever route or conveyance affords the means of transit least likely to lead to rough usage. Transhipment or change of conveyance should be avoided if possible.

Method of Reading the Barometer.

To facilitate taking accurate readings of the barometer, a small moveable scale, called a "vernier," so called after its

inventor Pierre Vernier (A.D. 1630), is attached to the instrument as shown in Fig. 1.

Fig. 1.



The general principle of this contrivance is that a given length of the vernier, equal to a certain number of divisions of the fixed scale, is divided into one more or one less than that number of divisions. In standard barometers the fixed scale is divided into inches, tenths, and half-tenths, each of which last is therefore ·050 of an inch. Twenty-five divisions of the vernier are made to coincide with twenty-four of the smallest divisions of the fixed scale; therefore a space on the scale is larger than a space on the vernier by the twenty-fifth part of ·050, that is to say by ·002 of an inch.

The vernier is moved by a rack and pinion which ends in a milled head. To set the vernier for reading, turn the milled head of the pinion so as to bring the lower edge of the vernier exactly on a level with the top of the mercurial column. When set properly, the front edge of the vernier, the top of the mercury, and the back edge of the vernier, must be in the line of sight, which line will thus just touch the middle and uppermost point of the convex or curved surface of the mercury in the tube. Great care should be taken to acquire the habit of setting the vernier with the eye exactly on a level with the top of the mercury, that is, with the line of sight at right angles to the tube, which, while the observation is being made, should hang freely in a truly vertical position, the instrument not being disturbed by being held or even touched; because any inclination will cause the column to rise in the tube.

A piece of white paper placed behind the tube to reflect the light assists in setting the vernier accurately, and at night a small bull's-eye lamp may for this purpose be held so as to throw a strong light on the paper.

The mode of reading off the height, when the vernier has been set, may be learned from a study of the diagrams, Figs. 2 and 3, in which A B represents part of the scale, and C D the vernier, the lower edge of which, D, has been brought to coincide with the top of the mercurial column. The scale is readily understood; B is 29·000 inches; the first line or division above B is 29·050; the second line or division 29·100, and so on. The first thing is to note the scale division just below D, and the next is to find out the division of the vernier which is in one and the same line with a division of the scale. In Figure 2 the lower edge of the vernier, D, is represented in exact coincidence with scale division 29·5; the barometer therefore reads 29·500 inches. Studying it attentively in this position it will be perceived that while the top C again coincides with a line on the scale, the other divisions of the vernier are more or less separated from the divisions of the scale nearest to them. As was before stated one division of the vernier is ·002 inch smaller than one division of the scale, consequently with the vernier in the position shown in Fig. 2 the division *a* is ·002 inch below the nearest line, *z*, of the scale. If, therefore, the vernier be moved upward, so as to place *a* in a line with *z*, the edge D would be raised ·002 inches, and it would read 29·502,

Fig. 2.

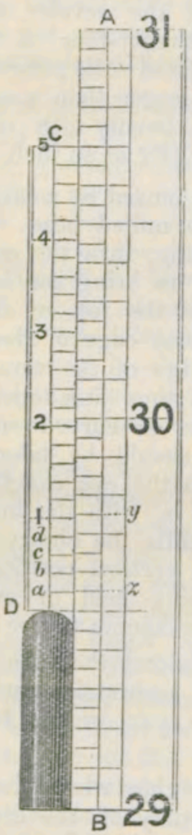
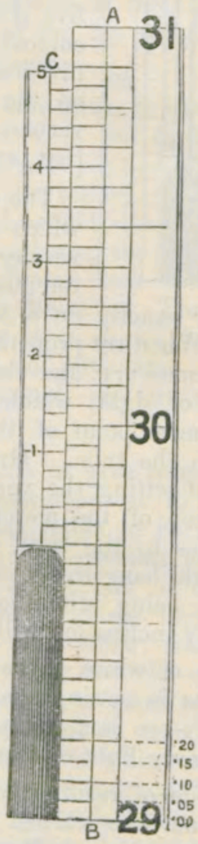


Fig. 3.



and this would be the height of D on the scale. In like manner it is seen that *b* on the vernier is ·004 inch below the line next above it on the scale: *c*, ·006 inch below that next above it; *d*, ·008 inch from that next above it; and 1, on the vernier, is ·010 below *y* on the scale. Hence, if the lines *b*, *c*, *d*, and 1 be moved in succession into line with the divisions next above them, D would be raised ·004, ·006, ·008, and ·010 in succession, and would read 29·504, 29·506, 29·508, and 29·510. Thus, coincidences of lines on the vernier and the scale at the numbers 1, 2, 3, 4, 5, on the vernier, indicate that D is raised above the scale line next below it by 1, 2, 3, 4, or 5 hundredths, and

coincidences at the intermediate lines mark the intermediate even thousandths of an inch.

The application of this will be seen from Fig. 3 (p. 6). The bottom of the vernier D having been brought into coincidence with the top of the mercury, the scale line just below D is 29·650. Looking carefully up the vernier, the third line above the figure 3 is seen to lie evenly with a line on the scale. The number 3 indicates ·030, and the third subdivision ·006; so that D is ·036 above the scale line next below it, and thus we get—

Reading on scale	... ...	29·650
Reading on vernier	... ...	{ ·030 ·006

Actual reading or height of mercury 29·686 inches.

Sometimes two pairs of lines will appear to be coincident, in which case the intermediate thousandth of an inch should be set down as the reading. Thus, suppose coincidences appear corresponding to 29·684 and 29·686, then 29·685, half way between them, should be adopted.

The Meteorological Council have adopted a form of vernier which allows of barometrical readings being taken to the nearest half-hundredth, or 0·005 of an inch. The divisions of the fixed scale are each 0·050 inch; nine of these are taken as the length of the vernier, which is therefore 0·45 inch. This length is divided into ten equal parts, consequently each division of the vernier is ·045 inch. Hence the difference of length between a division of the scale and one of the vernier is

$$·050 - ·045 = ·005 \text{ inch.}$$

Corrections of Readings of the Barometer.

As the column of mercury lengthens when heated and shortens when cooled, it is necessary to apply to the readings of the instrument the Correction for Temperature, to show what the reading would have been at the temperature of 32° F., which has been adopted as the standard temperature to which all barometrical readings are reduced. A similar correction is also required to compensate for the variations of temperature of the brass scale. It is therefore essential to take, and register, a careful reading of the thermometer fixed to the instrument, usually called the attached thermometer, whenever an observation of the barometer is made. When the thermometer attached to the barometer is above 28°, the correction, for which a table will be found in the Appendix (p. 45), must be subtracted, and when at, or below, 28°, must be added.

The readings taken on board ship, where the temperature is usually above the freezing point, will therefore commonly be higher than the values given on charts which show the mean height of the barometer, corrected for temperature, the difference depending on the temperature at which the barometer on boar' happens to be at the time the reading is taken. For a temperature of 80° and a barometrical reading of 30 inches, the correction, to be subtracted from the observed height, would be 0·138 inches.

The marine barometer which is issued to observers by the Meteorological Office is so constructed as to obviate the necessity for applying corrections, either for capillarity, which tends to depress the mercury in the tube, or for the varying quantity of mercury in the cistern, which are required for some barometers. Where such corrections are needed their amount is commonly engraved on the instrument.

As the pressure of the air is reduced as we rise above the sea level, a correction of the barometer readings is also required to obtain the pressure at sea level. This amounts to about ·001 inch for each foot above the sea, and is always to be added. On board ship, the height of the barometers above the sea level being usually small, this correction will commonly be unimportant, but in some of the large ocean steamers the instrument may be 30 or 40 feet above the sea, and in such cases the correction for altitude should be applied.

BAROMETRICAL PRESSURE.

Connexion of Changes of Barometrical Pressure with Changes of Weather.

All wind is air in sensible motion, owing to differences of pressure in the atmosphere at different places, supposed to be at the same level; the force and dangerous character of the wind, as well as the changes of weather generally, being closely related to the amount of the disturbance of pressure which accompanies or causes them, and to the rapidity with which those disturbances take place. The barometer furnishes the seaman with the means of ascertaining with considerable certainty both the magnitude of these disturbances and the manner in which they are occurring, and it is the object of this Manual to explain how this knowledge may be best obtained and applied.

If readings of the barometer be taken carefully and regularly at equal intervals of time, it will be found that consecutive readings will rarely exactly coincide with one another. By such observations the changes which take place from hour to hour and from day to day in the pressure of the atmosphere may be observed, and useful indications obtained of the approach of disturbances likely to be accompanied by strong winds and storms.

The barometer should therefore be set and read at regular hours, if possible at 4-hour intervals, or in doubtful weather recorded more frequently, and the readings entered in the log. This is of primary importance, for if such a record is not kept, the person who consults the barometer will have no means of knowing when the instrument was last set, or at what rate any change he may notice is taking place.

The changes of pressure shown by the barometer may conveniently be classed as regular or irregular in their occurrence, or, in other words, periodical or non-periodical. The periodical changes of pressure, which depend on the time of the day or year, are hardly connected with changes of weather, it being the non-periodical which specially call for attention, as being indicative of probable strong winds or dangerous storms.

Influence of Temperature on Barometrical Pressure.

All changes in the pressure of the air, whether periodical or non-periodical, depend mainly on the changes of temperature, which take place at different hours of the day, or at the various seasons of the year, or arise at different places on the earth from various causes, among which may be mentioned, position with respect to latitude, distribution of land and sea, greater or less abundance of cloud or rain or quantity of vapour in the air. Speaking generally, since air expands with heat and contracts with cold, the result of any place being more heated than its neighbourhood is that the air over it expands, and the higher strata flow away from it over the surrounding less heated area. Conversely, over a relatively cold area the air will contract, and the upper strata will flow in towards it from the neighbouring areas. Over those tracts from which the air thus flows the pressure will be reduced, while over those to which it flows the pressure will be increased.

The accompanying charts (Plates I. and II.) to which frequent reference will be made hereafter, and which were drawn in 1884, show the mean barometer pressure over the globe for the months of January and July respectively. On these charts lines are drawn, showing where certain barometrical pressures indicated by the figures upon them are observed. These lines are termed isobaric lines, or isobars, because they pass over places having equal barometrical pressure, and they are here given for each tenth of an inch of the barometer.

From these charts it will be seen that, speaking generally, in both hemispheres, in the winter, the barometer is higher over the land, which is then colder than the sea; and lower over the sea, which is then warmer than the land. In the summer the barometer is lower over the great continents, which are then relatively hot, and higher over the sea, which is then relatively cool. In the Southern Hemisphere these changes are not nearly so marked as in the Northern. The summer and winter occurring at opposite times of the year in the North and South Hemispheres, the greatest development of high pressure in the Northern Hemisphere is seen in the January chart, and in the Southern Hemisphere in the July chart, and *vice versâ*.

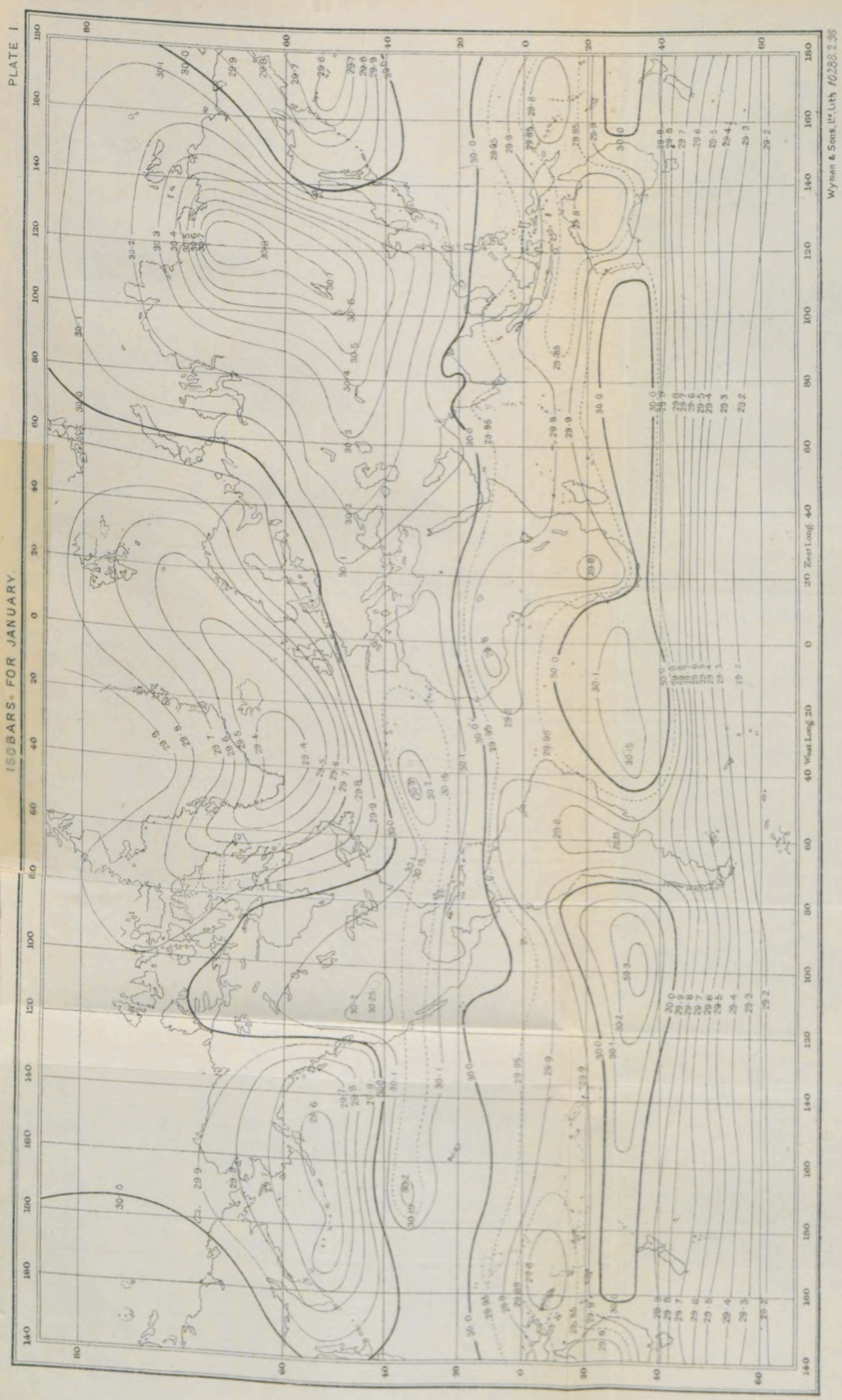
Over the Equator, and between the tropics, where the temperature is always comparatively high, the barometer is low relatively to the neighbouring zones just beyond the tropics, where the temperature is relatively low, and the barometer is high.

