M.O. 61 (1932)

AIR MINISTRY

METEOROLOGICAL OFFICE

A

# Barometer Manual

## For the Use of Seamen:

# A TEXT BOOK OF MARINE METEOROLOGY

WITH AN INTRODUCTION AND APPENDICES

ELEVENTH EDITION

*Published by the Authority of the Meteorological Committee*



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## PREFACE

The Barometer Manual for the use of Seamen was originally issued by the Meteorological Council in 1884 as a revised edition of the Barometer Manual prepared by Admiral FitzRoy, which had then long been out of print.

The previous editions which have been issued from the Meteorological Office are as follow :—

| | |
|---|---|
| First edition | 1884 |
| Second ,, | 1894 |
| Third ,, | 1896 |
| Fourth ,, | 1900 |
| Fifth ,, | 1905 |
| Sixth ,, | 1909 |
| Seventh ,, | 1912 |
| Eighth ,, | 1916 |
| Ninth ,, | 1919 |
| Tenth ,, | 1925 |

Altogether, about 60,000 copies of the work have been issued. There are a few minor changes in this edition.

May, 1932.

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# THE BAROMETER MANUAL FOR THE USE OF SEAMEN

## INTRODUCTION.

### Importance of the Barometer to Seamen.

There are two special reasons why the barometer deserves the attention of seamen who, in common be it said with the rest of mankind, are interested in the weather.

The first is that the barometer enables us to get a measure of the pressure of the atmosphere, and experience has shown that in all parts of the world outside a zone a few degress north and south from the equator, there is an unmistakable relation between the winds over the sea and the distribution of atmospheric pressure at sea level. As we shall see later on, a map is the best way of representing the distribution of pressure at sea level in order to illustrate the relation between wind and pressure. But, using general terms, the winds and local pressure differences go together; the wind is strong in those parts of the earth where the local differences of pressure at sea level are large, and light where the local differences are small.

It is the custom nowadays to deal with all questions of weather by charting the various particulars on maps. Before that practice was introduced it used to be thought that the height of the mercury in the barometer was an indication of the weather to come, and legends were inscribed against certain heights, such as *change* to 29·5 inches, which we now call 1,000 millibars, *very dry* to 31 inches (1,050 millibars), *stormy* to 28·0 inches (948 millibars). The barometer was often spoken of as a *weather glass*. But when we look at the distribution of pressure on a map we see lines indicating the places where the pressure is the same, and the weather, if we include the wind, is certainly not the same at all points of a line of equal pressure. One can see from the maps why those who had only their own barometer and their own weather to guide them might be led to think that it was the actual height of the mercury that mattered. Very low pressures are generally only found in what we now call "deep depressions," where the local changes of pressure are very marked and the weather is stormy; but it can be very stormy without the barometer being very low. And on the other hand, very high pressure is often to be found when there is very little local difference of pressure, very little wind and fine dry weather. But on land, if not at sea, the air is often very damp in the night and early morning when the barometer is very high; and at sea, as on land, the air can be relatively very dry without the pressure being abnormally high.

The legends against the different heights on the dial of a barometer, which are still to be seen occasionally, were, it is said, introduced by Dr. Hooke, the first secretary of the Royal Society of London, in the latter half of the seventeenth century. They suggest the experience of London. A sailor, whose experience of the weather comes from all parts of the world, could never have set much store by them, and by the middle of the nineteenth century, when Admiral FitzRoy was placed in charge of the Meteorological Department of the Board of Trade to collect meteorological information for the use of seamen, it was already recognised that the legends were misleading and that the changes of the position of the mercury in progress were more important in forming an idea of coming weather than its actual position at any particular time. FitzRoy formulated a series of rules as guides to the weather changes to be expected from the changes noticed in the barometer and published them in a "Barometer Manual" to which this book is the successor. They are summarised in the explanatory sheet which is reproduced here.

## EXPLANATORY OF WEATHER GLASSES IN NORTH LATITUDE.

In other latitudes substitute the word south, or southerly or southward, for north, &c.

| THE BAROMETER RISES | THE BAROMETER FALLS |
|---|---|
| for northerly wind, (including from NW. by the *north*, to the eastward) for dry, or less wet weather, for less wind, or for more than one of these changes :— | for southerly wind, (including from SE., by the *south*, to the westward) for wet weather, for stronger winds, or for more than one of these changes :— |
| EXCEPT on a few occasions when *rain* (or snow) comes from the northward with *strong* wind. | EXCEPT on a few occasions when *moderate* wind with *rain* (or snow) comes from the northward. |
| For change of wind towards *any* of the above directions :— THE THERMOMETER FALLS. | For change of wind towards the *upper* of the above directions :— THE THERMOMETER RISES. |

Moisture or dampness in the air (shown by a hygrometer) increases BEFORE or with rain, fog, or dew.

On barometer scales the following contractions may be useful in *north* latitude :—

| RISE | FALL |
|---|---|
| for | for |
| NEly. | SWly. |
| NW.—N.—E. | SE.—S.—W. |
| DRY | WET |
| or | or |
| LESS | MORE |
| WIND. | WIND. |
| Except wet from NEd. | Except wet from NEd. |

And the following summary may be useful *generally* in *any* latitude :—

| RISE | FALL |
|---|---|
| for | for |
| COLD | WARM |
| DRY | WET |
| or | or |
| LESS | MORE |
| WIND. | WIND. |
| Except wet from cooler side. | Except wet from cooler side. |



In 1860 he began collecting reports of the weather by telegraph from a number of stations on the British and French coasts and plotting them on maps. The great astronomer, Leverrier, had done the same for France, and now weather charts showing the distribution of weather, wind and pressure are issued daily in many countries besides Great Britain and France, as Canada, United States, Portugal, Spain, Algiers, Holland, Belgium, Norway, Sweden, Denmark, Germany, Switzerland, Austria, Italy, Russia, Egypt, India, China, Japan, the Argentine, Chile and Australia. So we have a great accumulation of facts about the weather, winds and pressure at the surface, and we have also by means of observations with kites, pilot balloons and the registering or sounding balloons, which are often called by their French name, *ballons sondes*, a great deal of information about pressure, temperature and air currents at different heights above the surface. The chief conclusion to be drawn from all the observations is that the winds are all part of a general circulation of air which is going on over the surface of the earth and in the air above as well. It is recognised that this circulation, with its local characteristics and its never-ending changes, has been going on since the world began and will continue to go on till the world ends. We see a brief part of its history—we were not there at its beginning and we shall not be there at its end. The main features of the circulation are permanent, the local variations which make our weather are transient. The weather is closely related to the winds and the distribution of pressure, but the relation is more complicated and not so definite and not, at present, so well understood as the relation between the winds and the distribution of pressure.

It is part of the purpose of this book to set out the ascertained facts about the distribution of pressure at the surface and to exhibit the relation of the winds thereto. By means of the general principles which have been thus established, the seaman is enabled to recognise by readings of his own barometer the local situation as regards wind and pressure, and thereby to make use of the information to his own advantage.

### THE NEED FOR ACCURACY IN BAROMETER READINGS.

One of the important points of the relation between winds and pressure distribution is that the differences of pressure at sea level, which are associated with high winds and gales, are not at all large, and that brings us to the second special reason why the barometer deserves the attention of seamen who are interested in the weather. It is this : the degree of precision required in the readings of a barometer in order to bring the pressure distribution into relation with the winds is a very high one, much higher than what has been thought necessary by those who are accustomed to read a barometer for their own information. In this connexion it is convenient to talk in millibars (mb.), the unit of atmospheric pressure which is now used at the Meteorological Office, because the average height of the barometer at sea level over the globe is 1,013 millibars (29·92 inches), not very different from the round number 1,000, and one millibar is, therefore, one-thousandth part of the ordinary pressure. For the purpose of accurate mapping, we require the pressure to one ten-thousandth part, one-tenth of a millibar, and that is a degree of accuracy which is just attainable but not easily attained. Yet it is necessary for good work.

If two captains, 100 miles apart were exchanging barometer readings by wireless, as they sometimes do, and it was found that the one reading was 8 millibars (¼ in.) higher than the other, it follows from our knowledge of the relation of wind to pressure that there ought to be a gale blowing across the space between the two in the one direction or the opposite according to which has the higher barometer ; and, on the other hand, if there is a gale blowing there ought to be a difference of about that amount between two ships in a line across the wind. If the line is down-wind or up-wind, there will be very little difference of pressure ; and, of course, we must not lose sight of the possibility of the wind blowing obliquely across the line. But before the two captains can compare their pressures, the readings must be corrected for index error, for temperature, and also for what is known as the variation of gravity, a very recondite correction which depends on the peculiar shape of the earth. The reading must also be reduced to sea level. It may seem almost absurd to suppose that so local a matter as wind and weather should have any regard for the shape and rotation of the earth ; but it certainly does, and the comprehension of the relation is the first step in the scientific study of weather. Hence, it is important to know how these operations of correcting and reducing can be conducted with the greatest accuracy and, at the same time, with the least possible expenditure of time and trouble. To do that, the first step is to understand how the correct value of the pressure is obtained from the barometer reading.

In the temperate latitudes the fluctuations of the barometer are often large and the pressure difference necessary for a certain wind, small as it is, is greater than it is nearer the equator. Between the tropics the differences of pressure are so small that it is a matter of curious speculation not yet settled as to whether two ships a hundred miles apart could ever agree as to which of the two had the higher and which the lower pressure if they exchanged their pressures by wireless. Yet the speculation has a practical interest for all those who are interested in the study of weather, because we ought to know more than we do about the relation of winds to the distribution of pressure in the inter-tropical regions. The laws and principles which we have already obtained are based upon observations further away from the equator, and we should like to know to what extent they are modified in the regions near the line.

The information which has been obtained from observations of the upper air in the last twenty years has thrown so much new light upon the fundamental question of the relation of the general circulation of the atmosphere to the distribution of pressure at the surface and in the upper air that it is necessary to think of it somewhat more closely than has been customary.



### The Problem of the Atmospheric Circulation.

It has always been recognised that the circulation of the atmosphere is what is technically called a dynamical problem ; by this we mean that, in order to understand it, we have to make out the adjustment of the velocity of the moving air and its changes, to the forces which produce, maintain, or alter it. Hitherto, meteorologists have regarded the motion of air as so complicated that it has seemed useless for any but the most accomplished mathematicians to attempt to trace its relation with the forces that produce it or alter it. We can understand that the same air sometimes takes part in the furious motion of a hurricane that sweeps away everything before it and at other times lies idly on the surface of the sea, a perfect example of peacefulness and rest, far too much so, indeed, for the sailing ship that wants to get on. But we cannot trace in any effective manner the steps by which the air passes from one state to the other. We cannot even answer so simple a question as this : When a breeze springs up where there has been a calm, does the stagnant air itself begin to move in consequence of some forces arising from causes outside, or does a current of air press forward from outside and brush the stagnant air aside and take its place ? In the light of our new information we find that we can learn a great deal about the dynamical conditions of the atmosphere by regarding the motion as taking place under balanced forces, supposing with some confidence that that state of things is truly representative of by far the greater part of the life history of the atmospheric circulation.

### Motion under Balanced Forces.

In illustration of the meaning let us think of other cases of which the same is true—the motion of a train on a railway, or of a ship at sea. We can learn a great deal about train motion by confining out attention to the times when trains are running at a uniform speed. We can leave out of account the times of stopping and starting : for many purposes they are unimportant. The engine driver may not think so ; he will be aware of all sorts of causes which slow him down or speed him up, but in the end he makes his scheduled time and for many purposes we may take the run as at a uniform speed, a condition that is realised when the force that is taken out of the engine is balanced by the resistance of the air and the friction of the moving parts : the slope of the ground is a disturbing cause, but not so disturbing as to make a journey of " forty miles an hour " between stations altogether meaningless. In like manner the voyage of a ship at sea is run at a speed that may vary sensibly from day to day but not sensibly from hour to hour. The time that is spent in getting up speed or in adjusting the speed to the conditions of weather or other circumstances is a very small fraction of the whole length of the voyage, and if we leave it out of account we shall still be able to understand a good deal about the propulsion of ships.

So with the atmospheric circulation, the air certainly does change its speed though we may not be able to tell how or when ; but the winds as we know them surprise us, not by the changes but by the uniformity of the speed with which they travel, and we may be sure that looking at the circulation exhibited on a map the times when the winds are altering their speed by any amount which would be dynamically significant are a small fraction of the whole time occupied in the completion of a voyage.

It is unnecessary to elaborate this idea, it must be familiar to seamen who think about it—and one has only to watch the steady regular progress of a balloon as it floats in the air to be assured that there is not much starting and stopping in the free air. Let us, therefore, not give too much attention to how the wind originally got up its speed but think of it as moving with its proper speed and think of the conditions necessary to maintain it, not to change it ; we shall not then be far away from the actual working condition of the atmospheric circulation.

In this way the dynamical problem of the atmosphere is vastly simplified from its original complexity. But it remains a dynamical problem still, so let us consider some essential aspects from that point of view. We take the following extracts from the "Weather Map," an introduction to modern meteorology, issued by the Meteorological Office* :—

THE ATMOSPHERE.

> The air which surrounds us and is carried along with the earth on which we live and which, regarded in its entirety, is called the atmosphere, is a mixture of gases. In the regions which are within our reach, up to 10 kilometres, 6 miles, or 33,000 feet, the greater part of it is nitrogen, one of the chemical constituents of ammonia and also of nitric acid and the nitrates which are so important in gunpowder and nearly all other explosives. In the atmosphere, however, nitrogen is a peculiarly inert gas. It merely dilutes the more active gas, oxygen, which forms about one-fifth of the atmosphere. Oxygen is one of the active substances in all forms of combustion. The burning of fires, and the slower processes which go on within the human body, are forms of combustion in which oxygen combines with substances like wood or coal or with the blood in the lungs. In the combination a proportionate quantity of heat is produced, and a corresponding amount of carbonic acid gas which mixes with the other gases of the atmosphere. Without oxygen no fire can be maintained and the chemical processes in the body necessary for life cannot go on. Thus the oxygen of the atmosphere is a very important element but in meteorology its special characteristics do not concern us. Combustion is constantly going on and oxygen is being used up, but there is a reverse process going on in growing plants. They act upon the carbonic acid gas in the air which surrounds them, take it into their structure and liberate oxygen. The result of these manifold chemical actions, with the mixing that is made by the winds, is to maintain the mixture of nitrogen and oxygen in the atmosphere practically unchanged.
>
> Besides these two constituents there are small amounts of other gases, one the inert gas argon and the other carbonic acid gas, one of the products of the combustion of wood, coal, etc. These are also practically invariable in the open air, but there is also always in the open air some water vapour which is very variable in its amount. The water vapour passes into the atmosphere as an invisible gas by evaporation from all surfaces of water, even when it is frozen, as well as, to a less extent, from nearly all forms of combustion.
>
> WATER VAPOUR : EVAPORATION AND CONDENSATION.
>
> Unlike the other constituents of the atmosphere water vapour is of the greatest importance in meteorology. It is the form in which the enormous quantities of water represented primarily by rain or snow, and secondarily by rivers, lakes, icebergs and glaciers, are transported from one part of the earth to another. All the water which falls as rain or snow in a year has been evaporated from the sea or other surfaces of water or ice or from plants or wet soil and transported in the form of invisible water-vapour mixed with the other gaseous constituents of the atmosphere. By natural processes which can be imitated quite easily and effectively in a physical laboratory, part of the invisible water-vapour in the air can be reconverted to visible water in drops as in clouds and rain, or as snow-crystals in certain kinds of cloud in the atmosphere itself, or on plants and buildings as dew or hoar-frost. The conversion of invisible vapour into visible drops or crystals is called condensation, it is the counterpart of evaporation.
>
> Evaporation and condensation are related to changes of temperature in the air and the study of these changes belongs, therefore, to the science of heat which in modern times finds its most effective illustrations in the working of the steam-engine. The atmosphere may, therefore, be looked upon as a steam-engine of huge dimensions, drawing its heat from the sun and ultimately sending it out again into space. At the end of a year so much heat has been taken by the earth from the sun, so much has been used up in the operations of running water and flowing air, so much sent out again into space. As, after the lapse of centuries, so far as we can tell, the whole earth becomes

* First edition.

neither warmer nor colder we must suppose that in the end the heat which has been taken in has been got rid of by radiation into space, but in the meantime the whole course of the wind and weather all over the world has been controlled and ordered by the process of warming and cooling, evaporation and condensation.

The weather which we experience in any particular locality is a small part of the great process going on in the whole atmosphere of which evaporation and condensation are the most striking incidents. Evaporation is included because if there were no evaporation condensation would soon come to an end but evaporation is a silent invisible process, whereas condensation furnishes in the form of cloud, rain, snow, thunderstorms, the most impressive manifestations of the energy of nature.

From recent researches by means of balloons it appears that only the lowest layer of the atmosphere, the troposphere, about 10 kilometres (33,000 ft.) thick, is concerned in the process of condensation and evaporation. That does not define the limit of the atmosphere itself. Observations of meteors, auroræ and other phenomena indicate that the atmosphere is still recognisable at a height of some 80 or 100 miles. At the greatest heights the composition is probably quite different from what it is near the surface. From 57 kilometres (36 miles) upwards it is thought to be mainly hydrogen. But it is with the lowest 10 kilometres, the region of nitrogen, oxygen and water-vapour that meteorology is concerned.

A cubic foot of atmosphere in ordinary circumstances weighs only an ounce and a quarter, less than one-tenth of a pound, but air is really a very weighty substance. A cube of it, thirty feet each way, weighs a ton. It is a small ship that does not carry ten tons of air below her main deck. One of the big airships displaces air which weighs about 25 tons, and that does not fill up much of the sky. The total weight of the atmosphere is known to a high degree of accuracy because it is the weight of the atmosphere which produces the pressure at the surface: it amounts to five thousand billion tons.

One-half of this enormous weight goes to form a bottom layer four miles thick; about three-quarters of it are within the ordinary height of the highest type of cloud, about 6 miles. The concentration towards the surface depends upon the fact that air is compressible. The weight of say, a cubic yard of air depends upon its pressure and its temperature. It is directly proportional to the pressure and inversely proportional to its temperature if the temperature is measured from what is called the absolute zero. Seamen generally measure temperature from Fahrenheit's zero, which is 32° below the freezing point of water. The absolute zero is 459° below that. The figure is determined by theoretical calculation into which we will not enter; the absolute zero has never been actually reached in practice, and there is good



reason to think it never will be, but those who work upon the liquefaction and solidification of such gases as oxygen and hydrogen have got within a few degrees of it. The temperature of the atmosphere has never been found anything like so low as that; the lowest temperatures on record have been found in the upper air over the equatorial region, and are about 350° on the Fahrenheit scale measured from the absolute zero: the highest have been found in the Californian and African summers and reach about 600° on the same scale. Within that range the density of air, as it is called, or the weight of a cubic yard, obeys the law of inverse proportionality to temperature with great fidelity.

Working at ordinary temperatures and pressures the variation of density is easily remembered. It goes up one per cent. with an increase of ten millibars of pressure and goes down one per cent. with an increase of 5° Fahrenheit of temperature.

Of the millions of tons of air which form the atmosphere nearly the whole is moving. The regions of calm at the surface at any one time taken all together do not form a large part of the earth's surface, and above the surface calm regions are still rarer. Let us remember that the motion of the air is always "circulation"; air cannot move forward or backward or upward or downward without displacing other air in front of it and being replaced by other air behind it. The circulation may be quite local and limited in extent, as is frequently the case when warm air rises or cold air sinks. In the course of investigations in the Meteorological Office into the life history of surface air currents we have traced air over long stretches of the surface of the Atlantic. We have found on one occasion the shores of Greenland to be fed with air that left the middle of the Atlantic four days previously, while in the course of six days air travelled from Spitsbergen to join the NE. Trade wind off the west coast of Africa. On another occasion the air that formed the wind off the south of Ireland was traced back to the north of Africa, but that which blew at the opening of the channel two days later came from Hudson's Bay, via the Azores. These long journeys were performed in a way that is in striking resemblance to the passage of a fast ship. More headway is made on some days than on others, and within any small number of hours there is no more variation of speed of travel in the wind than there is in a ship, and so we come to draw a parallel between the dynamics of the moving ship and that of the moving air, and in the one case as in the other we may leave out of account the starting and stopping and take account only of the motion under balanced forces.

There is, however, a difference between the movement of a ship and that of the wind, under balanced forces. In the case of the ship the balance is between the push of the screw at the back and the head resistance of the water and air. The wind when it has become established, has not to push its way through a resisting environment as the ship does through the water, it is part of a circulation in which the environment itself shares. It does not push the air in front nor is it pushed by the air behind:

that kind of action belongs to the times of starting and stopping with which we are not just now concerned. The whole length of the current flows on like a string of carriages in a line of traffic. The air is not pushed by the air behind, any more than a carriage in the line is pushed by the one behind. It might happen; but in that case there would be a collision; some re-adjustment would have to be made in consequence.

Instead of having to meet head-resistance like a ship the air has to bear the difference of pressure on the two sides of the current which does not affect the speed but determines the direction in which the air moves. The best analogy to the motion in this case is perhaps the motion of the moon round the earth. The moon moves in its orbit round the earth because it is always being pulled aside towards the earth by the attraction of gravitation, which is very nearly at right angles to the moon's path. In the same way, the air moves over the surface, its course being determined by its being pushed aside by the difference of pressure on the two sides.

A great deal can be learned about the motion of air in these circumstances by watching the ball-governor of a steam-engine. With the engine running at a fixed speed the balls stand apart from the rod a certain distance and as long as the speed remains the same they keep their position. Speed up the engine and they fly out a bit further and very soon adjust their position to the new speed—stop the engine and the weight of the balls brings them down to the rod. The weight is always acting, and it acts with greater leverage when the balls are spread out wide. When the spin is faster it takes more leverage to keep them going round in a circle. Each position, therefore, corresponds with a certain definite speed. The weight—which is balanced—is always at right angles to the path of the balls.

So with moving air the force which is balanced is the force due to the distribution of pressure acting across the path of the air. It is balanced by the speed of the air which corresponds with the spin of the governor-balls. The spin to which the air is subjected and which enables it to balance the pressure distribution is of two kinds, which we shall consider separately. One is the spin in a small circle which is most clearly shown in a tropical hurricane, a great whirl of air with a diameter of 100 miles, more or less. Tornadoes are whirls of smaller diameter, 10 miles or so. The spin is sometimes tremendous. So is the pressure difference; the mercury in a barometer near the centre may go out of sight, while that in one on the outer margin of the storm remains at its usual level. These circulations generally begin in the inter-tropical regions and travel round the great areas of high pressure that make up the tropical belt.

The same kind of spin is also shown in the circular cyclonic depressions which occasionally visit these islands and have been traced back in some cases to a cyclone passing from the south-west after turning the tropical area of high pressure of the North Atlantic.



This kind of circulation, which is of the same nature as a vortex or whirlpool, is very common, and has many forms in water or air. A vortex is always formed when water runs out through a hole in the bottom of a basin; and if one could imagine a condition of things in the atmosphere in which a similar persistent downward flow over a very limited area occurs we should expect a corresponding vortex to result from the condition. We cannot point with confidence to any actual example of that kind in nature, but the corresponding case in which air is drawn out from the top instead of running out at the bottom is on view at any time in the Science Museum at South Kensington in a model constructed by Mr. W. H. Dines, F.R.S. If the motive power drawing the air out of the top is set a-going for a little while a fine vortical core is formed extending from the aperture through which the air is running, down to the base. It is made visible by supplying the case with steam.

About this experiment it is important to notice that when the air is flowing through the hole in the ceiling the vortex forms in the space that the air is *leaving*, not in that into which it *flows*. We may conclude from that that if an upward current of air could be established in the atmosphere, which is not at all an improbable occurrence, we ought to look for the vortex *below* where the upward current starts; and on the other hand if we could establish a downward flow of air over some limited area we ought to find a vortex in the space *above* where the downward flow begins. One or two important conclusions flow from this consideration; the first is that a local upward current of heated air rising from the earth's surface is not likely to give rise to a vortex in the air through which the current is moving. If it were, we ought to find a well-developed vortex over every gas-jet that has been kept burning for some time. Secondly, if we do actually find a vortex in the lower atmosphere, and we want to associate it with rising or falling air, it is the *upward flow of air at the top of the vortex* that has to be provided for, upward flow at the bottom is of no avail. If the vortex is formed in the free atmosphere away from the surface of the earth, *a downward flow from the bottom* of the vortex will start it or maintain it.

The importance of these considerations in the study of the atmosphere is that when once an atmospheric vortex is started it is a serious dynamical fact that may have developments of many kinds. When the pressure and spin have been adjusted a vortex 100 miles in diameter and only one mile high will be in effect a fly wheel or a pair of governor-balls of about fifty thousand million tons. It is a good deal to set going and a good deal to stop.

CHAPTER I.

## 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. Two kinds are in use for observations at sea, the mercury and the aneroid. The principle of the mercury barometer was discovered by Torricelli in 1643; but the instrument was not utilized by seamen until a century had elapsed, and its form had undergone several modifications in the interval. A mercury barometer consists of a glass tube closed at one end, which is filled with pure 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 with 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. A small hole in the upper part of the cistern, H, Fig. 1, admits access to the superincumbent air; and a washer of leather permits of the atmosphere exerting pressure but prevents the mercury escaping from the cistern. English instruments are graduated either for mercury inches and decimals of an inch, or for centibars and millibars; the average pressure at the sea level being rather less than 30 inches, or 1015 mb., though the mercury sometimes rises to slightly above 31 inches, 1050 mb., and falls below 27·5 inches, 930 mb.

In all mercury barometers of the Kew pattern issued by the Meteorological Office the glass tube is considerably contracted for the greater part of its length in order to prevent unsteadiness of the mercury column or "pumping," as this is called; also to strengthen the tube, and to lessen the weight of mercury.

The tubes are furnished with an "air trap" to prevent air from working into the space at the top of the mercury column. The air trap consists of a small funnel or "pipette" which is introduced between the cistern and the wider portion of the tube (*see* Fig. 1). By means of this arrangement any air entering the tube becomes imprisoned at the shoulder A, and therefore cannot interfere with the efficiency of the instrument. In marine barometers of this pattern a part of the contracted portion of the tube is further constricted with the object of reducing the pumping caused by the labouring of a vessel in a seaway. In Fig. 1,



a Meteorological Office barometer is shown suspended from a bulkhead; a principal section of the tube, in which A indicates the air trap and C a specially contracted portion of the capillary tube, is also shown.

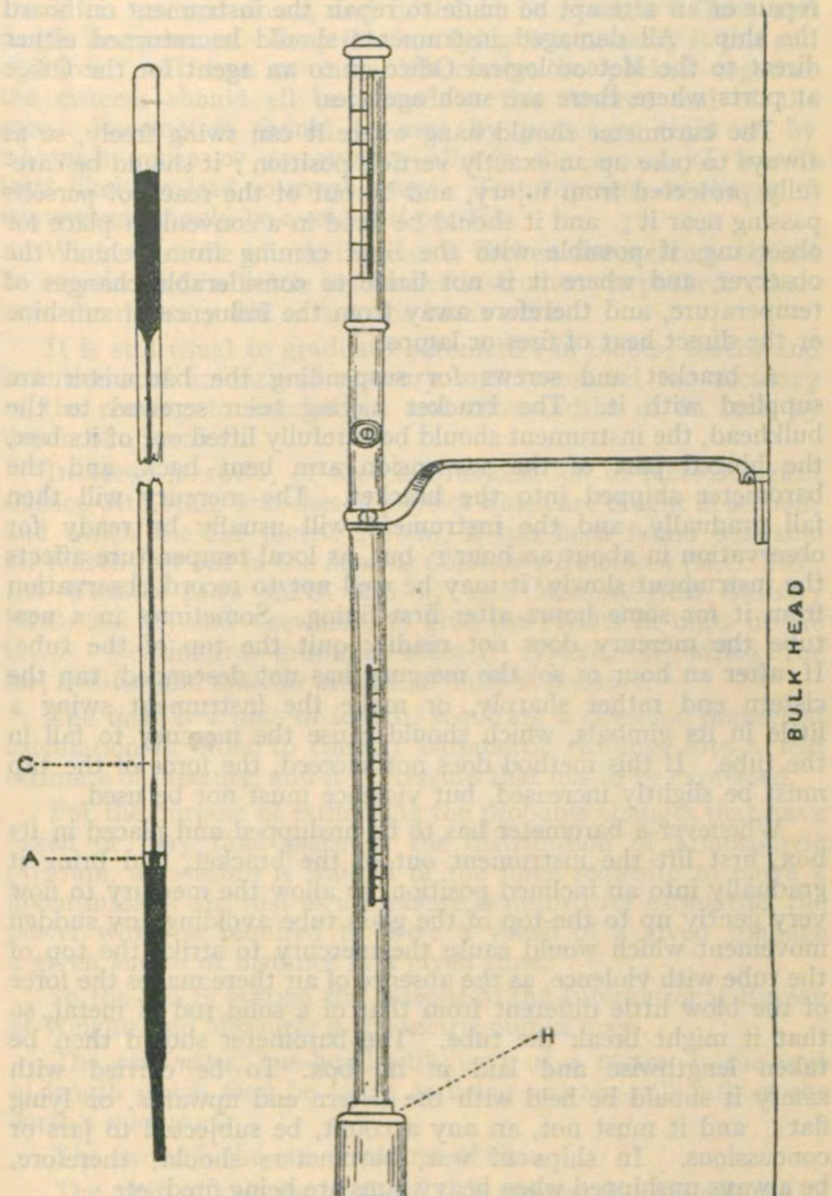



FIG. 1.

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 that has been repaired, and not verified by comparison with an instrument the error of which is known, may prove useless.

On no account should a barometer or other instrument belonging to the Meteorological Office be sent to an optician for repair or an attempt be made to repair the instrument on board the ship. All damaged instruments should be returned either direct to the Meteorological Office or to an agent for the Office at ports where there are such agencies.

The barometer should hang where it can swing freely, so as always to take up an exactly vertical position ; it should be carefully protected from injury, and be out of the reach of persons passing near it ; and it should be 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 to the bulkhead, the instrument should be carefully lifted out of its box, the hinged part of the suspension arm bent back, and the barometer shipped 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 observation 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 gimbals, which should cause the mercury to fall in the tube. If this method does not succeed, the force of the tap must be slightly increased, but violence must not be used.

Whenever a barometer has to be unshipped and placed 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, as the absence of air there makes 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, an any account, be subjected to jars or concussions. In ships of war, barometers should, therefore, be always unshipped when heavy guns are being fired, etc.

Experience has shown the advisability of giving directions for 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 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 on the end of the case which is next the cistern of the barometer before the lid is screwed down, 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.



When the tube of a barometer is broken the mercury should be emptied into a bottle before the instrument is packed, otherwise the mercury will attack the brass work.

It is still usual to graduate barometers in inches, tenths and twentieths of an inch of mercury and to extend the accuracy of the reading to hundredths and thousandths of an inch by means of a vernier.

In view, however, of the close association of meteorological science with other branches of physics which are taught in schools, and which use the metric system, it has been found desirable for reasons set out in the *Marine Observer's Handbook* (M.O. 218), the *Weather Map* (M.O. 225 i.) and *Meteorological Glossary* (M.O. 225 ii.) and elsewhere, to give the results in units of the C.G.S. (centimetre—gramme—second) system, in which the *bar*, *centibar* and *millibar* are actual units of *pressure*.

The inch is a unit of length, requiring a tiresome numerical calculation in order to convert barometric readings into a real estimate of pressure, and it is pressure that has to be expressed.

For the purpose of estimating the probable changes that have taken or may take place in the distribution of atmospheric pressure, a measure is wanted of the force requisite to move a given mass of air, just as a measure is needed for estimating the power which is required to drive a vessel of a given tonnage a given length or distance in a given time.

In the C.G.S. system the *gramme* of the International Bureau of Weights and Measures is the metric unit of mass.

The *centimetre*, one-hundredth part of a metre, is the unit of length which may be taken as being one ten-millionth of the earth's quadrant.

The *second* is the universal unit of time.

The unit of *velocity* in the C.G.S. system is the velocity of one centimetre per second.

The unit of *acceleration* in the C.G.S. system is an acceleration of one unit of velocity per second.

The unit of *force* in the C.G.S. system is the force which produces an acceleration of one centimetre per second per second in a mass of one gramme. In physics this unit is called a *dyne*.

The unit of *pressure* in the C.G.S. system is the dyne per square centimetre, which is so small that a practical unit of atmospheric pressure, the megadyne per square centimetre, has been substituted, which is one million times as great, and may be called the C.G.S. " atmosphere."

The megadyne is equivalent to a pressure of 29·53 inches or 750·1 millimetres of mercury at the freezing point in latitude 45°.

In expressing this unit the name *bar* has been adopted by meteorologists, from the Greek *baros*, weight. It is the hundredth and thousandth parts of a bar : the *centibar* and *millibar* respectively, which are adopted as working pressure units in the C.G.S. system ; the latter being approximately a thousandth part of the ordinary pressure of the air at sea level.

More strictly the mean pressure at sea level is 14¾ lb. per square inch ; corresponding with 760 mm., 29·92 inches of mercury at the freezing point, in latitude 45°. 1000 mb. are very nearly 750 mm., 29·5 inches, 14½ lb. per square inch ; 1 mb. is one thousandth part of this.

The relation between the centibar and the commoner units, the inch and the millimetre, is shown in Fig. 2 and in the following table :—

Equivalents in Millimetres and Centibars of Inches of Mercury at 32° F. and Latitude 45°.

| Mercury inches. | Mercury millimetres. | Centibars. | Mercury inches. | Mercury millimetres. | Centibars. |
|---|---|---|---|---|---|
| 28·0 | 711·2 | 94·8 | 29·5 | 749·3 | 99·9 |
| 28·1 | 713·7 | 95·2 | 29·6 | 751·8 | 100·2 |
| 28·2 | 716·3 | 95·5 | 29·7 | 754·4 | 100·6 |
| 28·3 | 718·8 | 95·8 | 29·8 | 756·9 | 100·9 |
| 28·4 | 721·4 | 96·2 | 29·9 | 759·5 | 101·3 |
| 28·5 | 723·9 | 96·5 | 30·0 | 762·0 | 101·6 |
| 28·6 | 726·4 | 96·9 | 30·1 | 764·5 | 101·9 |
| 28·7 | 729·0 | 97·2 | 30·2 | 767·1 | 102·3 |
| 28·8 | 731·5 | 97·5 | 30·3 | 769·6 | 102·6 |
| 28·9 | 734·1 | 97·9 | 30·4 | 772·2 | 102·9 |
| 29·0 | 736·6 | 98·2 | 30·5 | 774·7 | 103·3 |
| 29·1 | 739·1 | 98·5 | 30·6 | 777·2 | 103·6 |
| 29·2 | 741·7 | 98·9 | 30·7 | 779·8 | 104·0 |
| 29·3 | 744·2 | 99·2 | 30·8 | 782·3 | 104·3 |
| 29·4 | 746·8 | 99·6 | 30·9 | 784·9 | 104·6 |

The graduation of thermometers attached to barometers, which are graduated in C.G.S. units, is usually in centigrade degrees from the absolute zero of temperature, which is 273° centigrade below the freezing point of water or—459° on the Fahrenheit scale. The zero represents, so far as our knowledge goes, the temperature at which the whole of the heat of any



Graduation of Kew Pattern Barometer and its Attached Thermometer : The latter with graduation in degrees of Fahrenheit added for comparison.

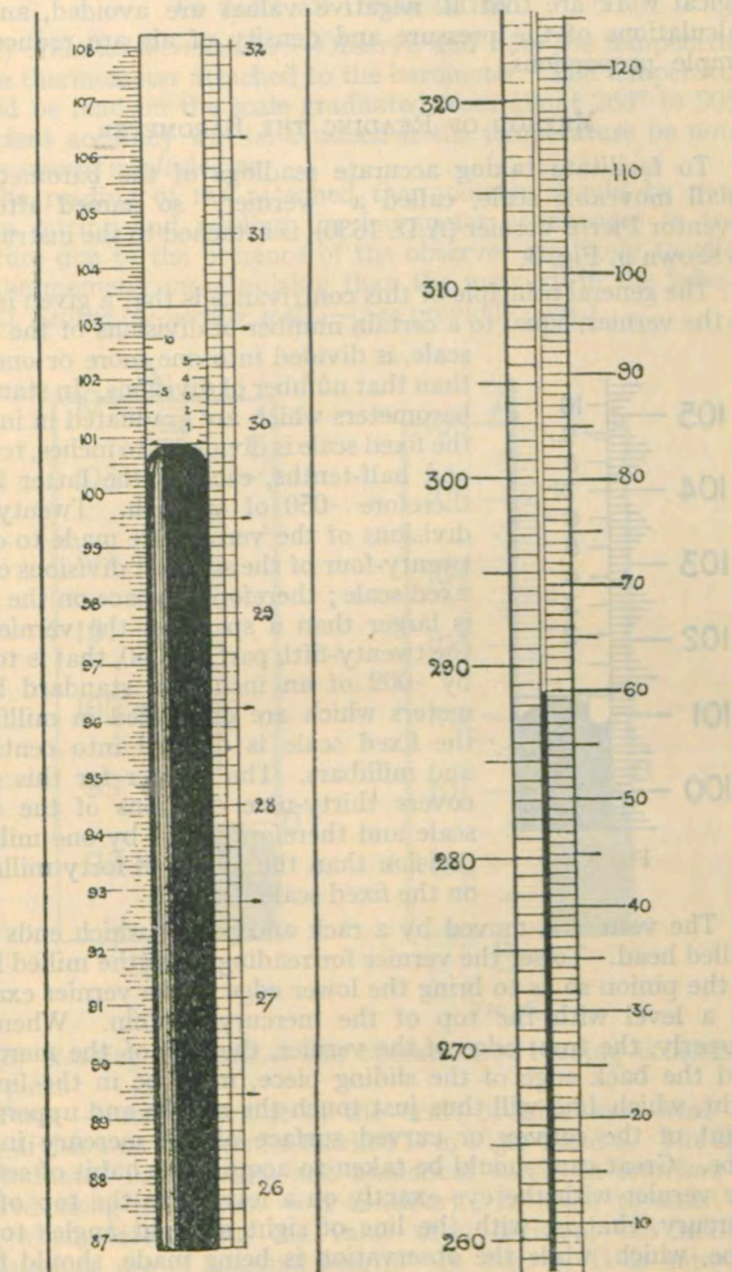



Fig. 2.

substance whatever would be converted into some other form of energy.

The principal advantages of the absolute scale for meteorological work are that all negative values are avoided, and all calculations of the pressure and density of air are reduced to simple proportions.

### Method of Reading the Barometer.

To facilitate taking accurate readings of the barometer, a small moveable scale, called a "vernier," so named after its inventor Pierre Vernier (A.D. 1630), is attached to the instrument as shown in Fig. 3.

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 which are graduated in inches, the fixed scale is divided into inches, tenths, and half-tenths, each of the latter being therefore ·050 of an inch. Twenty-five divisions of the vernier are made to cover 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. In standard barometers which are graduated in millibars, the fixed scale is divided into centibars and millibars. The vernier for this scale covers thirty-nine divisions of the fixed scale and therefore is less by one millibar division than the length of forty millibars on the fixed scale.

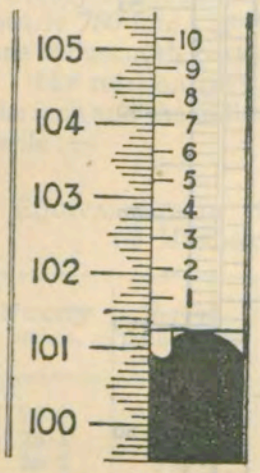


Fig. 3.

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 mercury column. When set properly, the front edge of the vernier, the top of the mercury, and the back edge of the sliding piece, 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 should not be 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 lamp,



preferably an electric lamp, may for this purpose be held so as to throw a strong light on the paper.

### To take an Observation.

(1) *Attached thermometer.*—Observe and note the temperature of the thermometer attached to the barometer. The temperature should be read on the scale graduated from about 265° to 305°. Sufficient accuracy will be attained if the temperature be noted to the *nearest whole* degree.

The reading of the attached thermometer should be noted before setting and reading the barometer as changes in temperature due to the presence of the observer are likely to affect the thermometer more quickly than the mercury in the tube.

(2) *Setting the vernier scale.*—(*See* previous page.)

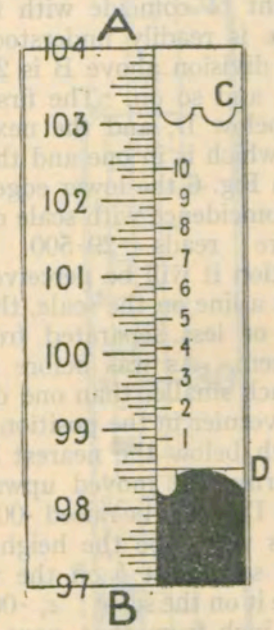


Fig. 4.

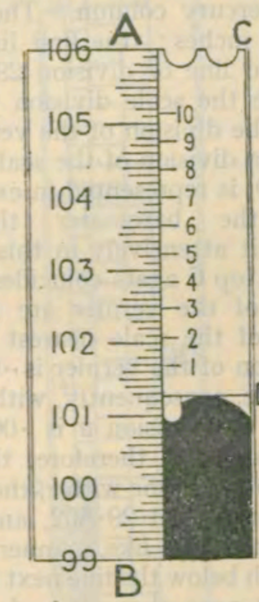


Fig. 5.

(3) *Reading the scale.*—The operation of reading consists of two parts:

*First.*—Note the value of the scale division *next below* the zero division on the vernier marked D in Figs. 4 and 5. The scale is graduated in *millibars*, and numerical values in *centibars* are figured along it (10 mb. = 1 centibar). In order to assist the eye when determining the value of a division, the millibar graduations are of unequal length. In Fig. 4, D is supposed to be in the same straight line with the fifth (the long) division above the scale division numbered 98, in other words with the graduation 985 mb. In Fig. 5 the graduation next below D is the second above the graduation numbered 101; its value is therefore 1,012 mb.

