THER·SCIENCE

L·F·MEFFERT·M·A

PEOPLE'S·BOOKS


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Alfred T de Lury
A.S. Carter

THE PEOPLE'S BOOKS

WEATHER SCIENCE

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INTRODUCTION

Weather Science or Meteorology may be regarded as a branch of the wider science Physics, but it is a branch which requires special methods of investigation. As in all sciences, the first step must be the observation and classification of the facts which have to be explained. The physicist proceeds by means of special experiments. In his laboratory he can arrange to exclude from the phenomena which he is investigating certain groups of influences while he gives special prominence to others. The use of this most potent weapon is denied to the meteorologist. With the possible exception of the case of the pollution of the air of our large towns by smoke, no efforts that man can make can influence the course of the weather. Like the astronomer, the meteorologist must take things as they come. He must collect his facts by patient and laborious observation, and hope that ultimately he may be in a position to regroup and combine them so that they may enable him to find answers to the questions which confront him.

Regular records of weather have been kept in isolated places for a long time. As a rule they have been the work of one man, and thus they have ceased with the individual's death or inability to continue the work. The oldest of these, of which we have knowledge, is the register kept by William Merle at Oxford, and later at Driby in Lincolnshire, during the years 1337–1344.

For a few places there are in existence records extending without a break from the last quarter of the eighteenth century to the present time. In view, however, of the great local variations of weather, it is clear that observations made at a few widely separated places must furnish very inadequate material for a comprehensive study of weather phenomena. A much more elaborate system has had to be devised for securing the raw material from which the science of Meteorology can be built up.

About the middle of the nineteenth century there came into existence in most countries organisations, either voluntary or State supported, for collecting observations of weather from a number of places and for summarising the observations when collected. At the present time, the land surface of the globe is covered by a network of stations at which regular observations of weather are made on a definite plan. Over wide areas, especially in the tropics, the network is of very wide mesh, so that many facts which it would be desirable to record escape notice. The organisation of the work is still imperfect in other respects also, but each year sees a further approach to the meteorologist's ideal of securing regular observations from the whole world, so that he may be able to study the world's weather changes as a whole. Nor is the ocean neglected, for most ocean-going ships keep a regular record of weather observations. Each station or ship forwards its records regularly to the central institution of its country for correlation with those taken elsewhere. In this way a vast amount of material is collected and made available for study or for application to the affairs of everyday life. The central institutions of different countries are kept in contact with one another by periodic conferences of their directors, which conferences elect from their members a committee to deal with current questions. The whole represents an international organisation of considerable magnitude.

The routine work of an observing station consists in recording certain set observations at specified hours each day, and in noting the general character of the weather during the intervals between the observations. The observations of the fixed hours comprise the reading of the barometer and thermometer, the observation of the direction and force of the wind and of the type of weather, *i.e.* whether it be rainy, foggy, fine, &c. Once a day the amount of rainfall has also to be measured. The more important stations are called observatories. They are equipped with instruments which write continuous records of the variations of the barometer, thermometer, or other instrument on charts moved by clockwork. The observations may be extended in various ways. Some observatories record the form and movement of clouds, the electrical state of the atmosphere, the heat received from the sun, and other phenomena. In recent years the investigation of the conditions prevailing in the upper atmosphere by means of kites or balloons has become of great importance. In the following pages we will first consider the observations of an individual station, and examine the processes which underlie the variations in the phenomena recorded, and then pass on to see what can be learned by combining the records from different places.

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CHAPTER I

METEOROLOGICAL OBSERVATIONS AND THE PROCESSES INVOLVED IN ATMOSPHERIC CHANGES

The Composition of the Atmosphere.—The atmosphere in which weather phenomena manifest themselves is in the main a mixture of the two gases, nitrogen and oxygen, approximately in the proportion of four volumes of nitrogen to one volume of oxygen. There are also present small quantities of carbonic acid, argon, and other gases, but the amounts of these are so small that we need not consider them further. There is, however, another constituent which is of the utmost importance to the meteorologist, and that is water in the form of invisible vapour. Its amounts may vary between wide limits.