The variations of pressure which thus arise over certain tracts of sea and land are related to permanent winds, such as the Trades, and also to periodical winds, such as the Monsoons, those last-named following a corresponding periodical change of pressure over the tracts where they are established.

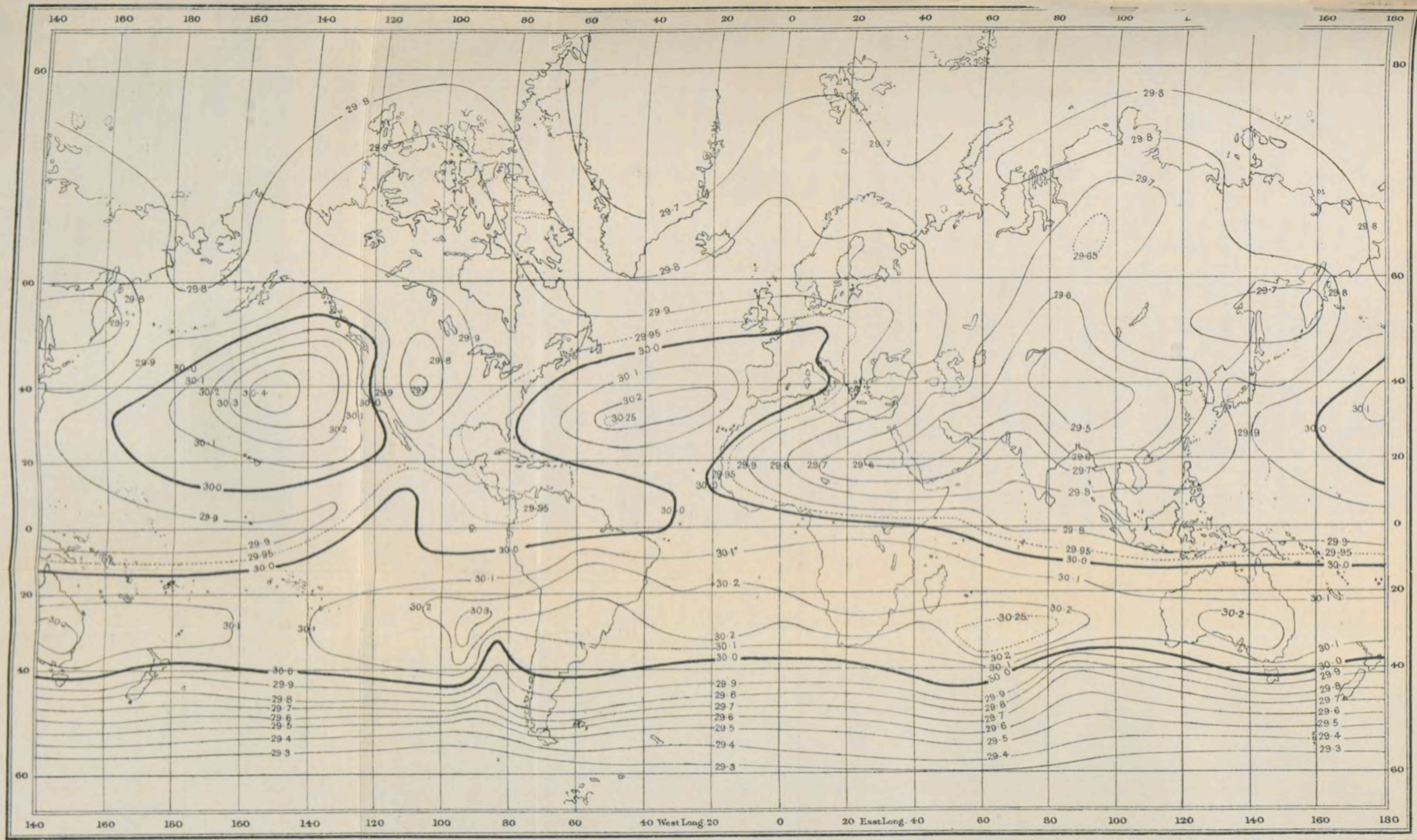
Distribution of Mean Barometrical Pressure.

Before proceeding to consider more at length the relations which exist between winds and barometrical pressure, it is desirable to convey to the seaman a general conception of the usual distribution of pressure over the globe, and of the readings he may expect to obtain, as well as of the inferences which he may deduce from his actual observations.

With this object it is necessary again to refer to Plates I. and II., on which are shown the average or mean barometrical pressure (reduced to the sea-level and for a temperature of



ISOBARS FOR JU



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32° Fahrenheit*) over the several oceans and seas. One chart is for the month of January; one for the month of July; these months having been selected because in them the pressure differs in opposite directions most widely from the mean of the year. It will not be difficult from these to estimate with fair accuracy the probable mean pressure for any of the intervening months.

The main features brought out by an examination of these charts are that over the sea the pressure is more uniform throughout the year than over the continents, and that, roughly speaking, the ocean, the part of the earth's surface which more immediately concerns the seaman, may be divided in respect of barometrical pressure into five great areas.

First, there is a belt of moderately low pressure over the equatorial regions. Then North and South of the equatorial region, are two belts of high pressure. Proceeding to the higher latitudes, we find two areas of low and diminishing pressure; a marked feature of the great Southern Ocean being a zone of low pressure forming a complete circuit of the globe, which, during the entire year, on the parallel of Cape Horn is indicated by an average depression of the column of mercury to 29·50 ins., or fully half an inch below the pressure prevailing generally over the navigable oceans.

In the equatorial parts of these great oceanic areas the barometer stands at, or close to, 30·0 inches; in the Atlantic Ocean for 10° of latitude on either side of the Equator the yearly mean is 29·97 ins. From the tropics to about the 40th parallels of North and South latitude, the barometrical readings are above

* The land observations have, in all cases, been corrected to the level of the sea, and both land and sea observations have been reduced to the temperature of 32° Fahrenheit. For purposes of comparison between the charts and barometer readings, as actually observed, it is therefore necessary for the navigator to allow for the temperature correction, which, as the readings will not vary greatly from 30 inches at the sea-level, will amount to about 0·014 of an inch for every 5° of temperature above or below 28½°, and should be added to the values shown on the charts, or subtracted from his own observations, according to the following table:—

Temp. by Attached Thermometer.	Correction. Height of Barometor 30·0 inches.	
35°	0·018	Add to values on charts, or Subtract from observed values.
40	0·031	
50	0·058	
60	0·085	
70	0·111	
80	0·138	
90	0·164	

For example, in the Atlantic Ocean on the Equator, with the barometrical line of chart 29·900, and the temperature 80° Fahr., the Navigator's barometer would be 30·038.

When the air temperature is below 28½° F. the corrections must be subtracted from the values on the charts, or added to the observed values, to admit of proper comparison.

See also page 7, on corrections of readings of the barometer.

30·0 inches, and in the central parts of the oceans readings as high as 30·2 are found over large areas.

Proceeding into the higher latitudes North and South of the parallels of 40°, the pressure diminishes, and, as before stated, markedly so in the Southern Hemisphere, for on the parallel of the southern part of New Zealand, lat. 45° S., the mean pressure during the year is not more than 29·70 ins., and on the parallel of Cape Horn, lat. 55° S., is about 29·50 ins. On the 70th parallel, as far as the available observations indicate, the barometer scarcely reaches 29·0 inches. In mid-winter in the northern part of the Atlantic Ocean, South of Greenland and Iceland, an area of low pressure, 29·4 inches, exists, which disappears in mid-summer, the barometer then standing half an inch higher.

In the British Islands and adjacent waters, proceeding from South to North, the mean barometrical pressure ranges during ordinary weather from 29·95 inches to 29·65 inches in mid-winter, and from 30·0 to 29·80 in mid-summer.

From these charts it will also be seen that during a voyage, made at any period of the year, from England to the Australian Colonies by way of the Cape of Good Hope and thence back to England by way of Cape Horn, the readings of the barometer will, in the average conditions of weather, and in the absence of any disturbing atmospheric causes, have varied as much as seven-tenths of an inch, that is between 30·2 inches, found in the high pressure areas of the North and South Atlantic Oceans, and 29·5 inches, found in the low pressure zone on the parallel of Cape Horn.

On the other hand, in a voyage from London by way of the Suez Canal to Bombay or Calcutta, or to ports in China, the barometer, under similar average conditions of weather, will not in mid-winter (January) stand below 29·9 inches, whereas in mid-summer (July) the readings will range from 30·1 inches in the Atlantic Ocean to 29·55 at the Indian ports, and 29·65 inches in the Chinese ports ; the low pressures last named mainly depending on the high summer temperature of the adjoining great continental masses of land, due to the influence of a nearly vertical sun.

VARIATIONS OF PRESSURE.

Variations of Pressure from Mean Values.

The mean barometrical pressure over the several oceans in the two months (January, July) in which the pressure differs most from the mean of the whole year having been explained, it is important to learn the extent of the variations from the mean values which are likely to be observed, and what is to be inferred from these variations.

In all climates and at all parts of the earth the pressure of the air, and therefore the height of the mercury in the barometrical column, are constantly varying. In the higher latitudes these variations have a range of two inches and more, and the familiar terms "high" and "low" barometer are applied when there is some marked difference in the readings above or below the average value at any place. Moreover, as wind is a direct consequence of alterations in the pressure of the atmosphere, it becomes desirable to discriminate carefully between the varying degrees of importance to be attached, in different seasons of the year and in different latitudes, to any observed high or low barometer, in relation to the winds which accompany, or result from, the alterations of pressure so indicated.

As before stated, changes of pressure may be classed under two heads,—periodical and non-periodical. The periodical changes recur at nearly regular intervals during the course of the day and the year, and the weather may be considered as practically independent of them ; on the other hand, the non-periodical or irregular changes are indicative of disturbances of the atmosphere which cause departures from the regular or average condition, and it is with these that the changes of weather which mainly concern the seaman are directly connected.

Periodical Variations of Pressure.

Of the periodical changes the Diurnal Variation, though small in its amount, chiefly demands the consideration of seamen when navigating in the tropical and adjacent seas, where it is one of the most regular of recurring phenomena.

This diurnal variation of pressure consists of a double oscillation, there being two periods of increase and two of decrease ; the barometer rising from about 4 a.m. to about 10 a.m., then falling to about 4 p.m., and again rising till about 10 p.m., when it once more falls to 4 a.m. The morning maximum is commonly, but not invariably, higher than the night maximum ; and the former usually occurs rather before than after 10 a.m., while the latter tends rather to be later than earlier than 10 p.m. The afternoon minimum is, with rare exceptions, lower than the morning minimum, and occurs rather after than before 4 p.m.

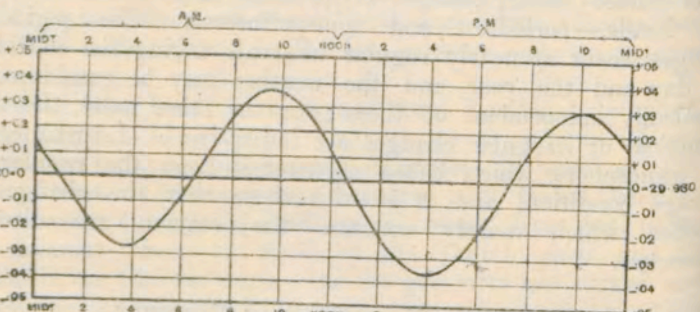
At sea the diurnal variation attains its greatest magnitude within the tropics, and gradually diminishes in higher latitudes, being hardly perceptible within the Arctic or Antarctic circles. The extent of the oscillation of the mercury due to this cause, at any place at different times of the year, depends much on the range of daily temperature, and the times of maxima and minima are influenced by the times of sunrise and sunset. At sea and within the tropics, therefore, the range of temperature and the length of the day not being subject to any considerable change in the course of a year, the diurnal variation does not change in any important feature from one month to another. On land and beyond the tropics it is otherwise, and the daily range of pressure fluctuates both in amount and period accordingly.

In tropical seas the daily range of the barometer between the highest and lowest may be taken at about 0·07 of an inch or 0·08 of an inch, the greatest rise above the mean of the 24 hours being somewhat less than the greatest fall below it. The mean pressure in these seas will be found to occur between noon and 1 p.m., and between 6 a.m. and 7 a.m.

At Calcutta the daily range varies from about 0·14 inch in April and May, when the range of temperature is greatest, to about 0·09 inch in July, when it is least.*

In the British Isles the changes of pressure due to this cause are hardly more than one fourth of those observed in the tropics

FIG. 4.



amounting on the average to about 0·02 inch, so that, unless in very calm settled weather, the daily oscillations can seldom be recognised in the hourly readings of a barometer during a

* The following examples are instructive; the values (in decimals of an inch) indicated by + and − signs, show approximately the mean rise or fall above and below the average reading of the barometer.

Calcutta [22½° N. lat.].			Ascension [8° S. lat.].		Mauritius [20° S. lat.].	
—	Jan.	July.	Mean Year.		Mean Year.	
3½ a.m.	−·019	−·017	3 a.m.	−·020	3½ a.m.	−·018
9½ a.m.	+·076	+·039	9 a.m.	+·035	9½ a.m.	+·030
4½ p.m.	−·051	−·054	3½ p.m.	−·040	3½ p.m.	−·040
10½ p.m.	+·008	+·026	10 p.m.	+·027	9½ p.m.	+·029

single day, though they become quite apparent in the means of such a period as a month.