*Second.*—Look along the vernier for a division which is in one and the same straight line with a scale division. The value of this division on the vernier gives the decimal place. In Fig. 4 the vernier division 0 is exactly coincident with a scale division; the reading of the barometer is therefore 985·0. In Fig. 5 the vernier division 7 is exactly opposite a scale division; the barometer reading is therefore 1012·7.

*If the vernier has not been shifted between two observations, it is advisable to check the previous reading before proceeding to a fresh setting.*

The mode of reading off the height, when the vernier has been set and the vernier is graduated in inches, may be learned from a study of the diagrams, Figs. 6 and 7 (p. 25) 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 mercury 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 Fig. 6 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. 6 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 inch, and it would read 29·502, 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. 7. 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<br>·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 with 29·684 and 29·686, then 29·685, half way between them, should be adopted.

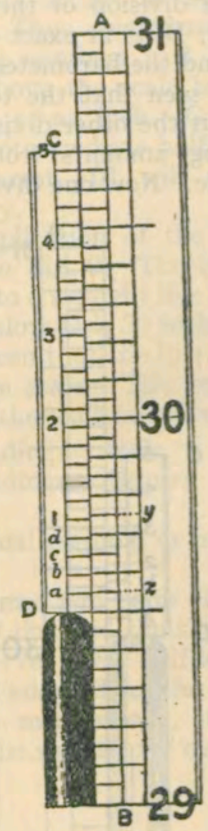


Fig. 6.

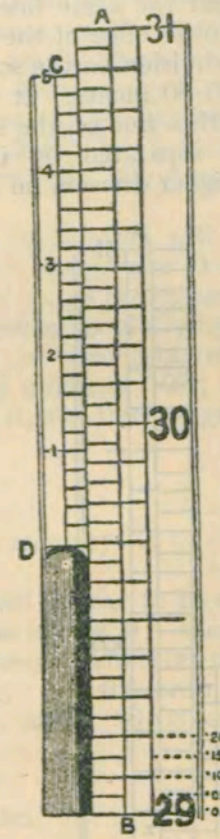


Fig. 7.

The Meteorological Office has issued a barometer for use at sea with a vernier which allows of barometrical readings being taken to the nearest half-hundredth, or ·005 of an inch. The divisions of the fixed scale are each ·050 inch; nine of these are taken as the length of the vernier, which is, therefore, ·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 inch.

It is not necessary, however, to record the height of the barometer at sea to thousandths of an inch, readings to hundredths are sufficiently accurate.

A comparison of Figs. 8 and 9 with Figs. 6 and 7 is sufficient to explain the method of effecting the change. In Figs. 8 and 9, AB represents part of the scale, and CD the vernier, the lower end of which, D, has been brought to coincide with the top of the mercury column. The scale is readily understood. B is 29·00 inches, the first line or division above B is 29·05, the second line or division is 29·10, and so on. First note the scale division just below D, next determine the division of the vernier which is in one and the same line with a division of the scale. In Fig. 8 the lower edge of the vernier, D, is in exact coincidence with 29·50 division on the scale; and the barometer reading is therefore, 29·50 inches. It will be seen that the top C again coincides with a line on the scale, but the other divisions of the vernier are separated by increasing amounts from the immediately higher division on the scale. Now one division of the

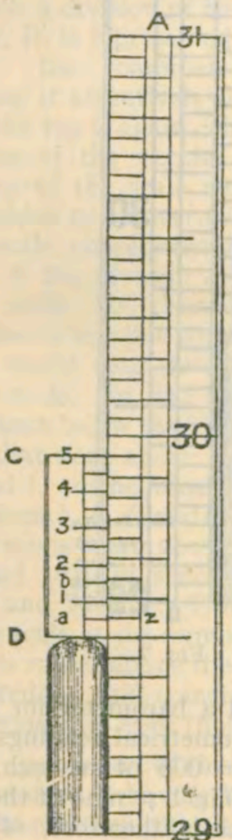



Fig. 8.

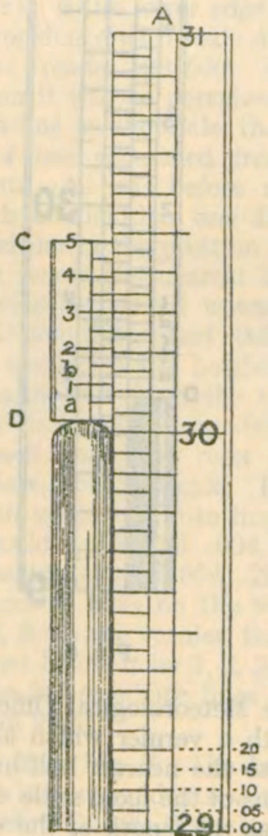



Fig. 9.



vernier, as stated above, is ·005 inch smaller than one division on the scale, and, therefore, with the vernier shown as in Fig. 8, the division *a* on the vernier is ·005 below the next higher division *z* on the scale. Hence, if the vernier be moved upward so as to place *a* in a line with *z*, the edge D would be raised ·005 inch, and it would indicate 29·505, and this will be the height of D on the scale. Similarly, it will be seen that 1 on the vernier is ·01 inch below the line next above it on the scale: *b*, ·015 inch below that next above it; 2 is ·02 inch from that next above it; and 5 on the vernier is ·05 below the 30 inch line. Hence, if the lines 1, 2, 3, 4, 5 be raised into line with the scale divisions next above them, D will be raised ·01, ·02, ·03, ·04 and ·05 inch, in succession; and the barometer readings of 29·51, 29·52, 29·53, 29·54, and 29·55, respectively, would be indicated. Thus coincidences of lines on the vernier and the scale at the numbers 1, 2, 3, 4, 5 on the vernier, show that D is raised above the scale line next below it by 1, 2, 3, 4 or 5 hundredths of an inch. Coincidences at the intermediate lines mark the intermediate half hundredths; but accurate readings to the nearest ·01 will suffice for the purposes of marine meteorology.

The application of the above explanation will be seen by reference to Fig. 9. The bottom of the vernier D having been brought into a straight line with the top of the mercury the scale line just below D is 30 inches. Looking carefully up the vernier it will be seen that the line against the figure 3 lies evenly with a line on the scale. The number 3 indicates ·03; hence D is ·03 above the scale line next below it, and thus we get—

| | |
|---|---|
| Reading on scale .. .. .. | 30·00 |
| Reading on vernier .. .. .. | ·03 |
| Actual reading, or height of mercury .. | 30·03 inches |

Sometimes two pairs of lines will appear to be coincident as with the 3 line and the shorter line in Fig. 9; then, if extreme accuracy is required, half way between them is 30·035, and that should be adopted as the reading. For the ordinary purposes of marine meteorology, however, either 30·03 or 30·04 will generally be sufficiently near.

## Pumping.

If the barometer is pumping at the time of observation the vernier should be set for reading when the mercury, rising and falling in the tube with the heave of the ship, has completed its downward movement. When a mercury barometer is examined on board ship in a sea way, it will be seen that the level is constantly fluctuating. This phenomenon is known as "pumping." Three separate causes may be operative in various degrees to produce this effect. The mobility of the heavy mercury comes in in two ways; first on account of the heave of the ship and secondly on account of the rocking of the instrument. Besides these, there is the effect of the wind on the air pressure in the room where the barometer is hung. An ordinary barometer with a tube of wide bore is so much affected by pumping that no useful reading is possible in a sea way. With the constricted tube of the marine barometer the effect is sufficiently reduced to make a reading possible, but there is still a residual pumping the cause of which has not yet been fully examined, and which makes the reading difficult and uncertain.

### Corrections of Readings of the Barometer.

*Correction for Temperature.*—As warm mercury is specifically lighter than cold, the column of mercury lengthens when heated and shortens when cooled ; it is therefore necessary to apply to the readings of the instrument a correction for temperature, to show what the reading would have been at the temperature of 32° F., or other standard temperature to which all barometrical readings are reduced. A 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 Appendix III. (p. 84), 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 board happens to be at the time the reading is taken and the height of the instrument above sea level. For a temperature of 80° and a barometrical reading of 30 inches, the correction, to be subtracted from the observed height, would be ·139 in. with the barometer cistern at sea level.

The marine barometer which is issued to observers by the Meteorological Office is so constructed as to obviate the necessity for applying corrections, which are required for some barometers, either for capillarity, which tends to depress the mercury in the tube, or for the varying quantity of mercury in the cistern. A label giving the results of a comparison with a standard is pasted in the case.

*Correction for Height.*—As the pressure of the air becomes less 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.

The correction for height above sea level in the days of small sailing ships was comparatively unimportant ; but with the barometer cistern say 70 ft. above sea level as in the largest liners,



this correction will be as much as + ·08, and may not be neglected as the table on page 86 shows. It is, however, advisable when practicable, to hang the barometer in a position near the centre of gravity of the ship, as then the mercury will oscillate least as the ship pitches or rolls.

*Correction for Latitude.*—When barometer readings from different parts of the world have to be compared by plotting on a chart, and an accuracy of a hundredth of an inch is required, a correction for gravity also is now applied, because, the earth being a spheroid, the force of gravity varies with the latitude, and places at the equator are at a greater distance from the earth's centre than places at the poles. Barometer readings, therefore, are reduced to standard latitude, for which the parallels of 45° N. and 45° S. have been adopted. The corrections required in this connexion are given in Table III, p. 86.

### Correction and Reduction to Sea Level of Millibar Barometers.

*Note.*—Barometers graduated to read in millibars are provided with an attached thermometer graduated according to the absolute scale of centigrade degrees (*see* p. 21) and the references to temperature in the following instructions are to the readings on that scale. In quoting the temperature the degree mark is omitted and instead of it a small " a " follows the number. Thus 273a on this scale corresponds with the freezing point of water, that is 0° C. or 32° F., and 283a corresponds with 10° C. or 50° F. A step of 10a in temperature is the same as a step of 18° F.

*Standard temperature as shown on the Certificate.*—The barometer will have been certified as *correct* in latitude 45° at a certain *temperature* which we call the *standard temperature*, and the certificate means that when the temperature has the specified value, the barometer reading will give the true value of the pressure in *millibars* at the *level of the barometer cistern* in the specified latitude.

*Example.*—Barometer M.O. A.2074. The standard temperature is 286·5a, that is in latitude 45° the barometer reads correctly at 286·5a, which is the same as 56·3° F.

With this information it is easy to make allowance for difference of latitude and difference of temperature ; it is also easy to allow for height above sea level in a similar manner and so put the observer in the position to compare his readings with a synoptic weather chart or with the normal for the locality, provided that the height above sea level is not greater than those at which ships' barometers are commonly fixed.

*Fiducial temperature.*—If the latitude is not 45° the reading will not be correct at the standard temperature, but there will be a temperature at which the reading would be correct if it were so chosen that the latitude correction would just balance the temperature correction. We call this temperature, at which the readings of the barometer need no correction, the *fiducial temperature* for the barometer in the particular latitude. For a station barometer with fixed latitude the fiducial temperature remains the same, but at sea the fiducial temperature is different for the different positions of the ship in latitude.

To allow for the height of the barometer above sea level the fiducial temperature can be adjusted because, in the ordinary circumstances in which the barometer is used at sea, the allowance to be made for 100 ft. of height lies between 3·3 mb. and 3·9 mb., and a correction of 3·6 mb. for 100 ft. would be sufficiently accurate in most cases.

*Correction and Reduction.*—The process of correction and reduction to sea level is therefore as follows :—

(1) *To determine the fiducial temperature for the latitude at which the barometer is read, use the following table :—*

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Latitude .. .. | 0° | 5° | 10° | 15° | 20° | 25° | 30° | 35° | 40° | 45° |
| Subtract from the Standard Temperature a .. .. | 15 | 15 | 14 | 13 | 11·5 | 9·5 | 7·5 | 5 | 2·5 | 0 |
| Latitude .. .. | 90° | 85° | 80° | 75° | 70° | 65° | 60° | 55° | 50° | 45° |
| Add to the Standard Temperature a .. | 15 | 15 | 14 | 13 | 11·5 | 9·5 | 7·5 | 5 | 2·5 | 0 |

*Example.*—Barometer M.O. A.2074. Standard temperature, the fiducial temperature in latitude 45°, is 286·5a. To find the fiducial temperature in latitude 52° add 3·5a (2·5a for latitude 50° and 1a for the additional 2°) : fiducial temperature required is 286·5a + 3·5a, that is, 290a.

(2) *To adjust the fiducial temperature in order to make allowance for the height above sea level.*

Increase the fiducial temperature by 1a for every 5 ft. or 1·5 metres of height.

*Example.*—Barometer M.O. A.2074 is set at 52·5 ft. (16 metres) above sea level.

Its fiducial temperature is therefore increased by 10·5a from 290a to 300a for 52° latitude.

(3) *Having obtained the adjusted fiducial temperature, to correct the barometer reading for the difference between the actual temperature as read on the attached thermometer (absolute scale) and the adjusted fiducial temperature.*

(*a*) When the attached thermometer reads *higher* than the adjusted fiducial temperature—

*Subtract* from the reading 1 mb. for every 6a in the difference " actual—adjusted fiducial."



The proportional parts are as follows :—

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Difference : actual—adjusted fiducial .. | 1a | 2a | 3a | 4a | 5a | 6a | 7a | 8a | 9a | 10a |
| Millibars .. .. | ·2 | ·3 | ·5 | ·7 | ·9 | 1·0 | 1·2 | 1·4 | 1·5 | 1·7 |

(*b*) When the attached thermometer reads *lower* than the adjusted fiducial temperature—

*Add* to the reading 1 mb. for every 6a in the difference.

The proportional parts are the same as before.

*Example.*—Barometer M.O. A.2074, 16 metres above sea level in latitude 52° N., reads 1017·6 ; attached thermometer 292·4a.

To find the true pressure in millibars—

| | |
|---|---|
| The adjusted fiducial temperature (2) is 300·5a, uncorrected reading .. | 1017·6 |
| Correction for defect of actual—adjusted fiducial (292·4 — 300·5), — 8·1a : add | 1·4 |
| Corrected reading .. .. | 1019·0 |

The reading is now ready for plotting on a synoptic chart, but when a high degree of accuracy is required, the calculation should be carried out to the tenth of a degree to avoid the accumulation of error, and the following points must be attended to.

*Supplementary corrections for special accuracy.*

(4) *Proportional adjustment of correction.*—The correction as set out in (3) is in reality a *fractional part* of the pressure and ought therefore to be adjusted proportionally for different points in the range of atmospheric pressure. The adjustment is very simple : add 1 per cent. to the correction for each 10 mb. above 1000, and subtract 1 per cent. for each 10 mb. below.

One per cent. only begins to be appreciable when the whole correction is about 10 mb., and the additional correction for proportional adjustment is only necessary on quite exceptional occasions.

*Example.*—Barometer M.O. 2000 with fiducial temperature 306a in latitude 20° gave a reading of 920 mb. at 290a (the lowest observed reading of a cyclonic depression).

| | | |
|---|---|---|
| Temperature correction .. .. | add | 2·7 mb. |
| Proportional adjustment (for 80 mb.)— | | |
| 8 per cent. .. .. .. | subtract | ·216 |
| Adjusted correction .. .. .. .. | | 2·5 mb. |
| True pressure .. .. | | 922·5 mb. |

(5) *Correction for scale error.*—This can be provided for by the table of Kew corrections which gives the standard temperature at different points of the scale. A properly graduated scale ought to have the same standard temperature throughout its range. If

correction for standard temperature in different parts of the scale is necessary, it can be worked by the table of (3).

*Example.*—Barometer M.O. 2015 had standard temperature 286·5a at 1000 mb., but 280a at 900 mb.

Find the correction for scale to the reading in Example 4.

Take the standard temperature at 920 mb. to be 281·5a or 5a less than for standard conditions.

That is equivalent to reducing the fiducial temperature by 5a, which involves a correction of ·8 mb. to be subtracted from the reading.

(6) *Summary.*—The process may be recapitulated and summarised as follows :—

Barometer M.O. A.2074, 16 metres (52·5 ft.) above sea level in latitude 52° N. reads 1017·6 with attached thermometer 292·4a.

| | |
|---|---|
| Standard temperature (fiducial temperature in latitude 45°), by the certificate the same at all points of the scale .. .. .. .. | 286·5a |
| For fiducial temperature in latitude 52° add .. | 3·5a |
| For adjusted fiducial temperature at 16 metres add .. .. .. .. .. .. | 10·5a |
| | 300·5a |

For adjusted fiducial − actual (300·5 − 292·4), = 8·1a add 1·4 mb. to 1017·6 mb.

Corrected reading .. .. .. .. 1019·0 mb.

Proportional adjustment 2 per cent of 1·4 mb. (negligible).

Scale error—nil.

(7) The marine observer is advised to have fixed up in the immediate neighbourhood of his barometer a card showing the adjusted fiducial temperature of his barometer for each degree of latitude. He can compile it for himself by the instruction given under (1) and (2). To correct a reading he has then only to consider the difference between the fiducial temperature and the actual temperature at the time of reading simply *adding* ·1 mb. to the reading for every ·6 of a degree by which the adjusted "fiducial" exceeds the "actual," or *subtracting* ·1 mb. for every ·6 of a degree if the difference is the other way.

### The Sea Barometer.

At the Meteorological Office a new dial has been introduced for aneroid barometers intended for use at sea, of which a representation is given in Fig. 10. The graduations are shown in "millibars" and the numbering in centibars, 100 centibars being the "standard atmosphere" in the C.G.S. (centimetre, gramme, second) system of units. On the barometer dial, graduations in inches and in millimetres are also shown, and it will be seen that the pressure of 100 centibars corresponds very nearly with that of 29½ inch or 750 mm. The dial shows a range from



below 93 centibars (27½ inches) to 105 centibars (31 inches) and so covers the whole range of pressure that is likely to be experienced at sea level in any part of the world. For the convenience of

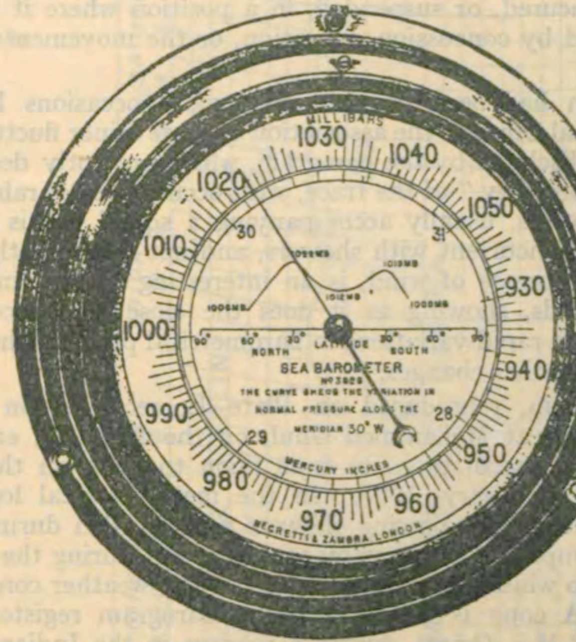



Fig. 10.

sailors, on the special form of instrument which is called a *sea barometer*, and which is figured here, marks are put in the rim against the figures which indicate the *mean annual pressure* in certain degrees of latitude along the meridian of 30° W.

This meridian goes over sea from the Arctic to the Antarctic and crosses the "Icelandic low," the "highs" of the tropics of Cancer and Capricorn, and the deep low of the higher southern latitudes. Similar variations are to be found in other oceans, so that the variations which are indicated by these marks on the dial are a guide to the average values which the mariner may expect. These values should enable him to judge first whether the instrument is in reasonable adjustment, or, secondly, whether the season of his voyage is a normal one so far as pressure is concerned.

### The Barograph.

A portable "barograph" (Plate V.), which is an aneroid barometer provided with a lever recording variations of pressure on a revolving drum, is in some respects a more valuable supplement to the mercury barometer on board ship than the aneroid of the ordinary form. It is not only useful in enabling an observer to detect casual errors in the readings of the mercury barometer, but also gives a continuous record of barometric pressure for reference (*see* Plates I. to IV.). Barograms, moreover, register minor fluctuations of atmospheric pressure which are seldom noticeable in the action of the mercury barometer, and without the uninterrupted evidence furnished by a sensitive self-recording instrument, are rarely detected. The instrument should be secured, or suspended, in a position where it will be least affected by concussion, vibration, or the movements of the ship.

Attention has been directed on several occasions by the Meteorological Office to the association of these minor fluctuations of pressure disclosed by the barogram, which are aptly described as the " embroidery " of the trace, with occurrences of rain, hail, or snow showers, usually accompanying a squall. This joggle in the trace concurrent with showers, and not infrequently with a transient increase of wind, is an interesting feature in barographic records, showing as it does the close connexion that exists between rapid variations in barometrical pressure, however slight, and weather changes.

A barogram, reproduced on Plate I., recorded on board H.M.S. *Merlin* at Mohammed Ghul, on the Red Sea, exhibits, small fluctuations of pressure from noon to noon on the 20th and 21st of February, 1907. In the meteorological log kept on board the *Merlin* passing showers are recorded during that period, accompanied at times by squalls ; but during the rest of the period to which the barogram relates fair weather conditions obtained. A copy is given also of a barogram registered on board the R.M.S. *Orient*, during a passage in the Indian Ocean between Ceylon and the Red Sea. Slight variations in pressure are discernible in this trace between noon and noon on the 18th and 19th which relates to July, 1908 ; and these minute joggles are found, by referring to the meteorological log kept on board the *Orient*, to be associated with the occurrence of a number of squalls accompanied by rain. Prior and subsequent to this period, during the week on which the trace was made the weather was overcast or cloudy, but not disturbed. The barograms reproduced in Plates III. (from s.s. *Virginian*) and IV. (from H.M.S. *Minotaur*) represent characteristic traces for the North Atlantic and the equatorial region respectively.

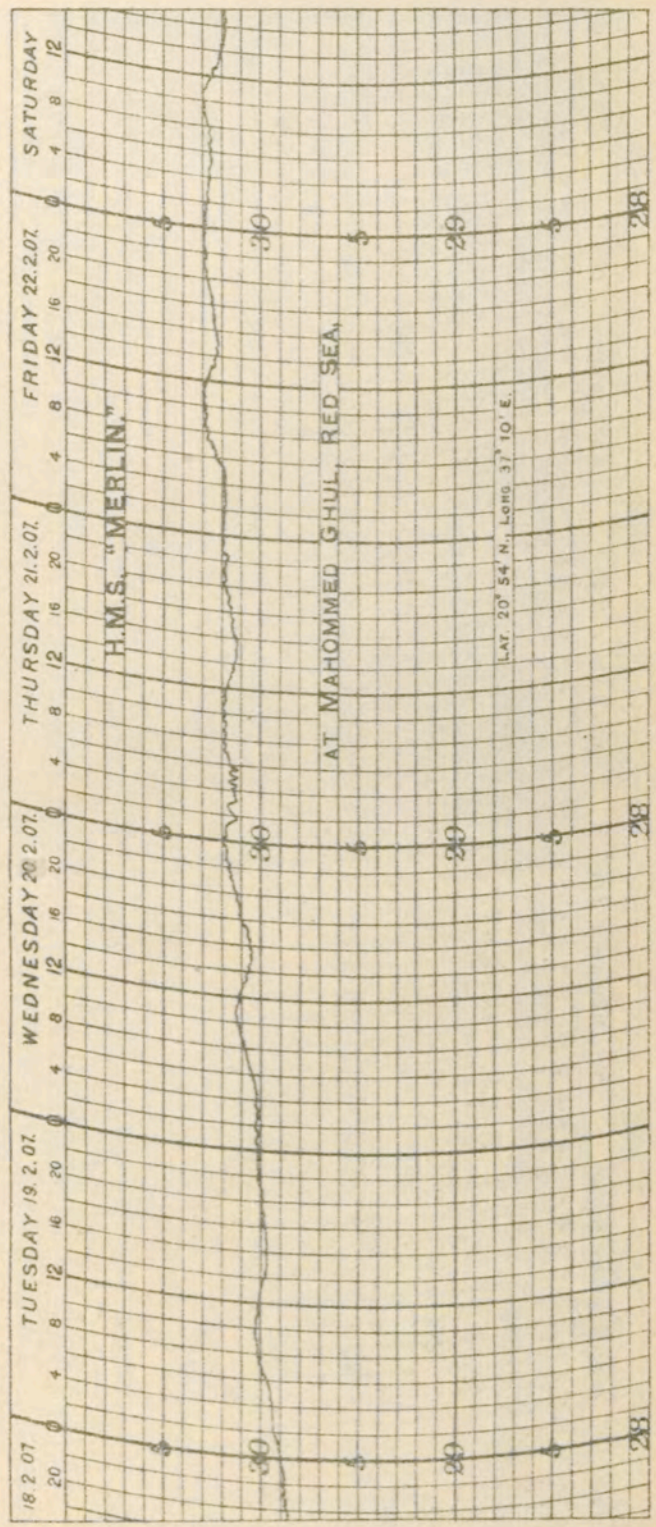
The action of the barograph, briefly, is as follows :—The circular metallic chamber, consisting of a series of vacuum metal boxes with elastic lids, is connected with the revolving drum by means of a lever carrying a pen filled with specially prepared ink. The rotation of the drum is effected by means of clockwork contained in the drum, which is designed to complete a revolution in seven days.

The variation in the volume of these vacuum boxes, caused by changes in atmospheric pressure, is transmitted through the lever to the pen, which registers the changes in a continuous line on a printed chart fitted round the drum.

The timepiece may be regulated by moving the pointer on the balance of the clockwork. Should the timepiece be fast the pointer should be moved in the direction R.S. (retard, slow) ;

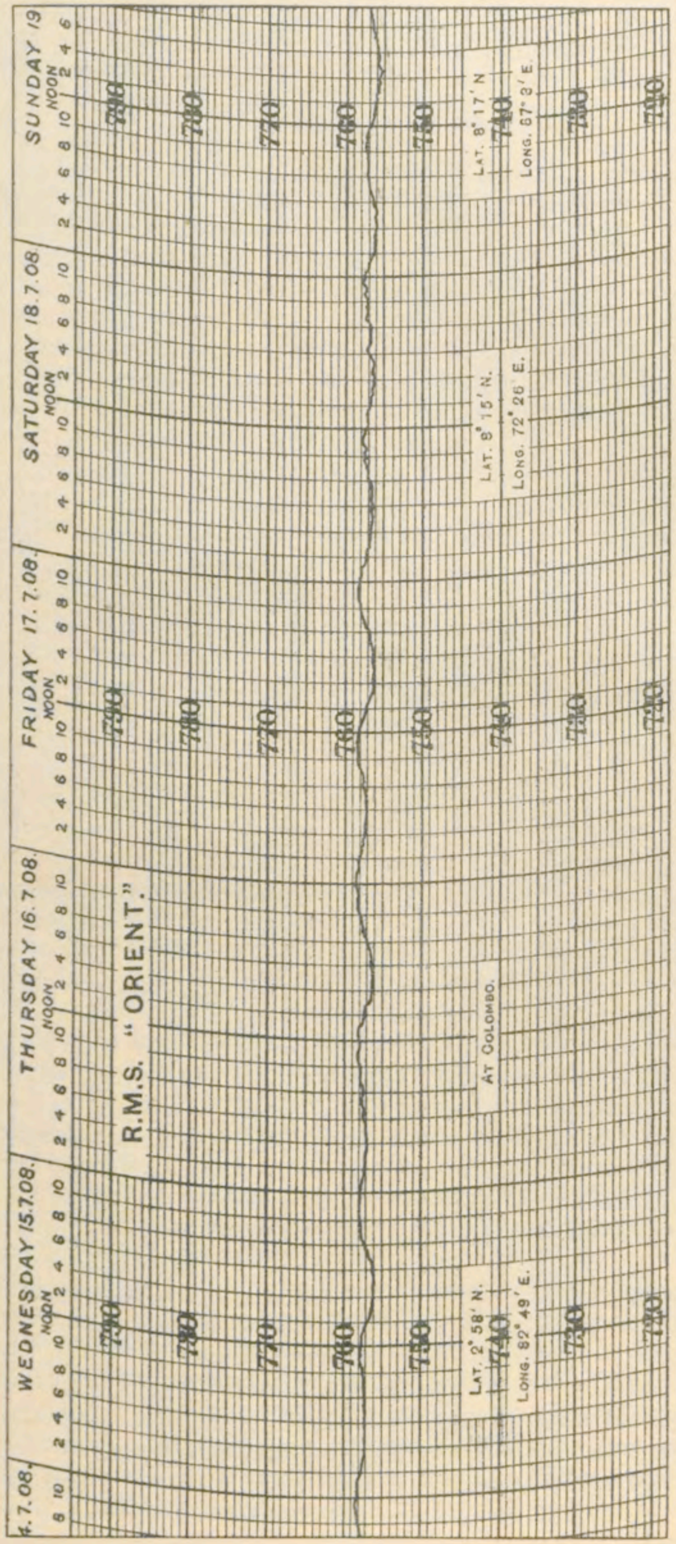
*Plate I.* *To face p. 34.*

BAROGRAPH TRACE.




*Exhibiting minor fluctuations of atmospheric pressure at Mahommed Ghul, Red Sea, on the 21st February, 1907.*

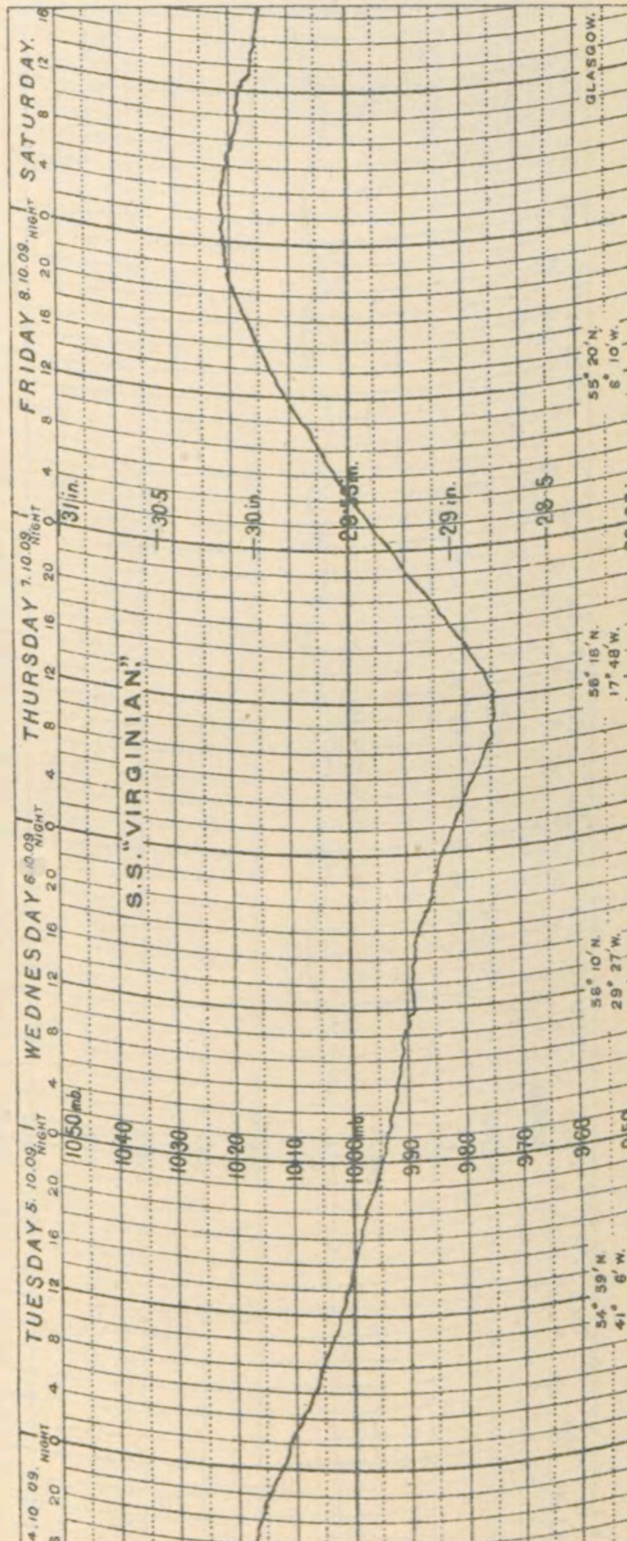
## BAROGRAPH TRACE.




*Exhibiting minor fluctuations of atmospheric pressure in the Indian Ocean between 8 a.m. on the 18th and 4 a.m. on the 19th July, 1908.*

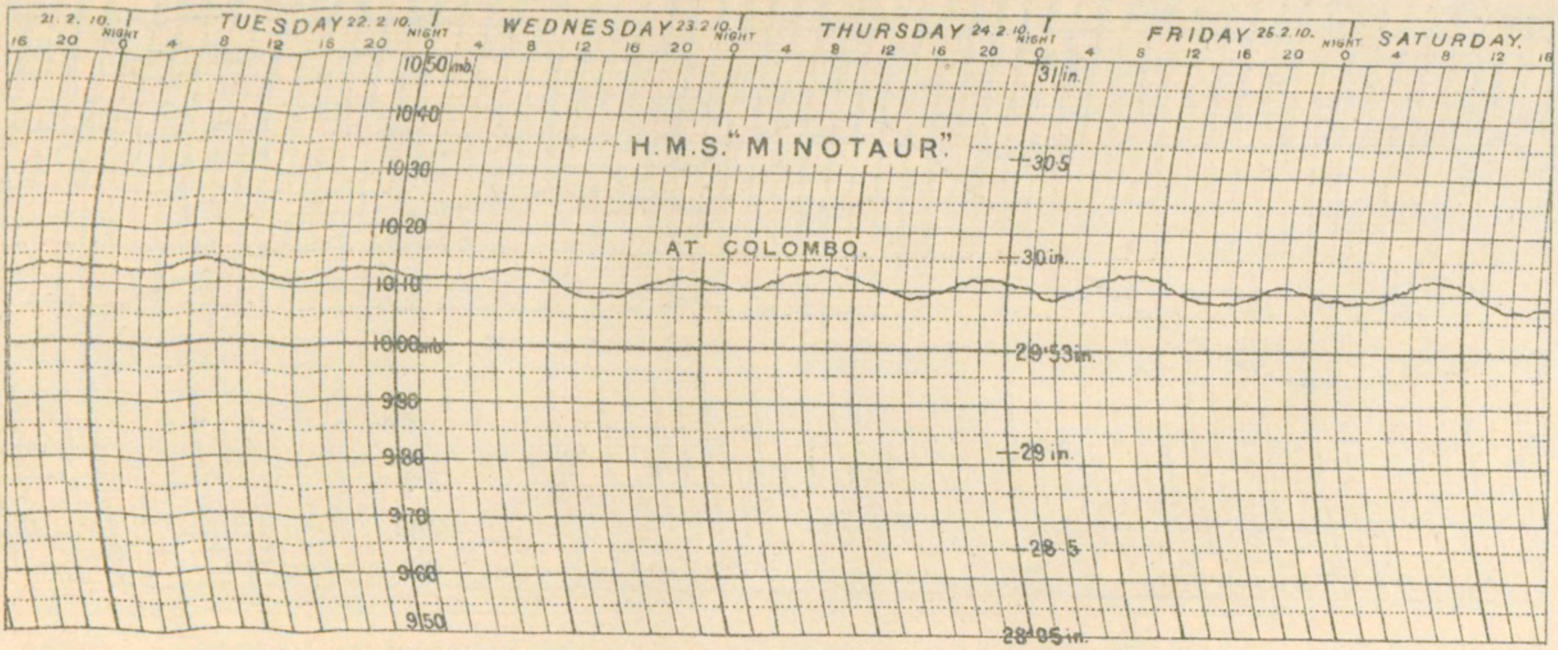


## BAROGRAPH TRACE.




*Illustrating a non-periodic change of atmospheric pressure associated with the passage of a cyclonic depression over the North Atlantic.*

# BAROGRAPH TRACE.

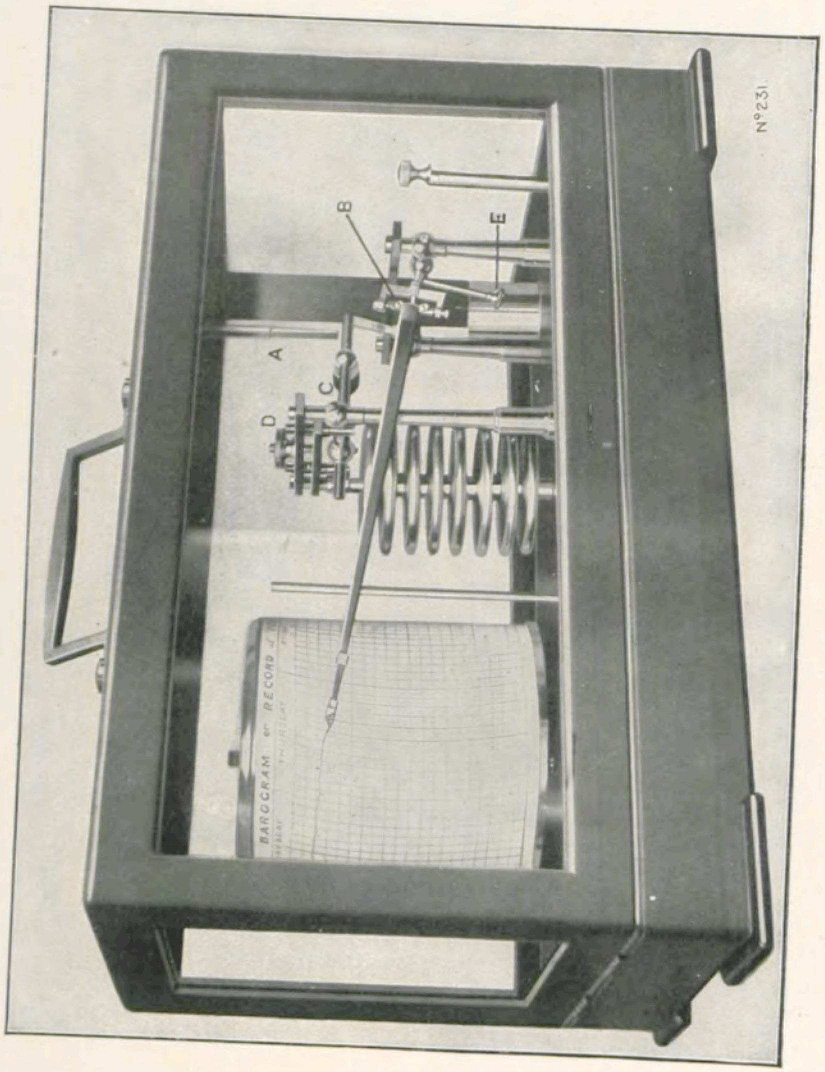



*Illustrating diurnal range of atmospheric pressure in the Indian Ocean.*

*Plate IV.*

To face page 35]

PLATE V.






if slow, in the direction A. F. (avance, fast); but frequent movement of the pointer should be avoided.

The setting of the barograph to time presents some difficulties, because ship's time changes from day to day during a passage, while the timepiece of the instrument, if in proper order, will keep the time at which it is originally set. Thus, if the pen is set correctly for ship's time in longitude 75° W., the instrument will continue to show the time for that longitude for the whole week, and at the end of the week may be as much as five hours slow of ship's time. It is, therefore, recommended that the pen be set to show Greenwich mean time correctly, and it will then continue to show that time however the position of the ship may change.

A time mark, showing Greenwich mean noon, should be made each day. If, however, for any special reason the observer sets the pen mark to ship's time on the chart at the beginning of the week he should mark ship's noon on the chart each day. In any case, the plan adopted in this connexion should be clearly stated on the back of the chart. The records of the instrument, or *traces* as they are termed, should be examined carefully by the observer from time to time, in order that inaccuracies caused by the pen pressing too closely on the chart may be discovered. The pen should press sufficiently on the chart to leave a clear uninterrupted trace. The records should be compared frequently, or when an opportunity occurs, with the readings of a reliable mercury barometer corrected for instrumental error and temperature, and the result noted on the back of the chart. Should it be found, however, that the difference between the barograph and the barometer readings is large the pen of the former should be reset.

A fine clear line should be traced by the pen of the barograph; if a thick line is produced it may be due to rough or badly sized paper, to bad ink, or to a foul pen. If the pen requires cleaning it should be carefully cleansed with a brush and as carefully dried. An implement such as a knife should on no account be used for this purpose.

The barograph, when used on board ship, may either be carried in a cradle slung on gimbals, the cradle being secured, or suspended from the deck above. It should be located in a position where it will be least affected by concussion, vibration, or movement of the ship. During gun firing the pen's point should be moved from the paper.

## CHAPTER II.

# ATMOSPHERIC PRESSURE.

### CONNEXION OF CHANGES OF ATMOSPHERIC PRESSURE WITH CHANGES OF WEATHER.

All wind is air in sensible motion. The force of the wind, and changes of weather generally, are closely related to the disturbances of pressure which accompany or cause 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 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 or storms.

The barometer should therefore be set and read at regular hours, if possible at 4-hour intervals, or in doubtful weather 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 is the non-periodical changes which specially call for attention, as being indicative of probable strong winds or dangerous storms.

### INFLUENCE OF TEMPERATURE ON ATMOSPHERIC PRESSURE.*

All changes in the pressure of the air, whether periodical or non-periodical, depend greatly 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 above it expands, and the upper strata flow away from it over the surrounding less heated area. Conversely, above a relatively cold area the air will contract, and the upper strata will flow in towards it from the neighbouring areas. When a difference of pressure is established air tends to flow from high pressure to low pressure. But it must be remembered that the pressure measured by the barometer is determined by the whole height of the atmosphere and not by the lower layers alone. The distribution of pressure in the upper air may mask the effects of the lower strata. Consequently it must not be expected that the distribution of surface pressure can always be accounted for by the distribution of temperature as recorded at the surface. The motion of the air is not direct from high pressure to low pressure. The flow is indeed generally round the areas of high or low pressure, though at the surface, there is as a rule an inclination towards the low pressure side from the high pressure side.