Pressure.—We will first consider the principal observations made at a meteorological station in their relation to the processes going on in the atmosphere. The most important is generally considered to be the measurement of the pressure of the atmosphere. This pressure is due directly to the weight of the air. At the level of the sea it amounts normally to about $15\frac{1}{2}$ pounds on each square inch of surface. It is measured by means of a barometer, an instrument in which the pressure exerted by the air is balanced against the weight of a column of mercury. It is customary to specify the pressure of the atmosphere by stating the length of the mercury column which will just suffice to maintain the balance. This length is spoken of as the "height of the barometer." The normal height of the barometer is 760 centimetres or 29·92 inches. As the pressure of the atmosphere on a given surface is due to the weight of the air vertically above that surface, it follows that the pressure must get less with increasing altitude. Near the earth's surface the barometer falls by about one-thousandth of an inch for an increase of height of one foot, but at higher levels the rate of decrease becomes less rapid. At an altitude of 18,000 feet or rather under 3½ miles, the pressure has only about half its value at the surface, while one quarter of the surface value is reached at an altitude of 36,500 feet, or about 7 miles. At 60,000 feet the pressure is only one-tenth part of that at the surface; in other words, a balloon which reaches this altitude has nine-tenths of the mass of the atmosphere below it. From these figures, it is evident that the atmosphere forms only a very thin shell round our earth. The globe is occasionally likened to an orange, but it would be quite wrong to push the analogy and compare the atmosphere with the peel of the fruit; its effective thickness is comparable rather with the thin tissue paper in which the orange is wrapped.

We have stated that the normal height of the barometer at sea level is 29·92 inches, the equivalent in British units of 760 millimetres. In the region of the British Isles the barometer stands normally between 28 and 31 inches, but both these limits have been exceeded. On January 31, 1902, the barometer at

Aberdeen read 31·113 inches, while on January 6, 1887, a reading as low as 27·332 inches was recorded at Ochtertyre in Perthshire.

Temperature and Radiation.—From observations of the pressure of the air, we pass on to those of its temperature. Among the causes which give rise to changes in the temperature of the air, the sun's heat is at once the most obvious and the most important. A continuous supply of radiant energy is being received from the sun at the confines of our atmosphere. We cannot follow out in detail all the transformations which it may undergo. Part of it is reflected back into space by dust or cloud particles, part is absorbed by the atmosphere, which is thereby warmed, and part may reach the earth's surface. The amount of direct solar radiation which gets through to the earth's surface varies greatly. A thick cloud may act as an almost perfect screen, and cut off all direct heat from the sun. Under more favourable circumstances a large proportion of solar heat may penetrate to the surface layers. Here part of the heat is reflected, but most of it is absorbed by a comparatively thin layer of the earth's crust, which is strongly heated thereby, and in turn heats the air immediately above it.

The effects produced at the surface depend both on the nature of the atmosphere through which the sun's rays have to pass, and on the nature of the surface on which they fall. They are greatest in the deserts of Africa and Asia, where an unusually transparent atmosphere allows a large amount of solar heat to reach the surface, which may be warmed to a remarkable degree. The sand surface has been known to attain a temperature of over 170°. The air does not get heated to the same extent, but readings of 110° to 115° in the shade are not uncommon in the record from desert stations.

At night, on the other hand, the surface of the earth has a cooling effect. If the atmosphere is clear, the earth cools rapidly by loss of heat by radiation, and the air in contact with it also suffers a rapid decrease of temperature. The desert stations of Algeria frequently report night frosts. Even in our own climate, if the sky be free from cloud, the differences between day and night temperature may be great, especially in the spring. As an example we quote the Easter week (March 24 to 30) of the year 1907. The sky was almost cloudless throughout, and during the day-time the thermometer at inland stations rose well above 60° on each day. At Oxford it reached 69°, and at Shrewsbury 68°. During the nights temperature below the freezing-point were general. The shade temperature 4 feet above the ground fell on one occasion to 29° at Oxford, and to 25° at Shrewsbury; the range of shade temperature was thus more than 40° at these two places. Thermometers exposed on the ground showed even lower values; at Birmingham a temperature 15° below the freezing-point was recorded by an instrument thus exposed.