The diagram (Fig. 4, p. 14), the scale of which is much enlarged, represents the mean curve of daily range of the barometer for the central portion of the Atlantic between lat. 5° N. and the Equator, which may be taken as typical of the daily variation in tropical seas. If, then, in the tropics, the seaman observes in the readings of his barometer any marked deviation from such a curve he may anticipate that some considerable atmospheric disturbance has arisen, and that a change of weather, possibly a hurricane, is impending.

The Annual Variation of pressure is also a well-marked phenomenon within the tropics both on land and sea, following the apparent motion of the sun North and South of the Equator, and giving rise to modifications of the Trade winds, and producing periodical winds such as the Monsoons of the Indian Seas. The extent of the variation thus caused is indicated on the charts. In the tropical seas it amounts to about 0·10 inch between the highest and lowest monthly mean; on approaching the land it becomes much greater, being about 0·30 inch at Bombay, while at Calcutta it reaches 0·45 inch, and in the interior of Asia the yearly variation is as much as 0·80 inch.

As, however, the annual variation takes place very gradually, it has no characteristics which make it of special importance to seamen in relation to possible sudden changes of weather, it therefore calls for no further comment here.

Non-Periodical Variations of Pressure.

The non-periodical changes of pressure, which, as before said, are those immediately associated with changes of weather, next demand notice. The extent of these changes, under ordinary conditions, and taking the average of the various seasons of the year, varies with the latitude, being smallest near the Equator and increasing as we recede from it.

Within the tropics, the ordinary fluctuations of the barometer, including the diurnal variation, seldom exceed three or four-tenths of an inch, except in the event of one of those furious and dreaded revolving storms commonly known as hurricanes, cyclones, or typhoons (according to the part of the globe in which they occur), when the barometer may fall much more, as will be more fully explained hereafter, and in the dangerous part of the storm field may fall to the extent of two inches or more.

At Ascension, in lat. 8° S., the greatest range observed in two years scarcely reached four-tenths of an inch. The highest reading, 30·178, was recorded in June, the lowest, 29·800, in April. Similarly, in the tropical zone of the Atlantic Ocean, between the Equator and 10° N. lat. and between 20° and 30° W. long. (as extracted from a large mass of observations extending over many years), the highest reading, 30·138, was observed in July, the lowest, 29·725, in December, a range of only 0·413 inch.

The range of the barometer gradually increases with the latitude, and appears to reach its maximum—at least in the Northern Hemisphere—between the 60th and 65th parallels; thence towards the pole decreasing. The magnitude of the range in the higher latitudes, as compared to the tropics, is exemplified in the British Islands, where the average range in the course of a month is about 1·7 inch for January, 0·9 inch for July.

Between the years 1841-58, the highest barometer reading at Greenwich was 30·695 inches; the lowest 28·460; the range being 2·235 inches. Older records give a range of 3 inches, 30·9 to 27·9, but these excessive ranges must be considered exceptional, and refer to a long series of years.*

The following tabulated values, arranged according to latitude, have been compiled from all available authorities, and may, under ordinary conditions, and excluding exceptional storms of great severity, such as tropical cyclones, be accepted as the approximate mean range of the barometer, in the months of January and July respectively, over the several oceans :—

——	January.	July.
	Ins.	Ins.
Between 65° and 60° N.	1·70 to 1·80	1·0
60° „ 50° „	1·80 „ 1·50	1·00 to 0·80
50° „ 40° „	1·50 „ 1·25	0·80 „ 0·60
40° „ 30° „	1·25 „ 0·65	0·60 „ 0·40
30° „ Tropic	0·65 „ 0·40	0·40 „ 0·30
Tropic „ Equator ...	0·40 „ 0·20	0·30 „ 0·20
Equator „ Tropic ...	0·20 „ 0·35	0·20 „ 0·35
Tropic „ 30° S.	0·35 „ 0·55	0·35 „ 0·60
30° „ 40° „	0·55 „ 0·80	0·60 „ 1·00
40° „ 50° „	0·80 „ 1·20	1·00 „ 1·60
50° „ 55° „	1·20 „ 1·30	1·75

For the smaller ranges the assumption that the variations of the height of the barometer are of nearly equal amount on each side of the mean reading is sufficiently exact for practical purposes; in the greater ranges it requires modification. An examination of the behaviour of the barometer at Greenwich, between 1841 and 1858 (excluding extraordinary disturbances), goes to show that in January—as typical of the winter months, when the fluctuations are greatest—the mercury falls below the mean reading in the proportion of about five parts of the whole range to a rise above the mean reading of three parts of the

* In the storm of Jan. 26, 1884, a reading of 27·33 ins. was recorded at Ochtertyre, Perthshire, and on Feb. 5, 1870, a reading of 27·33 ins. had also been recorded on board R.M.S. "Tarifa" in 51° 3′ N. 23° 39′ W. The absolutely highest reading on record in these islands is 31·108 inches at Ochtertyre, on January 9th, 1896.

whole range; while in July—as typical of the summer months, when the fluctuations are least—the rise and the fall in the range appear nearly equally divided.

Thus with an average barometer reading in the English Channel of 29·95 inches we should have in the winter, with a range of 1·5 inch, a fall of 0·95 and a rise of 0·55 as representing the lowest and highest barometer (29·00 and 30·50) that might be expected. Under similar conditions in the Southern Hemisphere, when off Cape Horn, with an average barometer of 29·50 inches and a winter range of 1·75 inch, 28·40 and 30·15 would represent the probable lowest and highest readings.

By the aid of these considerations, an estimate can be formed, with a fair approach to precision, from the figures in the above table, and those entered on the isobaric charts, of the probable ordinary range of a high or a low barometer at any place where a vessel may be, from which, when compared with the barometrical readings taken in the vessel, a judgment may be come to whether there is any serious departure in these readings from the mean value of the pressure either in the way of excess or deficiency, and this knowledge, combined with observations of the actual direction and force of the wind, and of the changes that take place in these, will furnish the seaman with the means of guiding his action with confidence, as will be further explained.

WINDS, THEIR CAUSES AND DISTRIBUTION.

Causes which Determine the Force and Direction of the Wind.

The force of a wind accompanying a difference of pressure over two areas is found to be greater as that difference is greater, and it therefore depends not on the mere height of the barometer at the ship, but on the difference between that height and that which subsists over the neighbouring seas. These differences of pressure are spoken of as barometrical gradients ; and the standard for their comparison that has been adopted is the difference of pressure, expressed in hundredths of an inch, in 15 miles of distance. The greater the difference, the steeper will be the gradient, the closer will be the isobaric lines on a chart representing the pressure, and the stronger will be the winds.

But the direction of the wind is governed by another very distinct influence, which it is important to understand clearly, as it fundamentally affects all classes of wind, and calls for special attention in the case of the most dangerous winds, namely, hurricanes or cyclones.

The air, when apparently wholly at rest, and a complete calm prevails, is in truth revolving with great rapidity together with the earth. The velocity of the earth's rotation at the Equator is about 1,000 miles per hour from West to East, and it gradually diminishes towards the poles, where it vanishes. So long as the air remains at rest (relative to the earth's surface), this movement of rotation is not sensible, but it at once becomes effective if the air is impelled to a latitude having either a higher or lower velocity of revolution. In the former case, air possessed of a less velocity from West to East reaches a part of the earth's surface having a higher velocity, and therefore appears to be impressed with a movement from East to West, or contrary to the earth's direction of revolution, equal to the difference between the two velocities, though the friction against the earth's surface of air passing from one latitude to another soon reduces the initial excess velocity of movement, or makes good the deficiency.*

In the Northern Hemisphere, for the reason thus stated, a current of air setting from a lower latitude to a higher gives rise to a South-westerly wind, and a current in the opposite direction to a North-easterly wind. When, therefore, an area of low pressure arises North of the Equator, surrounded by comparative high pressure, the primary tendency of the air to flow from the outside towards the centre of the area of low pressure will be modified so as to impart a more Easterly direction to the wind in the northern half of that area, and a more Westerly direction

* This explanation is sufficient for the purposes of this Manual, though not a complete statement of the laws that govern the movement of the air on the earth's surface, which could not be given in a treatise such as the present.

to the wind in its southern half, the joint influence of which will be to set up a circulation round the centre of lowest pressure from West by South, through East and North, round again to the West. In the Southern Hemisphere a similar circulation would be established, but in the opposite direction. Winds thus circulating round an area of low pressure are spoken of as cyclonic, as they have the characteristic motion of the great storms known as cyclones.

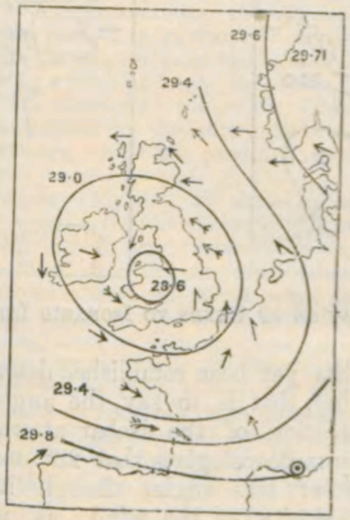
It will readily be seen that in like manner air flowing from an area of high pressure on all sides into a surrounding area of low pressure, will in the Northern Hemisphere develop a circulation in the opposite direction to that caused round an area of low pressure, that is, passing from East by South through West and North back to East. Winds thus circulating round an area of high pressure are termed anticyclonic, because they revolve in a direction opposite to that of the cyclonic winds.

What has been termed Buys Ballot's law, it having been first publicly announced in Europe by Professor Buys Ballot, of Utrecht, is the general statement of the facts thus explained and it may be thus enunciated :—

In the Northern Hemisphere.	In the Southern Hemisphere.
Stand with your back to the wind, and the barometer will be lower on your left hand than on your right.	Stand with your back to the wind, and the barometer will be lower on your right hand than on your left.

In the Northern Hemisphere, whenever we are within or on the borders of an area of low barometrical readings, the wind blows round it in a direction contrary to the movement of the

Fig. 5.



Circulation of the Wind in a Cyclonic System. Northern Hemisphere.

hands of a watch, and whenever we are within, or on the border of, an area of high readings, the wind blows round it in the same direction as watch hands. In the Southern Hemisphere the converse is true in both cases.

Fig. 5 (p. 19) illustrates the application of the foregoing observations to the Northern Hemisphere. It shows the conditions of barometrical pressure, and the direction and force of the wind consequent on the formation of an area of low pressure over the British Isles.

The lines drawn on the map are isobars, which, as before stated, are lines indicating equal barometical readings. The arrows indicate the direction and force of the wind; arrows with one barb signifying light winds, two barbs stronger winds, those representing gales being feathered.

It will be seen that, in accordance with Buys Ballot's law, the wind blows so that at each point the observer with his back to the wind would have a lower barometer on his left hand than on his right. Further, though circulating generally round the isobaric lines, the arrows cut these lines at an acute angle, and generally so as to show an indraft towards the area of lowest pressure.

Fig. 6.

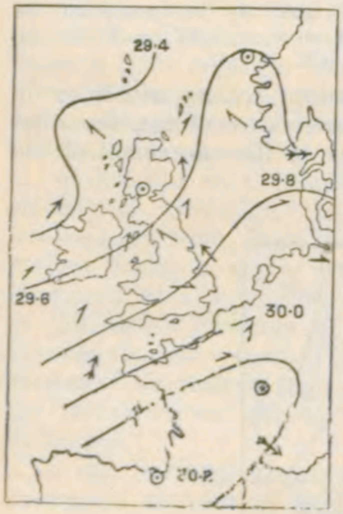
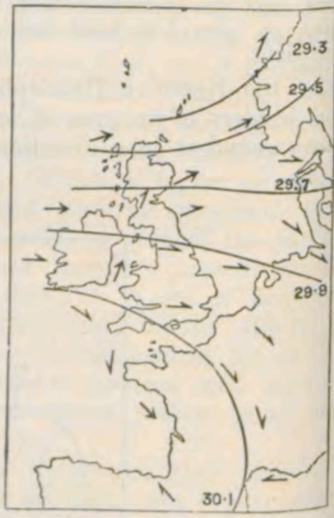


Fig. 7.



RELATION OF WINDS TO ISOBARIC LINES.

No general law has yet been established determining the angle of indraft of the wind, that is to say, the angle which the wind makes with the direction of the isobar at the place, but it is generally agreed by meteorologists that 20° may be taken as a fair average value of this angle, though it certainly varies greatly with the velocity of the wind, as well as with the position as regards the centre of the area of low pressure, and the movement of progression thereof.

Inasmuch as the distribution of barometrical pressure is subject to almost infinite variety and change, the occurrence of regularly formed areas of high or low pressure over any place is comparatively rare, but the more violent the wind the more regular does the distribution of the isobars round the centre of a cyclone tend to become, and whatever be the arrangement of the isobars, the winds will be found to blow along or round them in accordance with the general principles that have been explained, as is shown in Figs. 6 and 7 (p. 20.)

PREVAILING WINDS AT VARIOUS SEASONS OVER DIFFERENT PARTS OF THE GLOBE.

From these considerations it will be seen how a knowledge of the relative distribution of mean atmospheric pressure on the earth's surface at different times of the year, will enable us to indicate the prevailing winds, and, conversely, how a knowledge of the prevailing direction and force of the winds will enable us to indicate the relative distribution of mean atmospheric pressure.