The charts (Plates XI. to XXIII.), to which reference will be made hereafter, show the normal or average distribution of air pressure over the globe as given by the barometer for each of the twelve months of the year. On these charts lines are drawn, showing where the average barometrical pressures indicated by the figures upon them are observed. These lines are termed isobaric lines, or isobars, because they pass through places having equal average barometrical pressure. They are drawn for each five millibars of pressure, one-and-a-half tenths of an inch of mercury. Seamen are familiar with lines of soundings, and variation curves, laid down on navigating charts; and isobars are similarly used with respect to barometer readings on meteorological charts.

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 Hemisphere, the greatest development of both high and low pressure in the Northern Hemisphere is seen in January, and in the Southern Hemisphere in July (*see* plates XI. and XVII.).

* In modern meteorology little stress is laid upon the effect of local heating in the production of local changes of pressure because it appears that the main features of the distribution of pressure in any locality are associated with more general causes.

Over the Equator, between the tropics, the barometer is low relatively to the neighbouring zones. Over the sea, just north of Cancer and south of Capricorn, the barometer is high with the exception of a few very rare occasions.

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, these last-named following a corresponding periodical change of pressure over the tracts where they are established.

## Distribution of Mean Atmospheric 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 XI. to XXIII. on which are shown the average or mean barometrical pressures over the several oceans and seas. The values used for the construction of the isobars have been corrected for index error of instrument, and reduced to the sea level at a standard temperature of 32° F. at the latitude of 45° N. or S.

Inasmuch as the earth is a spheroid flattened at the poles, the weight of a given body, a column of mercury for example, is greatest at the Poles. As the weight of the same column of mercury increases from the Equator to either Pole, it is necessary for the sake of precision in comparison that some latitude shall be agreed upon as the standard for the measurement of weight. The latitude chosen is 45°. In latitudes lower than 45° N. or S., the mercurial column is longer than that at 45° for the same atmospheric pressure; and shorter in latitudes higher than 45° N. or S. Hence the necessity for the reduction of barometer readings to standard gravity at 45°.

For purposes of comparison between an actual reading by a mercury barometer on board ship with the average value given on the chart of isobars in this manual, at the same geographical position and for the same month, the seaman must correct the reading in the manner described on pp. 28–32; if his barometer be graduated only in inches, he must apply the correction for index error, if any, and then allow for the corrections for the temperature shown by the thermometer attached to the barometer, the height of the barometer cistern above sea level, and



the reduction to standard gravity, by the aid of the following table:—

Corrections for Reducing Barometric Readings in Mercury Inches.

| To Temperature of 32° F. | | To Sea Level. | | To Standard Gravity at Latitude 45° N. or S. | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Temp. by Att. Ther. | Correction. | Height in feet. | Correction. | Lat. N. or S. | Correction. At 27 in. | Correction. At 30 in. | Lat. N. or S. | Correction. At 27 in. | Correction. At 30 in. |
| ° | in. − | ft. | in. + | ° | in. − | in. − | ° | in. + | in. + |
| 30 | 0·00 | 10 | 0·01 | 0 | 0·07 | 0·08 | 90 | 0·07 | 0·08 |
| 35 | 0·02 | 20 | 0·02 | 10 | 0·07 | 0·07 | 80 | 0·07 | 0·07 |
| 40 | 0·03 | 30 | 0·03 | 20 | 0·05 | 0·06 | 70 | 0·05 | 0·06 |
| 50 | 0·06 | 40 | 0·04 | 25 | 0·05 | 0·05 | 65 | 0·05 | 0·05 |
| 60 | 0·09 | 50 | 0·05 | 30 | 0·04 | 0·04 | 60 | 0·04 | 0·04 |
| 70 | 0·11 | 60 | 0·07 | 35 | 0·02 | 0·03 | 55 | 0·02 | 0·03 |
| 80 | 0·14 | 70 | 0·08 | 40 | 0·01 | 0·01 | 50 | 0·01 | 0·01 |
| 90 | 0·16 | 80 | 0·09 | 45 | 0·00 | 0·00 | 45 | 0·00 | 0·00 |

The correction is to be added when the sign +, and subtracted when the sign —, is at the head of the column.

The corrected reading must then be converted into millibars (*see* Table V., Appendix III.).

Turning to Plate XI., it will be seen that in January, in about 10° N. 25° W., the average barometer is 1015 mb. (29·97 inches); suppose that the seaman desires to find the approximate error of his barometer from a mean of six consecutive four-hourly observations which is 30·06, the attached thermometer 78°, and the height of the barometer cistern 50 feet above sea level. The above table shows that with the given values, the corrections for temperature, height and gravity, are —·14, +·05, and —·07, respectively. Combining these, the correction necessary to apply is —·16, and the reading for comparison with the chart is 30·06 — ·16 = 29·90 inches (1012·5 mb.). Hence his barometer is 2·6 mb. too low; or requires a correction of + 2·5 mb., in addition to corrections for temperature, height and gravity in order to make the readings comparable with those of the chart.

If an aneroid is used, the corrections for temperature and latitude are not required when making a comparison.

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 belts of high pressure. Proceeding to the higher latitudes, we find two areas of lower pressure. A marked feature of the great Southern Ocean is 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 below 1000 mb., or fully 17 mb. 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, 1012·5 mb.; in the Atlantic Ocean for 10° of latitude on either side of the equator the yearly mean is about 1011 mb. From the tropics to about the 40th parallels of north and south latitude, the barometrical readings are above 1015 mb., and in the central parts of these areas readings as high as 1025 mb. are found.

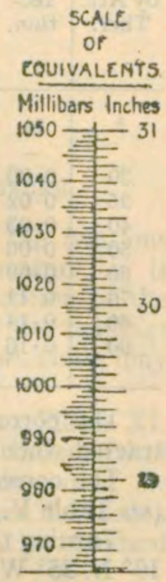


Fig. 11.

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 1009 mb., and on the parallel of Cape Horn, lat. 55° S., is about 999 mb. In the northern part of the Atlantic Ocean, south of Greenland and Iceland, an area of low pressure is shown on all maps of monthly averages, but on the average in mid-summer, the barometer is three-tenths of an inch (10·2 mb.) higher there than in mid-winter.

In the British Islands and adjacent waters, proceeding from south to north, the mean barometrical pressure ranges from 1016 mb. to 1009 mb. in mid-winter, and from 1016 mb. to 1011 mb. 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 Australia or New Zealand by way of the Cape of Good Hope and thence back to England by way of Cape Horn, the readings of the barometer will, under average conditions of weather, have varied as much as 24 mb., that is, between 1023 mb., found in the high pressure areas of the North and South Atlantic Oceans, and 999 mb., 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 1010 mb., whereas in mid-summer (July) the readings will range from 1016 mb. in



the Atlantic Ocean to 999 mb. at the Indian ports, and 1006 mb. in the Chinese ports; the low pressures last named mainly depending on the high summer temperature of the adjoining great continental masses of land.

## The Trade Winds, and the Doldrum Regions.

The average direction and force of the NE., and SE. Trade winds of the Atlantic and Pacific Oceans; also of the SE. Trade and Monsoonal winds of the Indian Ocean, Eastern Archipelago, and China Seas, during the months of June and December are represented graphically by means of wind roses on Plates XXIV. to XXXVI.

The wind systems, together with the Doldrum and other equatorial regions of variable winds, move northward and southward, following the motion of the sun in declination, but with a considerable lag in this motion, which, presumably, is associated with a check in the seasonal rise and fall of air temperature due to the retarding influence of the lag in the seasonal change of temperature in the surface of the sea. The Doldrums are farthest north in July, August and September, and farthest south in February, March and April.

It will be observed that the SE. Trade winds extend over a far larger area than that occupied by the northern tropical wind systems. This inequality is doubtless caused by the preponderance of water in the Southern Hemisphere over that in the Northern, and the consequent greater stability of temperature and pressure in the higher parallels of the former.

The region within the equatorial belt of low pressure over the Atlantic of calms, variable winds, humid weather, frequent precipitation, and occasional squalls of wind and torrential rain is represented on the charts of barometrical pressure on Plates XI. to XXIII. by somewhat dark shading.

In the Indian Ocean and Eastern Archipelago between the SE. Trade wind and the NW. or SW. Monsoon; also within the equatorial belt of the Pacific Ocean similar zones are shown by a lighter shading.

In these regions, however, calms are less frequent; winds not so light; and precipitation not so frequent.

While, moreover, the conditions in the equatorial region of variable winds in the Pacific are more nearly allied to those of the Atlantic Doldrum, the conditions that obtain in the Indian Ocean region differ materially. The instability of the wind, as represented on the charts of these regions, is due to an *annual*, as distinct from a *seasonal*, oscillation of the northern limit of the SE. Trade wind.

As a consequence of this oscillation the region may be under the influence of Monsoonal winds (NW. or SW.) in some years, but in others the SE. Trade wind may still hold, or a transitional period of variable winds may prevail.

CHAPTER III.

## VARIATIONS OF PRESSURE.

### VARIATIONS OF PRESSURE FROM MEAN VALUES.

The mean barometrical pressure over the several oceans having been studied, 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 parts of the earth, the pressure of the air, and therefore the height of the mercury in the barometrical column, is constantly varying. In the higher latitudes these variations have a range of nearly 150 mb. or about 4 inches of mercury, 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 directly connected with 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 or the year; 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.

### 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 tropical or in sub-tropical 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 within 24 hours; 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 about 4 a.m. The forenoon maximum is commonly, but not invariably, higher than the afternoon maximum; and the former usually occurs rather before than after 10 a.m., while the latter tends to be later rather than earlier than 10 p.m. The afternoon minimum is, with rare exceptions, lower than the morning minimum, and occurs after rather than before 4 p.m.



In a paper by M. Alfred Angot, entitled *Etude sur la Marche Diurne du Baromètre*, which appears in the *Annales du Bureau Central Météorologique de France*, of 1887, the author furnishes formulæ for calculating the diurnal range of barometrical pressure for any parallel of latitude. M. Angot divides the actual diurnal variation of pressure into two parts: (1) the principal or semi-diurnal wave having a 12-hour period; (2) the thermal wave, which has a 24-hour period. The variations for different latitudes attributable to the " principal wave " are shown in the accompanying diagram, Fig. 12.

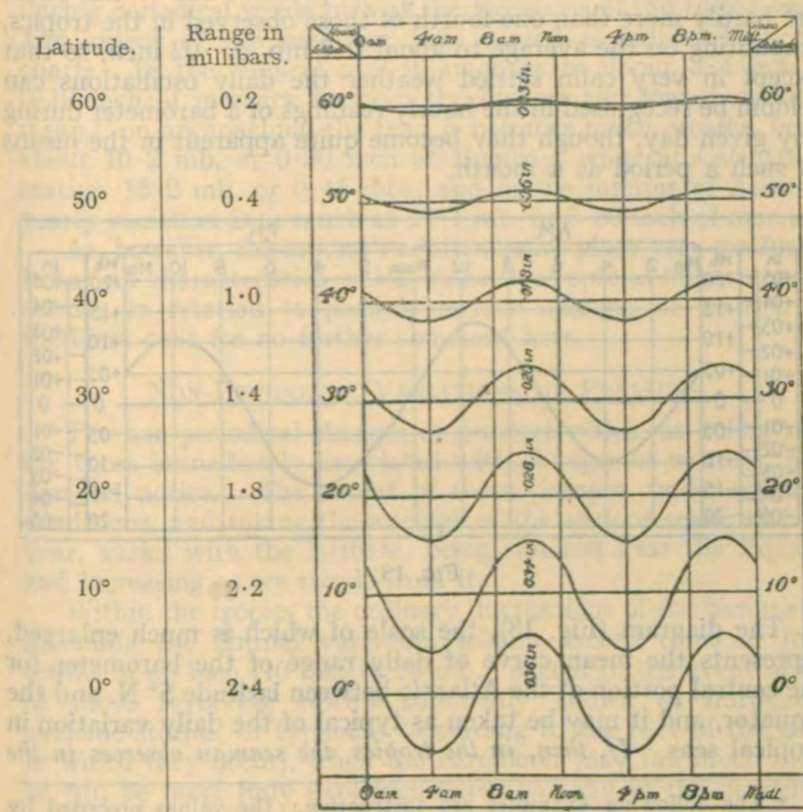



FIG. 12.

At sea the diurnal variations 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 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.

In tropical seas the daily range of the barometer between the highest and lowest may be taken at about 2·4 to 2·7 mb., or ·07 to ·08 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 midnight and 1 a.m., 6 a.m. and 7 a.m., noon and 1 p.m., and about 7 p.m.

At Calcutta the daily range varies from about 4·7 mb. or 0·14 inch in April and May, when the range of temperature is greatest, to about 3·2 mb. or 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, amounting on the average to about 0·7 mb. or ·02 inch, so that except in very calm settled weather the daily oscillations can seldom be recognised in the hourly readings of a barometer during any given day, though they become quite apparent in the means of such a period as a month.

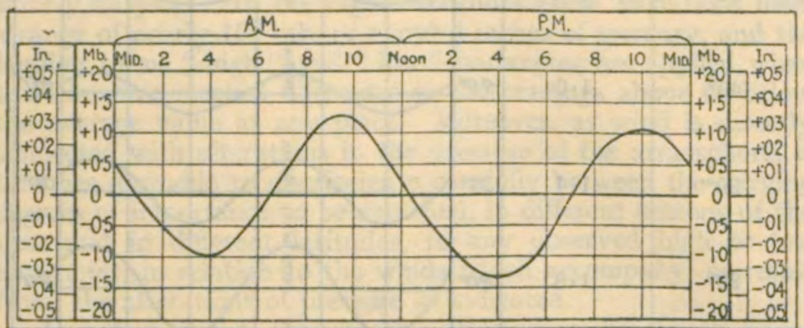



FIG. 13.

The diagram (Fig. 13), 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 latitude 5° N. and the Equator, and it may be taken as typical of the daily variation in tropical seas. *If, then, in the tropics, the seaman observes in the*

* The following examples are instructive; the values preceded by + and — signs show approximately the mean rise or fall (in millibars) above and below the average pressure for the day :—

| Calcutta [22½° N. lat.] | | | Ascension [8° S.lat.] | | Mauritius [20° S.lat.] | |
|---|---|---|---|---|---|---|
| Hour. | Jan. | July. | Mean Year. | | Mean Year. | |
| | mb. | mb. | hr. | mb. | hr. | mb. |
| 3½ a.m. | — 0·7 | — 0·6 | 3 a.m. | — 0·7 | 3½ a.m. | — 0·6 |
| 9½ a.m. | + 2·6 | + 1·4 | 9 a.m. | + 1·2 | 9½ a.m. | + 1·0 |
| 4½ p.m. | — 1·7 | — 1·8 | 3½ p.m. | — 1·4 | 3½ p.m. | — 1·4 |
| 10½ p.m. | + 2·7 | + 0·9 | 10 p.m. | + 0·9 | 9½ p.m. | + 1·0 |



*readings of his barometer any marked deviation from such a curve he may anticipate that some considerable atmospheric disturbance is in existence in the neighbourhood. It is an indication that a change of weather, possibly a hurricane, is impending. Such deviations have not been observed with reliable barometers except in those regions where hurricanes are experienced.*

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 3·4 mb. or 0·10 inch of mercury between the highest and lowest monthly mean ; on approaching the land it becomes much greater, being about 10·2 mb. or 0·30 inch at Bombay, while at Calcutta it reaches 15·2 mb. or 0·45 inch, and in the interior of Asia the yearly variation is as much as 27·1 mb. or 0·80 inch of mercury.

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 (10 mb. to 14 mb.), except in the event of one of those revolving storms commonly known as hurricanes, cyclonic storms, 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 the depression may be as much as 75 mb., or more than 2 inches of mercury.

At Ascension, in latitude 8° S., the greatest range observed in two years scarcely reached four-tenths of an inch (13 mb.). 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. latitude, and between 20° and 30° W. longitude, based upon a large number of observations extending over many years, the highest reading, 30·138 (1020·6), was observed in July, the lowest, 29·725 (1006·6), in December, a range of only ·413 inch (14·0 mb.).

The average 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 this range in the higher latitudes, as compared with the tropics, is exemplified in the British Islands, where the average range in the course of a month is about 58 mb., or 1·7 inch for January, 30 mb. or 0·9 inch for July.

In 90 years, from the beginning of the year 1841 to 1930, the highest corrected reading of the barometer at the Royal Observatory, Greenwich, was 30·972 inches (1048·8 mb.) on January 18th, 1882; the lowest, 28·272 inches (957·4 mb.), on January 13th, 1843—the absolute range, therefore, being 2·700 inches (91·4 mb.). These extreme values, however, must be considered quite exceptional, instances above 30·8 inches (1040 mb.) and below 28·5 inches (965 mb.) being very rare.*

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 :—

MEAN RANGE OF BAROMETRIC PRESSURE IN MILLIBARS AND IN INCHES OF MERCURY.

| Latitude. | January. | July. | January. | July. |
|---|---|---|---|---|
| Between | mb. | mb. | in. | in. |
| 65° ,, 60° N. .. | 58 to 61 | 34 | 1·70 to 1·80 | 1·00 |
| 60° ,, 50° .. | 61 ,, 51 | 34 ,, 27 | 1·80 ,, 1·50 | 1·00 to 0·80 |
| 50° ,, 40° .. | 51 ,, 42 | 27 ,, 20 | 1·50 ,, 1·25 | 0·80 ,, 0·60 |
| 40° ,, 30° .. | 42 ,, 22 | 20 ,, 13·5 | 1·25 ,, 0·65 | 0·60 ,, 0·40 |
| 30° ,, Nn. Tropic | 22 ,, 13·5 | 13·5 ,, 10 | 0·65 ,, 0·40 | 0·40 ,, 0·30 |
| Tropic ,, Equator | 13·5 ,, 7 | 10 ,, 7 | 0·40 ,, 0·20 | 0·30 ,, 0·20 |
| Equator ,, Sn. Tropic | 7 ,, 12 | 7 ,, 12 | 0·20 ,, 0·35 | 0·20 ,, 0·35 |
| Tropic ,, 30° S. .. | 12 ,, 18·5 | 12 ,, 20·5 | 0·35 ,, 0·55 | 0·35 ,, 0·60 |
| 30° ,, 40° .. | 18·5 ,, 27 | 20·5 ,, 34 | 0·55 ,, 0·80 | 0·60 ,, 1·00 |
| 40° ,, 50° .. | 27 ,, 41 | 34 ,, 54 | 0·80 ,, 1·20 | 1·00 ,, 1·60 |
| 50° ,, 55° .. | 41 ,, 44 | 59·5 | 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-eighths of the whole range to a rise above the mean reading of three-eighths of the whole

* In the storm of Jan. 26, 1884, a reading of 27·36 in. (926·5 mb.) was recorded at Ochtertyre, Perthshire, and on Feb. 5, 1870, a reading of 27·33 in. (925·5 mb.) had also been recorded on board R.M.S. "Tarifa" in 51° 3′ N., 23° 39′ W. The absolutely highest record for sea-level in these islands is 31·139 in. (1054·5 mb.) at Ochtertyre, on Jan. 9, 1896.



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 1014 mb. we should have in the winter, with a range of 51 mb., a fall of 32 mb., and a rise of 19 mb., as representing the lowest and highest barometer (982 mb. and 1033 mb.) that might be expected. Under similar conditions in the Southern Hemisphere, when off Cape Horn, with an average barometer of 999 mb., and a winter range of 59 mb., 962 mb., and 1021 mb. 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 on 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.

## CYCLONIC DEPRESSIONS AND ANTICYCLONES.

The most marked changes of weather associated with non-periodical variations of pressure in any locality are usually due to the approach of cyclonic depressions, or of their opposites, anticyclones, and their passage over the locality.

Over any area where atmospheric pressure is below that of the surrounding region a cyclonic circulation is developed. In consequence of the rotation of the earth instead of flowing as might be expected, towards the centre of depression, air currents have a motion round it, but inclined inwards towards the centre. The wind circulating about an area of low pressure in the Northern Hemisphere has a movement against that of watch hands, while in the Southern Hemisphere the movement is in the same direction as watch hands. Such a distribution of pressure and wind was called by Piddington a *cyclone*; and is now known as a *cyclonic depression*.

In recent years the term *cyclone* has largely become associated with atmospheric disturbances in which the wind blows with violence round a central area of low pressure, and is often used to express the force of the wind rather than a characteristic distribution of pressure and wind.

The term *cyclone* was, however, originally adopted by Piddington in a publication entitled *Sailor's Horn Book* (1848) in connexion with the classification of winds. He says: *I suggest that we might for this last class of circular, or highly curved winds, adopt the term "cyclone" from the Greek* Κύκλος (*which* *signifies, amongst other things, the coil of a snake), as neither affirming the circle to be a true one, though the circuit may be complete, yet expressing sufficiently the tendency to circular motion in these meteors.*

Thus, in a cyclonic depression the wind has a *tendency* to circulate round an area of relatively low pressure ; it may be of moderate force, and in some parts of the system even light, or it can be strong to a gale, and, especially in the tropics, may attain to the force of a hurricane.

Over any area where pressure is high, and decreases in all directions from the maximum, an anticyclonic circulation of wind is developed ; for air setting outward from a high pressure area is deflected to the right, or to the left, according to the hemisphere in which the system is situated, and thus acquires a motion round the high pressure, but inclined outward from it. The circulation of the wind about the high pressure will, therefore, in the Northern Hemisphere, be in the same direction as watch hands ; but in the Southern Hemisphere it will be in a contrary direction to watch hands. Such a distribution of pressure and wind is called an *anticyclone.*

Cyclonic depressions when formed travel, generally speaking, in temperate latitudes towards some easterly point in either hemisphere. The passage of a succession of depressions, with intervening high pressures, which may appear as separate anticyclones, or simply relatively high pressure areas between lows, is indicated on a barometrical chart by the alternations of low and high barometer such as are illustrated in Fig. 19, p. 66.

These constitute the non-periodical changes of pressure.

Until recently it has been customary to explain the characteristics of cyclonic and anticyclonic circulation by supposing the observer's distribution of pressure to be set up and maintained by convection and to cause a flow of air from high to low deviated from the direct line by the rotation of the earth. The increase of our knowledge of the upper air makes it difficult to accept this explanation. The relation of wind to pressure distribution is so much according to rule in the upper air that the surface conditions seem to be a disturbance of the recognised relation not a stage in the development of a new order.

For further information as to nature and behaviour of cyclonic depressions, and anticyclones, see *Forecasting Weather* by Sir Napier Shaw, F.R.S., Sc.D., (Second Edition) 1923, and *The Seaman's Handbook of Meteorology* ; a companion to this Manual.



CHAPTER IV.

# WINDS, THEIR CAUSES AND DISTRIBUTION.

## CAUSES WHICH DETERMINE THE FORCE AND DIRECTION OF THE WIND.

The force of a wind accompanying a difference in barometric pressure at two places at the same instant is greater as that difference is greater ; and it therefore depends, not on the mere height of the barometer on board a ship, but on the difference between that height and the height which obtains over a neighbouring ship, or place. Civil engineers speak of a gradient in connexion with the slope of a road ; and a gradient of one in sixty, for example, signifies that the road rises one unit vertically for each sixty such units measured horizontally. When the rise or fall of a railway-level is stated thus, the amount is termed the gradient ; and a comparison of two gradients then becomes simply that of two numbers. Meteorologists have conveniently adopted the term gradient to express a difference of atmospheric pressure between two places. A slight gradient or a steep, gradient, is a description which is equally applicable to a railway-slope or to difference in barometric pressure between two places. The civil engineer applies the same unit of measurement to both his horizontal and vertical scales ; but the meteorologist employs miles of distance in the former, and inches of pressure or millibars in the latter. 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 sea-miles of distance or in millibars per degree. The greater the difference, the closer will be the isobaric lines on a chart representing the pressure, the steeper will be the gradient, 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 cyclonic storms.

The air, when it is apparently wholly at rest, and a complete calm prevails, is in truth moving 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 is zero. So long as the air remains at rest (relative to the earth's surface), this movement 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. If a body move in any direction on the earth's surface, there is a deflecting force arising from the earth's rotation which deflects to the right in the Northern Hemisphere but to the left in the Southern Hemisphere.

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 comparatively 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 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 W. through S. to E. and N., round again to the W., *i.e.*, against the motion of the hands of a watch. In the Southern Hemisphere a similar circulation would be established, but in the opposite direction, or with the motion of the hands of a watch. Winds thus circulating round an area of low pressure are spoken of as cyclonic, and they are related in a manner similar to that of the winds of the great storms known as tropical revolving storms.

It will readily be seen that, in like manner, air flowing from an area of high pressure to areas of relatively 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 E. through S. to W. and N. back to E. 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.

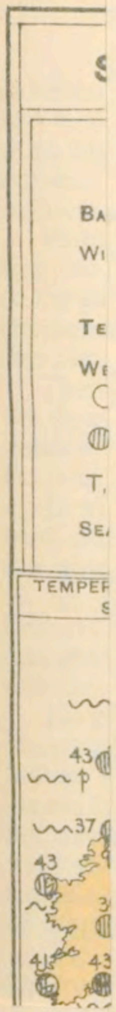
The general statement of the facts, thus explained, is known as Buys Ballot's law, because it was first publicly announced in Europe by Professor Buys Ballot, of Utrecht. It may be enunciated thus :—*

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

In the Northern Hemisphere, within, or on the borders of, an area of low barometrical readings, the wind blows round it in a

* Buys Ballot reversed the expressions, and supposed the observer to stand with his back to the wind, but as a seaman invariably faces the wind when he wishes to ascertain its direction, it is put here as above.

*To face*



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

Plate VI. illustrates the application of the foregoing observations to the Northern Hemisphere. They show the conditions of barometrical pressure, and the direction and force of the wind consequent on the formation of areas of low and high pressure over, and in the neighbourhood of, the British Isles.

The lines drawn on the map are isobars, which, as before stated, are lines indicating equal barometrical readings. The arrows indicate the direction and force of the wind and the number of feathers denotes force of wind in Beaufort scale.

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

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.

Fig. 14 indicates the wind circulation of the Southern Hemisphere. It also shows the height of the barometer, and the

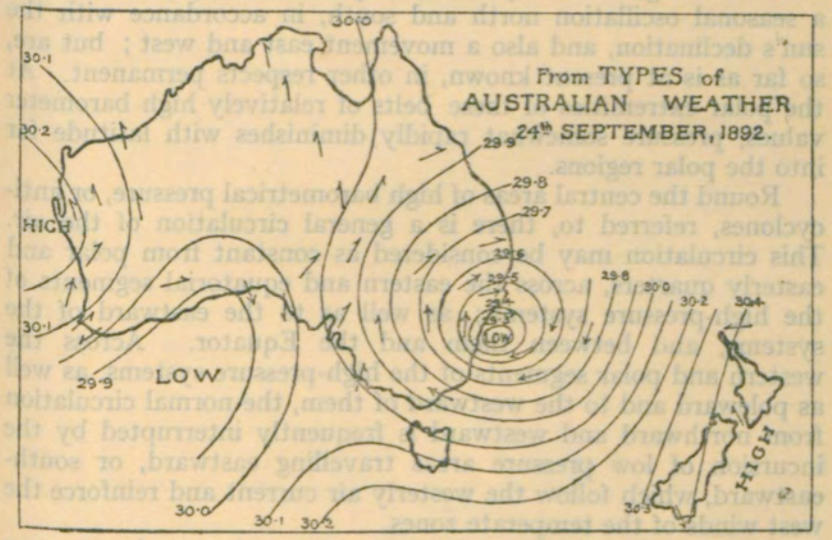



FIG. 14.

CIRCULATION OF WIND IN A CYCLONIC SYSTEM. SOUTHERN HEMISPHERE.

direction and force of the wind, during a cyclone central over the east coast of Australia.

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 Plate VI.

### Prevailing Winds at various Seasons over different Parts of the Globe.

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

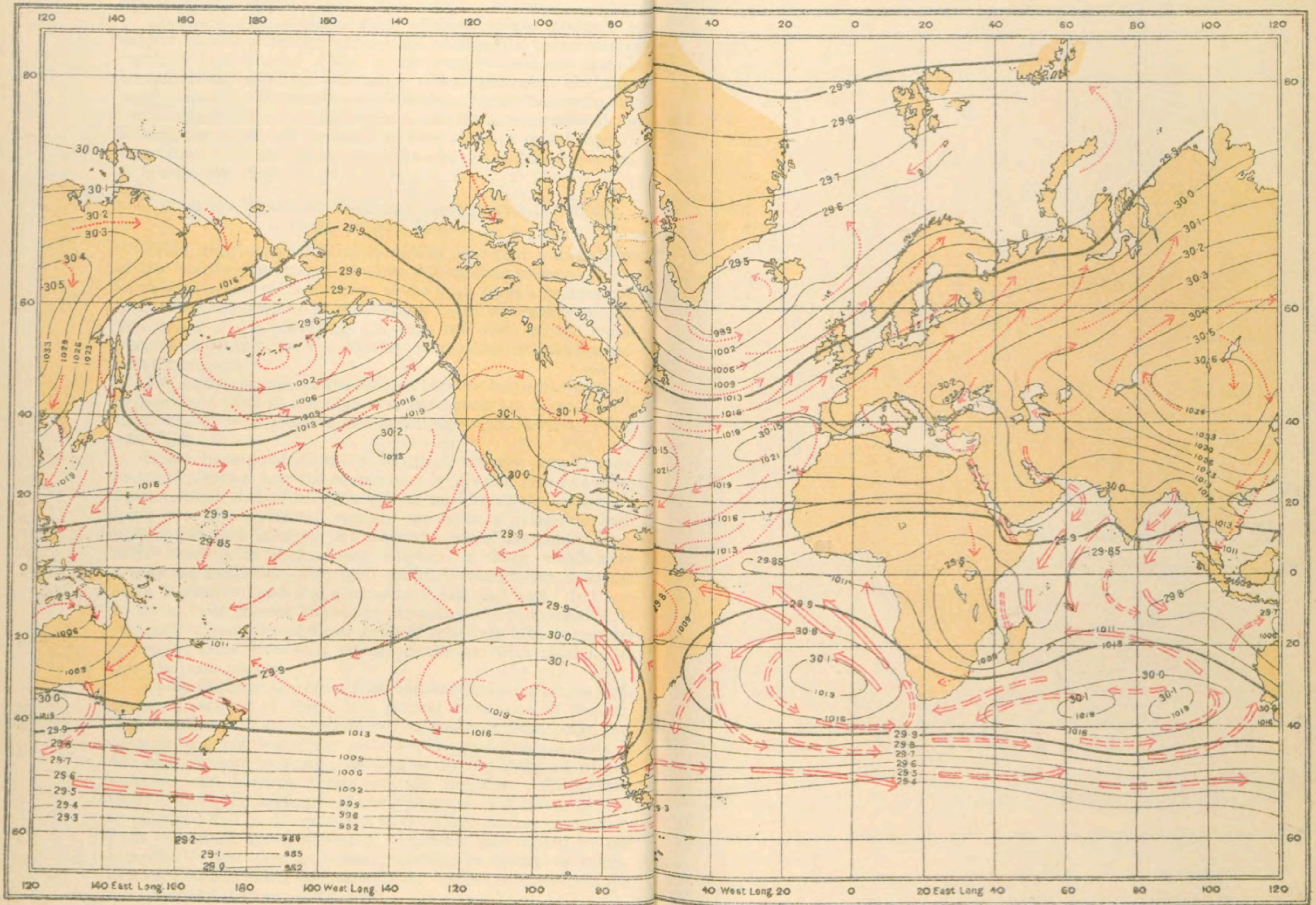
The leading features of the relation between mean barometrical pressure and wind distribution over the oceans are shown on the maps dealing with pressure and prevailing winds (*see* Plates VII and VIII).

It has been pointed out (p. 39) that, broadly stated, barometrical pressure over the oceans may be divided into five great areas. North and south of a belt of moderately low pressure, lying over the equatorial regions, are belts of relatively high pressure, in each of which are situated areas of maximum barometer reading, or anticyclones, elliptical in shape, which have a seasonal oscillation north and south, in accordance with the sun's declination, and also a movement east and west; but are, so far as is at present known, in other respects permanent. At the polar extremities of these belts of relatively high barometer values, pressure somewhat rapidly diminishes with latitude far into the polar regions.

Round the central areas of high barometrical pressure, or anticyclones, referred to, there is a general circulation of the air. This circulation may be considered as constant from polar and easterly quarters, across the eastern and equatorial segments of the high-pressure systems; as well as to the eastward of the systems, and between them and the Equator. Across the western and polar segments of the high-pressure systems, as well as poleward and to the westward of them, the normal circulation from northward and westward is frequently interrupted by the incursion of low pressure areas travelling eastward, or south-eastward, which follow the westerly air current and reinforce the west winds of the temperate zones.

The constant air currents from polar and easterly quarters referred to are known as Trade winds.

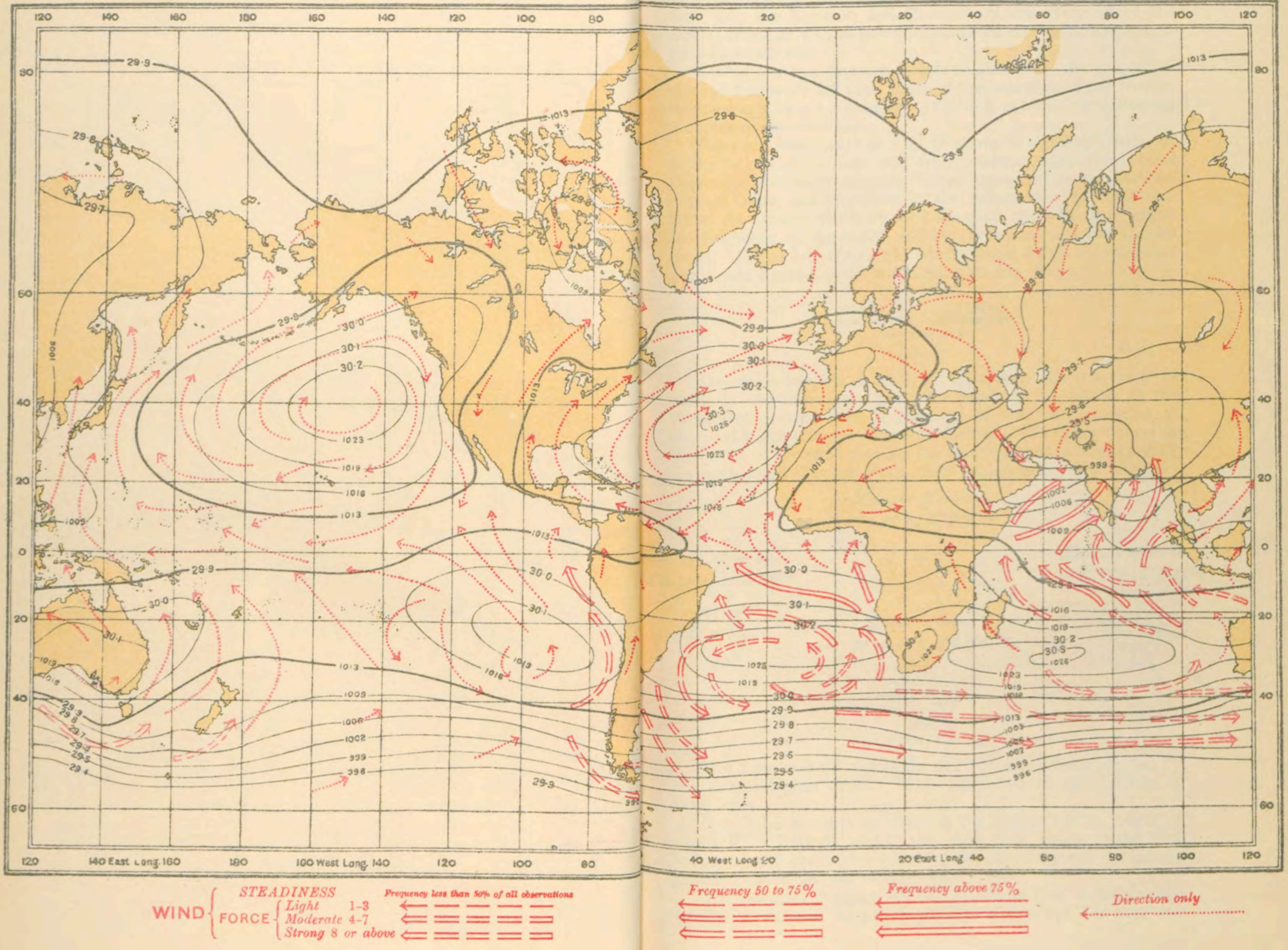
 **PRESSURE AND WIND** **JANUARY.** 




WIND { *STEADINESS* — *Frequency less than 50% of all observations* — *Frequency 50 to 75%* — *Frequency above 75%* — *Direction only*

FORCE { *Light* 1-3 / *Moderate* 4-7 / *Strong* 8 *or above*

*Between pp. 52 and 53.* **PRESSURE AND WIND** **JULY.** *Plate VIII.*



The constancy of the wind eastward of these central areas of high barometrical pressure in the great oceans, as well as between them and the Equator, and its unsteadiness westward of the central areas, as well as poleward, are well shown by the accompanying windroses.

A wind rose is a diagram designed to illustrate the proportion of wind frequency for each point of the compass, or for characteristic winds, over a given area. It is used, as a rule, for indicating the force of the wind also.

The wind roses given in Fig. 16 relate to the South Atlantic in the month of October, and are reproduced from the "Wind Charts for the South Atlantic Ocean," prepared in the Meteorological Office, and published by the Admiralty. In these diagrams the arrows, which fly with the wind, show by their length the frequency of the wind, and by their thickness the various forces. Forces 1 to 3 are light winds, forces 4 to 7 are moderate winds, and forces 8 to 12 are gales. (*See* Fig. 15.)

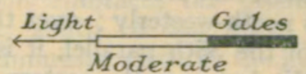



FIG. 15.

The circle supplies a scale for estimating the frequency of winds in any direction. From the heads of the arrows to the circumference represents 5 per cent of the whole number of observed winds (100 per cent = $2\frac{1}{2}$ inches). The upper figures in the centre of the wind rose are the total number of observations, the percentage of calms being given underneath. (*See* Fig. 16.)

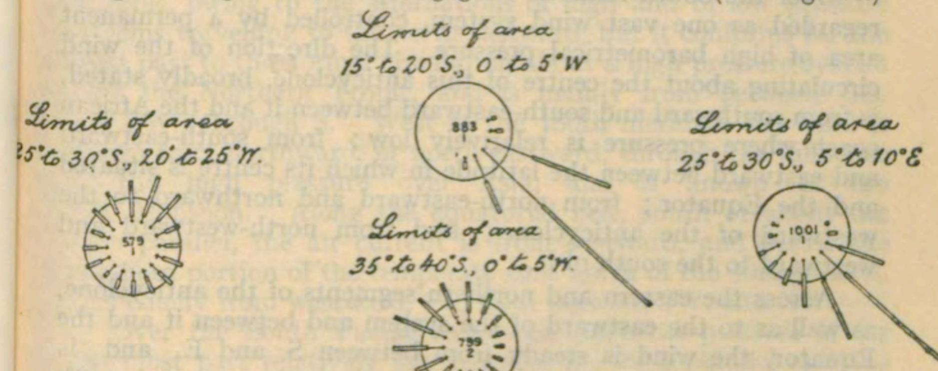



FIG. 16.

This form of wind rose is the one which has been adopted by the Meteorological Office. There are, however, many forms of wind roses.

It will be shown later that in the Indian Ocean, north of about 10° S. latitude, and in the China Seas, owing to the land influence, the conditions which obtain in the great oceans, as outlined above, are not reproduced.

The chart for January (Plate VII) shows that under average conditions an area of low barometrical pressure lies over the greater portion of the North Atlantic, north of the 40th parallel, and that pressure is lowest between Iceland and the southern extremity of Greenland. Between the 40th and 20th parallels, barometrical pressure is relatively high; areas of maximum barometer readings of 1021 mb. extending along the parallel of 30° N. Round this and similar high-pressure areas we have a definite anticyclonic circulation. Further south, near the Equator, we reach a region of variable winds and calms, called the Doldrums (*see also* Plates XI to XXIII), which is always to be found somewhere near the Equator. In January the region of Doldrums is south of its mean annual position. It extends westward from the African coast in about 7° N. to about the 45th meridian in 2° S. where the breadth of the belt is narrow. Pressure is high over southern Europe and the extreme north of Africa, and over the greater portion of North America. Following the law enunciated by Buys Ballot, the prevailing wind over the eastern half of the North American continent, and immediately to the eastward of the coast from the Arctic Circle to the 35th parallel of latitude is north-westerly; over the greater portion of the Atlantic, north of the 35th parallel, it is westerly, *i.e.*, from between NW. and SW., but over the eastern side of the Atlantic, and near the western seaboard of north-western Europe far into the Arctic Ocean, it is south-westerly. Between the 35th and 30th parallels, the wind is for the most part variable, while across and to the eastward of the eastern segment of the anticyclone it is north-easterly, and south of the 30th parallel from between NE. and E.

Over the South Atlantic the atmospheric circulation may be regarded as one vast wind system, controlled by a permanent area of high barometrical pressure. The direction of the wind circulating about the centre of this anticyclone, broadly stated, is from southward and south-eastward between it and the African coast where pressure is relatively low; from south-eastward and eastward between the latitude in which its centre is situated and the Equator; from north-eastward and northward to the westward of the anticyclone; and from north-westward and westward to the south of it.