There is an important difference between the effects due to heating by day, and cooling by night. When the earth gets warmed by radiation, the first effect is that the air in contact with the surface gets warmed. It consequently expands—in other words, its density decreases. It therefore tends to rise, and its place at the surface is taken by cooler air from above. The air does not rise up bodily. Local differences in the nature of the surface cause the heating to be more intense in one place than in another, and thus the effect is to cause little irregular streams of rising and falling air, which produce the peculiar flimmering which may be observed on any hot sunny day when we look across a heated land surface. We see then that the heating of the air by day is not confined to the layers in immediate contact with the surface, but extends also to those higher up. Hence the shade temperature in the air a few feet above the ground remains considerably lower than that of the heated soil. At night, on the other hand, when the earth's surface cools by radiating heat into space and the air in contact with it is chilled, there is no tendency for the cooled air to move away if the ground be level. The cooling process in the lowest layer of the air is a cumulative one if there be no wind to cause mixing with the layer above, and we may find the air in contact with the ground very much colder than that a few feet above it. If the surface be a sloping one, the cooled air will tend to drain away towards the bottom of the slope. Hence we get an accumulation of cold air at the bottom of valleys. It is no uncommon thing for delicate crops planted at the bottom of a valley to suffer severely from frost on a calm clear night, while those planted a little higher up on the slopes of the hillside escape.

The process of the vertical interchange of cold and warm air is known as convection. It does not always occur in small local streamlets of air. We shall find examples later on in which large masses of air are displaced bodily by colder ones. Under such circumstances the process involves important weather changes.

Thermometer Exposure.—Seeing that the temperature variations of the ground, and generally of bodies on the earth, are greater than those of the air, it becomes a matter of importance how we expose the thermometers which we use for measuring the temperature of the air. If they are placed on the ground or otherwise exposed to direct sun, they will tend to indicate the more extreme variations of temperature of the ground rather than the more restricted variations of the air. In this country thermometers used for meteorological observations are exposed in Stevenson screens, large wooden boxes with double louvre sides, which should be placed in the most open position available, at a height of 4 feet above the ground. The box protects the thermometer from the direct sunshine, while the louvres allow of sufficient ventilation to secure that the air in the screen shall be a fair sample of that outside. The arrangement is not ideal under all conditions of weather, but it has the great merit that it is adopted almost universally in so far as this country is concerned. It is not suitable for tropical climates.

Effect of the Sea.—We stated above that the nature of the surface on which the radiant heat from the sun falls, is a matter of great importance in determining the effects which result. The greatest contrasts are found between land and water surfaces. If the solar radiation fall on a water surface, the absorption in the uppermost layers of the water is not nearly so complete as is the case with a land surface. The water is transparent to some of the radiation which therefore passes through it to be gradually absorbed by the lower layers. The heat is thus more widely distributed, and the rise of temperature in the surface layers is proportionately reduced. Still more important is the fact that water has a much greater so-called specific heat than soil or rock—that is to say, a much greater amount of heat has to be absorbed by a pound of water than by a pound of earth to produce a given rise of temperature. The net result is that the surface layer of the water is warmed very much less than the land surface, and, as a result, the air above the water is also warmed to a less degree. On the other hand, at night time, a water surface radiates less heat into space than a land surface under similar circumstances would do. Moreover, any cooling which may take place at once calls into play convection processes in the water itself. The cooled water becomes more dense and sinks, and warmer water from below takes its place. Thus there is a great tendency for a water surface to remain at a more or less constant temperature both by day and by night, and for the changes of temperature due to changes of season to be reduced in magnitude.

This difference in the behaviour of a water surface and a land surface has a most important climatic effect. In small oceanic islands, the contrast between day and night temperature almost disappears, and the seasonal changes between summer and winter are much reduced. Thus in the Scilly Isles, the average difference between the day and night temperature is 7·3°, and the difference between the mean temperature of the hottest and coldest months is 15·6°, whereas in Western Siberia, in the same latitude, the corresponding figures are 32·6° and 72·2° respectively. The moderating influence of the sea on the climate of the British Isles is well known. Even at an inland station like Cambridge, which may be taken as typical of the most continental type of climate, which we experience, the average difference between day and night temperature is only 16·8°, and the difference between the mean temperature of the coldest and the hottest month is 25°.

Heating by Compression.—The heat of the sun is not the only cause of change of temperature. Large variations may occur on days when the sky remains overcast throughout and the direct action of the sun is entirely cut off, if wind brings air from hotter or colder regions. There is, however, another cause of actual change of temperature of air which plays a most important part in weather phenomena. The fact that air becomes heated while undergoing compression is familiar to most of us. It forces itself upon the notice of everyone who has occasion to use a bicycle pump. In the operation of blowing up a tyre, we have an example of the conversion into heat of the energy which we expend in compressing air into the tyre. In precisely the same manner, if a portion of air in the free atmosphere is compressed, it must become warmed during the process unless heat is removed from it in some secondary manner. Conversely, expansion is associated with cooling. Now a little reflection will show us that all up and down motion in the atmosphere must be accompanied by changes of volume, and therefore by cooling or heating. If we could ear-mark a cubic foot of air at the level of say 6000 feet, where the pressure of the air is only about 24 inches, and bring it down to the surface when the pressure is 30 inches, we should find that its volume would be reduced by about one-fifth in consequence of the increase of pressure which it has undergone. At the same time we should find that this compression had increased the temperature of the air by about 33° F., the change being at the rate of 1° F. for each 180 feet of change of level. Conversely, if we start with air at ground level and raise it to a higher level, it is inevitably cooled during the process unless a sufficient amount of heat is supplied to it from some independent source. Moreover, the amount of heating or cooling is quite independent of the path which the air may follow.