The main features of the relation between the mean barometrical pressure and the prevailing winds over the globe are well described in the following extract from a work published in 1880 under the authority of the Meteorological Council, and entitled "Aids to the Study and Forecast of Weather," by the Rev. W. Clement Ley, and will usefully supplement what has been previously said on these subjects:—*

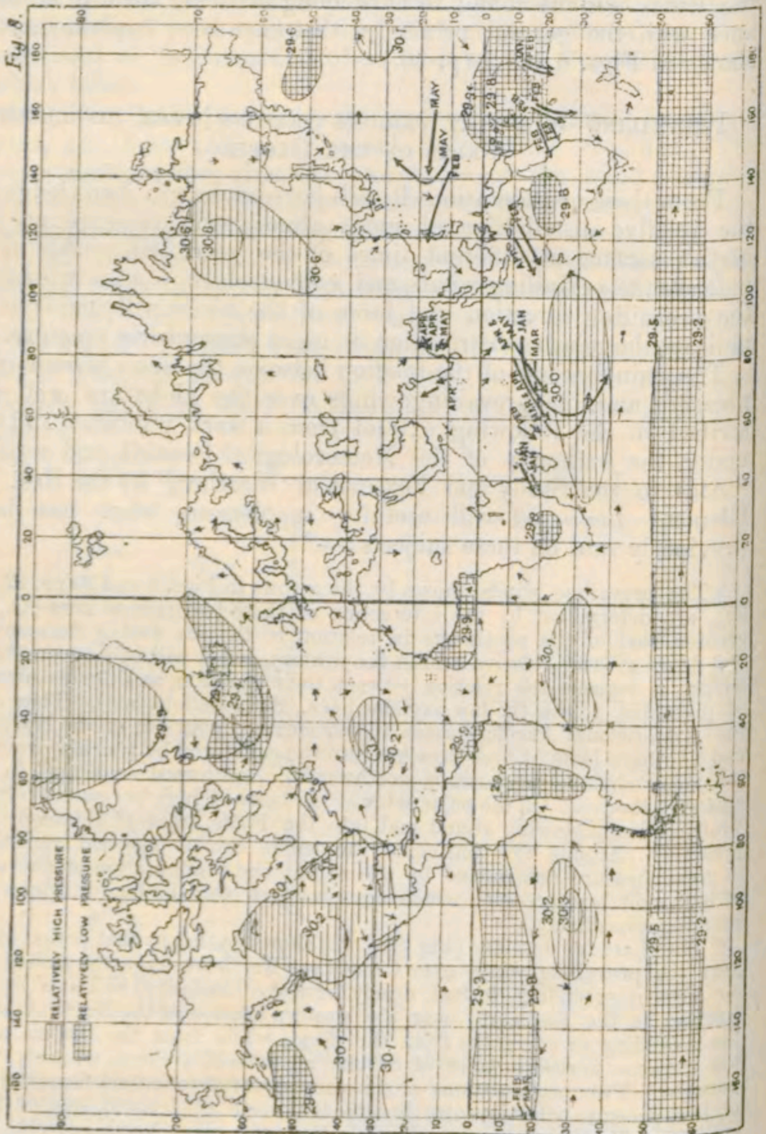
"The prevailing winds, shown by the arrows in Figs. 8 and 9 (pp. 22 and 23), are determined by the interaction of these two general laws (*i.e.*, the greater heat of the continents in relation to the sea during the summer, and their greater relative cold in the winter), and it will be seen that these winds, as regards the relation between their direction, and the distribution of pressures, follow the law explained (*i.e.*, Buys Ballot's law). Thus over the Atlantic and Pacific Oceans the air currents pour out of the Northern and Southern belts of high pressure into the equatorial belt of low pressure, the latter shifting its position northward or southward according to the season of the year. On the polar sides of the belts of high pressure Westerly winds prevail, blowing round and into the Polar areas of relatively low pressure. Around the continents the winds exhibit seasonal variations, in great measure determined by the extent and configuration of the areas of high and low pressure which are produced over the land in winter and summer respectively.

"The chart for January (Fig. 8, p. 22) shows us that at that period of the year the prevailing winds over Canada are North-westerly, the belt of this air current extending, in fact, nearly from the Mississippi to Davis' Straits. Further to the Eastward, over the western portion of the North Atlantic, the prevailing air current is from the West, while from the Azores up to the extreme northern point of Siberia an extensive South-westerly wind prevails. Two prolongations or arms are observed to extend from the area of low pressure whose centre lies to the south of Iceland, one of these stretching North-westward to Baffin's Bay, the other North-eastward over the Arctic Sea. An area of relatively high pressure existing over Greenland, Northerly and North-easterly winds are experienced in the high latitudes of the Atlantic and the Polar Seas. The area of reduced pressure over the northern portion of the North Pacific is somewhat similar to that

* The charts which accompanied Mr. Ley's memoir have been modified and reduced in scale, as shown in Figs. 8 and 9, pp. 22, 23.

over the North Atlantic, but does not extend into such high latitudes. North-westerly winds therefore prevail at this season over the eastern portion of the continent of Asia, sweeping round through westerly and South-westerly to South-easterly winds between Behring's Straits and Vancouver Island. Over the greater part of North America a well-marked area of high pressure exists at this season, the nucleus of which is nearer to the Pacific than to the Atlantic coasts, a fact which is probably due

Fig. 8.



PRESSURE AND PREVAILING WINDS.—JANUARY

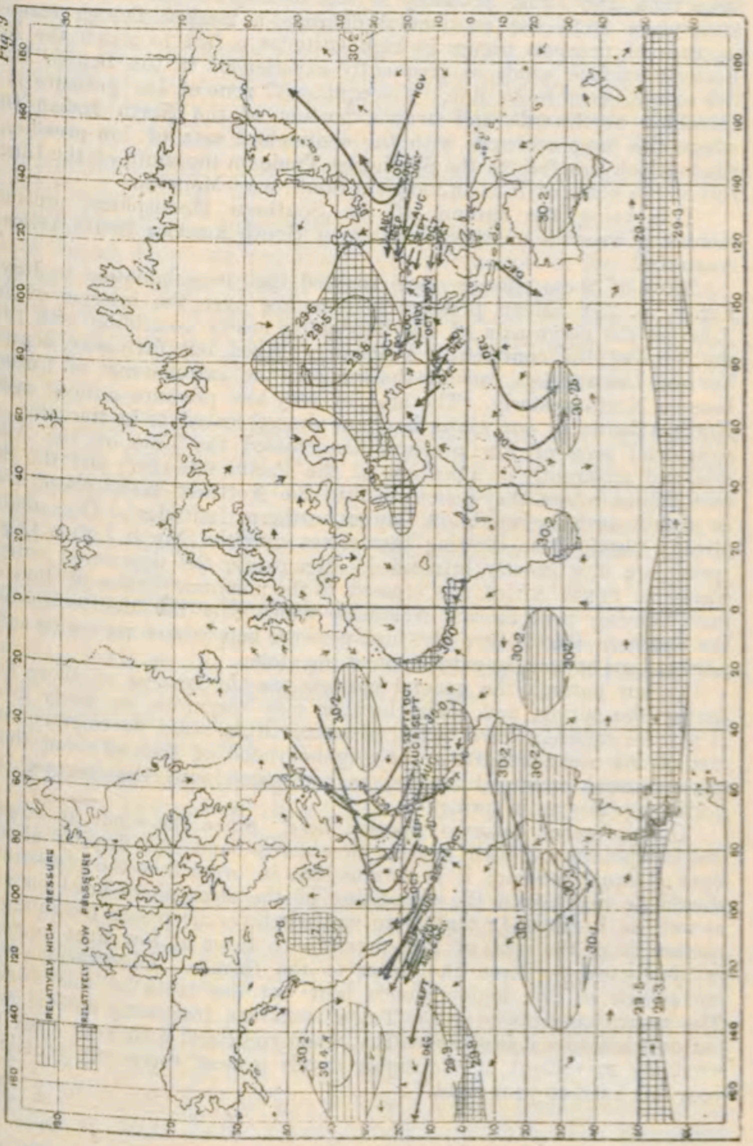
TRACKS OF HURRICANES.—JANUARY TO JUNE.

to the retention or banking up of the cold and dense atmosphere by the Rocky Mountains, which render it less easy for the air to escape westward toward the Pacific than in an eastward direction, where the earth's surface presents fewer obstacles to its movements. A corresponding, but very much greater and more remarkable area of high pressure, covers nearly the whole of Asia. This area has a somewhat similarly shaped nucleus which, probably, for a corresponding reason, lies near the eastern shores of the continent.

"South of latitude 30° N. we find predominant North-easterly winds round the greater portion of the globe, extending in most regions to the Equator. In the Indian Ocean these air currents cross the line, and, changing in their direction in obedience to the law of relation between wind and pressure for the Southern Hemisphere, there blow from North-west, and constitute a North-west "Monsoon," or periodical wind.

"January being a summer month in the Southern Hemisphere, areas of low pressure are exhibited over the interiors of the Southern Continents,

Fig. 9.



PRESSURE AND PREVAILING WINDS.—JULY.

TRACKS OF HURRICANES.—JULY TO DECEMBER.

South America, the southern part of Africa, and Australia, round which the winds necessarily tend to circulate in a direction from the front towards the right hand. These last-mentioned continental districts form at this season interruptions in the Southern Hemisphere high-pressure belt.

"To the South, again, of this belt the mean pressure rapidly decreases, and as far as ships go, south of latitude 40° S., Westerly and North-westerly winds appear to be predominant round the globe, blowing with a force and persistency which has given to this region, in the language of the sailors, the title of the 'Roaring Forties.'

"In the spring of the Northern Hemisphere a great and rapid change takes place in the distribution of mean pressures over that half of the globe. This change is least marked in the oceanic districts of the high-pressure belt. Over the interior of the continents the barometers fall briskly, this change being much the most serious over the southern part of Asia. At the same time, and owing probably to this dislodgment of a portion of the atmosphere from the continental districts, a marked though temporary increase of pressure occurs in high latitudes, a fact to which the North-Easterly surface winds, so frequently experienced in the British Isles at this season, seem to be due. The equatorial zone of low pressure is now travelling northwards, and over a portion of the North Indian Ocean, where this zone coalesces with the continental area of low-pressure, the winds which are felt as the South-east Trade on the south of the Line, are felt on the north of it as an incipient South-west Monsoon.

"This being the autumn of the Southern Hemisphere, pressure is increasing over the southern portion of South America, South Africa, and Australia.

"Most of these changes have reached their consummation in July (see Fig. 9, p. 23). Mean pressure is now low over the interior of North America, the major axis of this depression nearly coinciding with that of the figure of the continent. A similarly shaped, but far vaster, depression lies over Central Asia, causing the winds in the extreme east of Europe to become North-westerly. The area of very low pressure noticed over the North Atlantic in our winter has now almost ceased to be traceable. The equatorial zone of low pressure has crossed the Line on the Atlantic side, and apparently on a portion of the Pacific side also; and the South-east Trades, where they penetrate into the Northern Hemisphere, are felt as South-westerly winds in lower northern latitudes. The conditions already described as showing themselves over the North Indian Ocean in spring are now greatly intensified. Meanwhile the depression noticed in winter in South Africa has crossed to the northern portion of that continent, causing predominant Northerly winds over the Mediterranean. In the Southern Hemisphere the high-pressure belt is now very wide and well marked, and appears to extend round the globe.

"In our autumn the general changes are the reverse of those noticed during the spring, and their character may therefore be easily inferred. It will be sufficient here to call attention to the rapid development of the area of low mean pressure in the neighbourhood of Iceland about the time of our usual autumnal storms, as contrasted with the increase of the northern pressures in spring.

"One inference deserves mention here. Since the winds, in respect of one component of their motion, flow across, and not directly along the lines of equal pressure, it is obvious that in order that the pressure areas should be maintained the circulation of the atmosphere must be vertical as well as horizontal; that is to say, whatever air passes over the earth's surface from the areas of high-pressure to those of low must be restored in upper-currents from the latter to the former. Observations on the movements of the higher clouds bear out the truth of this statement. The return currents over the Trade winds are frequently noticed; and in our own latitudes it is observed that when you stand with your back to the wind the movement of the higher clouds is most commonly a little from your left hand to your right."

WINDS AND STORMS OF THE TEMPERATE ZONES.

WINDS OF THE ATLANTIC OCEAN, WHICH ARE TYPICAL OF THOSE OF OTHER SEAS.

The Atlantic Ocean will supply types of the winds usually met with in other seas. From Fig. 8, p. 22, it will be seen that an area of high pressure occurs in the North Atlantic between the parallels of 30° and 40° North; according to Buys Ballot's law, the wind draws round it, being Northerly on its Eastern, Easterly on its Southern, Southerly on its Western, and Westerly on its Northern side. The wind-arrows on Fig. 8 indicate such a circulation of the air.

A ship, therefore, outward bound from England, say, to the Cape of Good Hope, passes from the North-east to the East and South-east side of an area of high pressure lying to the Westward of her, and as she approaches the coast of Portugal the wind very generally comes from the North-west, gradually shifting to North and North-east as she proceeds to the Southward.

On the other hand, when a homeward-bound ship approaches the Northern verge of the N.E. Trades, she finds that the wind draws to the Eastward, with a rising barometer. As the area of highest pressure is reached the barometer ceases to rise, and the wind dies away. These are the dreaded "Calms," or, as Maury calls them, "Doldrums of Cancer." There being no difference of pressure, there is no wind, and these calms coincide with a large area of high and even pressure, where a ship will experience little or no wind until she has crept to a part of the sea where the pressure commences to decrease.

If, as occasionally happens, it is found that the N.E. Trade gradually turns into a S.E., S., and S.W., wind, it will be understood from what has already been said, that a vessel experiencing these changes has passed round the S.W., W., and N.W. sides of this area of high pressure, thereby avoiding the region of calms altogether.

There is a similar area of high pressure in the South Atlantic, with a corresponding circulation of the wind round it.

The homeward-bound ship, after rounding the Cape of Good Hope, is at the polar edge of the S.E. Trade on the Eastern side of the South Atlantic, just as the outward-bound ship is at the polar edge of the N.E. Trade when off the coast of Portugal (see Fig. 8, p. 22), and the first wind she experiences is from S.W., changing to S. and S.E. as she proceeds to the Northward, which (according to Buys Ballot's law, when applied to the Southern Hemisphere), shows that she has passed along the S.E., E., and N.E. sides of an area of high pressure.

Again, the outward-bound ship, as she draws towards the Southern verge of the S.E. Trades on the Western side of the South Atlantic, very generally experiences changes of wind to

N.E., N., and N.W., which are the winds met with in the Southern Hemisphere on the N.W., W., and S.W. sides of an area of high pressure corresponding to the winds already noticed as being experienced on the Western side of the North Atlantic.

The study of Figs. 8 and 9 (pp. 22 and 23) will show how areas of high barometrical pressure occur in many other parts of the ocean, similar to those of the Atlantic, and that corresponding winds circulate round them.