Across the eastern and northern segments of the anticyclone, as well as to the eastward of the system and between it and the Equator, the wind is steady from between S. and E. and is called the SE. Trade wind; to the west, south-west, and south of the anticyclone, especially to the west of it, the northerly wind which belongs to the normal circulation of the air, although fairly constant in this month, is at times interrupted by the passage of of alternations of high and low-pressure areas travelling eastwards and south-eastward. South of 35° S. latitude the prevailing winds are westerly, *i.e.*, from between NW. and SW. They have a considerable northerly component, in harmony with decreasing pressure poleward. These westerly winds extend to high latitudes, and have been experienced in regions well within the Antarctic circle. Their southern limits in Antarctica vary with the locality



but probably reach to some parallel where sea meets land and the slope of the pressure gradient is slightly reversed inducing an easterly air current.

The salient features in the average distribution of barometrical pressure over the North Pacific, as shown on the chart for January, are as follow:—An extensive area of relatively low barometrical pressure covers the ocean north of the 40th parallel, its centre probably situated over, or immediately south of the Aleutian Islands, between the 140th meridian of west longitude and the 160th meridian of east longitude. A large anticyclone lies to the south-east of this low-pressure area, within a belt of relatively high pressure between the 40th and 15th parallels, extending right across the Ocean. This anticyclone has its centre in about 35° N. latitude, 140° W. longitude, where the average barometer reading is 1023 mb., or slightly above. It extends westward to about the 170th meridian of west longitude. A high pressure system covers Asia, and its south-eastern segment embraces the China Sea. Right along the equatorial belt, south of the 15th parallel, pressure is relatively low, and diminishes towards the Equator.

In harmony with this average distribution of atmospheric pressure, the general circulation of the air is roughly as follows:—To the south of the eastern anticyclone to about the 15th parallel and to the eastward of it, as well as across its southern and eastern segments, the wind direction is mainly from between N. and E.—the NE. trade wind. To the west of the anticyclone, to about as far as the 180th meridian, the wind is somewhat variable, owing to the alternations of high and of low pressure systems travelling to the north-eastward, but it conforms for the most part to the normal circulation about a high pressure system near the Northern Tropic, and is mainly from between SE. and SW., through S. West of the 180th meridian the wind is drawn from northward, or north-eastward, through the influence of the high pressure over Asia, and is known as the NE. Monsoon. Along the equatorial belt, south of about the 15th parallel, the air current is from eastward, and across the southern portion of the temperate zone north of the 40th parallel, it is chiefly from westward, *i.e.*, from between SW. and NW.

Over the South Pacific Ocean barometrical pressure is for the most part relatively low between the 20th parallel and the Equator. It is low also from the 45th parallel southward, diminishing with latitude as far south, at least, as the Antarctic Circle. Over the south-eastern part of the ocean, between the 20th and 40th parallels, pressure is high and increasing to a central maximum situated between 30° S. and 40° S. latitude, 90° W. and 120° W. longitude. Over South America pressure is relatively low.

Associated with this average distribution of barometrical pressure over the South Pacific the circulation of the air is from between S. and E. to the eastward and northward of the high pressure or anticyclone, as well as across its eastern and northern segments. West of the anticyclone to about as far as 160° W. longitude, as well as across its western segment, the circulation is mainly from north-eastward, northward, and north-westward. West of 160° W. longitude, between the Equator and 20° S. latitude, the wind is chiefly from northward, but gradually draws to the south-eastward through E. with increase of latitude to about 35° S., and to the southward and south-westward to about 38° S., south of which latitude the westerly winds prevail. These westerly winds are strongest and have most westing in them between the 40th and 50th parallels.

In the month under notice, when mean atmospheric pressure is relatively high over Asia, and high over southern Siberia and northern China, it is relatively high also over the Arabian Sea and Bay of Bengal, but diminishes with latitude to about 15° S. over the Indian Ocean. Pressure is relatively low over Africa south of about the 15th parallel of N. latitude.

In the South Indian Ocean, between the 20th and 42nd parallels of south latitude, there exists a belt of comparatively high, or high, barometrical pressure, in which are two areas of maximum intensity, with average barometer readings of 1019 mb. and above. One of these areas is situated between 34° S. and 37° S., 60° E., and 75° E., the other between 31° S. and 38° S., 85° E. and 95° E.

South of the 42nd parallel, pressure diminishes with increase of latitude to the Antarctic Circle, if not still farther south.

The general circulation of the air over the Indian Seas resulting from this average distribution of atmospheric pressure may be briefly summarised thus :—North of the equator the wind is north-easterly—the NE. Monsoon ; between the equator and about 10° S. latitude, it is mainly from north-westward—the NW. or Equatorial Monsoon. The latter appears as an extension southward of the NE. Monsoon, and the westerly component in this northerly wind south of the equator is due to the rotation of the earth on its axis, as is the easterly component of the northerly wind north of the equator.

Between 10° S. and 36° S. latitude the air current is chiefly from south-eastward—the SE. Trade—except in the locality of the highest pressure, where the wind is variable. Between 36° S. and 45° S. latitude the wind is usually from some point between N. and W., and south of 45° S. it is mainly from between NW. and SW., the northerly component predominating in the lower latitudes, and the southerly component in the higher.

The distribution of atmospheric pressure and wind over the oceans in the month of January, as outlined in the foregoing, may be regarded as largely characteristic of pressure and wind distribution during the five months of November to March.

In April the equatorial belt of low pressure surrounding the globe is travelling rather rapidly northward with the sun, and the belts of relatively high, or high, pressure north and south of the equatorial belt are moving with it.



The cooled land in temperate latitudes of the northern hemisphere is gaining heat ; the warmed land in corresponding latitudes of the southern hemisphere is losing it ; and the adjacent seas and oceans are undergoing similar changes more slowly and in a modified degree. The month of April, therefore, is one of transitional conditions.

The chart for July (*see* Plate VIII) shows that over the Atlantic in that month, under average conditions, barometrical pressure in high northern latitudes is considerably higher than it is in January, but that north of the 50th parallel it is still relatively low. A relatively high, or high pressure system covers that portion of the ocean which lies between the 15th and 50th parallels of north latitude, increasing in intensity towards a central area of maximum pressure, situated between 35° N. and 38° N., 30° W. and 38° W., where the average barometer is as high as 1026 mb. and above.

Between latitudes 15° N. and 10° S., barometrical pressure is relatively low, and the region of Doldrums is found from about 8° N. to 12° N. Between latitudes 10° S. and 40° S. pressure is relatively high right across the ocean ; and this belt of high barometer extends eastward and westward over those regions of South Africa and South America which are within these parallels.

Within this high pressure area the barometer is highest, 1023 mb. and above, between 20° S. and 35° S. South of about 37° S. pressure steadily diminishes with increase of latitude to some parallel within the Antarctic Circle.

Responsive to this average pressure distribution the prevailing wind is south-westerly to the north of the North Atlantic high pressure system, as well as over its northern segment, as far as the 60th parallel of north latitude, or still farther north ; it is north-easterly to the eastward of the system, and over its eastern segment ; north-easterly to easterly to the southward of the system to about 10° N. latitude ; and variable to south-westerly to westward of it. From 10° N. latitude to 20° S. the wind is easterly to south-easterly, except in the region of Doldrums, where it is light and variable, and off the West Coast of Africa, between Bathurst and the Cameroon River, where it draws to the S. and SW. under the influence of the heated land. This SW. Monsoon is experienced during the height of the northern summer, occasionally as far seaward as twelve hundred miles from the coast, between the 6th and 10th parallels of north latitude.

Within the anticyclonic belt between 20° S. and 35° S. the wind is mainly south-easterly over the eastern half of the ocean area, but northerly and variable over the western half, owing to the passage eastward of depressions. South of 35° S. westerly winds prevail and extend to latitudes bordering on, or within, the Antarctic Circle.

Over the Pacific Ocean in July barometrical pressure has undergone the following changes with regard to average distribution :—The North Pacific anticyclone is located farther north than it is in January, and has expanded considerably. It now occupies a large portion of the North Pacific between the Aleutian Islands and the 15th parallel of north latitude, from the American coast to the 165th meridian of east longitude.

It increases in intensity towards a central area of maximum pressure situated between 30° N. and 45° N., 135° W. and 165° W., where the mean barometer reading is 1023 mb. or above.

Barometrical pressure is low over Asia, and over the China Seas, but it increases eastward towards the high pressure system referred to.

The South Pacific anticyclone occupies an area extending over the greater portion of the ocean, between the 5th and 40th parallels of south latitude, east of the 130th meridian of west longitude. The equatorial belt of relatively low pressure is, therefore, farther north in this month than it is in the month of January, and its area is more restricted. The highest barometer readings in the South Pacific anticyclone, 1019 mb. and above are found in the south-eastern segment of the ellipse. From 45° S. latitude poleward pressure diminishes rather rapidly; therefore, the barometrical gradient immediately south of this central area of high pressure is steep and the winds, which are principally from westward, are correspondingly strong.

A neck of relatively high pressure joins the South Pacific anticyclone to a high pressure system which lies over Australia and extends eastward over the South Pacific to about the 170th meridian of east longitude.

The effect of these changes in average pressure distribution upon the general circulation of the air is :—(1) To contract the area of westerly winds in the North Pacific Ocean, and to augment that of the NE. Trade wind ; (2) to induce a southerly wind—the SW. Monsoon—in the China Seas in place of the NE. Monsoon of the northern winter ; (3) to contract the SE. Trade wind area on the eastern side of the South Pacific ; to augment it on the western side ; and greatly to reduce the width of the equatorial belt of variable winds and calms.

In July, and also in August and September, it is difficult to define in the Pacific the southern limits of the NE. Trade, and the nothern limit of the SE. Trade as they appear to merge one into the other without interruption.

Barometrical pressure is low, or relatively low, in July, over the whole of Asia ; and, broadly stated, is lowest over Northern India and Baluchistan. It is low, or relatively low, over the Arabian Sea, the Bay of Bengal, and the Indian Ocean to about the 10th parallel of south latitude, pressure being lowest in the north and increasing southwards towards the high pressure belt in the South Indian Ocean.

Barometrical pressure is relatively high, or high, between the 10th and 40th parallels of south latitude, and from the African coast to the 100th meridian of east longitude. It is highest, 1026 mb. and above, between the 32nd and 35th parallels, and the 55th and 70th meridians. East of 100° E. longitude, the



isobars of 1019 mb. to 1005 mb., turn to the north-eastward to about 120° E., where they take on the shape of the southern coastline of Australia.

Dominated by this average distribution of atmospheric pressure in July, the prevailing winds are from southward and south-eastward—the SE. Trade—north of 30° S. latitude to the equator ; and from south-westward—the SW. Monsoon—north of the equator. South of 30° S. latitude the prevailing winds are westerly and north-westerly to the Antarctic circle, where, there is reason to believe, the slope of the pressure gradient is reversed so that in still higher latitudes the prevailing winds are easterly.

The conditions obtaining in July may be considered as typical of the conditions existing in the months of May, June, August and September. In October, the equatorial belt of low pressure is travelling somewhat rapidly southward, and the belts of relatively high pressure with it. The land in temperate latitudes of the Northern Hemisphere is losing the warmth acquired during the northern summer, and the cooled land in corresponding parallels of the Southern Hemisphere is gaining heat. The adjacent seas and oceans are undergoing similar changes more slowly, and in a lesser degree. In the month of October then, as in the month of April, the distributions of atmospheric pressure and wind are in a state of transition.

## Chapter V.

# WIND AND GALES OF THE TEMPERATE ZONES.

### Winds of the Atlantic Ocean, which are typical of those of other Seas.

The North Atlantic supplies types of the winds usually met with in all oceans. From Plates XI to XXIII it will be seen that an area of high pressure occurs in the North Atlantic between the parallels of 20° N. and 40° N.; according to Buys Ballot's law, the wind draws round it, being Nly. on its eastern, Ely. on its southern, Sly. on its western, and Wly. on its northern side. The wind arrows on Plates VII and VIII indicate such a circulation of the air.

Vessels, therefore, outward bound from England to the Cape of Good Hope, pass from the north-east to the east and south-east side of an area of high pressure lying to the westward, and as the coast of Portugal is approached the wind very generally comes from the NW., gradually shifting to N. and NE. as more southing is made.

On the other hand, homeward-bound vessels approaching the southern verge of the NE. Trade, with a rising barometer, find the wind draws to the eastward. As the area of highest pressure is reached the barometer ceases to rise, and the wind dies away. These are the "calms," and light baffling winds known as the "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, and a ship will experience little or no wind until a part of the sea is reached where the pressure commences to decrease.

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

There are, as has been already shown, similar areas of high pressure in the South Atlantic, North and South Pacific, and South Indian Oceans, with a corresponding circulation of the wind round them germane to the Hemisphere.

Homeward-bound vessels, after rounding the Cape of Good Hope, are at the polar edge of the SE. Trade on the eastern side of the South Atlantic, just as the outward-bound ship is at the polar edge of the NE. Trade when off the coast of Portugal (*see* Plates VII and VIII), and the first wind experienced is from SW., backing to S. and SE. as northing is made, which (according to Buys Ballot's law, when applied to the Southern Hemisphere) shows that the vessel has passed along the south-east, east, and north-east sides of an area of high pressure.



Again, outward-bound vessels drawing towards the northern verge of the SE. Trades on the western side of the South Atlantic, very generally experience changes of wind to NE., N., and NW., which are the winds met with in the Southern Hemisphere on the north-west, west and south-west sides of an area of high pressure corresponding with the winds already noticed as being experienced on the western side of the North Atlantic.

The study of Plates XI to XXIII 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.

In reference to the terms "veering" and "backing," there appears to have been some uncertainty in former years as to the meaning of the words as applied to the changes in the direction of the wind in the Southern Hemisphere. At the International Conference of Directors of Meteorological Institutes and Observatories, held at Innsbruck in 1905, a question was raised in this connexion. The Conference having ascertained the rule in use at the British Meteorological Office agreed that the same should be recommended for general adoption by passing the following resolution :—"That Meteorologists in the Southern Hemisphere, as in the Northern Hemisphere, are requested—without regard to other weather phenomena—to employ the term 'backing,' whether at an observing station or on board ship, exclusively to denote a change in direction against the hands of a watch, *i.e.*, W-S-E-N.; and the term 'veering' for changes in the opposite direction, *i.e.*, W-N-E-S."

### 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. As represented on a synoptic pressure chart, that is to say, a chart showing the distribution of pressure, these low-pressure areas are represented by a series of isobars curving sharply round a low-pressure centre. The completed isobars may be either approximately circular or V-shaped. These travelling areas of low pressure frequently give rise to gales, to the characteristics of which attention will be next given.

Along the tracks of steamships engaged in the trans-Atlantic trade these gales very frequently travel eastward in the region of the westerly wind which forms a part of the oceanic high pressure system. Their centres are often far north of the vessels using the adopted routes; and therefore these disturbances generally commence with a wind from the south-westward and cease with the wind from the north-westward. Should, however, the storm centre be south of the observer, as sometimes happens, then the first wind of the system is from the south-eastward and the last is from the north-eastward. The force of the easterly winds is comparatively light, very often owing to the fact that the cyclones of the temperate zones of the North Atlantic do not have the barometric gradient so steep on the northern side as on the side nearer to the equator. In other words, the isobars, or lines of equal barometric pressure, are much more widely separated on the polar side of the system than elsewhere.

The gales of the Temperate Zone of the Southern Hemisphere are similar in character to those of the Northern Hemisphere. In either Hemisphere, in the Temperate Zone, the areas of low barometric pressure travel eastward ; and the strength of the wind is determined by the amount of the difference between the barometer readings at places not far distant from each other. In the Southern Hemisphere the wind circulation of a cyclone is from the opposite direction to that of the Northern Hemisphere. Hence these atmospheric disturbances in the South Temperate Zone, when passing over a ship that is north of the centre, commence with the wind from NW. and terminate with a shift to SW. ; but from NE. and SE., respectively, when the centre is north of the observer.

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 east-north-eastward, the wind in the rear of it will veer through ESE. 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 Sly. 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 the shape of an area of low pressure could be foretold, its gradients, the rate at which it is increasing or decreasing in intensity, the direction in which it is moving, and its speed, it would be possible to calculate very correctly what sort of weather would be experienced at a land station or on board vessels at sea, and it is upon observations of this description, made simultaneously at many places, that forecasts of weather are based ; but the seamen 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.*

* The general introduction of wireless telegraphy now enables ships at great distances to exchange barometer readings, and thus it is possible for a synoptic chart to be prepared at sea. (*See* M.O. Publn. No. 236 "*Weather Forecasting in the North Atlantic and Home Waters for Seamen,*" by Commander L. A. Brooke-Smith, R.D., R.N.R., published by H.M. Stationery Office, price 6*d*.).



Moreover, it must always be remembered that, although it is most commonly in connection with considerable falls of the barometer that storms are experienced, yet the sudden large increase of pressure, which is not infrequent with such depressions, is usually 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 cyclones 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 tropical cyclones (*see* p. 70) ; but it is advisable for a captain to know on which tack it will be safer to lie-to if obliged to do so, and this will be the same as that for the tropical cyclones of the respective hemispheres.

The most sudden shift of wind which is to be expected in these cylcones in latitudes generally frequented by shipping is that from SW. to NW. in the Northern Hemisphere, or from NW. to SW. 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 NW. or SW. wind, as the case may be, according to the hemisphere.

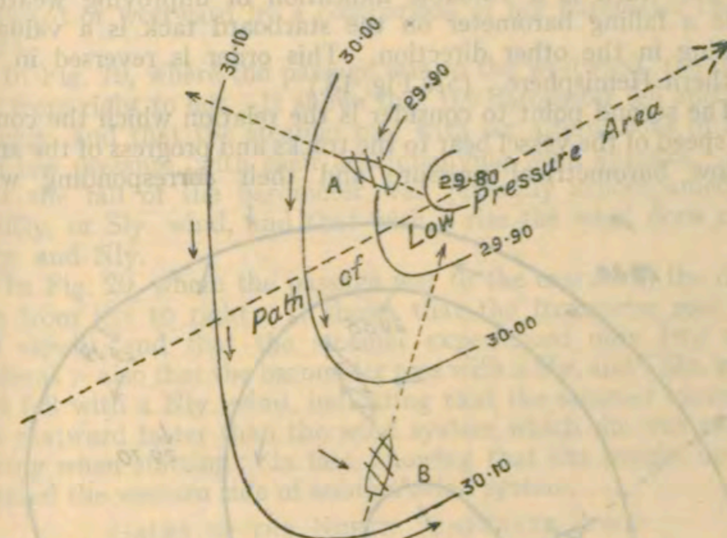



Fig. 17.

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

The pressure-equivalents of the isobaric lines are : 29·80 in. 1009·1 mb. ; 29·90 in., 1012·5 mb. ; 30·00 in., 1015·9 mb. ; 30·10 in., 1019·3 mb.

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 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. 17) the lower barometer is on your right when your face is turned to the wind, and as, when you are thus placed, a vessel on the starboard tack is advancing towards your left, she goes towards the higher barometer and recedes from the lower. In the Southern Hemisphere this is reversed, and the vessel 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 position of the area of barometrical pressure, and it may so happen that a high pressure, towards which the vessel 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 vessel 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 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. (*See* Fig. 18.)

The second point to consider is the relation which the course and speed of the vessel bear to the tracks and progress of the areas of low barometrical pressure and their corresponding wind

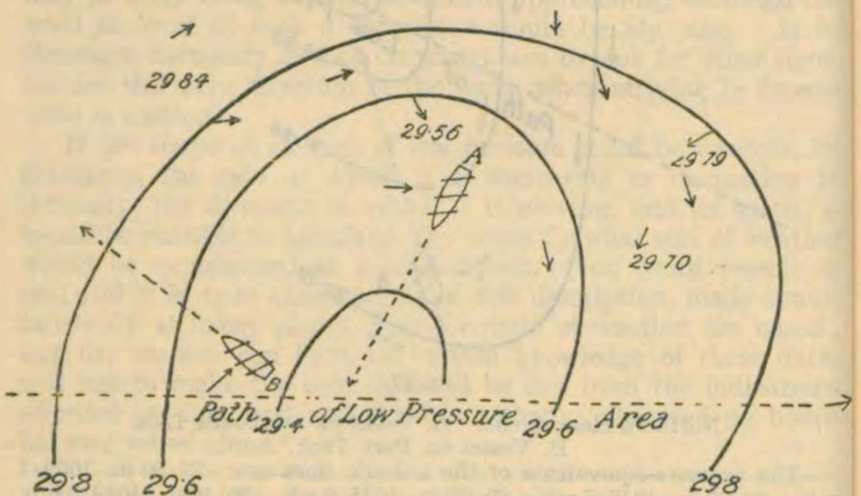



FIG. 18.
Southern Hemisphere. A. Vessel on Starboard Tack.
B. Vessel on Port Tack.
The pressure-equivalents of the isobaric lines are : 29·4 in., 995·6 mb. ; 29·6 in., 1002·4 mb. ; 29·8 in., 1009·1 mb.



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 low pressure system is advancing eastward at the rate of, say, 20 miles an hour, and the vessel is steaming at the average rate of, say, 10 miles an hour, the result will be that when going westward the vessel will have a relative rate of motion towards the low pressure of 30 miles an hour, but when going eastward, of only 10 miles an hour.

In other words, vessels when outward bound across the Atlantic meet the advancing low pressure 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. 19 and 20 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 the late Capt. W. Watson, of the Cunard steamer *Algeria*, Fig. 19, during a passage *to* New York, and Fig. 20 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.

In Fig. 19, 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 SEly. or Sly. wind, and that with a rise the wind drew more Wly. and Nly.

In Fig. 20, 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 Sly. and SEly. wind, and fell with a Nly. wind, indicating that the steamer 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.

Gales of the North Temperate Zone which are experienced in latitudes frequented by shipping usually commence at SE., S., or SW. and end at W. or NW. because the central area of the wind system with which these winds are associated generally is situated in higher parallels. If a vessel travels on a path that is situated in higher parallels. If a vessel travels on a path that is situated in higher parallels.

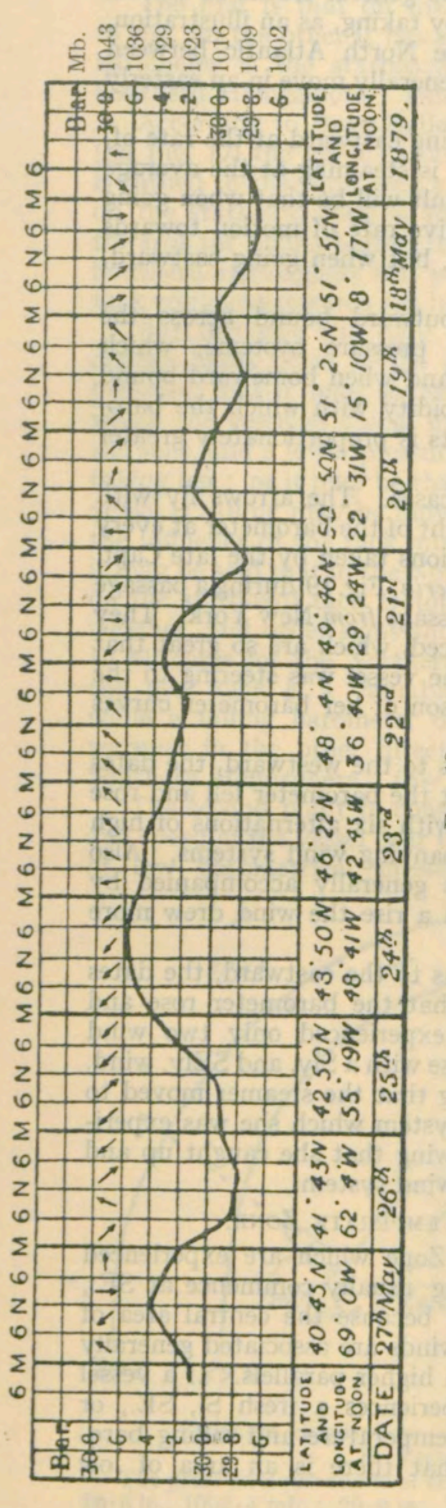

Bar.
Mb.
LATITUDE AND LONGITUDE AT NOON
DATE
27th May
26th
25th
24th
23rd
22nd
21st
20th
19th
18th May 1879.

Fig. 19.

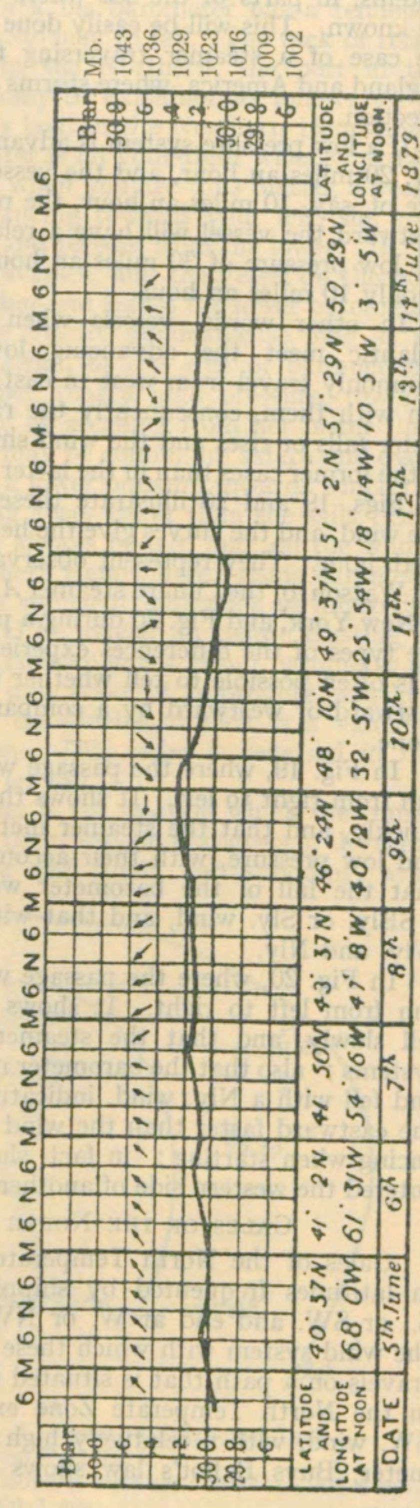
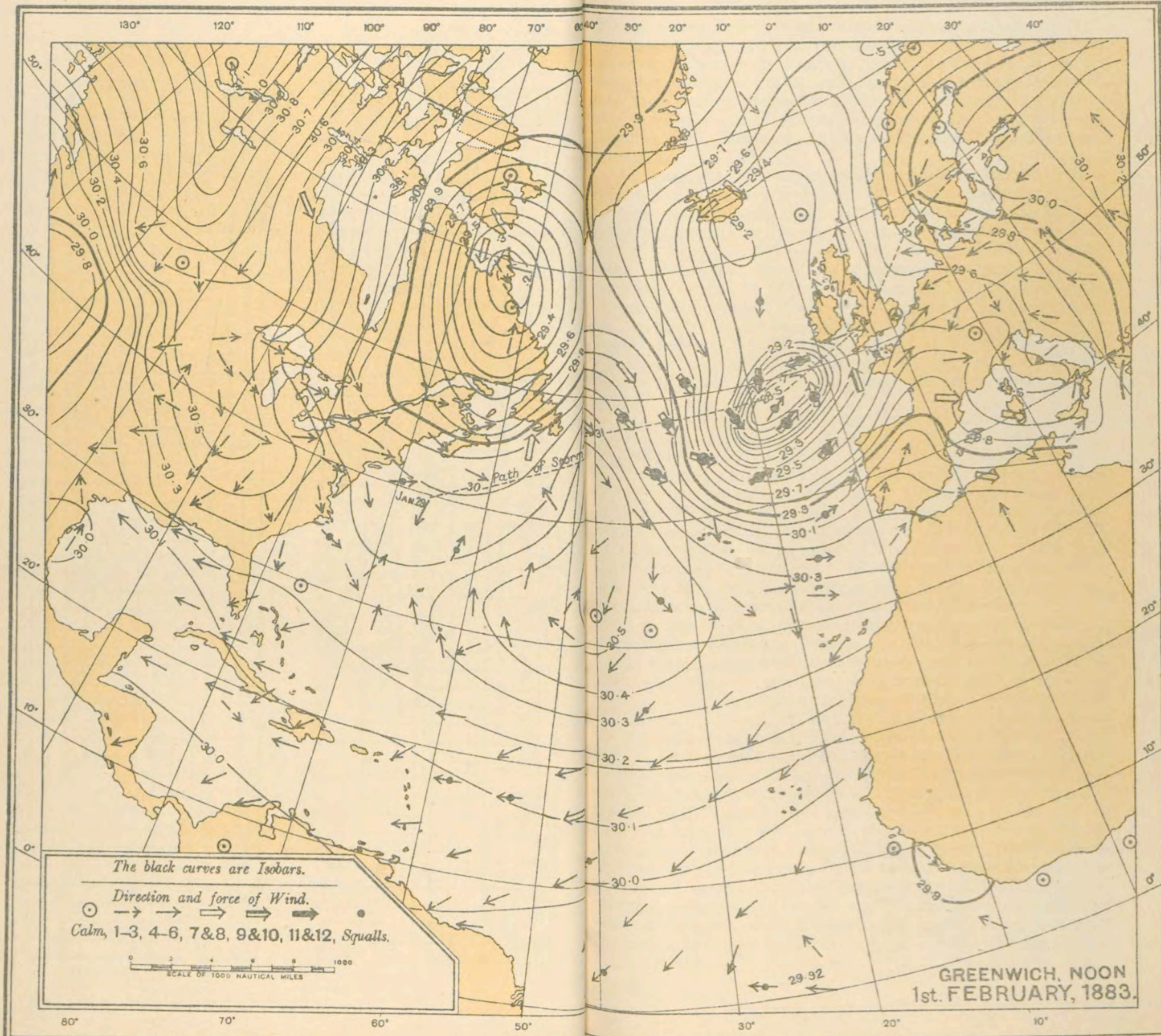

Bar.
Mb.
LATITUDE AND LONGITUDE AT NOON
DATE
5th June
6th
7th
8th
9th
10th
11th
12th
13th
14th June 1879.

Fig. 20.




From "Synchronous Weather Charts of the North Atlantic and adjacent Continents 1st August, 1882, to 3rd September, 1883." Published by Meteorological Office, 1886 pressure to the west or south-west of her ; and, as already said, it is probably travelling to the east or north-east. Experience shows that whether the vessel 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 NW. wind will set in. (*See* Plate IX.)

The general belief that the rate at which the barometer falls is an indication of the strength of a Sly. wind of gale force in these latitudes requires some qualification. The fact that the force of the 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 comparatively 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 vessel's course and speed in connexion with the course and speed of the area of low pressure, as already remarked on p. 64, and illustrated by Figs. 17 and 18.

The following instance may be cited as an illustration of what frequently occurs to a sailing vessel. A homeward-bound vessel in about 45° N., 30° W., falls in with a fresh Sly. 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 or north-east ; but his vessel is also going in the same direction, 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 vessel 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 in this connexion, as before said ; a fall of 1½ to 3½ mb. (·04 to ·10 of an inch) per hour is usually considered to be a serious indication of the approach of a Sly. wind of gale force, which may be followed by an equally fast rise accompanied by a W. or NW. wind of gale force.

From what has been said it will be clear to the navigator that, in northern latitudes, at the setting-in of a Sly. 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, for her captain may be led to anticipate worse weather than is really coming.

With a Sly. wind and falling barometer, a sailing vessel bound to the westward might gain by running to the northward, with the object of reaching the northern side of the approaching system and a wind backing to E. Again, it might be possible for a sailing vessel, with the first of the S. wind which exists on the east side of the area of low pressure, to get less wind by running north, but as the extent in latitude of the disturbed area is not known, and, consequently, there is no certainty of running into more moderate weather, the manœuvre might be contrary to her interests, especially as the path of the storm would be crossed. (*See* Plate IX.)

It seems, then, probable that a sailing vessel bound to the southward or westward must face one of these gales if she meets it. A weak vessel, with which it is desired 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 SW., W., or NW. This would, of course, be the best plan for any vessel which found the gale too heavy for her. But a well-conditioned vessel, bound to the westward, might keep on the port tack until the wind shifts to W. 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 it is assumed the captain is aware of and prepared to meet these risks.

When the wind has shifted to NW., the starboard tack takes a vessel away from the centre of such a disturbance, though she may soon sail into the S. 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 the South Temperate Zone resemble those of the 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," a series of gales will probably be experienced, which, commencing at N. or NE., end at W. or SW. Now with a Nly. 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. Vessels which keep a steady W. wind for days as they run to the eastward in comparatively 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 is the case with steamers in the North Atlantic bound to ports in America, while those from America frequently keep a steady barometer and Wly. wind for days. This receives abundant confirmation from the frequency of the barometrical oscillations and changes of wind experienced



by vessels bound to the westward, in rounding either the Cape of Good Hope or Cape Horn.

The best method of manœuvring in a heavy gale, or with a weak vessel in an ordinary gale, is reversed for southern latitudes : there the port is the " coming-up " tack, which enables her to stem the sea, as the wind usually shifts from N. through NW. to SW., the centre being south of the ship, and the port tack with a SW. 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 Nly. wind on the eastern side of another low-pressure area 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 NW. until it shifts to W. and SW., 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.

## CHAPTER VI.

# TROPICAL REVOLVING STORMS.

The wind in a cyclone blows round a central area of relatively low barometric pressure; the direction of revolution being opposite to that of the hands of a watch in the Northern Hemisphere, but with watch hands in the Southern Hemisphere. The statement of this rule more familiar to seamen is—in either hemisphere the wind travels round the central area of a cyclonic system in a direction contrary to that of the apparent diurnal course of the sun in the heavens. The westerly wind of a cyclone in either hemisphere is, therefore, always found on that portion of the whirl which is nearest to the equator. It has already been shown that when facing the wind of a cyclone in the Northern Hemisphere the barometer is always lower on the observer's right hand than it is on his left hand; and, similarly, in the Southern Hemisphere, facing the wind of a cyclone the barometer is always lower on the observer's left than it is on his right. A close acquaintance with this law is most important. By its aid the seaman who comes under the influence of a tropical revolving storm, and who has to rely solely upon the indications of his own barometer, supplemented by observations of wind, clouds and weather, is able to determine the approximate geographical position of the centre of a cyclone; and with this knowledge may manœuvre his ship so as to avoid this region of maximum danger in the vicinity of which the force of the wind is greatest, the changes in its direction are most sudden, and the sea most dangerous.

The wind force in a cyclonic system does not necessarily attain to that of a gale, as estimated by Beaufort's scale; the air circulation may be complete, but, if the barometric gradient is slight, the wind may be moderate or even light. The direction and strength of the wind depend upon the direction and steepness of the barometric gradient which, as already stated, may be defined as the difference in atmospheric pressure in hundredths of an inch for each 15 miles.

This specification agrees with that of continental countries where the number of millimetres of pressure difference per degree of 60 nautical miles is specified. We should prefer to use the number of millibars per hundred kilometres but, as a matter of fact, gradients are seldom evaluated in meteorological practice. We use instead the distance apart of consecutive isobars on the map, the distance being generally expressed in nautical miles because every map practically carries a scale of nautical miles by its lines of latitude.

In alluding to a cyclone we are referring to a characteristic circulation of air round a central area of low atmospheric pressure without regard to the force of the wind associated with it. The



term "cyclone" therefore includes not only the revolving storms of the tropics, in which the wind blows with great violence, but also all wind systems, of high and low latitudes, in which the air circulation is cyclonic. In these storms the same air particles do not keep with the whirl throughout its career; as there is a continual degradation and re-formation as it moves along the earth's surface. For the purposes of the practical navigator, however, it may be assumed that the tropical revolving storm is invariable in its composition over small distances of the track followed.

### HURRICANES, TYPHOONS OR CYCLONES OF TROPICAL SEAS.

The cyclone of tropical origin, or tropical revolving storm, with which we have now to deal, is known in different localities by distinctive names. In the West Indies and in the islands of the South Pacific these storms are called hurricanes, in the North-West Pacific and China Sea they are known as typhoons, and in the Indian Seas simply as cyclones. Of all the atmospheric disturbances the approach of which the barometer indicates, and consequently enables the seaman to avoid, these storms are the most serious. They are seldom experienced within 5° or 6° of the equator; but their track occasionally extends from the tropics to high latitudes.*

The geographical conditions which are most favourable to their formation and development are found where the coastlines of large continents, in which are many bays and indentations, run north and south, and face to the eastward a wide expanse of sea, in which are many islands. Such conditions are more or less fulfilled in the regions to which reference has been made.

Revolving storms have a progressive movement. The wind blows in a more or less spiral direction towards the centre, and at the same time the storm field advances on a straight or curved track. Cases exist in which the velocity of advance of the system has amounted to as much as 45 miles an hour, and in others the translation was not more than two miles an hour.

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

| Region and Period. | Jan. | Feb. | Mar. | April | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. | Total. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| West Indies, 300 years .. | 5 | 7 | 11 | 6 | 5 | 10 | 42 | 96 | 84 | 69 | 17 | 7 | 355 |
| South Indian Ocean, 70 years (1848–1917)† .. | 113 | 115 | 98 | 68 | 25 | 3 | 2 | — | — | 7 | 33 | 58 | 522 |
| 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 |
| Arabian Sea, 1890–1912 | 2 | — | — | 2 | 5 | 11 | 3 | — | 2 | 10 | 8 | 2 | 45 |
| Bay of Bengal, 1877–1903 | — | — | — | 1 | 8 | 4 | 4 | 2 | 6 | 8 | 17 | 6 | 56 |
| South Pacific, 1789–1891 | 36 | 22 | 35 | 8 | 1 | — | — | — | 2 | 1 | 4 | 16 | 125 |
| North Pacific, 1902–1918 | 9 | 5 | 6 | 11 | 20 | 18 | 49 | 74 | 80 | 47 | 27 | 22 | 368 |

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

Fig. 21 illustrates the average paths followed by storms

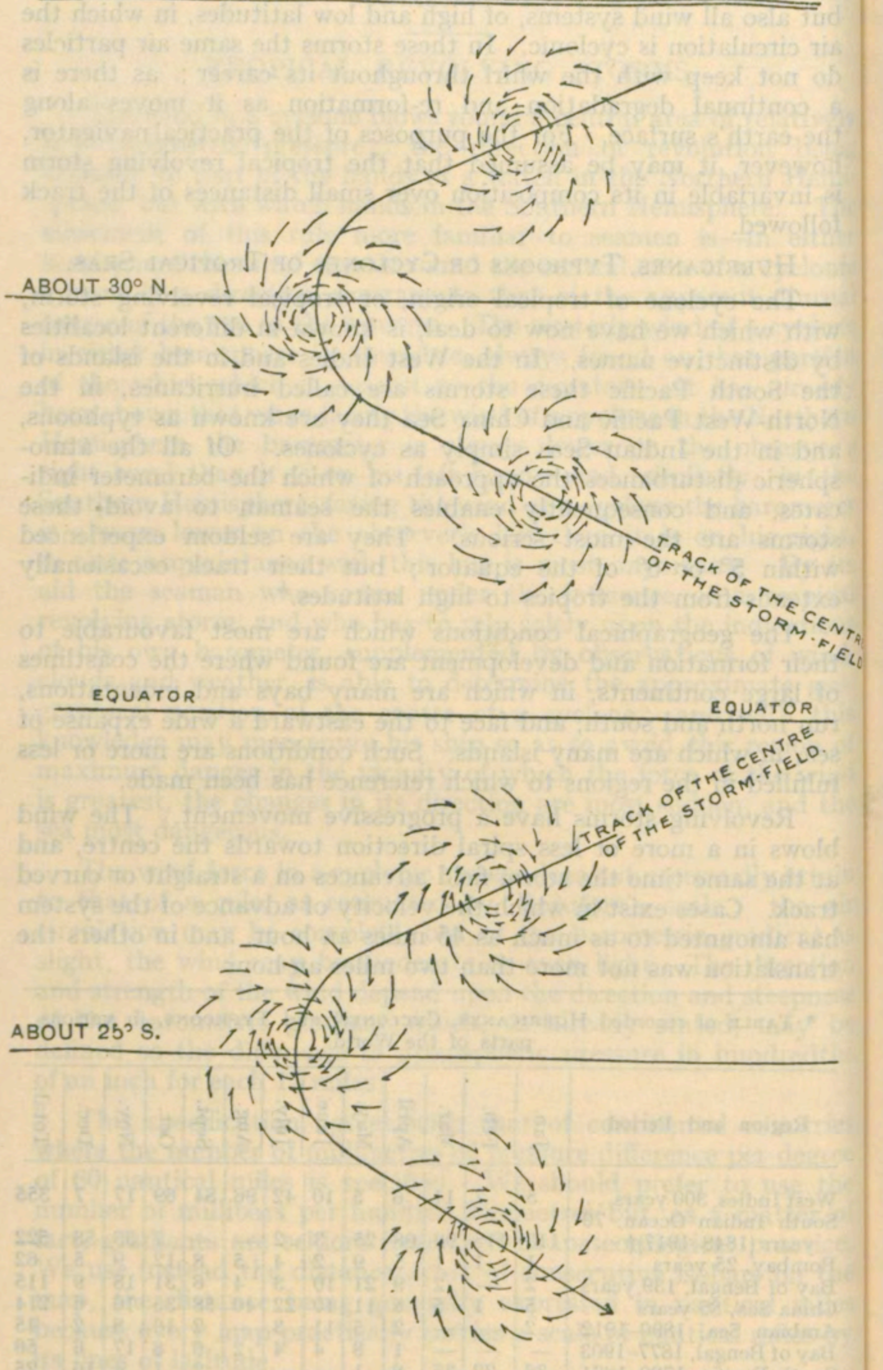
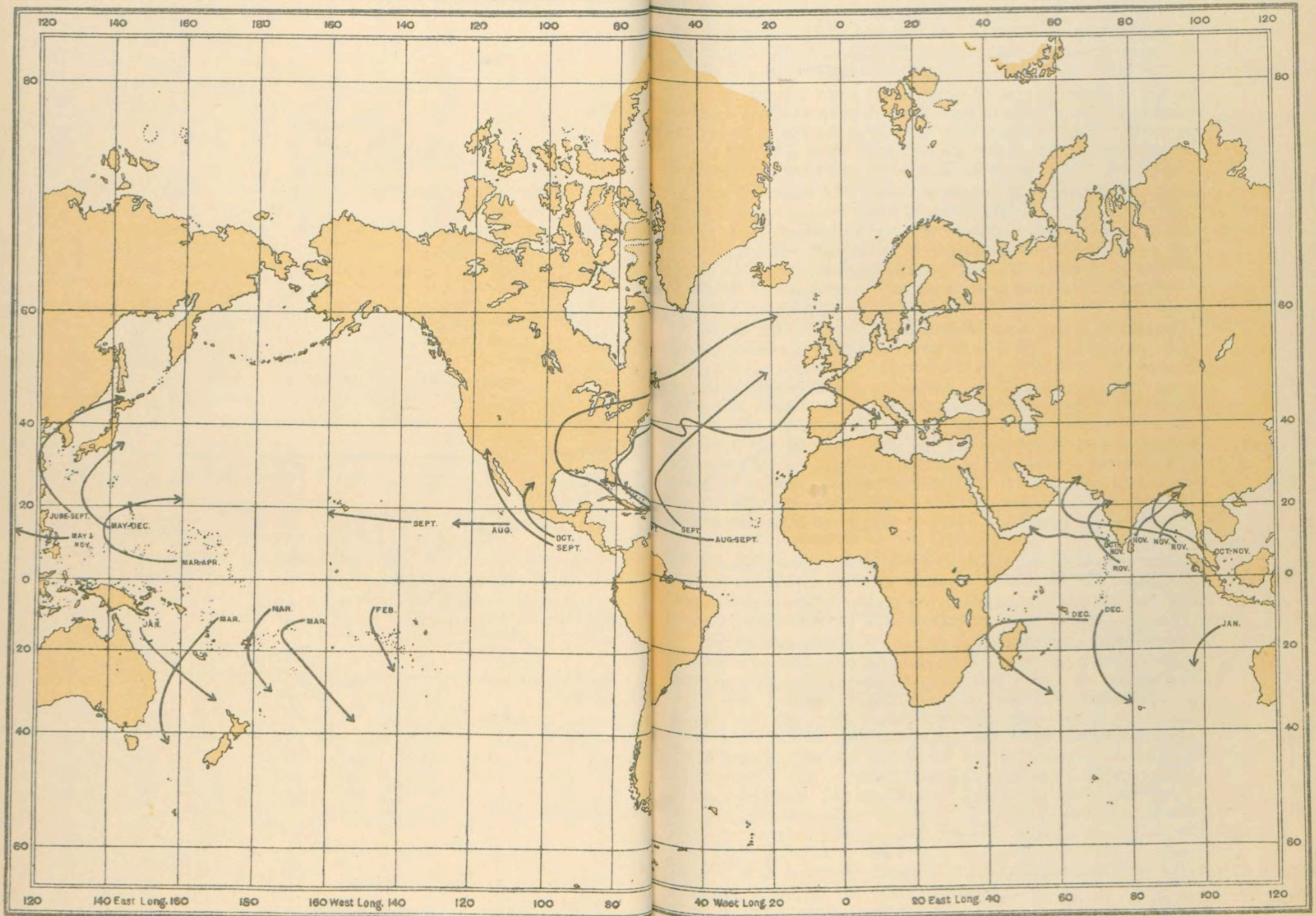



FIG. 21.