No matter whether the air moves vertically up or down as it would if confined in a lift-shaft, or along an inclined plane of very small angle, the amount by which the temperature will have changed by the time it gets to the end of its journey depends only on the change of level which it has undergone.

Observations taken at the surface do not often afford direct evidence of variations of temperature due to this cause, but occasionally we come across examples of it. The Föhn wind of Alpine valleys is the most familiar. This is a strong wind which sweeps down the valleys from the mountain tops and passes, and is characterised by great warmth and dryness. Both dryness and high temperature are effects of the compression which the air experiences in consequence of its change of level. Temperature observations made at the top of the passes show that the air there is cold, clear evidence that the air gets warmed during its rush down the valley. Simultaneous observations made in the valley and on the pass during the occurrence of Föhn always show a difference of temperature at the rate which theory would lead us to expect, viz. 1° per 180 feet.

The breaking out of a Föhn completely modifies the weather conditions. In the Grindelwald valley a Föhn has been known to remove a covering of snow two feet thick in about twelve hours. Even more striking are the effects due to the Chinook winds which sweep down the eastern slopes of the Rocky Mountains. By preventing a permanent covering of snow, they render large tracts of country in Montana, Wyoming, and the Dakotas suitable for the winter pasturing of cattle. In his textbook on *Climatology*, Hann gives an example of the effects of the Chinook which is so remarkable that no apology is needed for quoting it here. The warm

November of the year 1896 was followed by a period of great cold, which threatened to prove disastrous to the cattle, as the pasture lands on which they depend for food were buried $2\frac{1}{2}$ feet deep beneath the snow. On the evening of 1st December, the temperature at Kipp, Montana, was $-13°$, or 45° below the freezing point. Suddenly dark ragged clouds appeared above the mountain tops in the south-west. A few minutes later a blast of warm dry air was felt. In the course of seven minutes the temperature rose to 36°, and in twelve minutes the snow had disappeared.

Moisture.—We have next to consider the observations connected with the moisture in the atmosphere. The amount present may vary greatly from time to time, but for every temperature there is a certain definite amount which cannot be exceeded. The higher the temperature the greater is the amount of water which the air can contain. Thus at 40° a cubic foot of air may contain 2·9 grains of water, in the form of invisible vapour, while at 60° the amount may be as great as 5·8 grains. If we start with air at 60° which contains its full allowance of 5·8 grains per cubic foot, and cool it to 40°, 2·9 grains of water will separate out from each cubic foot. The excess of water will condense in the form of drops on the sides of the containing vessel, or as a fog or cloud on the dust particles floating in the air. Air which contains the maximum amount of water in the form of invisible vapour appropriate to its temperature is said to be saturated. If we start with unsaturated air and cool it, a temperature will be reached sooner or later when the water vapour actually present will be just sufficient to saturate it. This temperature is called the dew point of the air. Saturated air produces a damp or moist sensation, for wet articles exposed to it cannot lose any of their moisture by evaporation. On the other hand, if we start with saturated air at 40°, and warm it to 60°, the air becomes comparatively dry, for each cubic foot can now hold an additional 2·9 grains of water in the form of vapour. If the air comes in contact with a wet surface evaporation will take place.

For this reason, the air of a Föhn wind must always be very dry. At the top of the mountain or pass it is at a low temperature, and therefore it can contain but little water vapour in each cubic foot even if it be saturated. By the time it reaches the bottom of the valley its temperature has been considerably raised, and hence its capacity for taking up moisture has been greatly increased. The air at the summit may not only be saturated—it may even contain a cloud of water droplets suspended in it, but the heating undergone during the descent soon causes the drops to evaporate. The process may often be watched in the case of a mist on a hilltop which is dispelled as it rolls down the hillside.