Cyclonic Gales of the Temperate Zones.

The great currents of the atmosphere, which give rise to the prevailing winds, are thus seen to be regulated by the positions of the permanent areas of high and low pressure, and in these currents, secondary areas of low pressure make their appearance, and are carried along with them, and these travelling areas frequently give rise to gales, to the characteristics of which attention will be next given.

In the Temperate Zone of the North Atlantic these gales, which almost invariably travel to the eastward with the prevailing atmospheric current from the West, generally commence at S. and end at W. or N.W., with little or no East wind. The probable reason of this is that the areas of low pressure to which they are related have steep gradients only on their E., S.E., S., and S.W. sides, there being little or no difference of pressure between their centre and the more permanent depression which lies to the North of them.

The ordinary gales of high southern latitudes are similar in character to those of the Northern Hemisphere. They also accompany areas of low pressure travelling to the Eastward, and, considering that an equatorial wind here is North instead of South, the winds are similar, for they commence at N., and end at W. or S.W., with little or no Easterly wind, probably because the pressure to the S. is much lower than that to the N. of the tract in which they occur.

Whenever areas of both high and low pressure are liable to pass over any region it is obvious that the direction of the wind, taken alone, will not be a sufficient guide as to what weather is to be expected. If, for instance, in the Northern Hemisphere an area of high pressure be passing off to the Eastward, the wind in the rear of it will veer through S.E. to S. Although this direction of the wind shows that the barometrical readings are lower to the Westward than to the Eastward, it is not by any means an indication that a serious diminution of pressure, which may possibly bring a storm with it, is approaching, although the wind in front of such a depression would be Southerly also. It is therefore necessary in such circumstances to look for other signs, besides the mere direction of the wind, when striving to foresee what is coming.

If we could tell the shape of an area of low pressure, its gradients, or the difference of pressure in a given distance on all sides, the rate at which it is increasing or decreasing in intensity, the direction in which it is moving, and its speed, we could calculate very correctly what sort of weather would be experienced at a land station or on board a ship at sea, and it is upon observations of this description, made simultaneously at many places, that forecasts of weather are based; but the seaman can have no certain knowledge of these data, and has to make the best estimate he can from the indications afforded by the wind and the barometer as observed on board his own vessel alone.

Moreover, it must always be remembered that, although it is most commonly in connexion with considerable falls of the barometer that severe storms are experienced, yet the sudden large increase of pressure, which not infrequently follows such depressions, or takes place in their proximity, may be accompanied by very violent winds. Caution, therefore, will always be requisite on the occasion of any sudden change of pressure, whether it be in the direction of increase or decrease.

The cyclonic storms of the Temperate Zones do not often present the phenomenon of a central calm, with the winds blowing from nearly opposite directions on each side of it. There is, therefore, not so much risk of being taken aback as in the tropical cyclones; but it is advisable for a captain to know on which tack it will be safest to lie-to if obliged to do so, and this will be the same as that for the cyclones of the respective hemispheres.

The most serious sudden shift of wind which is to be expected in these storms is that from South-west to North-west in the Northern Hemisphere, or from North-west to South-west in the Southern. This is generally accompanied by heavy rain or hail, with thunder and lightning, while the temperature falls several degrees with the first blast of North-west or South-west wind, as the case may be, according to the hemisphere.

In considering how to act in such circumstances, there are two matters to which the seaman's attention should be directed, as they seriously affect the conclusions he should draw from his barometer readings.

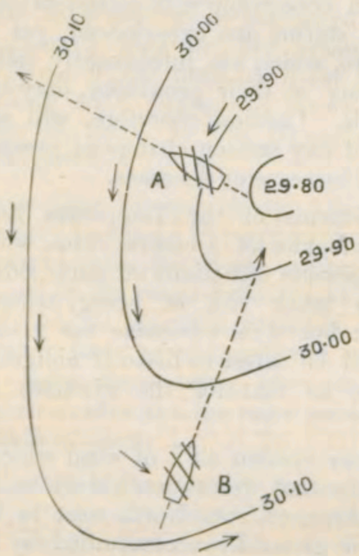
The first is that on the one tack his barometer has a tendency to rise, on the other it has a tendency to fall. The tack of rising barometer is the starboard in the Northern, the port in the Southern Hemisphere. This may be explained as follows:—

According to Buys Ballot's law, in the Northern Hemisphere (see Fig. 10, p. 28) the lower barometer is on your left when your back is turned to the wind, and as when you are thus placed a ship on the starboard tack is advancing towards your right, she goes towards the higher barometer and recedes from the lower. In the Southern Hemisphere this is reversed, and the ship on the port tack advances towards the higher and leaves the lower barometer.

But this rule will only be strictly applicable so long as no change takes place in the barometrical pressure, and it may so happen that a high pressure, towards which the ship is going, may be receding from her faster than she sails, and a lower pressure may be coming up astern and overtaking her; or it may be that a lower pressure towards which the ship is sailing may be moving away faster than she sails. Still the influence of the tack must always be felt, and, on the whole, it may be said that in the Northern Hemisphere a rising barometer on the starboard

Fig. 10.

A. Vessel on Starboard Tack.
B. Vessel on Port Tack.



tack is not a sufficient indication of improving weather, and other signs should be looked for before trusting it. In all cases for the Northern Hemisphere a rising barometer on the port tack is a valuable indication of improving weather, while a falling barometer on the starboard tack is a valuable warning in the other direction. This order is reversed in the Southern Hemisphere.

The second point to consider is the relation which the course and speed of the ship bear to the tracks and progress of the areas of low barometrical pressure and their corresponding wind-systems, in parts of the sea where the general tracks of storms are known. This will be easily done by taking, as an illustration, the case of a steamer traversing the North Atlantic between England and America, where storms generally move in an Easterly direction.

If a storm is advancing Eastwards at the rate of, say, 20 miles an hour, and if the ship is steaming at the average rate of, say, 10 miles an hour, the result will be that when going westward

the ship will have a relative rate of motion towards the storm of 30 miles an hour, but when going eastward, of only 10 miles an hour.

In other words, ships when outward bound across the Atlantic meet the advancing storm systems, which commonly travel from West to East, and when homeward bound run with them, consequently the rapidity with which the barometer falls or rises and the wind shifts is proportionately greater in the former cases than in the latter.

Figs. 11 and 12 illustrate these cases. The arrows fly with the wind, and the curves give the height of the barometer at every sixth hour. They represent observations taken by Capt. W. Watson, of the Cunard steamer "Algeria," Fig. 11, during a passage to New York, and Fig. 12 during a passage from New York. They are types of the differences experienced, which are so great that it is often possible to tell whether the vessel was steering to the eastward or westward by a comparison of her barometer curves alone.

Fig. 11

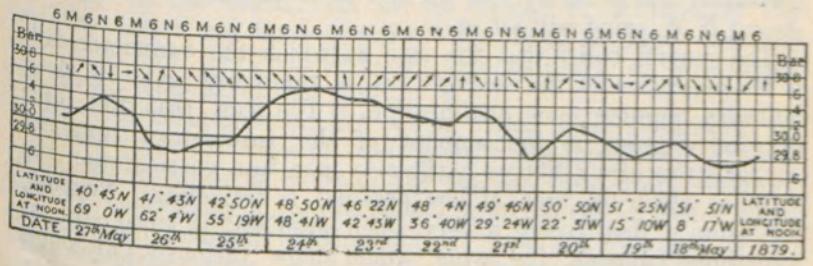
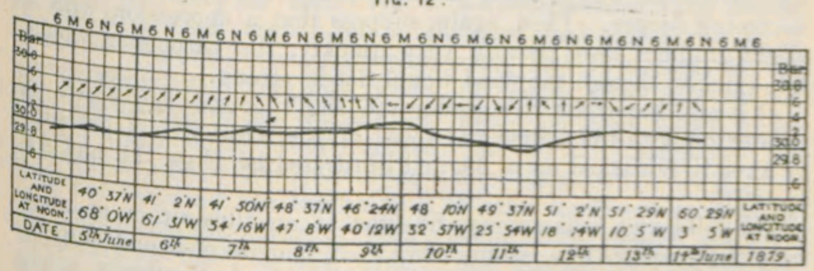


Fig. 12.



In Fig. 11, where the passage was to the Westward, the dates run from right to left. It shows that the barometer fell and rose quickly, and that the steamer met with six alternations of high and low pressure, with their accompanying wind-systems. Also that the fall of the barometer was generally accompanied by a South-easterly or Southerly wind, and that with a rise the wind drew more Westerly and Northerly.

In Fig. 12, where the passage was to the Eastward, the dates run from left to right. It shows that the barometer rose and fell slowly, and that the steamer experienced only two wind-systems;

also that the barometer rose with a Southerly and South-easterly wind, and fell with a Northerly wind, indicating that she moved to the Eastward faster than the wind-system which she was experiencing when starting; in fact, showing that she caught up and entered the Western side of another wind-system.

Gales of the North Temperate Zone.

The ordinary gales of the North Temperate Zone commence at S.E. or S. and end at W. or N.W. If a ship in these latitudes experiences a fresh S. or S.E. wind, with a relatively high temperature and falling barometer, Buys Ballot's law shows that there is an area of low pressure to the W. or S.W. of her; and, as already said, it is probably travelling to the E. or N.E. Experience shows that whether the ship be hove to or stands to the Westward, the barometer will fall until the wind shifts to the Westward (which generally happens during a heavy shower of rain, together with a sudden fall of temperature), when the barometer will probably rise as fast as it previously fell, and a strong N.W. wind will set in.

The general belief that the rate at which the barometer falls is an indication of the strength of a Southerly gale in these latitudes requires some qualification. The fact that the force of wind depends on the amount of the barometrical gradient supports this idea; but we must also take into consideration the speed at which the area of low pressure is travelling. Suppose, for instance, that having a very steep gradient, it stood still, as sometimes happens, the wind would blow furiously, although the barometer would cease falling, unless the depression were becoming deeper. Then, again, suppose that a depression with a slight gradient were passing very quickly, the barometer would fall quickly, though the wind would not be strong.

It is also important to consider the ship's course and speed in connexion with the course and speed of the area of low pressure as already remarked on p. 28, and illustrated by Figs. 11 and 12 (p. 29).

The following instance may be cited as an illustration of what frequently occurs to a sailing ship. A homeward-bound ship in about 45° N. and 30° W., falls in with a fresh Southerly wind, and from what has been said, the captain knows that there is a lower pressure to the West of him, and he may safely consider that it is travelling to the Eastward; but his ship is also going East, and his barometer may remain steady, or even rise, if he is outstripping the low pressure in its advance.

If in such a case, on taking into consideration the state of sea and other weather indications, the conclusion is come to that a gale is coming up from the Westward, and the ship is likely to have to reduce her speed, on closing with the land, or otherwise, it may be well to prepare for worse weather. In the event of heaving to, the amount of fall in the barometer per hour is a good, though not certain guide, as before said; a fall of ·04 to ·10 of an inch per hour is usually considered to be a serious indication of the approach of a Southerly gale, which may be followed by an equally fast rise, accompanied by a W. or N.W. gale.

From what has been said it will be clear to the navigator that in Northern latitudes, at the setting in of a Southerly wind, a sailing ship, as well as a steamer, bound to the Westward will, by her course and speed, cause the barometer to fall quicker than if she hove-to or stood to the Eastward, so that in this case also the state of the sea and other appearances ought to be considered, or her captain may be led to anticipate worse weather than is really coming.

With a Southerly wind and falling barometer, a ship bound to the Westward might gain by running to the Northward, with the object of causing the wind to back to the Eastward, but the type of gale in which this is possible resembles a cyclone, and does not represent the ordinary gales of these latitudes, which begin at S. and end at W. or N.W. Again, it might be possible for a ship, with the first of the Southerly wind which exists on the East side of the area of low pressure, to get less wind by running to the North, but as the extent in latitude of the cyclone area is not known, and as there is no certainty that she would get into more moderate weather by doing so, she might do herself more harm than good.

It seems, then, probable that a ship bound to the Southward or Westward must face one of these gales if she meets it. A weak ship, whose object is to stem the sea and get safely through, without considering progress, should lie-to on the starboard tack, as the wind generally shifts from S. to S.W., W., and N.W. This would, of course, be the best plan for any ship which found the gale too heavy for her. But a well-conditioned ship, bound to the Westward, may keep on the port tack until the wind shifts to West with a rising barometer, and then tack to the South-westward. This plan, would, of course, tend to bring her into the trough of the sea, and she would be more likely to be caught aback as the wind changed, but we are assuming that her captain will be prepared to meet these risks.

When the wind has shifted to N.W. the starboard tack takes her away from the centre of such a disturbance, though she may soon sail into the Southerly wind of the Eastern side of another low-pressure area coming towards her. This would be a very common occurrence in winter.

Gales of the South Temperate Zone.

The prevailing gales of high Southern latitudes resemble those of Northern, and in describing them it is only requisite to remember that there North and South change places. For instance, as a ship bound to Australia gets into 40° S., "the Roaring Forties," she experiences a series of gales which, commencing at N. or N.E., end at W. or S.W. Now with a Northerly wind in the Southern Hemisphere there is a low pressure to the

Westward, and the way in which the wind usually changes proves that those areas of low pressure are also travelling to the Eastward. Ships which keep a steady Westerly wind for days as they run to the Eastward in high Southern latitudes, are probably keeping company with one of these areas of low pressure, and if they had hove-to or commenced beating to the Westward they also would have experienced many changes just in the same manner as our steamers bound to America do, whilst those from America frequently keep a steady barometer and Westerly wind for days. This receives abundant confirmation from the frequency of the barometrical oscillations and changes of wind experienced by ships bound to the Westward, in rounding either the Cape of Good Hope or Cape Horn.

The best method for dealing with a heavy gale, or with a weak ship in an ordinary gale, is reversed for high Southern latitudes: there the port is the "coming up" tack, which enables her to stem the sea, as the wind usually shifts from N. by N.W. to S.W., and the port tack with a S.W. wind takes her away from the low pressure to which the wind is related, though of course it may, and in the winter months most probably will, soon take her into the Northerly wind of the Eastern side of another low pressure coming towards her.