DIAGRAM SHOWING THE AVERAGE SHAPE AND TRACKS OF CYCLONIC STORMS, NORTH AND SOUTH OF THE EQUATOR.

## SELECTED EXAMPLES OF TRAC OF TROPICAL REVOLVING STORMS.





travelling from the tropics into the temperate zones ; also the circulation of the wind in the storm field.

The track which the centre of the storm follows is known as the path of the storm, and that part of the storm on the right of the path, as it advances, is named the right-hand semicircle, and on the left, the left-hand semicircle.

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 varying force, sometimes lulling into little more than a strong breeze, and as the centre is approached often rising into a blast of almost irresistible fury.

One semicircle of a storm is known as the dangerous semicircle because a vessel might be driven when in it across the path of the storm, and would certainly cross the path if she ran before the wind. The right hand is the dangerous semicircle in the Northern Hemisphere, and the left-hand semicircle in the Southern Hemisphere. The other semicircle, in each case, is termed navigable.

In the Atlantic and South Indian Oceans these storms commence to the eastward and travel along a path not exactly west, but inclining a point or two towards the pole of the hemisphere in which they have been generated ; as they advance they curve away still more towards the pole, and finally move to the north-east in the Northern Hemisphere and to the south-east in the Southern Hemisphere. They move in fact round the sub-tropical high-pressure areas. The Atlantic storms almost always wheel round to the northward in the vicinity of the Bahamas, and follow the sea-board of North America ; but some recurve in the Gulf of Mexico, and a few appear to pass on to Mexico without recurvation.

Tracks of some of the most remarkable hurricanes, or cyclonic storms, are shown by thick arrows on Plate X ; 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 71.

The cyclone season of the South Indian Ocean may be considered to commence in November and end in May ; but cyclones occasionally occur in October, June and July. In August and September, however, it would appear that they are altogether absent from the South Indian Ocean, as there are no records of their occurrence in these months. The maximum frequency is found between January and March, and the minimum from May to October. The probability of encountering a South Indian Ocean cyclone is therefore greatest when the sun's declination is south, and least when it is north. These cyclones frequently originate on the tenth parallel of south latitude, travel south-west along a parabolic track to a vertex in about 21° S., then recurve, and eventually move to the south-eastward. At rare intervals, however, the point of curvature is as far north as 8° S., or as far south as 32° S. As regards the longitude of the vertex, it may be on any meridian between Keeling Island and the Mozambique Channel. The cyclone tracks of this ocean are similar to those of the North Atlantic, but are apparently more nearly in agreement with a smooth curve. South Indian Ocean cyclones travel but slowly, the average rate being about six miles an hour.

The late Dr. C. Meldrum, C.M.G., F.R.S., when stationed at Mauritius, was favourably situated for receiving reports from sailing ships which had suffered from cyclones in the South Indian Ocean and put into Mauritius for repairs. He dealt with the cyclones of that ocean in great detail, and his tracks, with additions, will be found on the *Monthly Meteorological Charts of the Indian Ocean and Red Sea*, which were issued by the Meteorological Office during the years 1906–9.

In the South Pacific the season for tropical revolving storms commences with December and ends with March, although an occasional hurricane may be experienced in April. They generally originate to the north-east of the Fiji Islands, and the rate of travel is said to vary from about two miles an hour in the lower latitudes to twenty miles an hour in 30° S. While passing over the island groups these storms appear to be almost stationary for a time.

Typhoons of the China Sea originate to the eastward of the Philippines, Carolines and Ladrones. In the lower latitudes the centres travel westward. Some pass over the mainland, some recurve to the eastward, and eventually reach the west coast of North America by way of Japan. Tracks of tropical storms of the North Pacific are very similar to those of the North Atlantic. The Rev. José Algué, S.J., Director of the Manila Weather Bureau, in his valuable report on " The Cyclones of the Far East," divides the tracks into two broad classes—those of the Pacific, which do not cross the meridian of 124° E., and those of the China Sea, which either cross that meridian or are formed in the China Sea.

Between December and March the centres of the former class of cyclones travel north-north-west, the latitude of the vertex lies between 15° N. and 19° N., and they travel thence to the north-north-east. In April and May, as also in October and November, the corresponding movement of the centres is north-west to about 16° N. to 21° N., thence north-east. Between June and September the tracks are north-west by north to about 21° N. to 25° N., thence north-east by north. Adopting three groups of the same months for the tropical storms of the China Sea, it is found that the tracks of the first period do not recurve over the sea. Of those of the second period only a portion have parabolic tracks ; and the vertices of these latter are found in the China Sea to the southward of Formosa Channel. During the months called by Algué typhoon months, cyclones belonging to the third of these groups recurve much more frequently than during either of the preceding periods. The parabolic tracks of China Sea typhoons, as shown on Plate XI, are similar to those of the Pacific cyclones belonging to the corresponding groups. The zone of origin for typhoons of the first group is bounded by the parallels of 5° N. and 12° N., and they reach the mainland between 8° N. and 15° N. ; that for typhoons of the second group is from 6° N. to 17° N., and they reach the coast of Asia between 12° N. and 23° N. ; and finally the zone of the third group is between 8° N. and 20° N., and they reach the mainland on parallels from 18° N. to 30° N.



A typhoon is considered to travel rapidly, in the vicinity of the Philippines, if its velocity of translation exceeds 12 miles an hour ; and slowly if it moves at a rate of less than 12 miles an hour. The same storm may be rapid, moderate, or slow during varying phases of its existence ; it may be moderate in the lower latitudes, almost stationary at point of recurvature, and rapid in the higher latitudes. Of typhoons that crossed the Archipelago, or the adjacent regions of the ocean, which have been traced, 40 travelled rapidly, 180 with moderate speed, 30 moved slowly, and a few remained stationary for several days.

The Bay of Bengal has not in recent years been visited by storms in January, February and March, and they seldom occur in April. During the remaining months of the year they are not infrequent, the maxima occurring in May and October. They are most violent in October and November. Storms of the Arabian Sea may be divided into two classes : those which have their origin over the sea, and those which reach the sea from the Bay of Bengal. Several have been traced from the Andamans across the southern portion of the Peninsula and over the Arabian Sea for a considerable distance.

In April, the storms of the Bay of Bengal originate in mid-ocean, between the Nicobars and Ceylon, and travel north-east ; in May some appear first near the Andamans, and proceed either north-east or north-west, and some originate near Madras and travel west-north-west. During June, July, August and September, storms commence in the head of the Bay and move north-west. In October, they have their origin to the north of 8° N., and travel either north-east or west-north-west. They either take a similar path in November, or cross the Peninsula and continue their course in the Arabian Sea. In December the majority have their birth between 8° N. and 16° N., to the north-east of Ceylon, move between north-west and west, and sometimes reach the Arabian Sea ; a few which originate a little to the westward of the Andamans, proceed north-east towards the head of the Bay.

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. Records seem to show that at the beginning or end of the hurricane season a considerable proportion of the storms in the Indian Ocean are either stationary or slow in movement.

The indications of the approach of a revolving storm are (*a*) a low barometer, the reading being well below the normal for the time and place; (*b*) 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; (*c*) a long heavy swell which generally comes from the direction in which the storm is approaching, or a confused sea.

In every case there is great barometrical disturbance, the barometer at the centres of some of these storms standing fully two inches lower than outside the storm-field.

## Practical Rules for Seamen in Tropical Cyclones.

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

When there is reason to believe that a storm is approaching, the two points necessary for the seaman to know are (*a*) the direction in which the centre of the storm is situated, and (*b*) in which semicircle of the storm the vessel is situated.

In order to ascertain these two points it is necessary that the observer should be stationary; the first thing, therefore, to be done is to stop head to wind, or heave-to, and as it is always wise to assume the vessel may be in the dangerous semicircle, she should be hove-to, on the starboard tack in the Northern Hemisphere, and on the port tack in the Southern Hemisphere. There should be no hesitation in heaving-to, as the sooner a clear knowledge of the position of the ship in the storm-field is ascertained the sooner can the necessary action be taken to avert the danger.

When hove-to, the bearing of the centre, if the observer faces the wind, will be from 12 to 8 points on the right hand in the Northern Hemisphere, and on the left hand in the Southern Hemisphere. At the beginning of a storm allow 12 points, when the barometer has fallen $\frac{3}{10}$ of an inch (10 mb.) about 10.

Having ascertained the bearing of the centre, the semicircle in which the vessel is situated may be found by observing in which direction the wind shifts. If it shifts to the right, the ship is in the right-hand semicircle; if to the left, in the left-hand semicircle; and if the wind is steady in direction, but increasing in force, with a falling barometer, the vessel is in the direct path of the storm. This law holds good in both hemispheres.

If a seaman has reason to think he is in the direct path of the storm's centre, the most prudent course to pursue is to run his ship, in the Northern Hemisphere, with the wind on the starboard quarter; in the Southern Hemisphere, with the wind on the port quarter, until the barometer has ceased to fall.

This course of action should be adopted in the case of a steamship as well as in that of a sailing vessel.

In the Northern Hemisphere, if your ship is in the right-hand semicircle, and she is a sailing vessel, remain hove-to on the starboard tack, so as to come up to wind and sea as the former continues to draw aft; if a steamship, heave-to with the wind ahead, if possible, if not with the wind on the starboard bow.



In the Southern Hemisphere, if your ship is in the right-hand semicircle, whether she be a sailing vessel or a steamship, run with the wind on her port quarter, until the barometer commences to rise.

In the Northern Hemisphere, if your ship is in the left-hand semicircle, whether she be a sailing vessel or a steamship, run with the wind on her starboard quarter, until the barometer commences to rise.

In the Southern Hemisphere, if your ship is in the left-hand semicircle, and she is a sailing vessel, remain hove-to on the port tack; if a steamship, heave-to with the wind ahead if possible, if not with the wind on the port bow.

The researches of Dr. Meldrum, formerly 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 E. or S. the passage of the centre with respect to the vessel's position may be approximately inferred.

If the wind shift from SE. decidedly towards the S. round to the NW., or if the wind remain steady at SE., and 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 north-west.

It is also stated that in the cyclones of the South Indian Ocean NEly. and Ely. 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 N. or NE. wind, with a falling barometer and threatening appearance of the weather, should warn them to heave-to in time.*

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* For recorded tracks of cyclones in the Southern Indian Ocean see the *Monthly Meteorological Charts of the East Indian Seas*, published by the Meteorological Office during the years 1906–9. For further information concerning tropical revolving storms the reader may consult Eliot's "Handbook of Cyclonic Storms in the Bay of Bengal," M.O. Publn. No. 220i, *Geophysical Memoirs*, No. 19: "Hurricanes and Tropical Revolving Storms," by Mrs. E. V. Newnham, M.Sc., published by H.M. Stationery Office, price 12*s*. 6*d*.; and Algué on "*The Typhoons of the Far East.*"

## APPENDIX I.

### THE THERMOMETER, HYGROMETER, AND HYDROMETER

*Thermometer.*—This instrument shows increase or decrease of temperature 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. 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 Polar regions, whereas spirit would not freeze. Mercury freezes at a temperature of about − 38·2° Fahr. = − 39° Cent.; spirit (pure alcohol) becomes a thick liquid at − 130° Fahr., and solidifies into a white mass at − 202° Fahr. 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 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 of very small bore, 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 marked on the tube and figured on the scale at its side, 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, provided sufficient time is allowed for the mercury to take up that temperature, by conduction of heat through the glass substance of the bulb.

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°). This graduation was adopted by Fahrenheit, a native of Danzig, in the year 1721. Other graduations were devised about twenty years later; one by Celsius, a professor at Upsala, in 1742; and another by Réaumur, a French physicist, at about the same period. Celsius suggested that the boiling-point be called zero, and the freezing-point 100°. In the modern Centigrade scale, which is an adaptation of the Celsius, and in general use at the present time in most Continental countries, the freezing-point is taken at zero, and the boiling-point at 100°. Réaumur framed a scale somewhat similar to the Centigrade but divided the interval between the freezing and boiling-points into eighty divisions. This scale, which at one time was commonly employed on the Continent, is now almost obsolete.

In order to convert readings of the Centigrade scale to that of the Fahrenheit: double the Centigrade number, diminish this by one-tenth of itself and add 32. To convert from Fahrenheit to Centigrade: subtract 32 from the former, increase the remainder by one-ninth of itself and take the half.



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.

*The Thermograph.*—A self-recording thermometer, or thermograph, may be employed with advantage on board ship for obtaining a continuous record of temperature, which, if studied in connexion with the record of a barograph for the same period, will demonstrate the close relation existing between the fluctuations in temperature and pressure respectively.

The instrument will be found, after the observer has had a little experience with it, a valuable aid in foretelling changes in weather conditions. For instance: a marked rise in temperature, detected by a glance at the thermogram, if associated with a shift of wind to an equatorial quarter, will frequently give warning of the approach of an atmospheric disturbance before the barometer has commenced to fall.

In some thermographs a bi-metallic spiral acts as the thermometer. The spiral is made of two strips of metal of different coefficients of expansion welded together so that it coils and uncoils with change of temperature. One end of the spiral is attached to the frame of the instrument, the other to the arm which carries the recording pen.

In other thermographs the thermometer consists of a slightly curved metal tube filled with spirit (Bourdon tube). One end of this is fixed rigidly to the instrument while the other is attached to the system of levers which actuates the recording pen.

From the nature of the case thermographs for meteorological use must be exposed out of doors, preferably in a Stevenson screen, and hence it is necessary to clean and oil their bearings much more frequently than is the case with barographs.

The instrument may be set by comparing its indications with the reading of a standard mercury thermometer placed beside it in the screen. The setting should only be attempted at times when the temperature is constant or changing slowly, and only when the pen is near the middle of its range. Bi-metallic thermographs respond much more rapidly than Bourdon-tube instruments to change of temperature.

The readings of the thermograph require frequent checking by comparison with standard instruments. A convenient plan is to place a standard maximum and a standard minimum thermometer in the screen with the instrument and to read and set these at regular hours, time marks being made at the hours of reading. It should be borne in mind that in cases when the trace shows that the extreme was of very short duration a difference between the reading of the standard and that of the recorder may be shown, this being due to a difference in the times required by the thermometer and thermograph respectively to take up the extreme temperature.

*Hygrometer.*—This instrument measures the humidity 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. It is known as Mason's hygrometer. 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 the ordinary thermometer, which has its bulb uncovered and is known as a dry-bulb thermometer.

The depression of the wet-bulb thermometer is caused by the evaporation from the moistened covering of the bulb. When the humidity of the atmosphere is very great, 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 less humid 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 10 degrees.

To ensure correct records of the temperature and humidity 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.

Fig. 22 shows the form of screen used for exposing the dry and wet-bulb thermometers on board ship; the screen should be fixed in a suitable position about five feet above the upper deck, in the open air, but protected from sun, rain, and spray, and as free as possible from radiation or warm currents of air from cabins, engine and boiler rooms, stoke-hold and funnel.

The glass, or other small holder of water should be as far as possible from the dry thermometer, as in Fig. 22. Either distilled or rain water should be used, or, if this be not procurable, the softest fresh water available, to avoid the deposit of lime, or other impurity on the bulb. Even rain water is not entirely free from impurities, containing as it does alkalis, salts, etc., which in time form a thin coating on the bulb. Should any incrustation be found on the bulb when the muslin and wick is changed, it should be scraped off with a sharp pen-knife. When needed, the vessel should be replenished with water, after, or some little time before observing; because observations are incorrect if made before the mercury in the wet bulb has fallen to the temperature it would acquire after sufficient exposure to the air.

The muslin and wick should be well washed before being applied, and occasionally while in use. Both should be changed once a month or oftener when necessary. The times of changing the muslin should be recorded in the log. Accuracy depends much on the care taken to ensure cleanliness, also on a proper supply of fresh water. The temperature of evaporation is a very important observation, therefore it requires special care. It should be borne in mind that observations of the wet-bulb thermometer are impaired by the presence of salt water on the cambric, therefore in the event of such impregnation taking place through spray, or by any other means, the cambric, or muslin and wick should be cleansed, or renewed. Care should also be taken when reading the dry-bulb thermometer to see that the bulb is dry. If it is wetted by rain or otherwise it becomes a wet bulb for the time being.



During frost, when the muslin is thinly coated with ice, the readings are still valid, because evaporation takes place from a surface of ice as

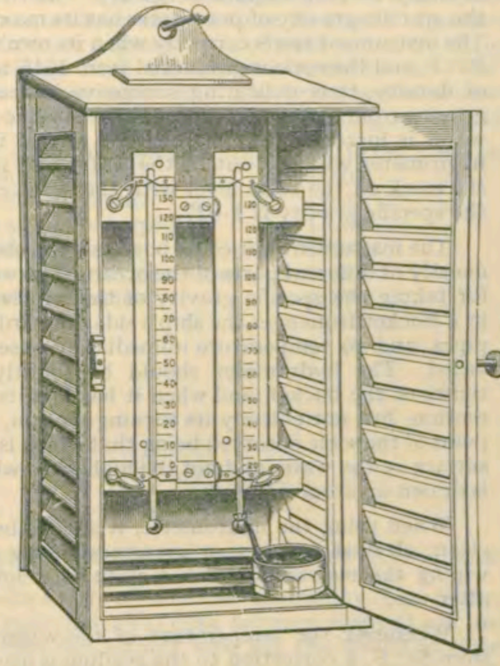


FIG. 22.

freely as from that of water, but if the muslin be dry, and there be no coating of ice, it must first be wetted, and then allowed time to freeze, before the thermometer is read.

*Sea Surface Temperature Thermometer.*—An ordinary thermometer is used for surface temperature observation and is protected by a metal case having a water-tight space at the bottom which will hold sufficient water to surround the bulb.

*Hydrometer.*—This instrument is employed for determining the specific gravity of liquids. The specific gravity of a liquid at any temperature is the ratio of the weight of any volume of the liquid at that temperature to the weight of an equal volume of water at a standard temperature. The hydrometer used at sea is constructed of glass and its form is shown in Fig. 23, p. 82. It consists of a glass tube ending in a globular bulb partly filled with 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 a cylindrical shape, to give the instrument sufficient volume for flotation; above this it is tapered off to a narrow upright stem closed at the top, inside which is fixed a paper scale. 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 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.

FIG. 23.

In the hydrometer used by the Meteorological Office, the specific gravity of distilled water at 39·2° F. is taken as unity or 1000 degrees of density. At this temperature the specific gravity of pure water has its maximum density. The instrument reads correctly when its own temperature is 59° F. and the scale is graduated from 1015 to 1035 degrees of density, thus indicating successive increases of specific gravity from 1·015 to 1·035. If the specific gravity of the water is increased by the presence of salt in solution the hygrometer will rise out of the water and if, say, 1,027 is the mark on the scale level with the surface of the water, the specific gravity is 1·027.

The instrument is used on board ship to show the relative density of different parts of the ocean. 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, and when it has lost its up and down motion, but not entirely its turning motion, it is read, the point of the scale observed being that which is level with the surface of the water and not the highest to which the liquid is drawn up around the stem.

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

Whenever the temperature of the water tested differs from 59° F. 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.

The specific gravity of sea-water depends upon its temperature and its salinity. A more accurate method therefore of estimating the specific gravity of the sea in a given locality is to determine by chemical analysis the saltness of a sample of water and convert this salinity into specific gravity. The salinity of sea-water is defined as the ratio of the weight of the salts to the weight of the pure water in which they are dissolved. There is no simple rule connecting salinity, temperature and specific gravity, but tables based on experiments have been constructed. The following table refers to surface water; below the surface the water is compressed and has a greater specific gravity for the same temperature and salinity.

*Table of Specific Gravity* of sea-water of known temperature and salinity compared with distilled water at maximum density.

| Salinity (Salts per thousand). | Temperature. | | | | | |
|---|---|---|---|---|---|---|
| | 273° 32° | 278° 41° | 283° 50° | 288° 59° | 293° 68° | 298° a 77°F. |
| 15 | 1·0121 | 1·0119 | 1·0115 | 1·0107 | 1·0097 | 1·0084 |
| 20 | 1·0161 | 1·0159 | 1·0153 | 1·0145 | 1·0134 | 1·0121 |
| 25 | 1·0201 | 1·0198 | 1·0192 | 1·0183 | 1·0172 | 1·0159 |
| 30 | 1·0241 | 1·0237 | 1·0231 | 1·0221 | 1·0210 | 1·0196 |
| 35 | 1·0281 | 1·0277 | 1·0270 | 1·0260 | 1·0248 | 1·0234 |
| 40 | 1·0322 | 1·0317 | 1·0309 | 1·0299 | 1·0286 | 1·0272 |



The solid matter dissolved in sea-water is made up of a number of different salts; more than three-fourths consist of sodium chloride or common salt. Although the salinity of the sea varies somewhat in different localities, times, and seasons, because its degree of saltness depends upon the removal from, or addition to it, of fresh water, by evaportion, precipitation, and drainage from the land, nevertheless the ratio of the different salts is substantially constant. The constituents of sea-water and their relative proportions are set forth in the accompanying table :—

| | | | |
|---|---|---|---|
| Sodium chloride (common salt) | 27·213 | per 1,000 parts of water. | |
| Magnesium chloride .. .. | 3·807 | ,, | ,, |
| Magnesium sulphate .. .. | 1·658 | ,, | ,, |
| Calcium sulphate (gypsum) .. | 1·260 | ,, | ,, |
| Potassium sulphate .. .. | 0·863 | ,, | ,, |
| Calcium carbonate and residue .. | 0·123 | ,, | ,, |
| Magnesium bromide .. .. | 0·076 | ,, | ,, |
| | 35·000 | | |

## APPENDIX II.

### METEOROLOGICAL INFORMATION BY RADIOTELEGRAPHY.

The development of wireless telegraphy has rendered possible the exchange of meteorological data between ships at sea and ships and land stations, so that the seaman now has the means of constructing his own synoptic chart which will give him the opportunity of forecasting the weather conditions likely to be experienced in the immediate future (See *Wireless and Weather, An Aid to Navigation,* M.O. 297, price 5*s*.)

Weather bulletins and storm warnings for use of ships at sea are now transmitted by W/T by nearly all the principal countries of the world. Full information concerning these can be found in the following publications :—

*Admiralty List of W/T Signals.*

*Decode for use with the International Code for Wireless Weather Messages from Ships,* M.O. 329, price 3*d*.

## APPENDIX III.—TABLES.

### TABLE I.

TABLE of CORRECTIONS 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. 26·0 | 26·5 | 27·0 | 27·5 | 28·0 | 28·5 | 29·0 | 29·5 | 30·0 | 30·5 | 31·0 | Temp. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ° | + | + | + | + | + | + | + | + | + | + | + | ° |
| 0 | ·068 | ·069 | ·070 | ·072 | ·073 | ·074 | ·076 | ·077 | ·078 | ·080 | ·081 | 0 |
| 1 | ·065 | ·067 | ·068 | ·069 | ·070 | ·072 | ·073 | ·074 | ·076 | ·077 | ·078 | 1 |
| 2 | ·063 | ·064 | ·065 | ·067 | ·068 | ·069 | ·070 | ·072 | ·073 | ·074 | ·075 | 2 |
| 3 | ·061 | ·062 | ·063 | ·064 | ·065 | ·066 | ·068 | ·069 | ·070 | ·071 | ·072 | 3 |
| 4 | ·058 | ·060 | ·061 | ·062 | ·063 | ·064 | ·065 | ·066 | ·067 | ·069 | ·070 | 4 |
| 5 | ·056 | ·057 | ·058 | ·059 | ·060 | ·061 | ·062 | ·064 | ·065 | ·066 | ·067 | 5 |
| 6 | ·044 | ·055 | ·056 | ·057 | ·058 | ·059 | ·060 | ·061 | ·062 | ·063 | ·064 | 6 |
| 7 | ·051 | ·052 | ·053 | ·054 | ·055 | ·056 | ·057 | ·058 | ·059 | ·060 | ·061 | 7 |
| 8 | ·049 | ·050 | ·051 | ·052 | ·053 | ·053 | ·054 | ·055 | ·056 | ·057 | ·058 | 8 |
| 9 | ·046 | ·047 | ·048 | ·049 | ·050 | ·051 | ·052 | ·053 | ·054 | ·054 | ·055 | 9 |
| 10 | ·044 | ·045 | ·046 | ·046 | ·047 | ·048 | ·049 | ·050 | ·051 | ·052 | ·053 | 10 |
| 11 | ·042 | ·043 | ·043 | ·044 | ·045 | ·046 | ·047 | ·047 | ·048 | ·049 | ·050 | 11 |
| 12 | ·039 | ·040 | ·041 | ·042 | ·042 | ·043 | ·044 | ·044 | ·045 | ·046 | ·047 | 12 |
| 13 | ·037 | ·038 | ·038 | ·039 | ·040 | ·040 | ·041 | ·042 | ·043 | ·043 | ·044 | 13 |
| 14 | ·035 | ·035 | ·036 | ·036 | ·037 | ·038 | ·039 | ·039 | ·040 | ·041 | ·041 | 14 |
| 15 | ·032 | ·033 | ·033 | ·034 | ·035 | ·035 | ·036 | ·036 | ·037 | ·038 | ·038 | 15 |
| 16 | ·030 | ·030 | ·031 | ·031 | ·032 | ·033 | ·033 | ·034 | ·034 | ·035 | ·036 | 16 |
| 17 | ·027 | ·028 | ·029 | ·029 | ·030 | ·030 | ·031 | ·031 | ·032 | ·032 | ·033 | 17 |
| 18 | ·025 | ·026 | ·026 | ·027 | ·027 | ·028 | ·028 | ·029 | ·029 | ·030 | ·030 | 18 |
| 19 | ·023 | ·023 | ·024 | ·024 | ·025 | ·025 | ·025 | ·026 | ·026 | ·027 | ·027 | 19 |
| 20 | ·020 | ·021 | ·021 | ·022 | ·022 | ·022 | ·023 | ·023 | ·024 | ·024 | ·024 | 20 |
| 21 | ·018 | ·018 | ·019 | ·019 | ·019 | ·020 | ·020 | ·021 | ·021 | ·021 | ·022 | 21 |
| 22 | ·016 | ·016 | ·016 | ·017 | ·017 | ·017 | ·017 | ·018 | ·018 | ·018 | ·019 | 22 |
| 23 | ·013 | ·014 | ·014 | ·014 | ·014 | ·015 | ·015 | ·015 | ·015 | ·016 | ·016 | 23 |
| 24 | ·011 | ·011 | ·011 | ·012 | ·012 | ·012 | ·012 | ·012 | ·013 | ·013 | ·013 | 24 |
| 25 | ·009 | ·009 | ·009 | ·009 | ·009 | ·009 | ·010 | ·010 | ·010 | ·010 | ·010 | 25 |
| 26 | ·006 | ·006 | ·006 | ·007 | ·007 | ·007 | ·007 | ·007 | ·007 | ·007 | ·007 | 26 |
| 27 | ·004 | ·004 | ·004 | ·004 | ·004 | ·004 | ·004 | ·004 | ·004 | ·005 | ·005 | 27 |
| 28 | ·001 | ·002 | ·002 | ·002 | ·002 | ·002 | ·002 | ·002 | ·002 | ·002 | ·002 | 28 |
| | — | — | — | — | — | — | — | — | — | — | — | |
| 29 | ·001 | ·001 | ·001 | ·001 | ·001 | ·001 | ·001 | ·001 | ·001 | ·001 | ·001 | 29 |
| 30 | ·003 | ·003 | ·003 | ·003 | ·003 | ·004 | ·004 | ·004 | ·004 | ·004 | ·004 | 30 |
| 31 | ·006 | ·006 | ·006 | ·006 | ·006 | ·006 | ·006 | ·006 | ·006 | ·007 | ·007 | 31 |
| 32 | ·008 | ·008 | ·008 | ·008 | ·009 | ·009 | ·009 | ·009 | ·009 | ·009 | ·009 | 32 |
| 33 | ·010 | ·011 | ·011 | ·011 | ·011 | ·011 | ·012 | ·012 | ·012 | ·012 | ·012 | 33 |
| 34 | ·013 | ·013 | ·013 | ·013 | ·014 | ·014 | ·014 | ·014 | ·015 | ·015 | ·015 | 34 |
| 35 | ·015 | ·015 | ·016 | ·016 | ·016 | ·017 | ·017 | ·017 | ·017 | ·018 | ·018 | 35 |
| 36 | ·017 | ·018 | ·018 | ·018 | ·019 | ·019 | ·019 | ·020 | ·020 | ·020 | ·021 | 36 |
| 37 | ·020 | ·020 | ·021 | ·021 | ·021 | ·022 | ·022 | ·022 | ·023 | ·023 | ·024 | 37 |
| 38 | ·022 | ·023 | ·023 | ·023 | ·024 | ·024 | ·025 | ·025 | ·026 | ·026 | ·026 | 38 |
| 39 | ·024 | ·025 | ·025 | ·026 | ·026 | ·027 | ·027 | ·028 | ·028 | ·029 | ·029 | 39 |
| 40 | ·027 | ·027 | ·028 | ·028 | ·029 | ·030 | ·030 | ·031 | ·031 | ·032 | ·032 | 40 |
| 41 | ·029 | ·030 | ·030 | ·031 | ·031 | ·032 | ·033 | ·033 | ·034 | ·034 | ·035 | 41 |
| 42 | ·032 | ·032 | ·033 | ·033 | ·034 | ·035 | ·035 | ·036 | ·036 | ·037 | ·038 | 42 |
| 43 | ·034 | ·035 | ·035 | ·036 | ·036 | ·037 | ·038 | ·038 | ·039 | ·040 | ·040 | 43 |
| 44 | ·036 | ·037 | ·038 | ·038 | ·039 | ·040 | ·040 | ·041 | ·042 | ·043 | ·043 | 44 |
| 45 | ·039 | ·039 | ·040 | ·041 | ·042 | ·042 | ·043 | ·044 | ·045 | ·045 | ·046 | 45 |
| 46 | ·041 | ·042 | ·043 | ·043 | ·044 | ·045 | ·046 | ·047 | ·047 | ·048 | ·049 | 46 |
| 47 | ·043 | ·044 | ·045 | ·046 | ·047 | ·048 | ·048 | ·049 | ·050 | ·051 | ·052 | 47 |
| 48 | ·046 | ·047 | ·047 | ·048 | ·049 | ·050 | ·051 | ·052 | ·053 | ·054 | ·054 | 48 |
| 49 | ·048 | ·049 | ·050 | ·051 | ·052 | ·053 | ·054 | ·055 | ·055 | ·056 | ·057 | 49 |
| 50 | ·050 | ·052 | ·052 | ·053 | ·054 | ·055 | ·056 | ·057 | ·058 | ·059 | ·060 | 50 |

*Note.*—The temperature of the "ATTACHED THERMOMETER" should be used when applying these corrections.

### TABLE I—*continued.*

N.B.—This table is strictly applicable only to barometers of the type known as "Fortin" or "Newman," in which the mercury in the cistern is always brought to a fixed point. With M.O. barometers of the "Kew" pattern the correction is about 5 per cent. greater than that given in the table.

| Temp | INCHES. 26·0 | 26·5 | 27·0 | 27·5 | 28·0 | 28·5 | 29·0 | 29·5 | 30·0 | 30·5 | 31·0 | Temp. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ° | — | — | — | — | — | — | — | — | — | — | — | ° |
| 51 | ·053 | ·054 | ·055 | ·056 | ·057 | ·058 | ·059 | ·060 | ·061 | ·062 | ·063 | 51 |
| 52 | ·055 | ·056 | ·057 | ·058 | ·059 | ·060 | ·061 | ·062 | ·064 | ·065 | ·066 | 52 |
| 53 | ·057 | ·059 | ·060 | ·061 | ·062 | ·063 | ·064 | ·065 | ·066 | ·067 | ·068 | 53 |
| 54 | ·060 | ·061 | ·062 | ·063 | ·064 | ·065 | ·067 | ·068 | ·069 | ·070 | ·071 | 54 |
| 55 | ·062 | ·063 | ·064 | ·065 | ·067 | ·068 | ·069 | ·071 | ·072 | ·073 | ·074 | 55 |
| 56 | ·064 | ·066 | ·067 | ·068 | ·069 | ·070 | ·072 | ·073 | ·074 | ·076 | ·077 | 56 |
| 57 | ·067 | ·068 | ·069 | ·071 | ·072 | ·073 | ·075 | ·076 | ·077 | ·078 | ·080 | 57 |
| 58 | ·069 | ·071 | ·072 | ·073 | ·074 | ·076 | ·077 | ·078 | ·080 | ·081 | ·082 | 58 |
| 59 | ·072 | ·073 | ·074 | ·076 | ·077 | ·078 | ·080 | ·081 | ·083 | ·084 | ·085 | 59 |
| 60 | ·074 | ·075 | ·077 | ·078 | ·080 | ·081 | ·082 | ·084 | ·085 | ·087 | ·088 | 60 |
| 61 | ·076 | ·078 | ·079 | ·080 | ·082 | ·084 | ·085 | ·087 | ·088 | ·090 | ·091 | 61 |
| 62 | ·079 | ·080 | ·082 | ·083 | ·085 | ·086 | ·088 | ·089 | ·091 | ·092 | ·094 | 62 |
| 63 | ·081 | ·083 | ·084 | ·086 | ·087 | ·089 | ·090 | ·092 | ·093 | ·095 | ·096 | 63 |
| 64 | ·083 | ·085 | ·086 | ·088 | ·090 | ·092 | ·093 | ·095 | ·096 | ·097 | ·099 | 64 |
| 65 | ·086 | ·088 | ·089 | ·091 | ·092 | ·094 | ·095 | ·097 | ·099 | ·101 | ·102 | 65 |
| 66 | ·088 | ·090 | ·091 | ·093 | ·095 | ·097 | ·098 | ·100 | ·101 | ·103 | ·105 | 66 |
| 67 | ·090 | ·092 | ·094 | ·096 | ·097 | ·099 | ·101 | ·102 | ·104 | ·106 | ·108 | 67 |
| 68 | ·093 | ·095 | ·096 | ·098 | ·100 | ·102 | ·103 | ·105 | ·107 | ·109 | ·110 | 68 |
| 69 | ·095 | ·097 | ·099 | ·101 | ·102 | ·104 | ·106 | ·108 | ·110 | ·112 | ·113 | 69 |
| 70 | ·097 | ·099 | ·101 | ·103 | ·105 | ·107 | ·109 | ·111 | ·112 | ·114 | ·116 | 70 |
| 71 | ·100 | ·102 | ·103 | ·105 | ·107 | ·109 | ·111 | ·113 | ·115 | ·117 | ·119 | 71 |
| 72 | ·102 | ·104 | ·106 | ·108 | ·110 | ·112 | ·114 | ·116 | ·118 | ·120 | ·122 | 72 |
| 73 | ·104 | ·106 | ·108 | ·110 | ·112 | ·114 | ·116 | ·118 | ·120 | ·123 | ·124 | 73 |
| 74 | ·107 | ·109 | ·111 | ·113 | ·115 | ·117 | ·119 | ·121 | ·123 | ·125 | ·127 | 74 |
| 75 | ·109 | ·111 | ·113 | ·115 | ·117 | ·120 | ·122 | ·124 | ·126 | ·128 | ·130 | 75 |
| 76 | ·111 | ·113 | ·116 | ·118 | ·120 | ·122 | ·124 | ·126 | ·128 | ·131 | ·133 | 76 |
| 77 | ·114 | ·116 | ·118 | ·120 | ·122 | ·125 | ·127 | ·129 | ·131 | ·134 | ·166 | 77 |
| 78 | ·116 | ·118 | ·120 | ·123 | ·125 | ·127 | ·129 | ·132 | ·134 | ·136 | ·138 | 78 |
| 79 | ·118 | ·121 | ·123 | ·125 | ·127 | ·130 | ·132 | ·135 | ·137 | ·139 | ·141 | 79 |
| 80 | ·121 | ·123 | ·125 | ·128 | ·130 | ·133 | ·135 | ·137 | ·139 | ·142 | ·144 | 80 |
| 81 | ·123 | ·126 | ·128 | ·130 | ·132 | ·135 | ·137 | ·140 | ·142 | ·145 | ·147 | 81 |
| 82 | ·125 | ·128 | ·130 | ·133 | ·135 | ·138 | ·140 | ·143 | ·145 | ·148 | ·149 | 82 |
| 83 | ·128 | ·131 | ·133 | ·136 | ·138 | ·140 | ·142 | ·145 | ·147 | ·150 | ·152 | 83 |
| 84 | ·130 | ·133 | ·135 | ·138 | ·140 | ·143 | ·145 | ·148 | ·150 | ·153 | ·155 | 84 |
| 85 | ·132 | ·135 | ·137 | ·140 | ·143 | ·146 | ·148 | ·151 | ·153 | ·156 | ·158 | 85 |
| 86 | ·135 | ·138 | ·140 | ·143 | ·145 | ·148 | ·150 | ·153 | ·155 | ·159 | ·161 | 86 |
| 87 | ·137 | ·140 | ·142 | ·145 | ·148 | ·151 | ·153 | ·156 | ·158 | ·161 | ·163 | 87 |
| 88 | ·139 | ·143 | ·145 | ·148 | ·150 | ·153 | ·155 | ·159 | ·161 | ·164 | ·166 | 88 |
| 89 | ·142 | ·145 | ·147 | ·150 | ·153 | ·156 | ·158 | ·161 | ·164 | ·167 | ·169 | 89 |
| 90 | ·144 | ·147 | ·150 | ·153 | ·155 | ·158 | ·161 | ·164 | ·166 | ·169 | ·172 | 90 |
| 91 | ·146 | ·150 | ·152 | ·155 | ·158 | ·161 | ·163 | ·167 | ·169 | ·172 | ·175 | 91 |
| 92 | ·149 | ·152 | ·154 | ·158 | ·160 | ·163 | ·166 | ·169 | ·172 | ·175 | ·177 | 92 |
| 93 | ·151 | ·154 | ·157 | ·160 | ·163 | ·166 | ·168 | ·172 | ·174 | ·178 | ·180 | 93 |
| 94 | ·153 | ·157 | ·159 | ·163 | ·165 | ·169 | ·171 | ·174 | ·177 | ·180 | ·183 | 99 |
| 95 | ·156 | ·159 | ·162 | ·165 | ·168 | ·171 | ·174 | ·177 | ·180 | ·183 | ·186 | 95 |
| 96 | ·158 | ·161 | ·164 | ·168 | ·170 | ·174 | ·176 | ·180 | ·182 | ·186 | ·188 | 96 |
| 97 | ·160 | ·164 | ·167 | ·170 | ·173 | ·176 | ·179 | ·182 | ·185 | ·188 | ·191 | 97 |
| 98 | ·163 | ·166 | ·169 | ·172 | ·175 | ·179 | ·181 | ·185 | ·188 | ·191 | ·194 | 98 |
| 99 | ·165 | ·169 | ·171 | ·175 | ·178 | ·181 | ·184 | ·188 | ·190 | ·194 | ·197 | 99 |
| 100 | ·167 | ·171 | ·174 | ·177 | ·180 | ·184 | ·187 | ·190 | ·193 | ·197 | ·200 | 100 |

### Table II.

Reduction of Barometric Readings to Mean Sea Level.
Reading, 30 inches.

| Height in feet. | Temperature of Air. (Dry Bulb in Screen.) 0° | 10° | 20° | 30° | 40° | 50° | 60° | 70° | 80° | 90° | Height in feet. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | ·006 | ·006 | ·006 | ·006 | ·006 | ·006 | ·006 | ·005 | ·005 | ·005 | 5 |
| 10 | ·012 | ·012 | ·012 | ·011 | ·011 | ·011 | ·011 | ·010 | ·010 | ·010 | 10 |
| 15 | ·019 | ·018 | ·018 | ·017 | ·017 | ·017 | ·017 | ·016 | ·016 | ·015 | 15 |
| 20 | ·025 | ·024 | ·023 | ·023 | ·023 | ·022 | ·022 | ·021 | ·021 | ·020 | 20 |
| 25 | ·031 | ·030 | ·029 | ·029 | ·029 | ·028 | ·027 | ·027 | ·026 | ·026 | 25 |
| 30 | ·037 | ·036 | ·035 | ·035 | ·034 | ·033 | ·032 | ·032 | ·031 | ·031 | 30 |
| 35 | ·043 | ·042 | ·041 | ·041 | ·040 | ·039 | ·038 | ·037 | ·037 | ·036 | 35 |
| 40 | ·049 | ·048 | ·047 | ·046 | ·045 | ·044 | ·043 | ·042 | ·042 | ·041 | 40 |
| 45 | ·056 | ·054 | ·053 | ·052 | ·051 | ·050 | ·049 | ·048 | ·047 | ·046 | 45 |
| 50 | ·062 | ·060 | ·059 | ·058 | ·056 | ·055 | ·054 | ·053 | ·052 | ·051 | 50 |
| 55 | ·066 | ·066 | ·065 | ·064 | ·062 | ·061 | ·060 | ·059 | ·057 | ·056 | 55 |
| 60 | ·074 | ·072 | ·071 | ·069 | ·068 | ·066 | ·065 | ·064 | ·062 | ·061 | 60 |
| 65 | ·080 | ·078 | ·077 | ·075 | ·074 | ·072 | ·071 | ·069 | ·068 | ·066 | 65 |
| 70 | ·086 | ·084 | ·083 | ·081 | ·079 | ·077 | ·076 | ·074 | ·073 | ·071 | 70 |
| 75 | ·092 | ·090 | ·089 | ·087 | ·085 | ·083 | ·082 | ·080 | ·078 | ·076 | 75 |
| 80 | ·098 | ·096 | ·094 | ·092 | ·091 | ·089 | ·087 | ·085 | ·083 | ·081 | 80 |
| 85 | ·105 | ·102 | ·100 | ·098 | ·097 | ·095 | ·093 | ·090 | ·089 | ·087 | 85 |
| 90 | ·111 | ·108 | ·106 | ·104 | ·102 | ·101 | ·098 | ·095 | ·094 | ·092 | 90 |
| 95 | ·117 | ·114 | ·112 | ·110 | ·108 | ·106 | ·103 | ·101 | ·099 | ·097 | 95 |
| 100 | ·123 | ·120 | ·118 | ·115 | ·113 | ·111 | ·108 | ·106 | ·104 | ·101 | 100 |

The correction is always Additive.

### Table III.

Corrections for reducing Barometric Readings to Standard Gravity in Latitude 45°.

| Lat. N. or S. | Correction. At 27. | Correction. At 30. | Lat. N. or S. | Correction. At 27. | Correction. At 30. | Lat. N. or S. | Correction. At 27. | Correction. At 30. | Lat. N. or S. | Correction. At 27. | Correction. At 30. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ° | in. | in. | ° | in. | in. | ° | in. | in. | ° | in. | in. |
| 0 | − ·070 | − ·078 | 23 | − ·049 | − ·054 | 46 | + ·002 | + ·003 | 69 | + ·052 | + ·058 |
| 1 | ·070 | ·078 | 24 | ·047 | ·052 | 47 | ·005 | ·005 | 70 | ·054 | ·060 |
| 2 | ·070 | ·078 | 25 | ·045 | ·050 | 48 | ·007 | ·008 | 71 | ·055 | ·061 |
| 3 | ·070 | ·077 | 26 | ·043 | ·048 | 49 | ·010 | ·011 | 72 | ·057 | ·063 |
| 4 | ·069 | ·077 | 27 | ·041 | ·046 | 50 | ·012 | ·013 | 73 | ·058 | ·064 |
| 5 | ·069 | ·077 | 28 | ·039 | ·043 | 51 | ·015 | ·016 | 74 | ·059 | ·066 |
| 6 | ·068 | ·076 | 29 | ·037 | ·041 | 52 | ·017 | ·019 | 75 | ·061 | ·067 |
| 7 | ·068 | ·075 | 30 | ·035 | ·039 | 53 | ·019 | ·021 | 76 | ·062 | ·069 |
| 8 | ·067 | ·075 | 31 | ·033 | ·036 | 54 | ·022 | ·024 | 77 | ·063 | ·070 |
| 9 | ·067 | ·074 | 32 | ·031 | ·034 | 55 | ·024 | ·027 | 78 | ·064 | ·071 |
| 10 | ·066 | ·073 | 33 | ·028 | ·032 | 56 | ·026 | ·029 | 79 | ·065 | ·072 |
| 11 | ·065 | ·072 | 34 | ·026 | ·029 | 57 | ·028 | ·032 | 80 | ·066 | ·073 |
| 12 | ·064 | ·071 | 35 | ·024 | ·027 | 58 | ·031 | ·034 | 81 | ·067 | ·074 |
| 13 | ·063 | ·070 | 36 | ·022 | ·024 | 59 | ·033 | ·036 | 82 | ·067 | ·075 |
| 14 | ·062 | ·069 | 37 | ·019 | ·021 | 60 | ·035 | ·039 | 83 | ·068 | ·075 |
| 15 | ·061 | ·067 | 38 | ·017 | ·019 | 61 | ·037 | ·041 | 84 | ·068 | ·076 |
| 16 | ·059 | ·066 | 39 | ·015 | ·016 | 62 | ·039 | ·043 | 85 | ·069 | ·076 |
| 17 | ·058 | ·064 | 40 | ·012 | ·013 | 63 | ·041 | ·046 | 86 | ·069 | ·077 |
| 18 | ·057 | ·063 | 41 | ·010 | ·011 | 64 | ·043 | ·048 | 87 | ·070 | ·077 |
| 19 | ·055 | ·061 | 42 | ·007 | ·008 | 65 | ·045 | ·050 | 88 | ·070 | ·078 |
| 20 | ·054 | ·060 | 43 | ·005 | ·005 | 66 | ·047 | ·052 | 89 | ·070 | ·078 |
| 21 | ·052 | ·058 | 44 | − ·002 | − ·003 | 67 | ·049 | ·054 | 90 | + ·070 | + ·078 |
| 22 | − ·050 | − ·056 | 45 | ± 0 | ± 0 | 68 | + ·050 | + ·056 | | | |



### Table IV.

Table for the Conversion of Temperature Readings on the Fahrenheit and Centigrade Scales to the Absolute Scale.

| Fahr. | Cent. | Abs. | Fahr. | Cent. | Abs. | Fahr. | Cent. | Abs. |
|---|---|---|---|---|---|---|---|---|
| 0 | −17·8 | 255·2 | 40 | + 4·4 | 277·4 | 80 | +26·7 | 299·7 |
| 1 | 17·2 | 55·8 | 41 | 5·0 | 78·0 | 81 | 27·2 | 300·2 |
| 2 | 16·7 | 56·3 | 42 | 5·6 | 78·6 | 82 | 27·8 | 0·8 |
| 3 | 16·1 | 56·9 | 43 | 6·1 | 79·1 | 83 | 28·3 | 1·3 |
| 4 | 15·6 | 57·4 | 44 | 6·7 | 79·7 | 84 | 28·9 | 1·9 |
| 5 | 15·0 | 58·0 | 45 | 7·2 | 80·2 | 85 | 29·4 | 2·4 |
| 6 | 14·4 | 58·6 | 46 | 7·8 | 80·8 | 86 | 30·0 | 3·0 |
| 7 | 13·9 | 59·1 | 47 | 8·3 | 81·3 | 87 | 30·6 | 3·6 |
| 8 | 13·3 | 59·7 | 48 | 8·9 | 81·9 | 88 | 31·1 | 4·1 |
| 9 | 12·8 | 260·2 | 49 | 9·4 | 282·4 | 89 | 31·7 | 304·7 |
| 10 | 12·2 | 260·8 | 50 | 10·0 | 283·0 | 90 | 32·2 | 305·2 |
| 11 | 11·7 | 61·3 | 51 | 10·6 | 83·6 | 91 | 32·8 | 5·8 |
| 12 | 11·1 | 61·9 | 52 | 11·1 | 84·1 | 92 | 33·3 | 6·3 |
| 13 | 10·6 | 62·4 | 53 | 11·7 | 84·7 | 93 | 33·9 | 6·9 |
| 14 | 10·0 | 63·0 | 54 | 12·2 | 85·2 | 94 | 34·4 | 7·4 |
| 15 | 9·4 | 63·6 | 55 | 12·8 | 85·8 | 95 | 35·0 | 8·0 |
| 16 | 8·9 | 64·1 | 56 | 13·3 | 86·3 | 96 | 35·6 | 8·6 |
| 17 | 8·3 | 64·7 | 57 | 13·9 | 86·9 | 97 | 36·1 | 9·1 |
| 18 | 7·8 | 65·2 | 58 | 14·4 | 87·4 | 98 | 36·7 | 9·7 |
| 19 | 7·2 | 265·8 | 59 | 15·0 | 288·0 | 99 | 37·2 | 310·2 |
| 20 | 6·7 | 266·3 | 60 | 15·6 | 288·6 | 100 | 37·8 | 310·8 |
| 21 | 6·1 | 66·9 | 61 | 16·1 | 89·1 | 101 | 38·3 | 11·3 |
| 22 | 5·6 | 67·4 | 62 | 16·7 | 89·7 | 102 | 38·9 | 11·9 |
| 23 | 5·0 | 68·0 | 63 | 17·2 | 90·2 | 103 | 39·4 | 12·4 |
| 24 | 4·4 | 68·6 | 64 | 17·8 | 90·8 | 104 | 40·0 | 13·0 |
| 25 | 3·9 | 69·1 | 65 | 18·3 | 91·3 | 105 | 40·6 | 13·6 |
| 26 | 3·3 | 69·7 | 66 | 18·9 | 91·9 | 106 | 41·1 | 14·1 |
| 27 | 2·8 | 70·2 | 67 | 19·4 | 92·4 | 107 | 41·7 | 14·7 |
| 28 | 2·2 | 70·8 | 68 | 20·0 | 93·0 | 108 | 42·2 | 15·2 |
| 29 | 1·7 | 271·3 | 69 | 20·6 | 293·6 | 109 | 42·8 | 315·8 |
| 30 | 1·1 | 271·9 | 70 | 21·1 | 294·1 | 110 | 43·3 | 316·3 |
| 31 | − 0·6 | 72·4 | 71 | 21·7 | 94·7 | 111 | 43·9 | 16·9 |
| 32 | ± 0·0 | 73·0 | 72 | 22·2 | 95·2 | 112 | 44·4 | 17·4 |
| 33 | + 0·6 | 73·6 | 73 | 22·8 | 95·8 | 113 | 45·0 | 18·0 |
| 34 | 1·1 | 74·1 | 74 | 23·3 | 96·3 | 114 | 45·6 | 18·6 |
| 35 | 1·7 | 74·7 | 75 | 23·9 | 96·9 | 115 | 46·1 | 19·1 |
| 36 | 2·2 | 75·2 | 76 | 24·4 | 97·4 | 116 | 46·7 | 19·7 |
| 37 | 2·8 | 75·8 | 77 | 25·0 | 98·0 | 117 | 47·2 | 20·2 |
| 38 | 3·3 | 76·3 | 78 | 25·6 | 98·6 | 118 | 47·8 | 20·8 |
| 39 | + 3·9 | 276·9 | 79 | +26·1 | 299·1 | 119 | +48·3 | 321·3 |

TABLE V.

PRESSURE VALUES.

Equivalents in Millibars of Inches of Mercury at 32° and Latitude 45°.

| Mercury Ins. | ·00 | ·01 | ·02 | ·03 | ·04 | ·05 | ·06 | ·07 | ·08 | ·09 |
|---|---|---|---|---|---|---|---|---|---|---|
| | Millibars. | | | | | | | | | |
| 27·0 | 914·3 | 914·6 | 915·0 | 915·3 | 915·7 | 916·0 | 916·3 | 916·7 | 917·0 | 917·4 |
| 27·1 | 917·7 | 918·0 | 918·4 | 918·7 | 919·0 | 919·4 | 919·7 | 920·1 | 920·4 | 920·7 |
| 27·2 | 921·1 | 921·4 | 921·8 | 922·1 | 922·4 | 922·8 | 923·1 | 923·4 | 923·8 | 924·1 |
| 27·3 | 924·5 | 924·8 | 925·1 | 925·5 | 925·8 | 926·1 | 926·5 | 926·8 | 927·2 | 927·5 |
| 27·4 | 927·9 | 928·2 | 928·5 | 928·9 | 929·2 | 929·5 | 929·9 | 930·2 | 930·6 | 930·9 |
| 27·5 | 931·2 | 931·6 | 931·9 | 932·3 | 932·6 | 932·9 | 933·3 | 933·6 | 933·9 | 934·3 |
| 27·6 | 934·6 | 935·0 | 935·3 | 935·6 | 936·0 | 936·3 | 936·7 | 937·0 | 937·3 | 937·7 |
| 27·7 | 938·0 | 938·3 | 938·7 | 939·0 | 939·4 | 939·7 | 940·0 | 940·4 | 940·7 | 941·1 |
| 27·8 | 941·4 | 941·7 | 942·1 | 942·4 | 942·8 | 943·1 | 943·4 | 943·8 | 944·1 | 944·4 |
| 27·9 | 944·8 | 945·1 | 945·5 | 945·8 | 946·1 | 946·5 | 946·8 | 947·2 | 947·5 | 947·8 |
| 28·0 | 948·2 | 948·5 | 948·8 | 949·2 | 949·5 | 949·9 | 950·2 | 950·5 | 950·9 | 951·2 |
| 28·1 | 951·6 | 951·9 | 952·2 | 952·6 | 952·9 | 953·2 | 953·6 | 953·9 | 954·3 | 954·6 |
| 28·2 | 954·9 | 955·3 | 955·6 | 956·0 | 956·3 | 956·6 | 957·0 | 957·3 | 957·7 | 958·0 |
| 28·3 | 958·3 | 958·7 | 959·0 | 959·3 | 959·7 | 960·0 | 960·4 | 960·7 | 961·0 | 961·4 |
| 28·4 | 961·7 | 962·1 | 962·4 | 962·7 | 963·1 | 963·4 | 963·7 | 964·1 | 964·4 | 964·8 |
| 28·5 | 965·1 | 965·4 | 965·8 | 966·1 | 966·5 | 966·8 | 967·1 | 967·5 | 967·8 | 968·1 |
| 28·6 | 968·5 | 968·8 | 969·2 | 969·5 | 969·8 | 970·2 | 970·5 | 970·9 | 971·2 | 971·5 |
| 28·7 | 971·9 | 972·2 | 972·6 | 972·9 | 973·2 | 973·6 | 973·9 | 974·2 | 974·6 | 974·9 |
| 28·8 | 975·3 | 975·6 | 975·9 | 976·3 | 976·6 | 977·0 | 977·3 | 977·6 | 978·0 | 978·3 |
| 28·9 | 978·6 | 979·0 | 979·3 | 979·7 | 980·0 | 980·3 | 980·7 | 981·0 | 981·4 | 981·7 |
| 29·0 | 982·0 | 982·4 | 982·7 | 983·0 | 983·4 | 983·7 | 984·1 | 984·4 | 984·7 | 985·1 |
| 29·1 | 985·4 | 985·8 | 986·1 | 986·4 | 986·8 | 987·1 | 987·5 | 987·8 | 988·1 | 988·5 |
| 29·2 | 988·8 | 989·1 | 989·5 | 989·8 | 990·2 | 990·5 | 990·8 | 991·2 | 991·5 | 991·9 |
| 29·3 | 992·2 | 992·5 | 992·9 | 993·2 | 993·5 | 993·9 | 994·2 | 994·6 | 994·9 | 995·2 |
| 29·4 | 995·6 | 995·9 | 996·3 | 996·6 | 996·9 | 997·3 | 997·6 | 997·9 | 998·3 | 998·6 |
| 29·5 | 999·0 | 999·3 | 999·6 | 1000·0 | 1000·3 | 1000·7 | 1001·0 | 1001·3 | 1001·7 | 1002·0 |
| 29·6 | 1002·4 | 1002·7 | 1003·0 | 1003·4 | 1003·7 | 1004·0 | 1004·4 | 1004·7 | 1005·1 | 1005·4 |
| 29·7 | 1005·7 | 1006·1 | 1006·4 | 1006·8 | 1007·1 | 1007·4 | 1007·8 | 1008·1 | 1008·4 | 1008·8 |
| 29·8 | 1009·1 | 1009·5 | 1009·8 | 1010·1 | 1010·5 | 1010·8 | 1011·2 | 1011·5 | 1011·8 | 1012·2 |
| 29·9 | 1012·5 | 1012·8 | 1013·2 | 1013·5 | 1013·9 | 1014·2 | 1014·5 | 1014·9 | 1015·2 | 1015·6 |
| 30·0 | 1015·9 | 1016·2 | 1016·6 | 1016·9 | 1017·3 | 1017·6 | 1017·9 | 1018·3 | 1018·6 | 1018·9 |
| 30·1 | 1019·3 | 1019·6 | 1020·0 | 1020·3 | 1020·6 | 1021·0 | 1021·3 | 1021·7 | 1022·0 | 1022·3 |
| 30·2 | 1022·7 | 1023·0 | 1023·3 | 1023·7 | 1024·0 | 1024·4 | 1024·7 | 1025·0 | 1025·4 | 1025·7 |
| 30·3 | 1026·1 | 1026·4 | 1026·7 | 1027·1 | 1027·4 | 1027·7 | 1028·1 | 1028·4 | 1028·8 | 1029·1 |
| 30·4 | 1029·4 | 1029·8 | 1030·1 | 1030·5 | 1030·8 | 1031·1 | 1031·5 | 1031·8 | 1032·2 | 1032·5 |
| 30·5 | 1032·8 | 1033·2 | 1033·5 | 1033·8 | 1034·2 | 1034·5 | 1034·9 | 1035·2 | 1035·5 | 1035·9 |
| 30·6 | 1036·2 | 1036·6 | 1036·9 | 1037·2 | 1037·6 | 1037·9 | 1038·2 | 1038·6 | 1038·9 | 1039·3 |
| 30·7 | 1039·6 | 1039·9 | 1040·3 | 1040·6 | 1041·0 | 1041·3 | 1041·6 | 1042·0 | 1042·3 | 1042·6 |
| 30·8 | 1043·0 | 1043·3 | 1043·7 | 1044·0 | 1044·3 | 1044·7 | 1045·0 | 1045·4 | 1045·7 | 1046·0 |
| 30·9 | 1046·4 | 1046·7 | 1047·1 | 1047·4 | 1047·7 | 1048·1 | 1048·4 | 1048·7 | 1049·1 | 1049·4 |

Thousandths of an inch.

| Inch. | ·001 | ·002 | ·003 | ·004 | ·005 | ·006 | ·007 | ·008 | ·009 |
|---|---|---|---|---|---|---|---|---|---|
| Millibars .. | ·0 | ·1 | ·1 | ·1 | ·2 | ·2 | ·2 | ·3 | ·3 |



# CHARTS

OF THE

# DISTRIBUTION OF PRESSURE

AT

# SEA-LEVEL OVER THE GLOBE

IN THE

# SEVERAL MONTHS OF THE YEAR.

BASED UPON THE CHARTS OF THE DISTRIBUTION OF PRESSURE OVER THE OCEANS PREPARED IN THE METEOROLOGICAL OFFICE AND EXTENDED ON THE LAND AREAS FROM OTHER SOURCES.

## EXPLANATION OF THE CHARTS.

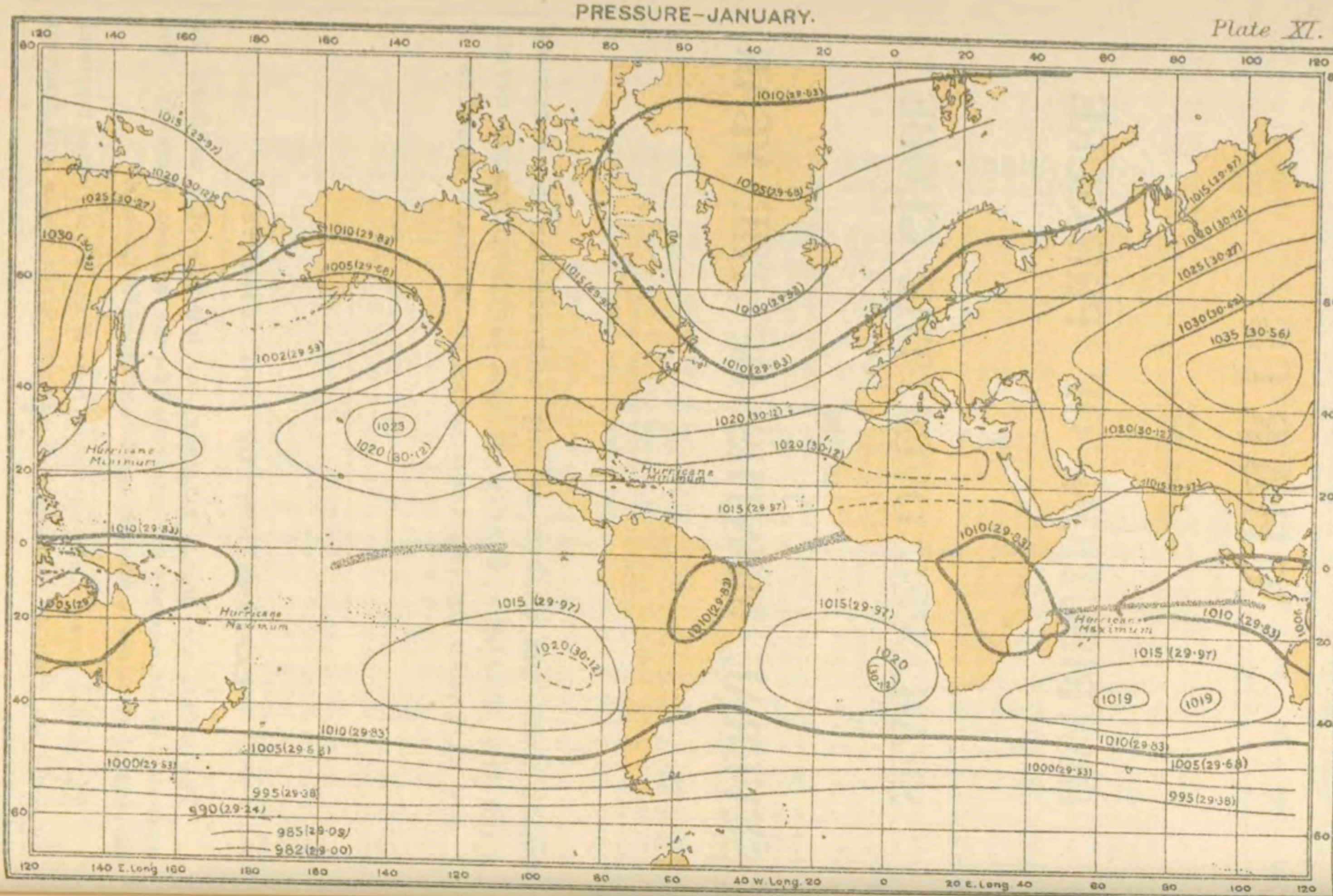
The isobars are drawn, generally, for intervals of 5 millibars, the equivalent of 15 mercury inches corrected for the variation of gravity. The corresponding values in mercury inches are added in brackets.

The shaded areas in the Equatorial belts of the Great Oceans represent the Doldrum regions, or regions of variable winds, calms and frequent precipitation.

The frequency of tropical hurricanes, during different months, in the several regions of their occurrence is also indicated on these Charts.

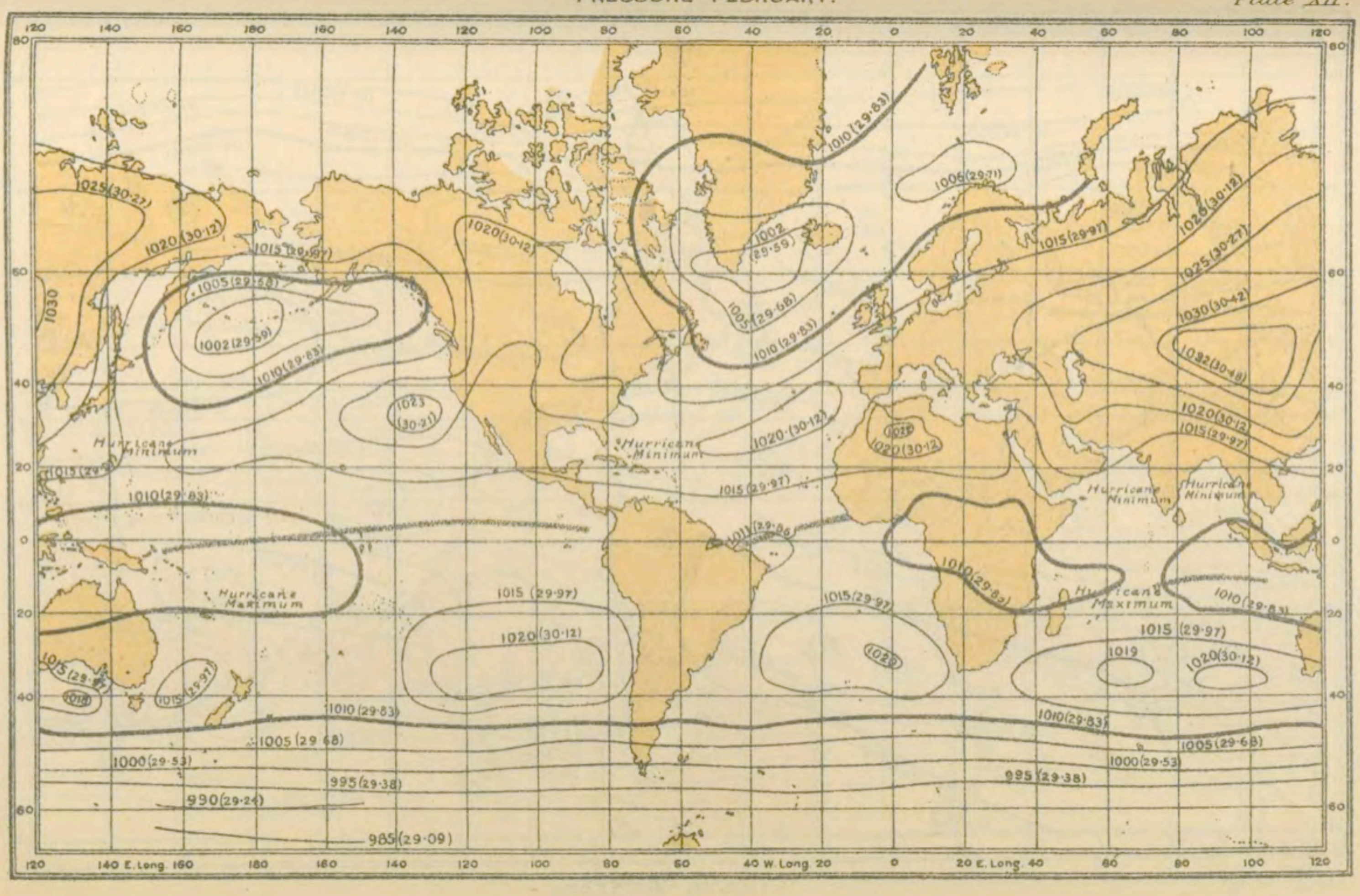
## PRESSURE–JANUARY.

Plate XI.



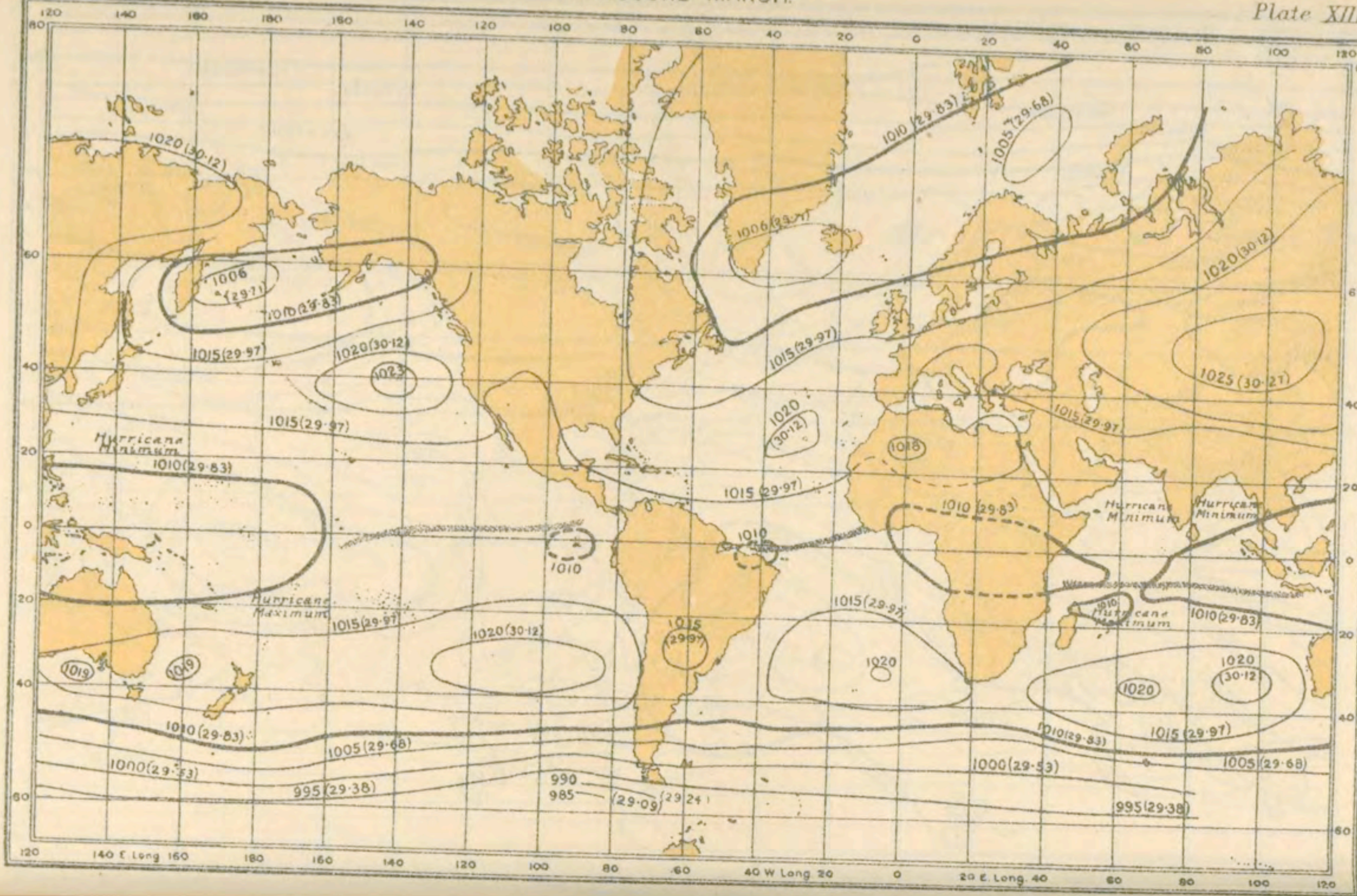

## PRESSURE– FEBRUARY.

Plate XII.



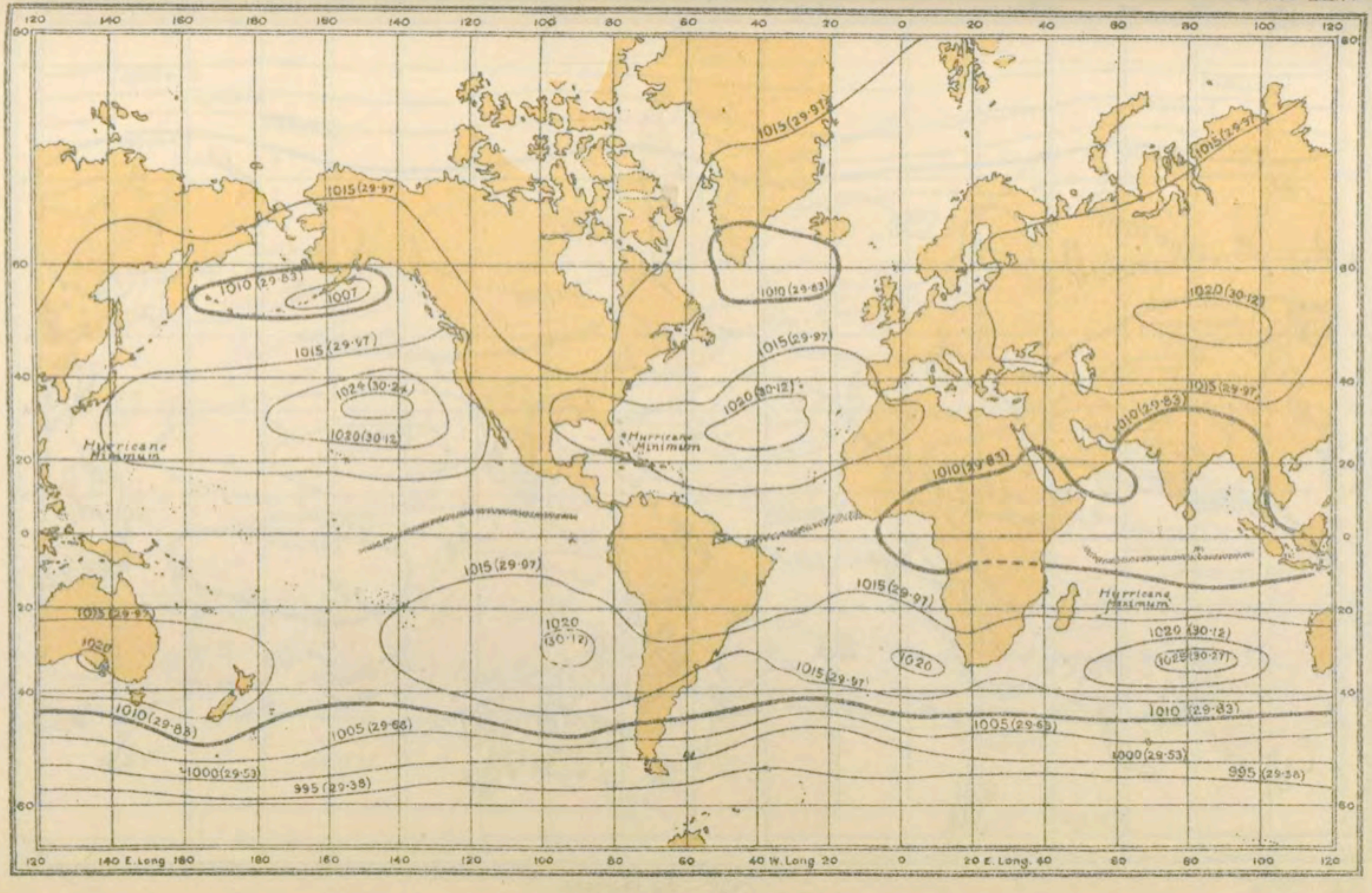
PRESSURE - MARCH.





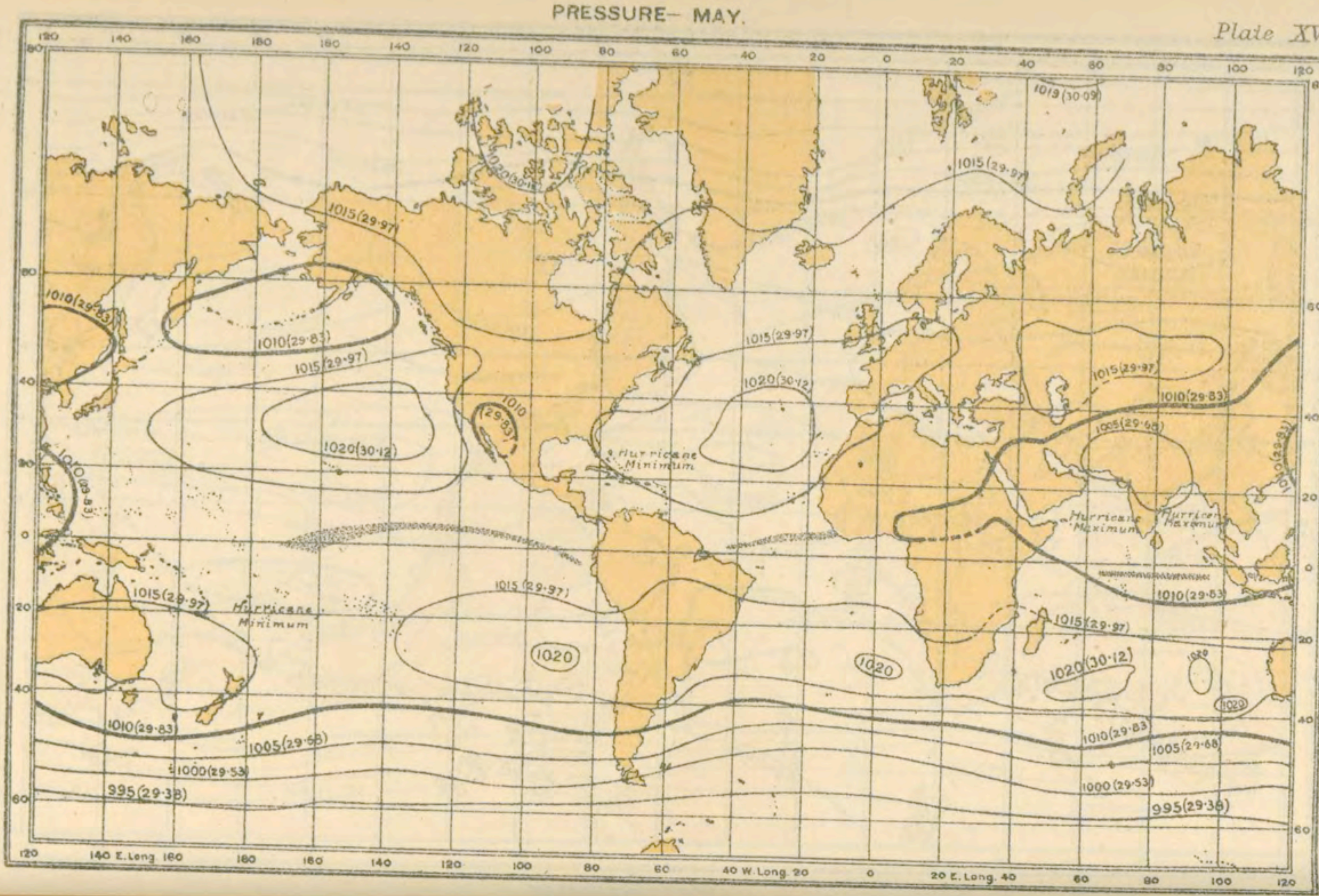

PRESSURE - APRIL.