For a ship beating to the Westward, of course the best progress is made by keeping on the starboard tack with the wind N. and N.W. until it shifts to W. and S.W., when she ought to tack to the North-westward; but it will be seen that, as in the best method for making progress to the Westward in high Northern latitudes, the ship will be headed off, and get into the trough of the sea; she will also be more liable to be taken aback as the wind changes than if she were on the port tack.

From what has been said respecting the ordinary gales of high latitudes, which have usually little or no Easterly wind, it must not be supposed that there are not some which have steep gradients on all sides, and consequently strong Easterly as well as Westerly winds. These are not nearly so common as the others, and must be treated like cyclones.

TROPICAL STORMS.

Hurricanes, Typhoons, or Cyclones of Tropical Seas.

Of all atmospheric disturbances whose approach the barometer can indicate, and whose dangers it may enable the seaman to avoid, by giving him warning of their proximity and position, the revolving storms of the tropics are the most serious.

These storms may all be properly termed cyclones, and they occur in the three great oceans, the Atlantic, Pacific, and Indian Oceans; but they are seldom experienced within 5° or 6° of the Equator, and have not been traced into very high latitudes. They appear to be most frequent and most severe in the West Indies, in the vicinity of Mauritius, in the Bay of Bengal, and in the China Seas. In the Arabian Sea and in the Bay of Bengal cyclones occur most frequently in May and June, and in October and November. They are commonly known as hurricanes in the West Indies, cyclones in the Indian Ocean, and typhoons in the China Seas.*

Cyclones, have, in addition to a motion round a centre, an onward movement. The wind blows in a more or less circular course round the centre, and at the same time the storm field advances on a straight or curved track, sometimes with great velocity, and sometimes appearing to pause or scarcely to advance more than a few miles in an hour.

The area over which these storms have been known to extend themselves varies from 20 or 30 miles to some hundreds of miles in diameter, the wind blowing with an ever-varying force, sometimes lulling into little more than a strong breeze, and as the centre is approached often rising into a blast of irresistible fury.

It is an invariable characteristic of their revolution that the gyration of the storm-field takes place in one direction; in the northern hemisphere in the opposite direction to the hands of a watch, and in the southern hemisphere with the hands of a watch. The knowledge of this law is most important, as it not only

* TABLE of recorded HURRICANES, CYCLONES, and TYPHOONS, in various parts of the World.

—	Jan.	Feb.	March.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	TOTAL.
West Indies, 300 years - -	5	7	11	6	5	10	42	96	80	69	17	7	355
South Indian Ocean (38 years, 1848 to 1885)† - - - -	71	61	59	50	19	3	2	—	—	5	25	33	328
Bombay, 25 years - - -	1	1	1	5	9	2	4	5	8	12	9	5	62
Bay of Bengal, 139 years - -	2	—	2	9	21	10	3	4	6	31	18	9	115
China Sea, 85 years - - -	5	1	5	5	11	10	22	40	58	35	16	6	214

† No information for the years 1849, 1850, and 1853.

supplies the seaman with direct means of distinguishing these storms from gales in which the direction of the wind varies little if at all, but also reveals to him the approximate position of the centre or vortex, the region of greatest danger, where the fury of the wind is most extreme, the changes of its direction most sudden, and the sea most to be dreaded.

These features of cyclones will be understood to be in great measure due to the causes already explained, which lead to the formation of a system of revolving winds round a central area of low pressure produced by some local atmospheric disturbance, towards which the surrounding air is drawn in from all sides.

In the Atlantic and South Indian Ocean these storms commence to the eastward; for some days they travel along a path not exactly West, but inclining a point or two towards the pole of that hemisphere which they are crossing; and as they advance, they seem more inclined to curve away from the equator. When they reach the 25th degree of latitude, they generally curve still more, until they move to the N.E. in the northern hemisphere and to the S.E. in the southern hemisphere. The Atlantic storms almost always wheel round to the Northward in the Mexican Gulf, or in its vicinity, and follow the sea-board of North America.

Tracks of some of the most remarkable hurricanes, or cyclones, are shown by thick arrows in Figs. 8 and 9 (pages 22 and 23); the months in which they occurred being given at the ends of the arrows. For a more complete list of their seasons, see the footnote to page 33. The tracks are copied from the "Wind and Current Charts of the Pacific, Atlantic, and Indian Oceans," published by the Admiralty.

The cyclones of the Bay of Bengal appear to originate near the Andaman Islands, those of the Arabian Sea near the Laccadives. These generally travel to the Westward and Northwestward, the former sometimes crossing the Indian Peninsula, sometimes passing off over Bengal and curving back to the Eastward. The typhoons of the China Seas commonly take a Westerly or North-westerly course.

The rate of movement of these storms, though variable, may be averaged at 300 miles a day in the West Indies; in the Arabian Sea, in the Bay of Bengal, and in the China Sea, 200 miles a day; whilst in the Southern Indian Ocean their rates vary from 50 to 200 miles a day.

The indications of the approach of a revolving storm are the usual ugly and threatening appearance of the weather which forebodes most storms, and the increasing number and severity of the gusts with the rising of the wind. These signs are in some cases preceded by a long heavy swell and confused sea, which come from the direction in which the strom is approaching, and travel more rapidly than the storm centre.

The best and surest of all warnings, however, will be found in the barometer. In every case there is great barometrical disturbance, the barometer at the centres of some of the storm

standing fully two inches lower than outside the storm-field. Accordingly if the barometer falls rapidly, or even if the regularity of its diurnal variation (see page 13) be interrupted, danger may be apprehended.

No positive rule can be given as to the amount of depression to be expected. There are numerous records of the barometer falling below 28 inches in the West Indies, and the suddenness of the fall may be realised by an authenticated record of a fall of 1·7 inches in one hour and ten minutes. Meldrum says that in the Southern Indian Ocean the barometer commonly falls below 28 inches, and in the Bay of Bengal a pressure of 27·58 inches is said to have been observed. The average barometrical gradient* near the centre of the most violent of these storms is said to be rather more than one inch in 50 nautical miles.

As the centre or vortex of the storm is approached, unless the vessel be on the line of its advance, the more rapid become the changes of wind, till at length, instead of veering gradually, as is the case on first entering the storm field, the wind flies round at once to the opposite point, the sea meanwhile breaking in mountainous and confused heaps. There are many instances on record of the wind suddenly falling in the vortex, and the clouds dispersing for a short interval, though soon the wind blows again with renewed fury. Few vessels have ever passed through the vortex without losing either masts or rudder, or meeting with some worse disaster, and therefore, at whatever cost, the central part of the storm-field should be avoided.

For the sake of simplicity, the motion of the wind in a cyclone will be treated as approximately circular. But this is not strictly the case, for there is evidence to show that frequently, especially in the outer parts of the storm-field, there is more or less indraft, and the centre may bear 10 or 12 points from the direction of the wind (reckoned to the left or right according to the hemisphere).

The first care of the master of a vessel caught in a cyclone will be to find how the centre bears from him. In the northern hemisphere let him with his back to the wind, take from twelve to eight points to the left of the direction of the wind, and that will be the approximate bearing of the centre; in the southern hemisphere take a similar number of points to the right. As a rule the further the centre of the cyclone, the greater should be the number of points allowed, and not until the barometer has fallen about five-tenths, is it safe to assume that the bearing of the centre of the storm is only eight points. Thus, in the northern hemisphere with the wind from N.E., the centre will bear from S. to S.E., and in the southern hemisphere with the wind from N.W., the centre will bear from S. to S.W.

His next care will be to ascertain on which side of the storm's path his vessel is situated, and the direction in which the storm is moving. In either hemisphere if she be situated on the right-hand side or semicircle of a cyclonic storm travelling

* For explanation of the term barometric gradient, see page 18.

in any direction—the wind will shift to the right, or with the hands of a watch, as from N. to N.E., E., S.E., S., &c. ; on the left-hand side of the storm the wind will shift to the left, or against the hands of a watch, as from S.E. to E., N.E., N., &c.

In speaking of the shift of wind such a shift is meant as would be observed on a vessel hove-to, for if the vessel be moving faster than the storm, and in the same direction, the shift may be in the opposite direction to what has been stated.

If, while the vessel is hove-to, the wind be found to remain in the same direction, increase in violence, and be accompanied by a falling barometer, it is probable she lies in the path of the advancing storm.

The wind in front of the storm-area is, from the nature of the case, directed across the path of the centre ; blowing towards the path on one side, and away from it on the other. Consequently, if we suppose the cyclone to be bisected by a line representing its path, a little consideration will show that in the semicircle on one side of the path, a ship running before the wind may probably be brought to cross the path of the storm in front of its centre, and therefore under circumstances of great danger ; in the semicircle on the other side of the path a ship running before the wind will probably cross the path in rear of the centre. The former of these semicircles is called the "dangerous" semicircle.

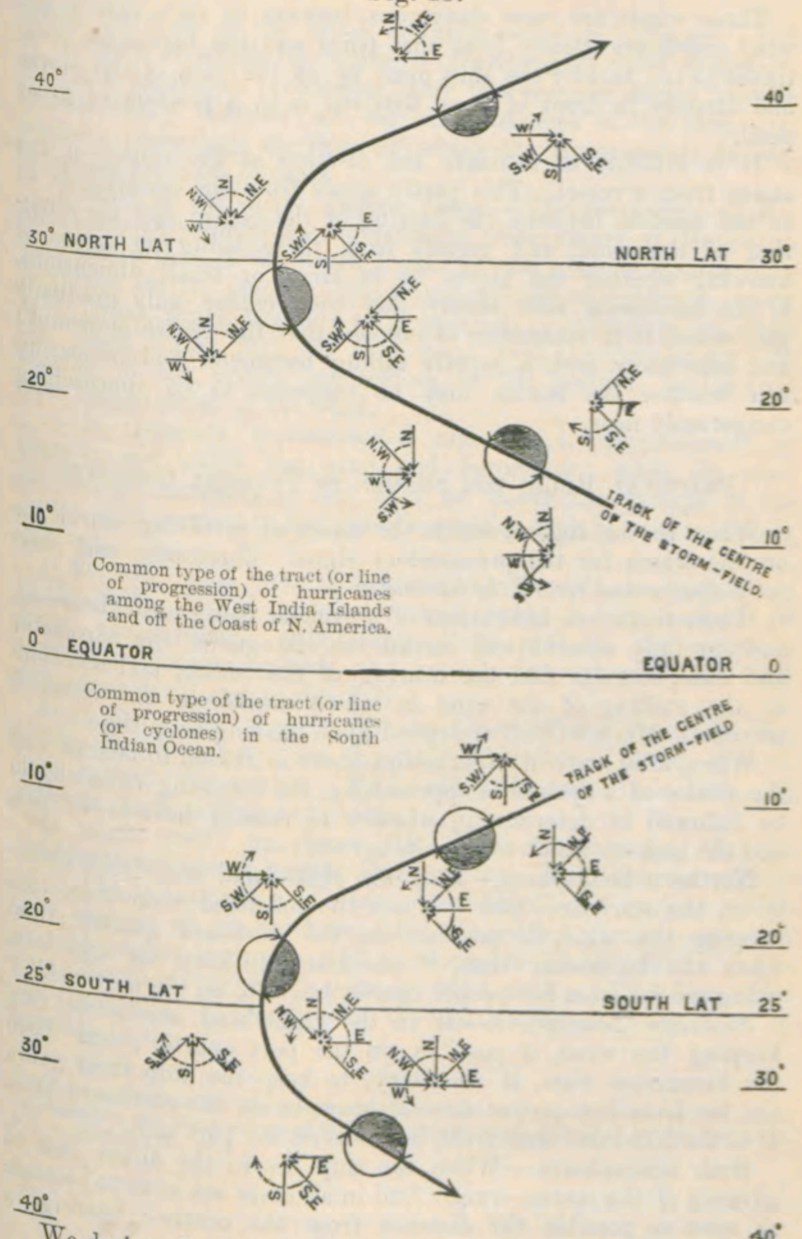
An inspection of the diagram (Fig. 13, p. 37) will best explain these and other important particulars. The circles represent the storm-field ; the arrow heads show the direction of its revolution in the northern hemisphere against the hands of a watch, in the southern hemisphere with the hands of a watch.

The shaded portions of the circles are the dangerous semicircles. The groups of arrows with the embracing dotted arrows, on either side of the track of the storm, indicate the directions in which the winds would be observed there to blow and shift by a vessel hove-to.

When looking in the direction in which the storm is travelling, the dangerous semicircle is always on your right hand in the northern hemisphere, on the left hand in the southern hemisphere.

The recurvature of the path always takes place towards the side on which the dangerous semicircle is situated, *i.e.*, to the right in the northern, to the left in the southern hemisphere. Hence in the northern hemisphere, so long as the storm system is travelling to the West, the winds in front of the advancing centre are North-easterly ; as the storm turns to the North, the winds in front are Easterly ; and after it has turned to the Eastward the winds in front are South-easterly. A similar sequence will arise in the southern hemisphere, but in the opposite order, the winds in front of the vortex beginning with South-east and ending with North-east when the vortex has turned to the Eastward. These directions of the wind are, of course, very approximate.

Fig. 13.



We derive, then, the following rules to find the most dangerous wind, supposing always that the track of the storm is such as is shown in Fig. 13, recurving in about lat. 32° N. or lat. 26° S. :—

Northern Hemisphere.		Southern Hemisphere.	
Between the Equator and 30° N. lat	N.E.	Between the Equator and 26° S. lat.	S.E.
About 33° N. lat.	E.	About 26° S. lat.	E.
Northward of 30° N. lat. ...	S.E.	Southward of 26° S. lat. ...	N.E.

These winds are most dangerous, because in each case if the wind continues steady from that point and the barometer continues to fall rapidly the ship must be on the path of the storm and directly in front of it, so that she is in a position of great peril.

It is difficult to estimate the distance of the centre of the storm from a vessel. This partly arises from the uncertainty as to the relation between the bearing of the centre and the direction of the wind, and greatly from there being no means of knowing whether the storm be of large or small dimensions. If the barometer falls slowly, and the weather only gradually gets worse, it is reasonable to suppose that the centre is distant; and conversely with a rapidly falling barometer and increasing bad weather the centre may be supposed to be approaching dangerously near.