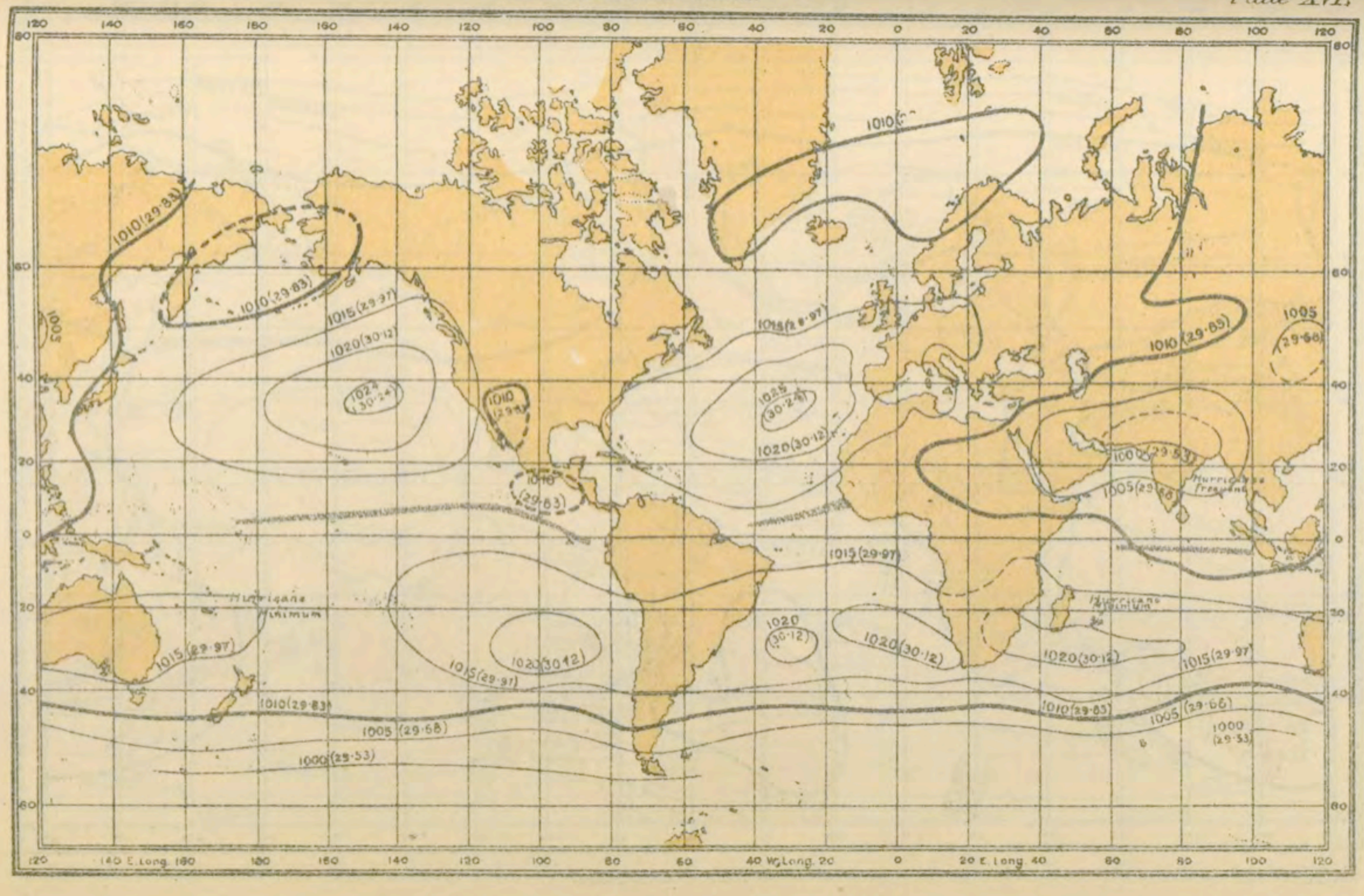
PRESSURE– MAY.

Plate XV.



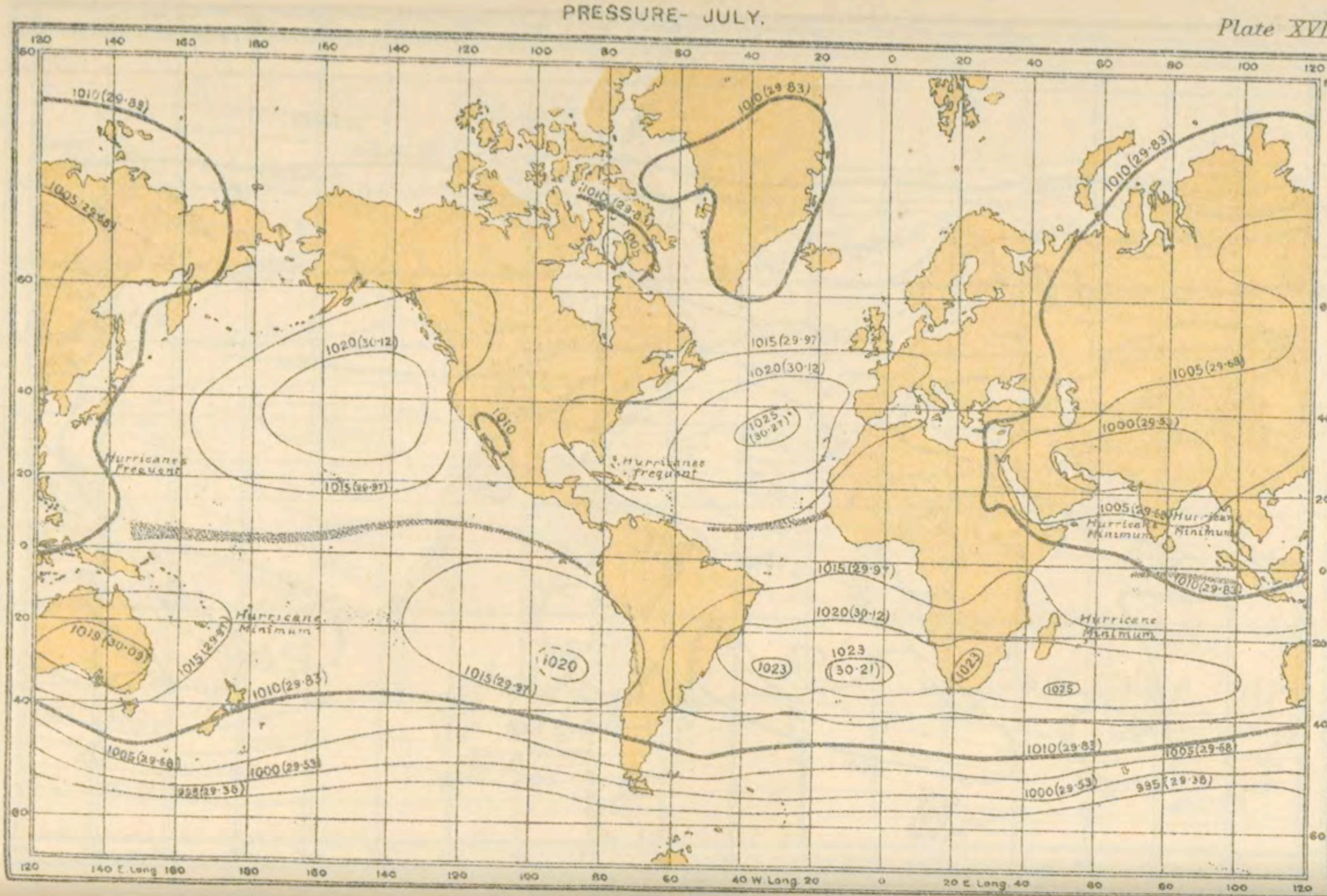

PRESSURE– JUNE.

Plate XVI.



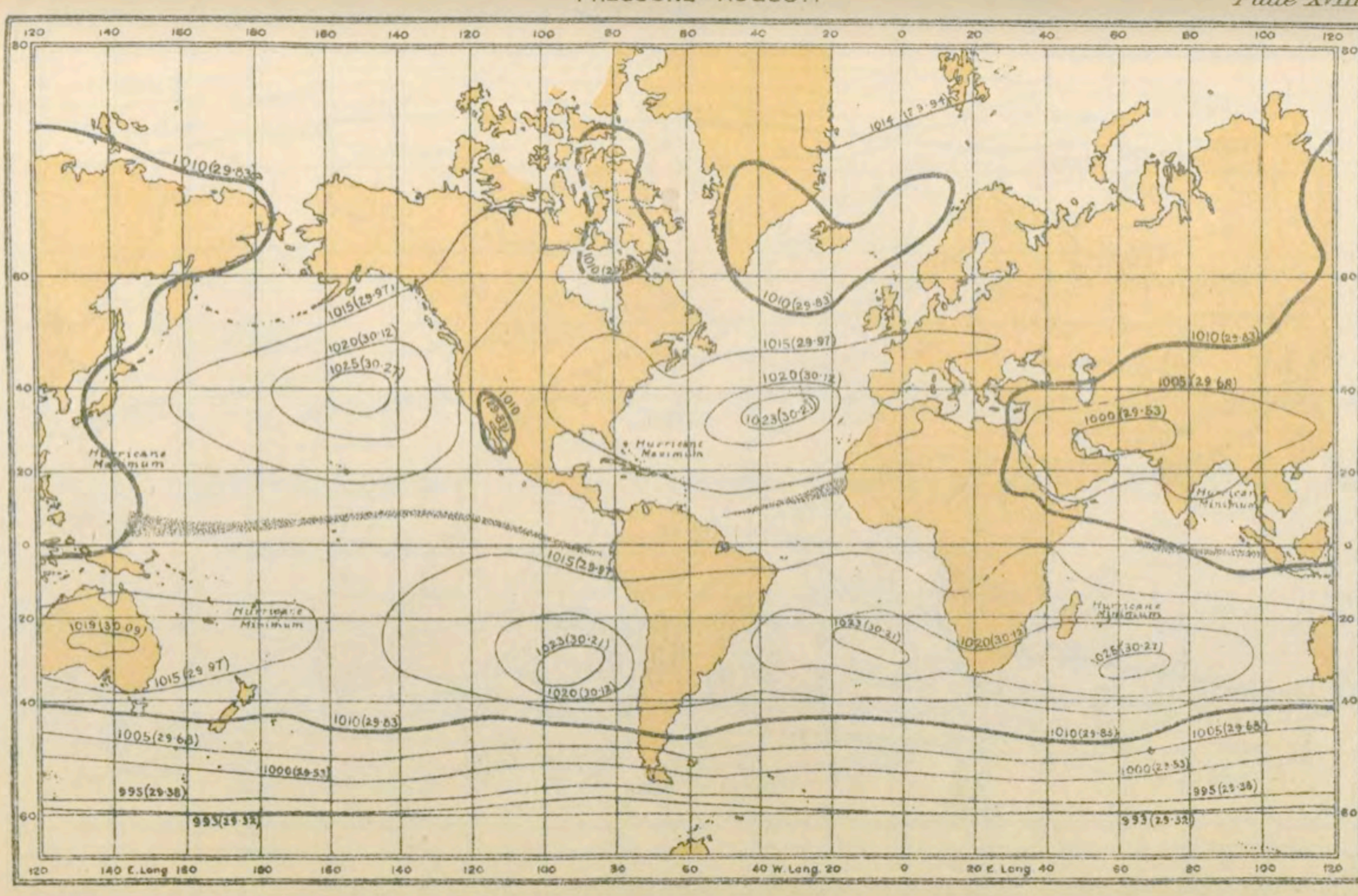
## PRESSURE- JULY.

*Plate XVII.*



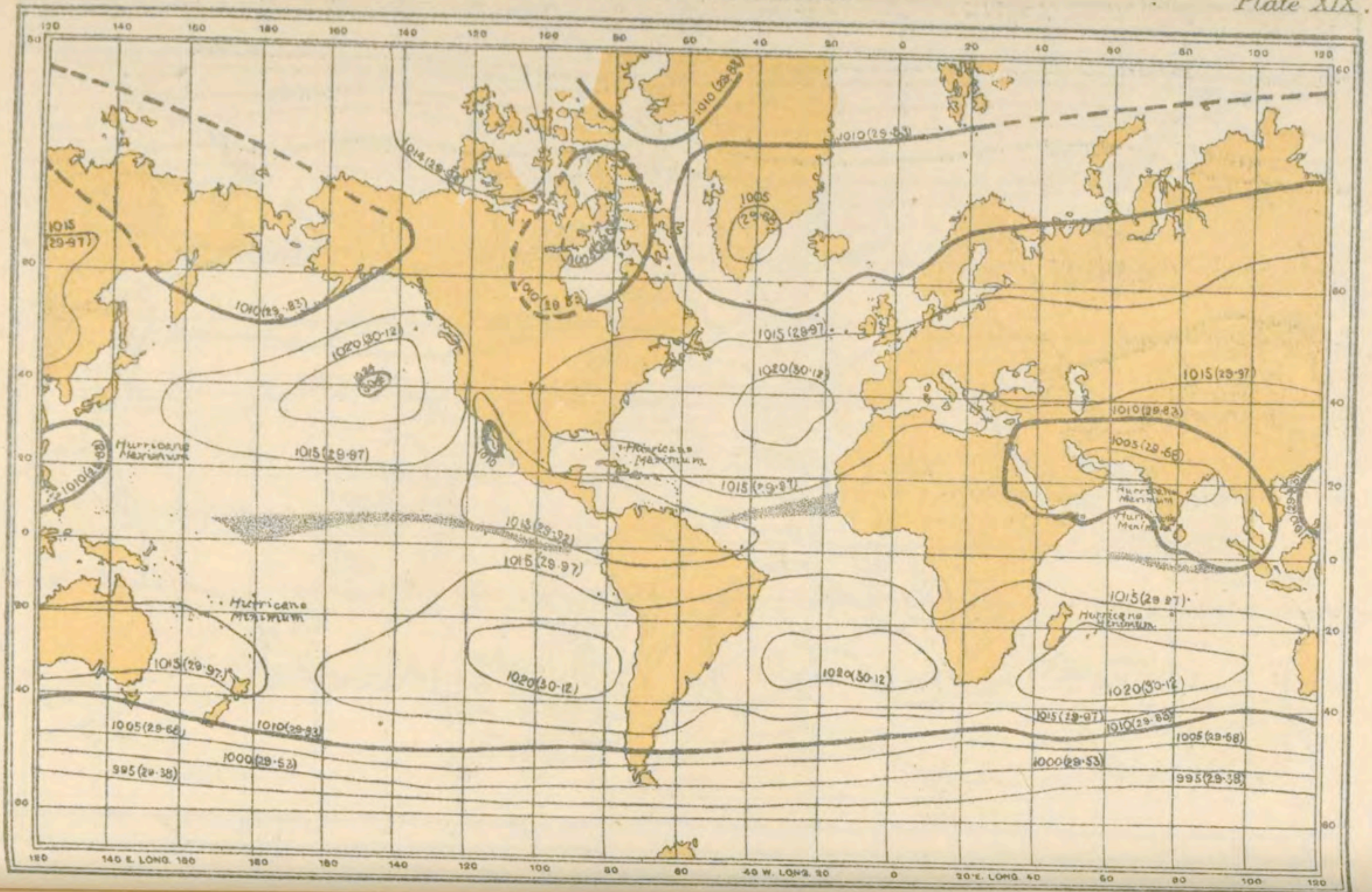

## PRESSURE- AUGUST.

*Plate XVIII.*



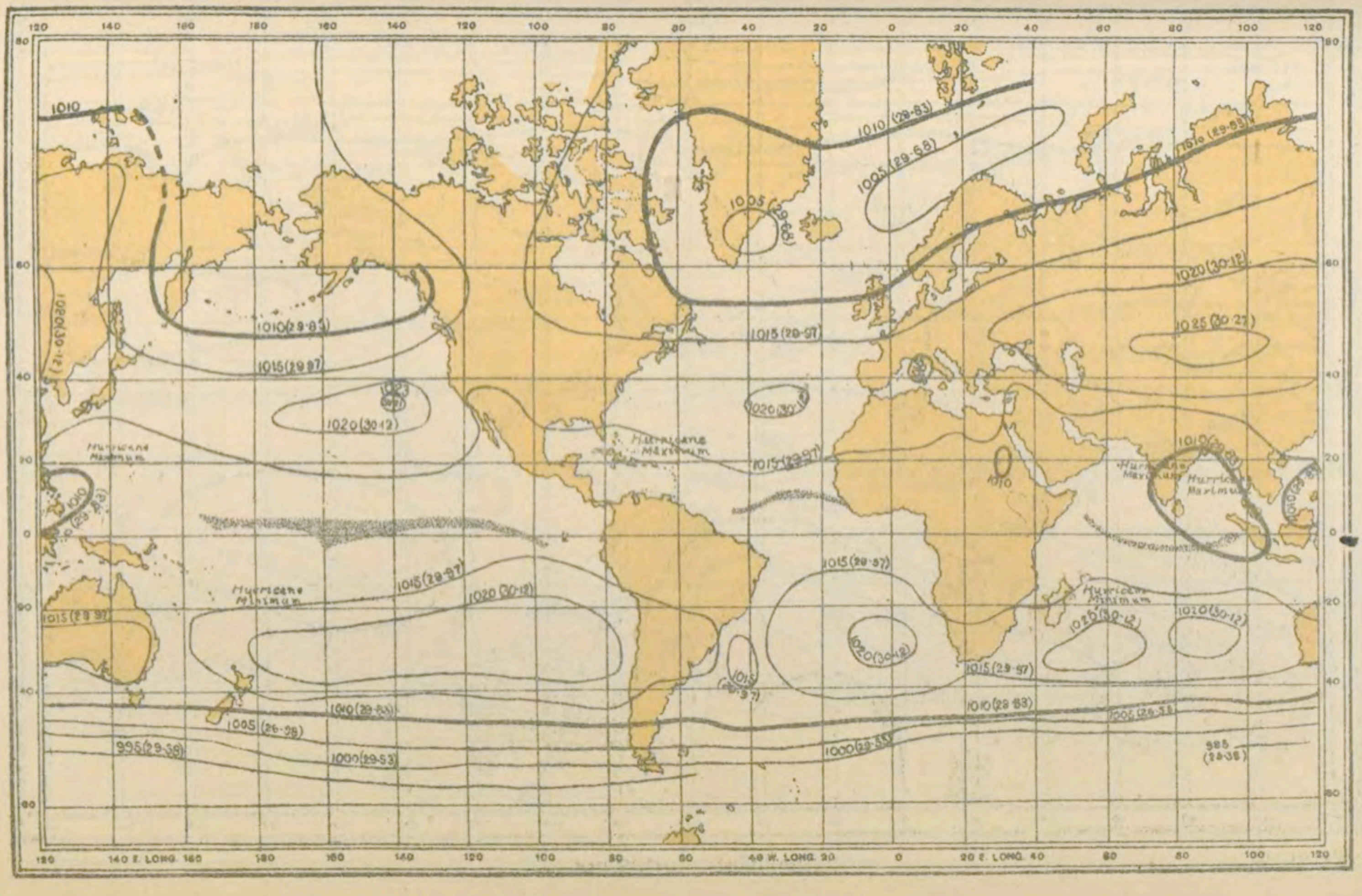
## PRESSURE—SEPTEMBER.

*Plate XIX.*



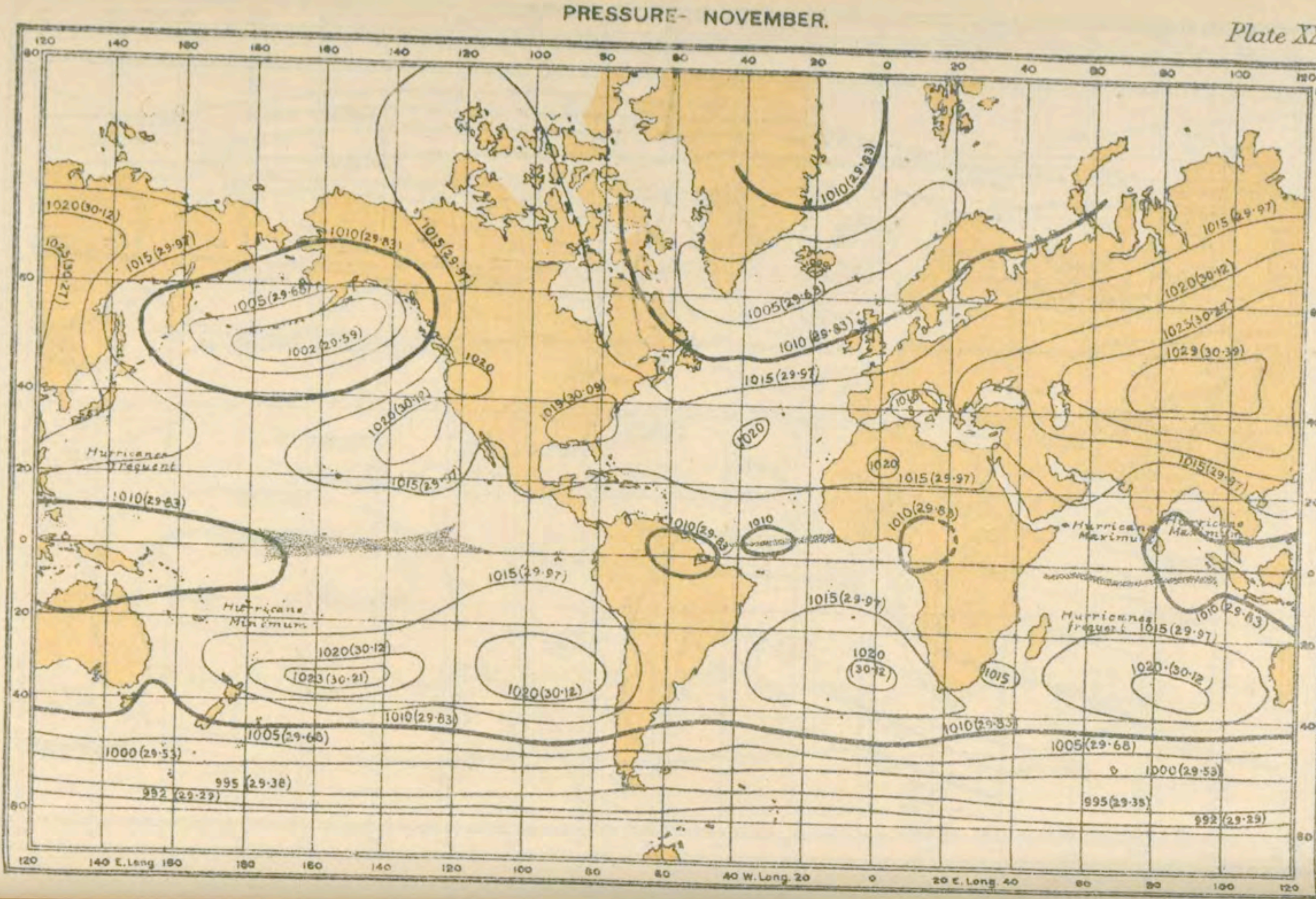

## PRESSURE—OCTOBER.

*Plate XX.*



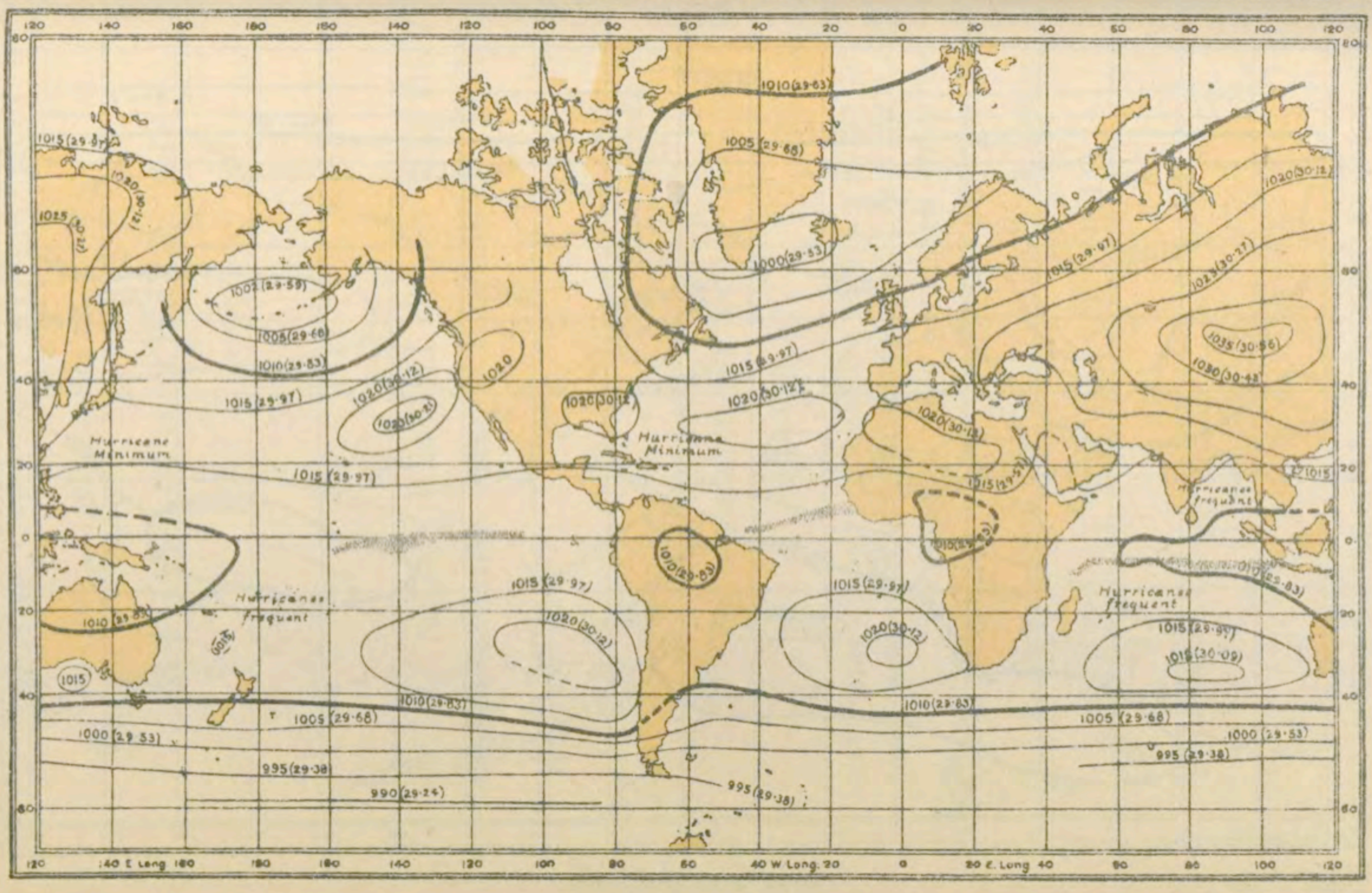
PRESSURE- NOVEMBER.

*Plate XXI.*




PRESSURE- DECEMBER.

*Plate XXII.*



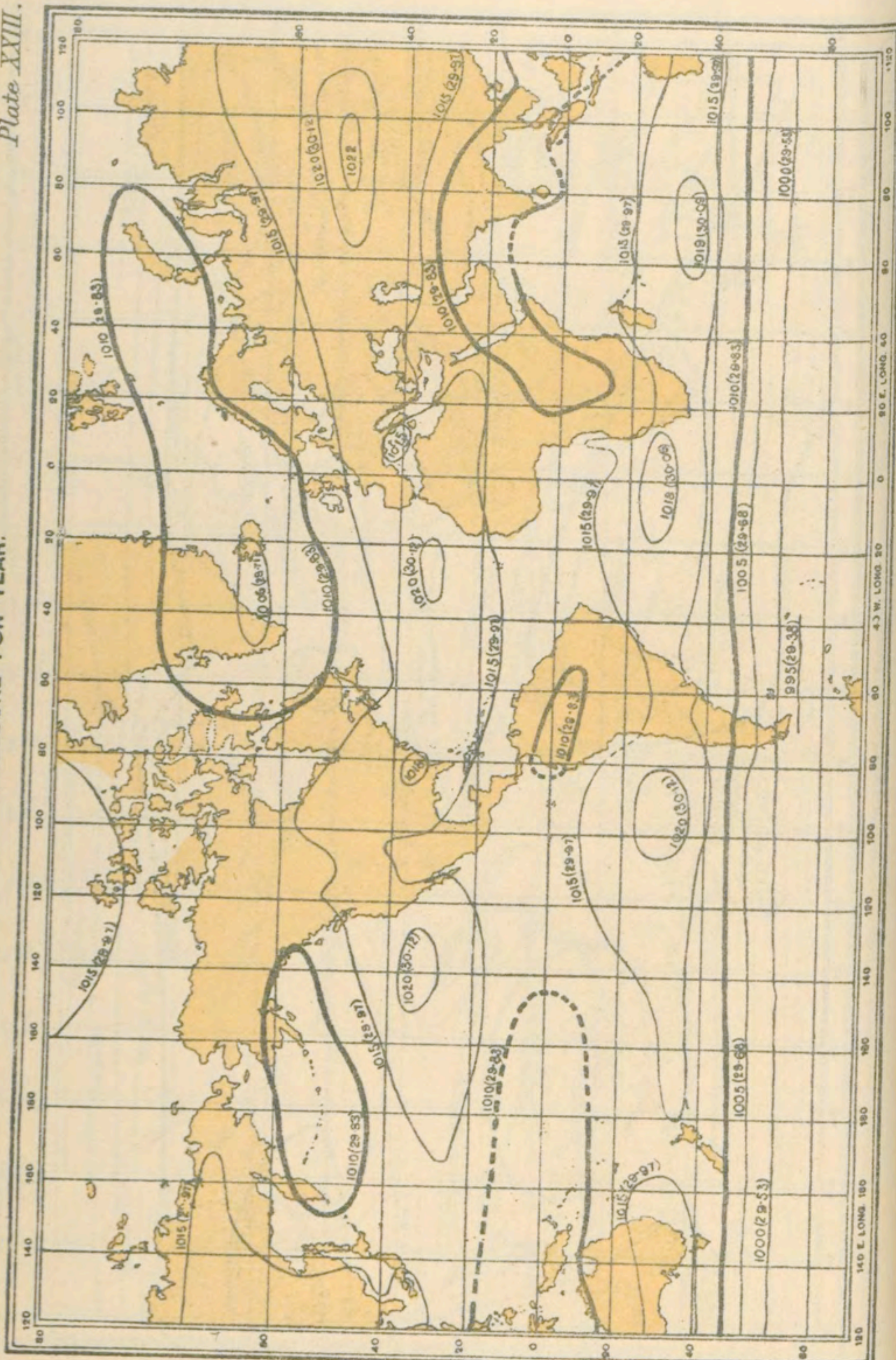


Plate XXIII.

PRESSURE FOR YEAR.



# CHARTS.

## WINDS OVER THE OCEANS

between 30°N. Lat. and 30°S. Lat. in four sections, viz:—

THE ATLANTIC OCEAN 80°W. LONG. TO 20°E. LONG.
THE INDIAN OCEAN 20°E. LONG. TO 120°E. LONG.
THE WESTERN PACIFIC OCEAN 120°E. LONG. TO 160°W. LONG.
THE EASTERN PACIFIC OCEAN 160°W. LONG. TO 80°W. LONG.

for the months of

JUNE AND DECEMBER.

*(Plates XXIV to XXXI)*

## WIND, BAROMETER, AIR TEMPERATURE, AND FOG OVER THE SOUTHERN OCEAN.

*(Plate XXXII)*

## SEA SURFACE TEMPERATURES

for the months of

FEBRUARY, MAY, AUGUST AND NOVEMBER.

*(Plates XXXIII to XXXVI)*

Plate XXIV.

WIND CHART OF THE INTERTROPICAL BELT OF THE ATLANTIC OCEAN—JUNE.

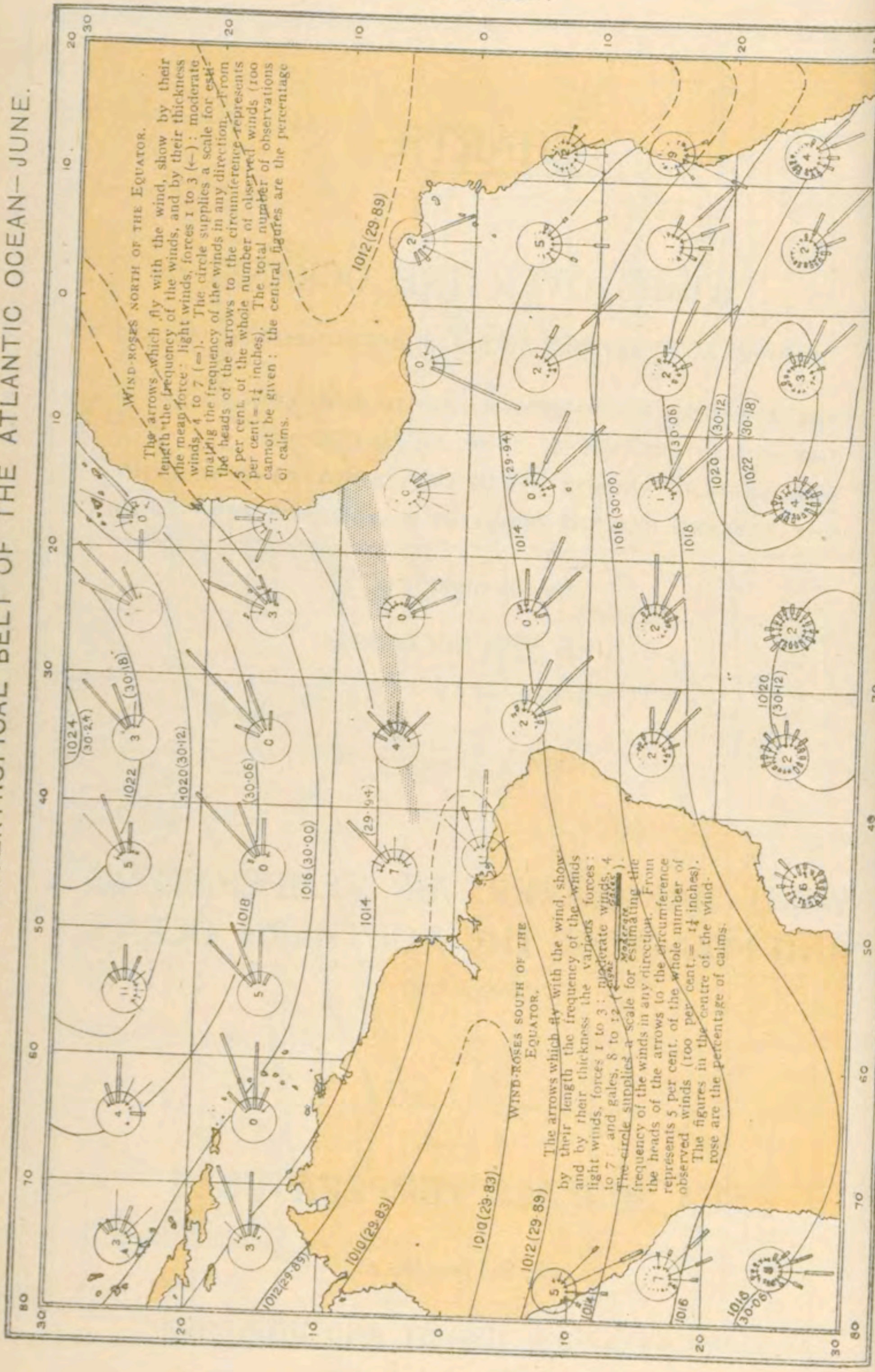
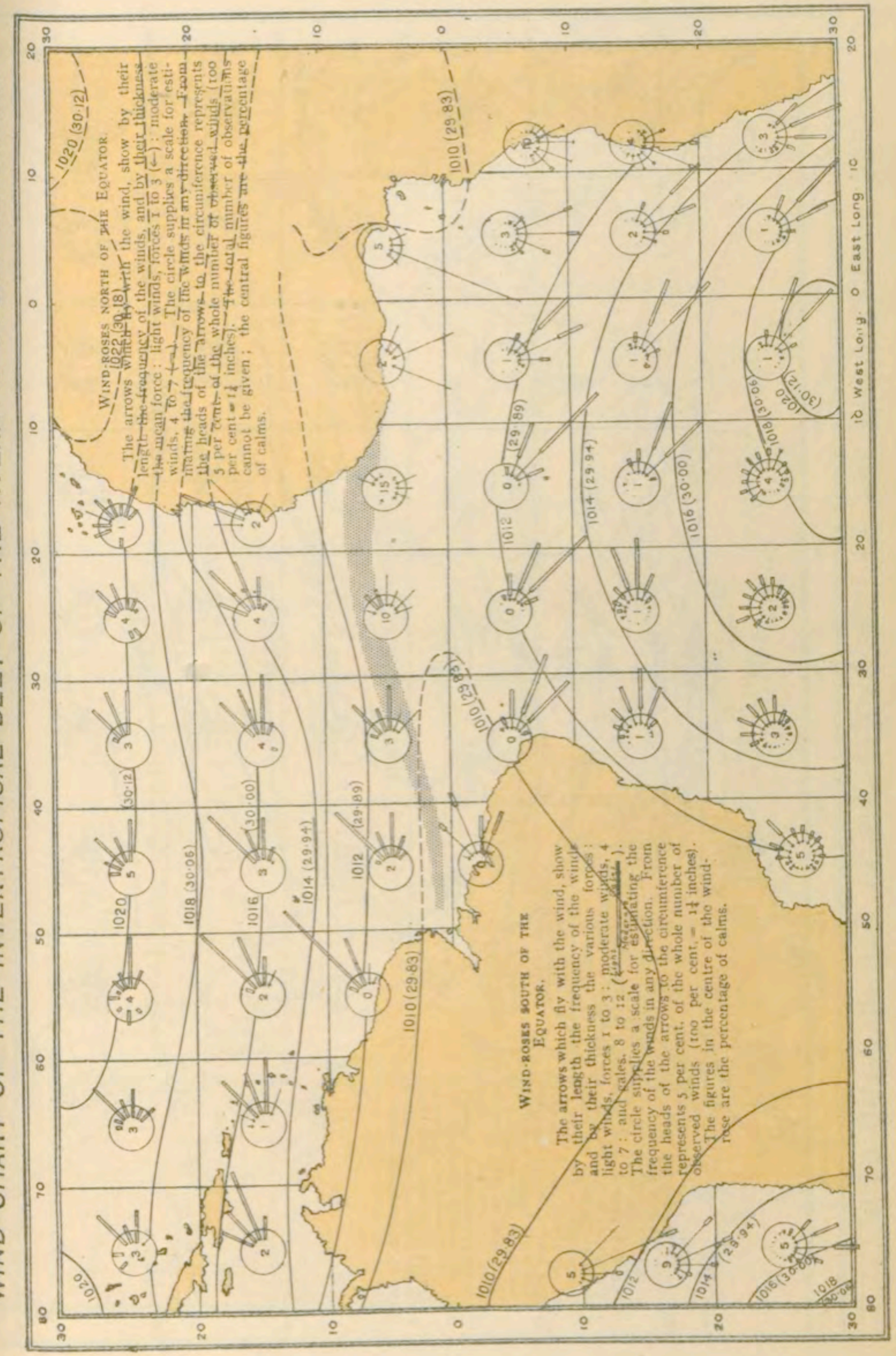
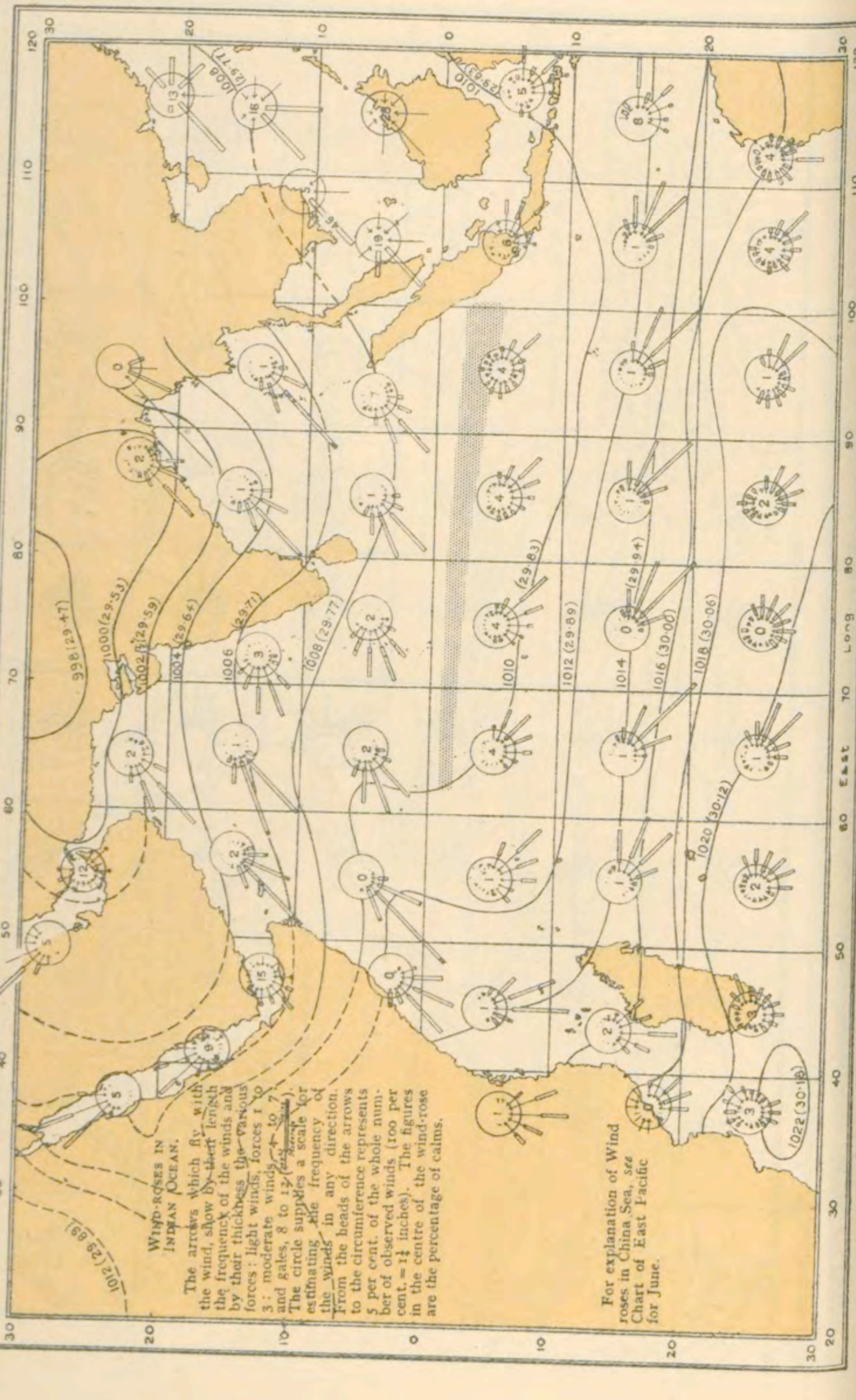



Plate XXV.

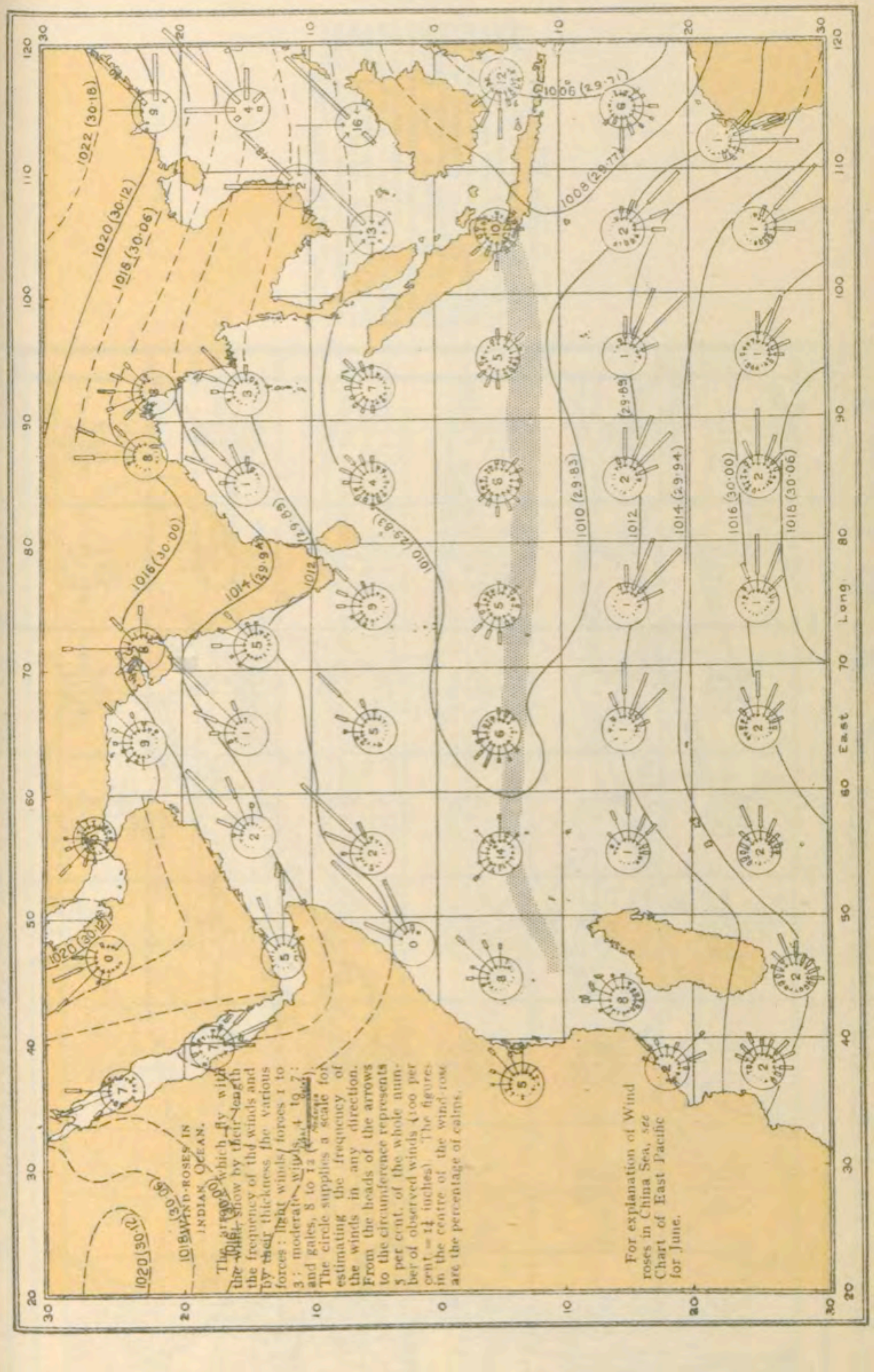
WIND CHART OF THE INTERTROPICAL BELT OF THE ATLANTIC OCEAN—DECEMBER.






WIND CHART OF THE INTERTROPICAL BELT OF THE INDIAN OCEAN–JUNE.

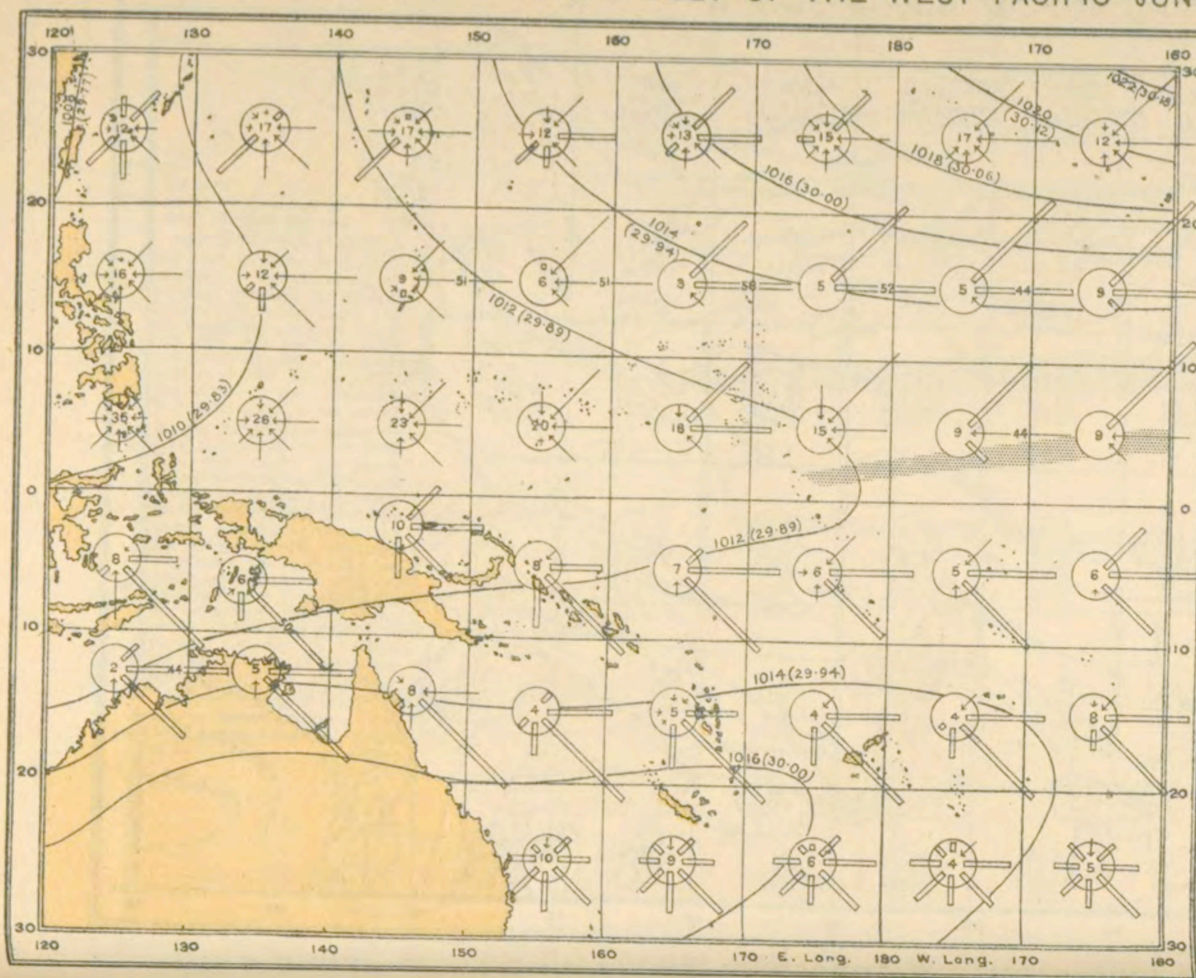





WIND CHART OF THE INTERTROPICAL BELT OF THE INDIAN OCEAN–DECEMBER.

Plate XXVIII.

WIND CHART OF THE INTERTROPICAL BELT OF THE WEST PACIFIC JUNE.

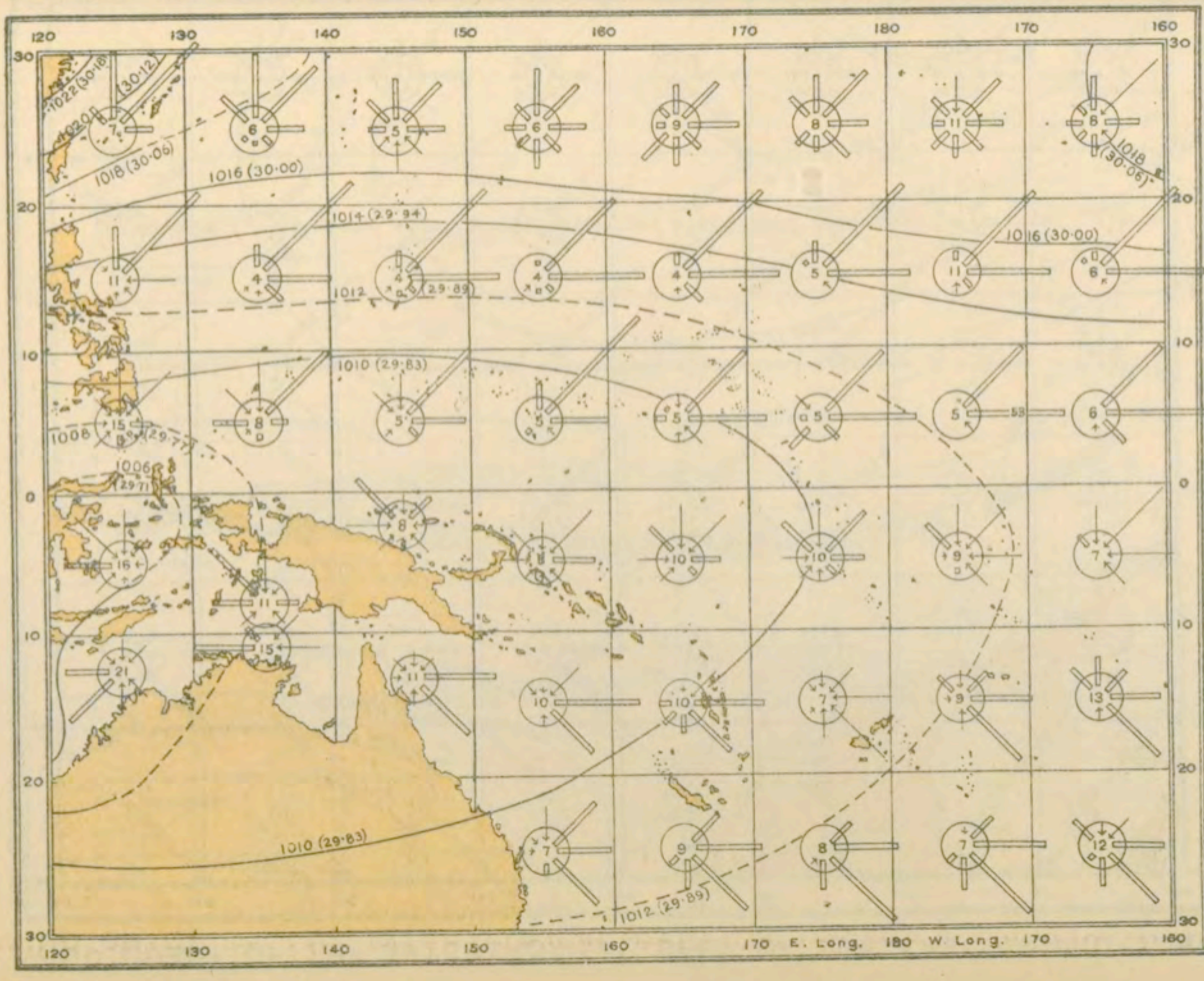



WIND-ROSES IN PACIFIC OCEAN.

The arrows which fly with the wind, show by their length the frequency of the winds, and by their thickness the mean force: light winds, forces 1 to 3 (←): moderate winds, 4 to 7 (⇐). The circle supplies a scale for estimating the frequency of the winds in any direction. From the heads of the arrows to the circumference represents 5 per cent. of the whole number of observed winds (100 per cent, = 1½ inches). The central figures are the percentage of calms. In some instances the full length of the arrow cannot be shown; the line is then broken, and the percentage given in figures between the broken lines.

Plate XXIX.

WIND CHART OF THE INTERTROPICAL BELT OF THE WEST PACIFIC— DECEMBER.

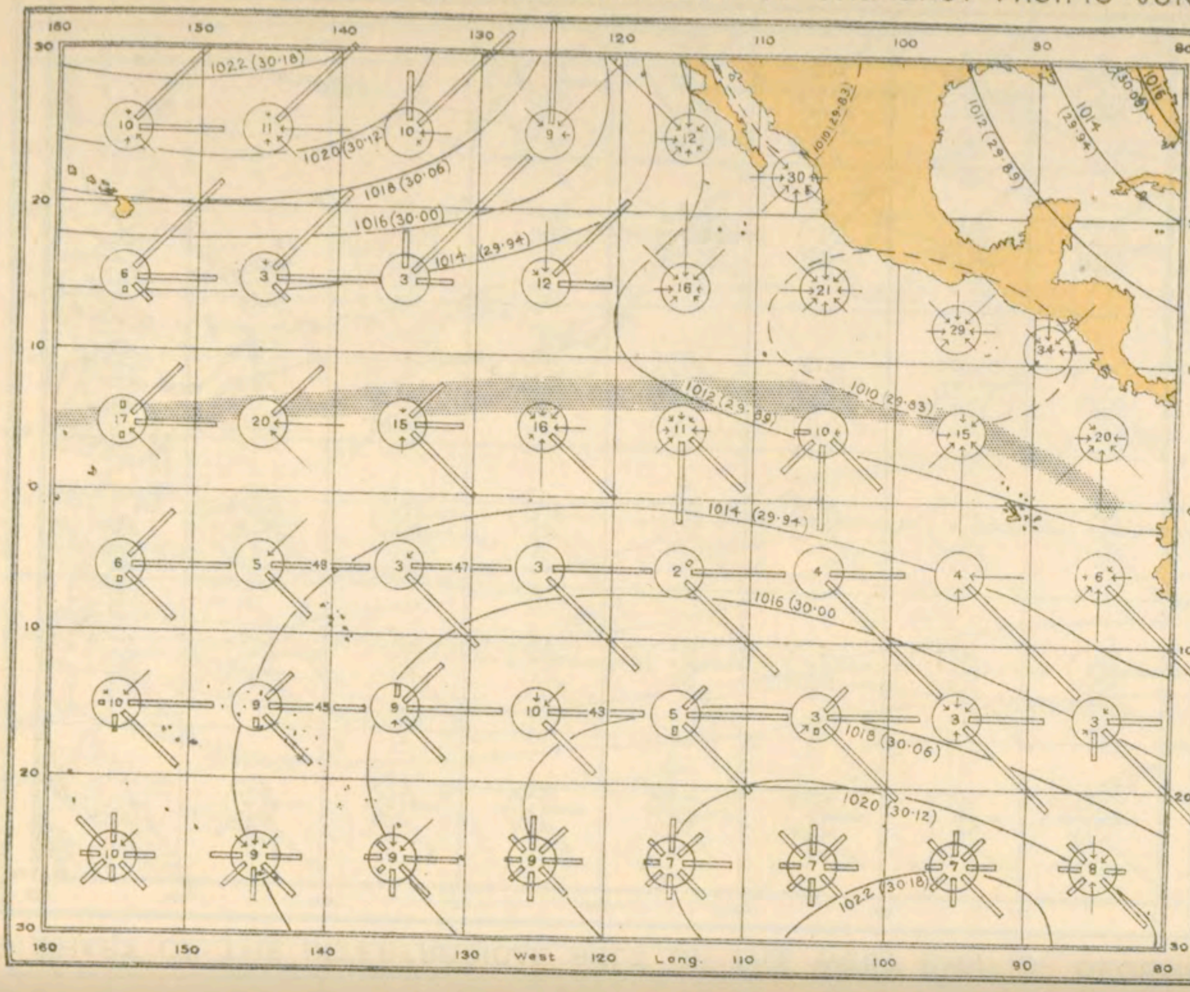



WIND-ROSES IN PACIFIC OCEAN.

The arrows which fly with the wind, show by their length the frequency of the winds, and by their thickness the mean force: light winds, forces 1 to 3 (←): moderate winds, 4 to 7 (⇐). The circle supplies a scale for estimating the frequency of the winds in any direction. From the heads of the arrows to the circumference represents 5 per cent. of the whole number of observed winds (100 per cent, = 1½ inches). The central figures are the percentage of calms. In some instances the full length of the arrow cannot be shown; the line is then broken, and the percentage given in figures between the broken lines.

*Plate XXX.*

## WIND CHART OF THE INTERTROPICAL BELT OF THE EAST PACIFIC—JUNE.

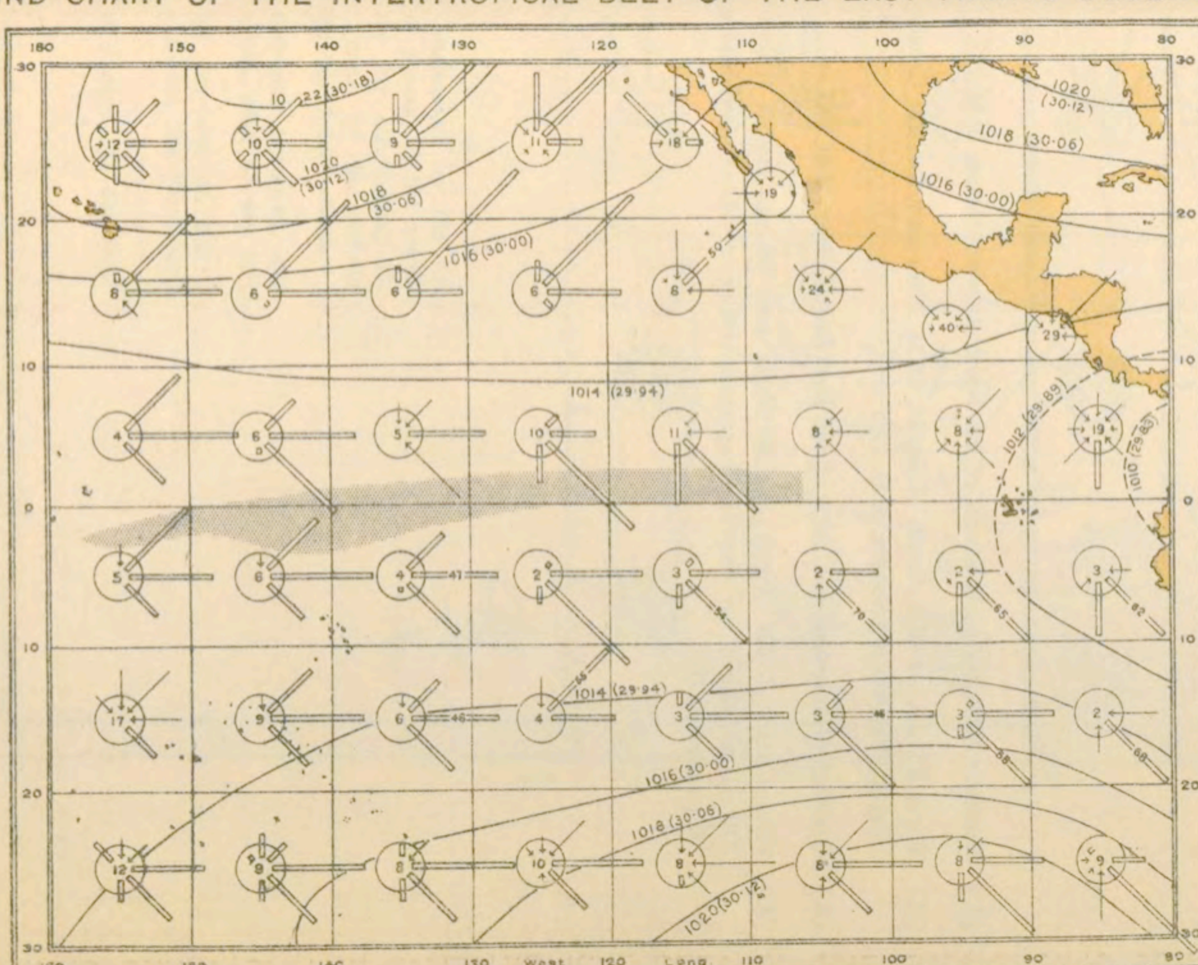



WIND-ROSES IN PACIFIC OCEAN.

The arrows which fly with the wind, show by their length the frequency of the winds, and by their thickness the mean force: light winds, forces 1 to 3 (←): moderate winds, 4 to 7 (⇐). The circle supplies a scale for estimating the frequency of the winds in any direction. From the heads of the arrows to the circumference represents 5 per cent. of the whole number of observed winds (100 per cent. = 1¼ inches). The central figures are the percentage of calms. In some instances the full length of the arrow cannot be shown; the line is then broken, and the percentage given in figures between the broken lines.

*Plate XXXI.*

## WIND CHART OF THE INTERTROPICAL BELT OF THE EAST PACIFIC—DECEMBER.




WIND-ROSES IN PACIFIC OCEAN.

The arrows which fly with the wind, show by their length the frequency of the winds, and by their thickness the mean force: light winds, forces 1 to 3 (←): moderate winds, 4 to 7 (⇐). The circle supplies a scale for estimating the frequency of the winds in any direction. From the heads of the arrows to the circumference represents 5 per cent. of the whole number of observed winds (100 per cent. = 1¼ inches). The central figures are the percentage of calms. In some instances the full length of the arrow cannot be shown; the line is then broken, and the percentage given in figures between the broken lines.

THE INFORMATION SHOWN IN THESE CHARTS IS BASED UPON—

(1.) Monthly Meteorological Charts of the North Atlantic Ocean, M.O. 149.

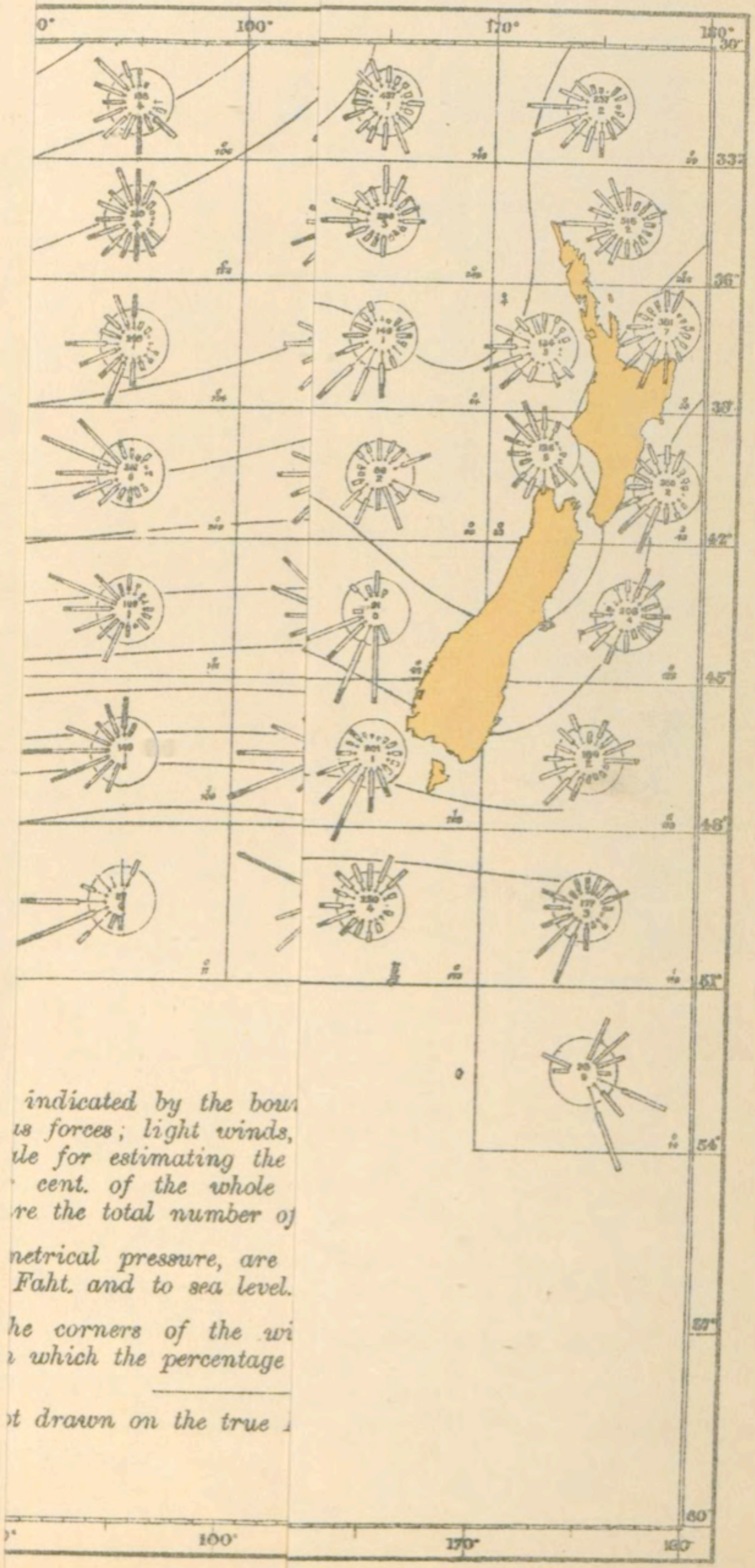
(2.) Wind Charts of the South Atlantic, M.O. 168; and for the Coastal Regions of South America, M.O. 159.

(3.) Monthly Meteorological Charts of the East Indian Seas, M.O. 181.

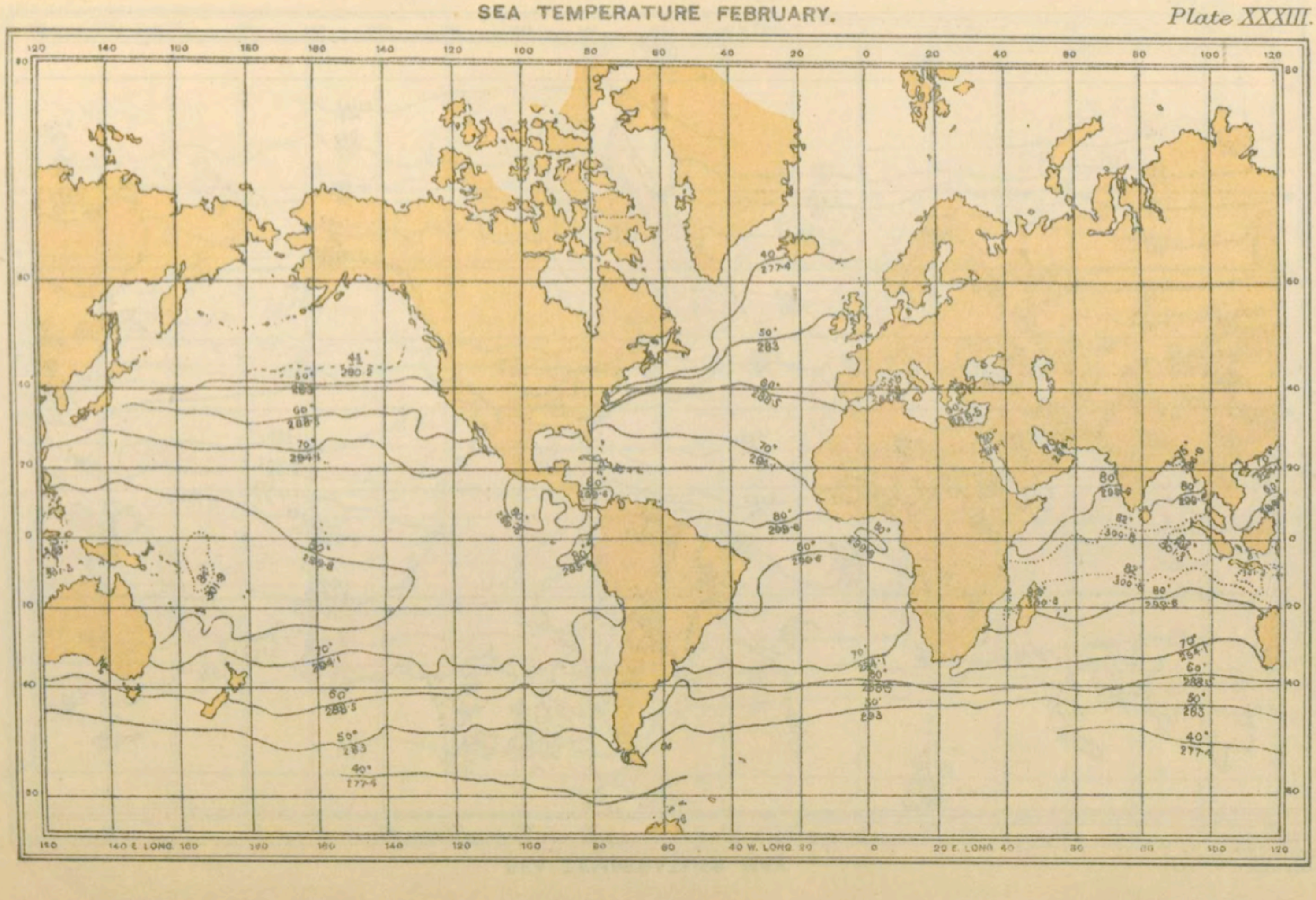
(4.) Pilot Charts of the North Pacific Ocean and of the South Pacific Ocean published by the Hydrographic Office of the United States, Washington, D.C.



AIR TEMPER JULY

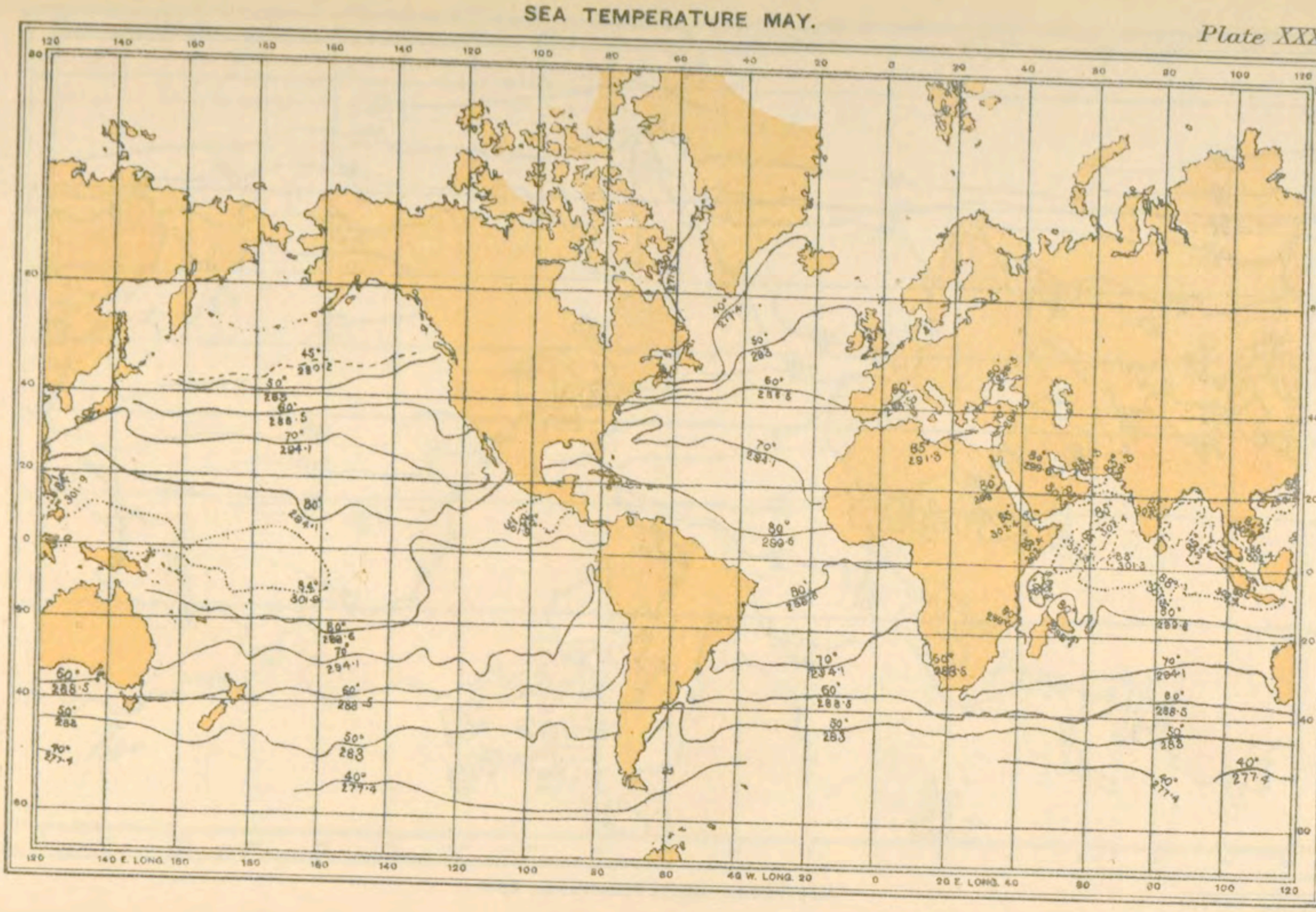


SEA TEMPERATURE FEBRUARY. Plate XXXIII.



## SEA TEMPERATURE MAY.

*Plate XXXIV.*




## SEA TEMPERATURE AUGUST.

*Plate XXXV.*

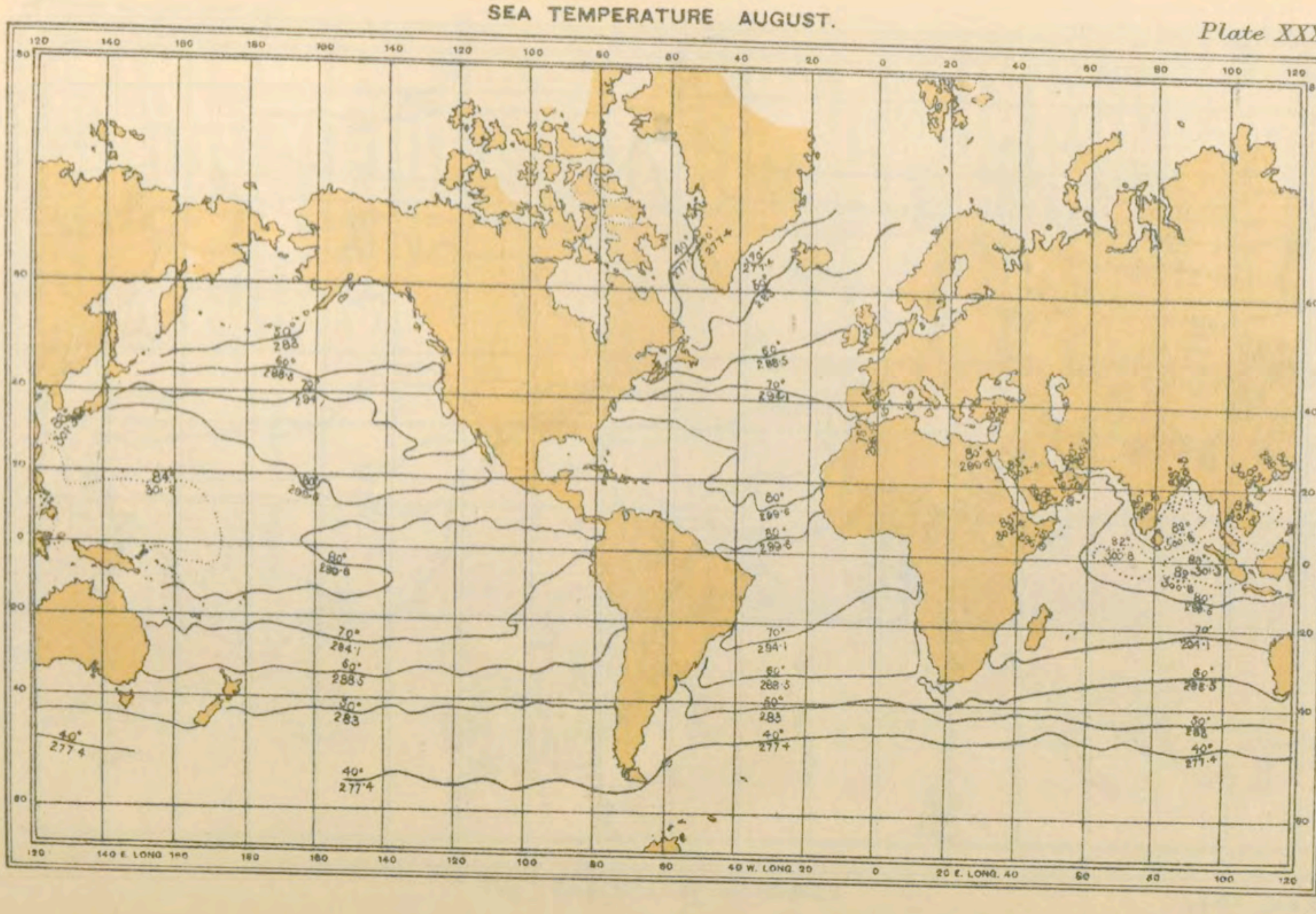
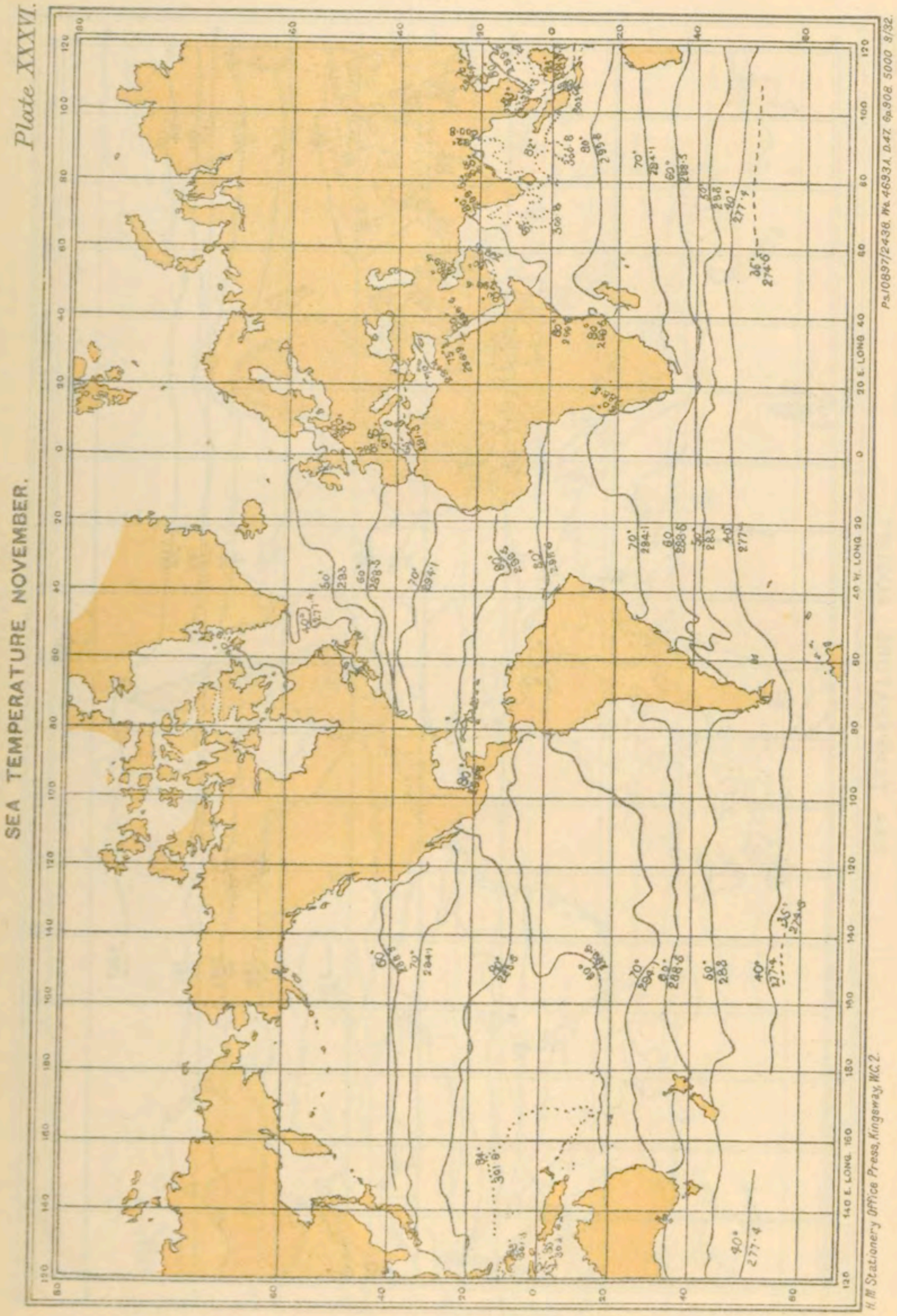


Plate XXXVI.

SEA TEMPERATURE NOVEMBER.



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# INDEX

**CHARTS OF MARINE METEOROLOGY**—*continued.*

**Atlantic (North) :—**

Charts of Meteorological Data for square 3, Lat. 0°—10° N., Long. 20°—30° W. (20 in. by 13½ in.), and Remarks to accompany the Monthly Charts, which show the Best Routes across the Equator for each Month, etc. (17 in. by 16½ in.) (No. 20. 1874.) 20*s.*

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**Pacific Ocean :—**

†Quarterly Current Charts of the Pacific Ocean. (No. 134. 1897.) (26½ in. by 28½ in.)

†Wind Charts of the Coastal Regions of South America. (No. 159. 1902.) (27 in. by 20½ in.)

**Red Sea :—**

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**Southern Ocean :—**

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* On sale by Mr. J. D. Potter, 145, Minories, London, E.1, and his Agents.

† Published by the Admiralty and on sale by Mr. J. D. Potter, 145, Minories, London, E.1, and his Agents.

## PUBLICATIONS OF RESEARCHES

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**Gales** experienced in the Ocean District adjacent to the Cape of Good Hope, between Lat. 30° and 50° S., and Long. 10° and 40° E. Report on. By Capt. H. Toynbee, F.R.A.S. (No. 44. 1882.) (4to.) 7*s*. 6*d*.

GEOPHYSICAL MEMOIRS. (4to.) :—

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