Practical Rules for Seamen in Tropical Cyclones.

When in the region, and in the season of revolving storms, be on the watch for the premonitory signs. *Constantly and carefully observe and record the barometer.*

When there are indications of a cyclone being near, heave-to, and carefully observe and record the changes of the barometer and wind, so as to find the bearing of the centre, and ascertain by the shifting of the wind in which semicircle the vessel is situated. Much will often depend upon heaving-to in time.

When, after careful observation, there is reason to believe that the centre of a cyclone is approaching, the following rules should be followed in determining whether to remain hove-to or not, and the tack on which to remain hove-to :—

Northern hemisphere.—If in the right-hand semicircle, heave-to on the starboard tack. If on the left-hand semicircle, run, keeping the wind, if possible, on the starboard quarter ; and when the barometer rises, if necessary, to keep the ship from going too far from her proper course, heave-to on the port tack.

Southern hemisphere.—If in the right-hand semicircle, run, keeping the wind, if possible, on the port quarter ; and when the barometer rises, if necessary, to keep the ship from going too far from her proper course, heave-to on the starboard tack. If in the left-hand semicircle, heave-to on the port tack.

Both hemispheres.—When the ship lies in the direct line of advance of the storm—run. And in all cases act so as to increase as soon as possible the distance from the centre ; bearing in mind that the whole storm-field is advancing.

Heaving-to, in both hemispheres.—If the ship be in the right-hand semicircle, heave-to on the starboard tack. In the left-hand semicircle, heave-to on the port tack ; these being the tacks on which the ship will "come up" as the wind shifts.

In receding from the centre of a cyclone, the barometer will rise, and the wind and sea subside.

It should be remarked that in some cases vessels may, if the storm be travelling slowly, sail from the dangerous semicircle across the front of the storm, and thus out of its influence. But as the rate at which the storm is travelling is quite uncertain, this is a hazardous proceeding, and the seaman should hesitate and carefully consider all the circumstances of the case, particularly observing the rate at which the barometer is falling, before he attempts to cross.

Cyclones of the South Indian Ocean.—The researches of Mr. Meldrum, Director of the Government Observatory at Mauritius, have shown that, in the South Indian Ocean, a vessel approaching a cyclone on its southern side almost always encounters a strong Trade wind, which freshens to a gale. It is difficult to tell when the Trade forms part of the storm area ; consequently the bearing of the centre can seldom, in this position, be inferred from the direction of the wind.

It is therefore recommended under such circumstances to heave-to and watch the wind and barometer ; when the wind has shifted decidedly to the East or South the passage of the centre with respect to the vessel's position may be approximately inferred.

If the wind shift from S.E. decidedly towards the South, run to the N.W. Or, if the wind remain steady at S.E., increase in force, the barometer still falling, it is probable the storm is advancing directly towards the vessel ; in such case, the most dangerous of all, run to the N.W.

It is also stated that in the cyclones of the South Indian Ocean, North-easterly and Easterly winds often, if not always, blow towards the centre. Such being the case, it is better to make as much easting as possible.

It might easily be shown, Dr. Meldrum remarks, that all the homeward-bound vessels that put into Mauritius for repairs do so in consequence of damage sustained in a cyclone which they entered on its northern side. There is a strong temptation to such vessels to run on with a favourable breeze ; but a freshening Northerly or North-easterly wind, with a falling barometer and threatening appearance of the weather, should warn them to heave-to in time.*

* For recorded tracks of cyclones in the Southern Indian Ocean see the charts published by the Meteorological Office on information compiled by Dr. Meldrum, F.R.S. (Official No. 90.)

APPENDIX I.

The Thermometer, Hygrometer, and Hydrometer.

Thermometer.—This instrument shows changes of heat and cold, but is not sensibly affected by changes of the pressure of the air. It consists of a glass tube of very small bore, closed at one end, and united at the other to a bulb, which is commonly filled with mercury.* Almost all substances expand when they are heated, and contract when they are cooled, but they do not all expand equally. Mercury expands more than glass, and so when the thermometer is heated the mercury in the bulb expands, and that portion of it which can no longer be contained in the bulb rises in the tube, in the form of a thin thread. The tube being very minute, a small expansion of the mercury in the bulb, which it would be difficult to measure directly, becomes readily perceived as a thread of considerable length in the tube. When the instrument is cooled the mercury shrinks, and the thin thread becomes shorter, as the mercury subsides towards the bulb. By observing the length of the thread of mercury in the tube, as measured by the graduation on the scale at its side, or marked on the tube, the thermometer shows the temperature of the bulb at the time, which thus indicates the temperature of the surrounding air, or of any liquid in which the bulb is immersed.

The indications of a thermometer are recorded in degrees, the scale for which is obtained as follows. There are two fixed points on the scale according to which thermometers are graduated, viz., that at which ice melts, and that at which water boils. In the thermometers in ordinary use in England, the distance between these two points is divided into 180 parts, or degrees. When surrounded by melting ice an accurate thermometer on this scale indicates thirty-two degrees (32°) and if placed in boiling water, when the barometer reading is 30 inches, the reading is two hundred and twelve degrees (212°).†

The usual range of a thermometer in the shade in the open air, in England, is about seventy degrees, viz., from 10° to 80°. In very hard frosts the temperature of the air sometimes falls below 10°, and on very hot summer days it rises above 80°. If the instrument is exposed directly to the rays of the sun, the mercury will rise much higher, and at night, if exposed to radiation to a clear sky, may fall many degrees below what would be due to the temperature of the surrounding air. It is therefore necessary to take precautions for protecting the instrument from the direct rays of the sun, or from exposure to the clear sky at night, in order to obtain a correct indication of the temperature of the air. The range of the thermometer, or more correctly of the temperature of the air, is greater in many other countries, especially in the interior of the great continents, where the winters are much colder and the summers much hotter than here. In islands of small extent in the warmer regions of the earth the range is much less than in the British Isles.

* Thermometers intended for use in very cold climates are filled with spirit instead of mercury, which would freeze and solidify at the low temperatures of the Arctic regions, whereas spirit would not freeze.

† This graduation is that adopted by Fahrenheit at the beginning of the eighteenth century. Another form of graduation is the Centigrade, in which the freezing point counts as 0°, and the boiling point as 100°.

Hygrometer.—This instrument measures the dampness of the air. There are several kinds of hygrometers, but the easiest to make and to manage consists of a pair of thermometers placed near each other. If one of these be fitted with a single thickness of fine muslin or cambric fastened tightly round the bulb, and this coating be kept damp by means of a few strands of cotton wick, which are passed round the glass stem close to the bulb so as to touch the muslin, and have their lower ends dipping into a cup of water placed close to the thermometer, it will usually show a temperature lower than that shown by the other thermometer which is near it, the amount of the difference, commonly called the depression of the wet bulb, being dependent on the degree of dryness of the air.

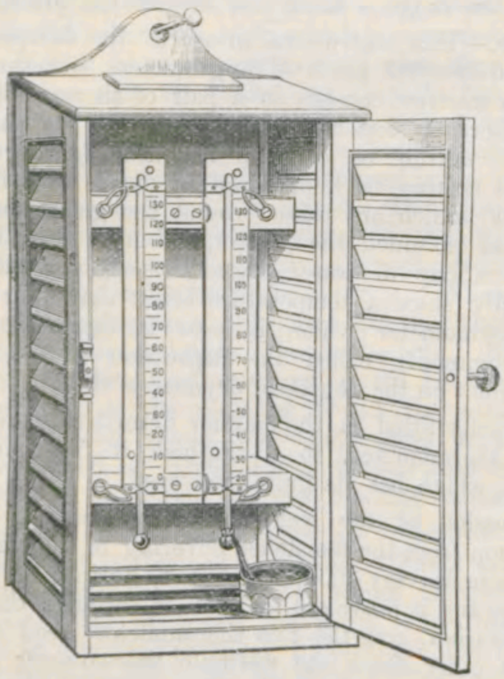
A thermometer fitted in the manner described above is called a wet-bulb thermometer, to distinguish it from an ordinary thermometer, which has its bulb uncovered.

The depression of the wet-bulb thermometer is caused by the evaporation from the moistened covering of the bulb. When the atmosphere is very damp or moist, during, or just before rain, or when fog is prevalent or dew is forming, there is little or no evaporation, and the two thermometers read very nearly alike, but at other times the wet-bulb thermometer reads lower than the dry, because the water dries off or evaporates from the muslin coating, in which process it passes into the state of invisible vapour, and absorbs heat from the mercury in the bulb of the thermometer, which consequently indicates a lower temperature. As the air becomes drier the evaporation is greater, and the fall of temperature of the wetted bulb is also greater, and accordingly the difference in readings between the dry and the wet-bulb is then also greater. The difference sometimes amounts to 15 or 20 degrees in England, and to more in some other parts of the world, but at sea the difference seldom exceeds 6 or 8 degrees.

To ensure correct records of the temperature and moisture of the air, the dry and wet-bulb thermometers should be placed in a screen, the sides of which are protected from the sun and rain by "jalousies," that is narrow sloping boards overlapping each other, but with spaces between, so as to let in the air freely.

The annexed engraving shows the form of screen used for mounting the dry and wet-bulb thermometers on board ship; it should be fixed in a suitable position about four feet above the upper deck, freely exposed to the external air, but protected from sun, rain, or spray, and as free as possible from radiation or warm currents of air from cabins and engine-rooms.

The glass, or other small vessel to hold the water required for the wet-bulb should be as far as possible from the dry thermometer, see figure. The water should be either distilled or rain



water, or, if this be not procurable, the softest fresh water which can be had, to avoid the deposit of lime or other impurity on the bulb. When fresh water is poured into the vessel it should be done after, or some little time before observing; because observations are incorrect if made before the temperature of the wet-bulb has fallen to that it would acquire, after being some time exposed to the air.

The muslin and wick should be well washed before being applied, and occasionally while in use. They should be changed once a month or oftener according to the quality of the muslin, &c., and the exposure to dust or blacks. Accuracy depends much on the care taken to ensure cleanliness, and also a proper supply of fresh water.

During frost, when the water on the muslin is frozen and thinly coated with ice, the readings are quite good, as evaporation takes place from a surface of ice as freely as from one of water, but if the muslin be dry, and no ice on it, it must first be wetted, and then allowed time to freeze and to take up its normal temperature before the observation is recorded.

Hydrometer.—The hydrometer used at sea is constructed of glass. If made of brass, the corrosive action of salt water soon renders the instrument erroneous in its indications. The form of the instrument in common use is shown in the engraving. It consists of a glass tube ending in a globular bulb partly filled with mercury or small shot, to act as ballast and to make the instrument float steadily in a vertical position. From the neck of the bulb the glass is expanded into an oval or cylindrical shape, to give the instrument sufficient volume for flotation; above this it is tapered off to a narrow upright stem which encloses an ivory scale, and is closed at the top. The divisions on the scale read downwards, so as to measure the length of the stem which stands above the surface of any fluid in which the hydrometer is floated. The denser the fluid, or the greater its specific gravity, the higher will the instrument rise; the rarer the fluid, or the smaller its specific gravity, the lower it will sink.

The indications depend upon the well-known principle, that any floating body displaces a quantity of the fluid which sustains it, equal in weight to the weight of the floating body itself. According, therefore, as the relative specific gravities of fluids differ from each other, so will the quantities of the fluids displaced by any floating body, or the depth of its immersion, vary, when it is floated successively in each.

The specific gravity of distilled water, or its relative weight compared, at the temperature of 62° F., to an equal volume of other substances, being taken as unity, the depth at which the instrument remains at rest when floating in distilled water is the zero of the scale on which its indications are recorded. If the specific gravity, or the density of the water be increased, as it is by the presence of salt in solution, the hydrometer will rise, and the scale is so prepared as to indicate successive increases of density up to 4 per cent., or 40 in the thousand parts. The graduations thus extend from 0 to 40; the latter corresponding to the mark on the scale which will be level with the surface when the instrument is placed in water, the specific gravity of which is 1·040. In recording observations, the last two figures only—being the figures on the scale—are written down.

The instrument is used on board ship to show the relative density of different parts of the ocean, and it floats at 40 or even higher in some parts of the Suez Canal, where the water is exceedingly salt. The water employed for taking the specific gravity of the sea should be drawn in a bucket from over the ship's side, forward of all ejection pipes, and its temperature immediately observed and recorded. The hydrometer should be slightly spun in the centre of the bucket; it soon loses any up-and-down motion, and the scale can be read before the turning motion has entirely ceased.

Whenever the temperature of the water tested differs from 62°, a correction to the reading is necessary, for the expansion or contraction of the glass, as well as for the temperature of the water itself, in order to reduce all observations to one generally adopted standard. Tables have been constructed for this purpose.

When using the hydrometer, all dust, smears, or greasiness, should be scrupulously got rid of by wiping the instrument with a clean soft cloth, before and after use.

APPENDIX II.

Table of Correction to be applied to Barometers with *Brass Scales*, extending from the Cistern to the top of the Mercurial Column, to reduce the Observation to 32° Fahrenheit.

Temp.	INCHES.															Temp.
	24·0	24·5	25·0	25·5	26·0	26·5	27·0	27·5	28·0	28·5	29·0	29·5	30·0	30·5	31·0	
°	Correction to be Added.															°
	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
0	·061	·063	·064	·065	·067	·068	·069	·071	·072	·073	·074	·076	·077	·078	·080	0
1	·059	·061	·062	·063	·064	·065	·067	·068	·069	·071	·072	·073	·074	·076	·077	1
2	·057	·058	·060	·061	·062	·063	·064	·066	·067	·068	·069	·070	·072	·073	·074	2
3	·055	·056	·057	·059	·060	·061	·062	·063	·064	·065	·067	·068	·069	·070	·071	3
4	·053	·054	·055	·056	·057	·058	·059	·061	·062	·063	·064	·065	·066	·067	·068	4
5	·051	·052	·053	·054	·055	·056	·057	·058	·059	·060	·061	·062	·063	·065	·066	5
6	·049	·050	·051	·052	·053	·054	·055	·056	·057	·058	·059	·060	·061	·062	·063	6
7	·046	·047	·048	·049	·050	·051	·052	·053	·054	·055	·056	·057	·058	·059	·060	7
8	·044	·045	·046	·047	·048	·049	·050	·051	·052	·053	·054	·054	·055	·056	·057	8
9	·042	·043	·044	·045	·046	·046	·047	·048	·049	·050	·051	·052	·053	·054	·054	9
10	·040	·041	·042	·042	·043	·044	·045	·046	·047	·047	·048	·049	·050	·051	·052	10
11	·038	·039	·039	·040	·041	·042	·042	·043	·044	·045	·046	·046	·047	·048	·049	11
12	·036	·036	·037	·038	·039	·039	·040	·041	·042	·042	·043	·044	·045	·045	·046	12
13	·033	·034	·035	·036	·036	·037	·038	·038	·039	·040	·040	·041	·042	·043	·043	13
14	·031	·032	·033	·033	·034	·035	·035	·036	·037	·037	·038	·038	·039	·040	·040	14
15	·029	·030	·030	·031	·032	·032	·033	·033	·034	·035	·035	·036	·036	·037	·038	15
16	·027	·028	·028	·029	·029	·030	·030	·031	·032	·032	·033	·033	·034	·034	·035	16
17	·025	·025	·026	·026	·027	·027	·028	·028	·029	·030	·030	·031	·031	·032	·032	17
18	·023	·023	·024	·024	·025	·025	·025	·026	·026	·027	·027	·028	·028	·029	·029	18
19	·021	·021	·021	·022	·022	·023	·023	·024	·024	·024	·025	·025	·026	·026	·027	19
20	·018	·019	·019	·020	·020	·020	·021	·021	·021	·022	·022	·023	·023	·023	·024	20
21	·016	·017	·017	·017	·018	·018	·018	·019	·019	·019	·020	·020	·020	·021	·021	21
22	·014	·014	·015	·015	·015	·016	·016	·016	·016	·017	·017	·017	·018	·018	·018	22
23	·012	·012	·012	·013	·013	·013	·013	·014	·014	·014	·014	·015	·015	·015	·015	23
24	·010	·010	·010	·010	·011	·011	·011	·011	·011	·012	·012	·012	·012	·012	·013	24
25	·008	·008	·008	·008	·008	·008	·009	·009	·009	·009	·009	·009	·009	·010	·010	25
26	·005	·006	·006	·006	·006	·006	·006	·006	·006	·006	·007	·007	·007	·007	·007	26
27	·003	·003	·003	·003	·004	·004	·004	·004	·004	·004	·004	·004	·004	·004	·004	27
28	·001	·001	·001	·001	·001	·001	·001	·001	·001	·001	·001	·001	·001	·001	·001	28
	Correction to be Subtracted.															
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
29	·001	·001	·001	·001	·001	·001	·001	·001	·001	·001	·001	·001	·001	·001	·001	29
30	·003	·003	·003	·004	·004	·004	·004	·004	·004	·004	·004	·004	·004	·004	·004	30
31	·005	·006	·006	·006	·006	·006	·006	·006	·006	·006	·007	·007	·007	·007	·007	31
32	·008	·008	·008	·008	·008	·008	·008	·009	·009	·009	·009	·009	·009	·010	·010	32
33	·010	·010	·010	·010	·011	·011	·011	·011	·011	·012	·012	·012	·012	·012	·012	33
34	·012	·012	·012	·013	·013	·013	·013	·014	·014	·014	·014	·015	·015	·015	·015	34
35	·014	·014	·015	·015	·015	·015	·016	·016	·016	·017	·017	·017	·018	·018	·018	35
36	·016	·017	·017	·017	·017	·018	·018	·019	·019	·019	·020	·020	·020	·021	·021	36
37	·018	·019	·019	·019	·020	·020	·021	·021	·021	·022	·022	·022	·023	·023	·024	37
38	·020	·021	·021	·022	·022	·023	·023	·023	·024	·024	·025	·025	·026	·026	·026	38
39	·023	·023	·024	·024	·024	·025	·025	·026	·026	·027	·027	·028	·028	·029	·029	39
40	·025	·025	·026	·026	·027	·027	·028	·028	·029	·029	·030	·030	·031	·031	·032	40
41	·027	·027	·028	·029	·029	·030	·030	·031	·031	·032	·033	·033	·034	·034	·035	41
42	·029	·030	·030	·031	·031	·032	·033	·033	·034	·034	·035	·036	·036	·037	·037	42
43	·031	·032	·032	·033	·034	·034	·035	·036	·036	·037	·038	·038	·039	·040	·040	43
44	·033	·034	·035	·035	·036	·037	·037	·038	·039	·040	·040	·041	·042	·042	·043	44
45	·035	·036	·037	·038	·038	·039	·040	·041	·041	·042	·043	·044	·044	·045	·046	45
46	·038	·038	·039	·040	·041	·042	·042	·043	·044	·045	·045	·046	·047	·048	·049	46
47	·040	·041	·041	·042	·043	·044	·045	·046	·046	·047	·048	·049	·050	·051	·051	47
48	·042	·043	·044	·045	·045	·046	·047	·048	·049	·050	·051	·052	·052	·053	·054	48
49	·044	·045	·046	·047	·048	·049	·050	·050	·051	·052	·053	·054	·055	·056	·057	49
50	·046	·047	·048	·049	·050	·051	·052	·053	·054	·055	·056	·057	·058	·059	·060	50

TABLE—*continued.*

Temp.	INCHES.															Temp.
	24·0	24·5	25·0	25·5	26·0	26·5	27·0	27·5	28·0	28·5	29·0	29·5	30·0	30·5	31·0	
	CORRECTION TO BE SUBTRACTED.															
°	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	°
51	·048	·049	·050	·051	·052	·053	·054	·055	·056	·057	·058	·059	·060	·061	·062	51
52	·050	·052	·053	·054	·055	·056	·057	·058	·059	·060	·061	·062	·063	·064	·065	52
53	·053	·054	·055	·056	·057	·058	·059	·060	·061	·063	·064	·065	·066	·067	·068	53
54	·055	·056	·057	·058	·059	·060	·062	·063	·064	·065	·066	·067	·068	·070	·071	54
55	·057	·058	·059	·060	·062	·063	·064	·065	·066	·068	·069	·070	·071	·072	·073	55
56	·059	·060	·061	·063	·064	·065	·066	·068	·069	·070	·071	·073	·074	·075	·076	56
57	·061	·062	·064	·065	·066	·068	·069	·070	·071	·073	·074	·075	·076	·078	·079	57
58	·063	·065	·066	·067	·069	·070	·071	·073	·074	·075	·077	·078	·079	·031	·082	58
59	·065	·067	·068	·070	·071	·072	·074	·075	·076	·078	·079	·080	·082	·083	·085	59
60	·068	·069	·070	·072	·073	·075	·076	·077	·079	·080	·082	·083	·085	·086	·087	60
61	·070	·071	·073	·074	·075	·077	·078	·080	·081	·083	·084	·086	·087	·089	·090	61
62	·072	·073	·075	·076	·078	·079	·081	·082	·084	·085	·087	·088	0.0	·091	·093	62
63	·074	·076	·077	·079	·080	·082	·083	·085	·086	·088	·089	·091	·093	·094	·096	63
64	·076	·078	·079	·081	·082	·084	·086	·087	·089	·090	·092	·094	·095	·097	·098	64
65	·078	·080	·082	·083	·085	·086	·088	·090	·091	·093	·095	·096	·098	·100	·101	65
66	·080	·082	·084	·085	·087	·089	·090	·092	·094	·096	·097	·099	·101	·102	·104	66
67	·083	·084	·086	·088	·089	·091	·093	·095	·096	·098	·100	·102	·103	·105	·107	67
68	·085	·036	·088	·090	·092	·094	·095	·097	·099	·101	·102	·104	·106	·108	·109	68
69	·087	·089	·090	·092	·094	·096	·098	·100	·101	·103	·105	·107	·109	·110	·112	69
70	·089	·091	·093	·095	·096	·098	·100	·102	·104	·106	·108	·109	·111	·113	·115	70
71	·091	·093	·095	·097	·099	·101	·102	·104	·106	·108	·110	·112	·114	·116	·118	71
72	·093	·095	·097	·099	·101	·103	·105	·107	·109	·111	·113	·115	·117	·119	·120	72
73	·095	·097	·099	·101	·103	·105	·107	·109	·111	·113	·115	·117	·119	·121	·123	73
74	·097	·099	·102	·104	·106	·108	·110	·112	·114	·116	·118	·120	·122	·124	·126	74
75	·100	·102	·104	·106	·108	·110	·112	·114	·116	·118	·120	·122	·125	·127	·129	75
76	·102	·104	106	·108	·110	·112	·114	·117	·119	·121	·123	·125	·127	·129	·131	76
77	·104	·106	·108	·110	·112	·115	·117	·119	·121	·123	·126	·128	·130	·132	·134	77
78	·106	·108	·110	·113	·115	·117	·119	·122	·124	·126	·128	·130	·133	·135	·137	78
79	·108	·110	·113	·115	·117	·119	·122	·124	·126	·128	·131	·133	·135	·137	·140	79
80	·110	·113	·115	·117	·119	·122	·124	·126	·129	·131	·133	·136	·138	·140	·143	80
81	·112	·115	·117	·119	·122	·124	·126	·129	·131	·134	·136	·138	·141	·143	·145	81
82	·114	·117	·119	·122	·124	·126	·129	·131	·134	·136	·138	·141	·143	·146	·148	82
83	·117	·119	·121	·124	·126	·129	·131	·134	·136	·139	·141	·143	·146	·148	·151	83
84	·119	·121	·124	·126	·129	·131	·134	·136	·139	·141	·144	·146	·149	·151	·154	84
85	·121	·123	·1:6	·128	·131	·133	·136	·130	·141	·144	·146	·149	·151	·154	·156	85
86	·123	·126	·128	·131	·133	·136	·138	·141	·144	·146	·149	·151	·154	·156	·159	86
87	·125	·128	·130	·133	·136	·138	·141	·113	·146	·149	·151	·154	·157	·159	·162	87
88	·127	·130	·133	·135	·138	·141	·143	·146	·149	·151	·154	·157	·159	·162	·165	88
89	·129	·132	·135	·137	·140	·143	·146	·148	·151	·154	·156	·159	·162	·165	·167	89
90	·131	·134	·137	·140	·142	·145	·118	·151	·153	·156	·159	·162	·164	·167	·170	90
91	·134	·136	·139	·142	·145	·148	·150	·153	·156	·159	·162	·165	·167	·170	·173	91
92	·136	·139	·141	·144	·147	·150	·153	·156	·158	·161	·164	·167	·170	·172	·175	92
93	·138	·141	·144	·147	·149	·152	·155	·158	·161	·164	·:67	·170	·172	·175	·178	93
94	·140	·143	·146	·149	·152	·155	·157	·161	·163	·166	·169	·172	·175	·177	·180	94
95	·142	·145	·148	·151	·154	·157	·160	·163	·166	·169	·172	·175	·178	·180	·183	95
96	·144	·147	·150	·153	·156	·159	·162	·165	·168	·171	·174	·178	·181	·183	·186	96
97	·146	·149	·152	·156	·159	·162	·165	·168	·171	·174	·177	·180	·183	·186	·189	97
98	·148	·152	·155	·158	·161	·164	·167	·170	·173	·176	·179	·183	·184	·188	·191	98
99	·151	·154	·157	·160	·163	·166	·169	·173	·176	·179	·182	·185	·188	·191	·194	99
100	·153	·156	·159	·162	·165	·169	·172	·175	·178	·181	·184	·188	·191	·194	·197	100

APPENDIX III.

NOTICE TO CAPTAINS OF SHIPS.

THE Meteorological Office lends instruments which are of first-rate character, and have been properly verified, to captains who are willing to keep a meteorological log for the Office.

The set of instruments supplied are :—

One barometer ; six thermometers, with a screen ; four hydrometers.

A form of meteorological log and a rough book for recording the observations are also supplied. The rough book becomes the property of the observer.

Various publications of the Office are presented to observers.

Those who are willing to help in a work which is calculated to be of very great advantage to navigators and to science generally, should apply in person, if possible, between the hours of 10 a.m. and 4 p.m., or else by letter, to the Marine Superintendent, Meteorological Office, 63, Victoria Street, S.W., who will supply all ships in London, and, in special cases, those in outports where the office has no agents.

The Meteorological Council will also be glad to receive observations of wind, weather, barometer, and temperature of air and sea, or as many of these as possible, from captains who cannot undertake to keep the full log of four-hourly observations, for which verified instruments are lent by the Office. In such cases it is important that the instruments employed should be described as fully as possible, and when practicable, that their readings should be compared with instruments on board ships which have been supplied by the Office, or with the standards which are available in certain ports.

Readings of a barometer, recorded in the log at 8 a.m. in European or American ports, afford a fair means for finding the error of that barometer, as a reference to the daily weather charts of the country enables the Office to find what those readings ought to have been.

The Office log and rough book will be sent to captains who will undertake to make such observations, on application by letter to, or by calling on, the Marine Superintendent.

It is hoped that captains who are interested in meteorology will assist in the work by observing for the Office.

The following gentlemen are the agents at their respective ports, and to them application should be made by captains at those ports :—

Cardiff	... ...	T. L. Ainsley, Bute Dock.
Dundee	... ...	Capt. A. Wood, Navigation School, 33, Dock Street.
Glasgow	... ...	Messrs. D. McGregor & Co., 37 and 38, Clyde Place.
Greenock	... ...	Messrs. D. McGregor & Co., 32, Brymner Street.
Hull	.. ..	Messrs. Castle & Co., Commercial Road
Liverpool	... ...	J. Gill, Nautical College, Colquitt Street.
Southampton	...	Capt. D. Forbes, 169, High Street.

At each agency a set of instruments is kept in working order for inspection by captains and officers, and intending observers can get from the agents any further information they may require on the subject.