Measurement of the Amount of Moisture.—From carefully made experiments, tables have been compiled showing the amount of moisture present in each cubic foot of the atmosphere at all possible dew points. Hence a simple method of determining the amount of moisture is to determine the dew point. This may be done in a rough and ready way with a tin can containing water, to which water cooled with ice is slowly added until a deposit of dew appears on the outer surface of the can. The contents of the can should be well stirred during the experiment, in order that we may be sure that the water and the surface of the can are at the same temperature. This temperature can then be read off on a thermometer placed in the water. The temperature indicated at the moment when the tin surface first becomes dimmed will be that of the dew point of the surrounding air.

The observation of the dew point, though simple in theory, is tedious in practice, and for the daily routine work of a meteorological station a more expeditious method of determining the water contents of the atmosphere is required. The determination is usually made with the dry and wet bulb thermometer. A wet bulb is made by covering the bulb of an ordinary thermometer with thin muslin, which is kept moist by attaching to it a few strands of worsted dipping into water. If the air is saturated, no water can evaporate from the wet bulb surface, and the thermometer indicates the same temperature as the neighbouring "dry bulb" thermometer.

On the other hand, if the air is unsaturated, evaporation takes place from the wet bulb. Now a considerable amount of heat is absorbed by water as it is converted from liquid to vapour. In the case of a boiling kettle, this so-called latent heat is supplied by the fire, but in the case of the wet bulb the heat is taken, in part, from the thermometer itself, which accordingly indicates a temperature below that of a thermometer which is kept dry. The greater the "dryness" of the air, the greater is the difference between the readings of the dry and wet bulb thermometers for a given temperature. Elaborate tables have been constructed showing for all possible combinations of dry bulb and wet bulb temperatures the amount of moisture present in each cubic foot of air.

Rainfall.—Meteorological stations differ considerably in the extent of the observations which they undertake; but almost all include the measurement of the amount of rainfall in their programme. The routine observation consists in determining the depth of rain which falls in successive intervals, usually of 24 hours. For the collection of the rain a circular vessel, known as a rain-gauge, is used. The rainwater which falls into the open top of the gauge is conducted by means of a funnel into an inner can or receiver, where it is stored in such a manner as to be protected from loss by evaporation until such time as the measurement has to be made. The water is then poured into a measuring glass, in which its amount can be read off.

Over the British Islands the average rainfall is about 25 inches per annum; but the amount varies greatly from year to year, and also from place to place. It is greatest in the West and North-west of the country. At Seathwaite in Cumberland, reputed the wettest spot in the British Isles at which regular observations have been made over many years, the average amount is 139 inches per annum. In tropical countries, where the air can contain much larger amounts of water vapour by reason of its higher temperature, much higher figures are recorded. Cherra Poonjee in Assam has an average rainfall of 439 inches per annum, the highest known rainfall for any station at which observations have been made for many years.

A day on which the rainfall exceeds one inch is regarded as one of heavy rain in all parts of the British Isles, though a glance through a set of rainfall tables for almost any year shows that this phenomenon may be expected to occur at least once in the course of each year at most British stations. The heaviest fall of rain ever recorded in one day in the British Isles again falls to the lot of Seathwaite, where, according to an interesting table of phenomenally heavy rainfalls given in "British Rainfall" for 1910, 8·03 inches of rain were measured on November 12, 1897. Even in our comparatively dry eastern counties very heavy falls may occur. The same table records seven instances of falls exceeding 4 inches in 24 hours in the county of Essex.

In tropical countries these amounts may, again, be vastly exceeded. For example, a typhoon which swept over the Philippine Islands between July 14 and 17, 1911, deposited at one station on four consecutive days 35, 29, 17, and 8 inches respectively, or a total of 89 inches in four days.

Considerable interest also attached to determining the rate at which rain falls in heavy downpours, particularly from the point of view of the civil engineer responsible for drainage schemes or for the stability of structures under stress of weather. As an indication of the extremes that may be met with in the British Isles, we quote a few instances from another table in "British Rainfall," giving particulars of well authenticated cases of phenomenally heavy falls of brief duration. A fall of $\frac{1}{3}$ of an inch in 2 minutes, or at the rate of 9·9 inches per hour, heads the list. Further, the table gives four instances of 1 inch or more of rain in 10 minutes or less, and two instances of more than 3·5 inches in 1 hour.

Formation of Cloud and Rain.—Cloud formation is invariably the first stage in the production of rainfall. Cloud is formed by the condensation of the invisible water vapour of the air in the form of small liquid drops. In order that condensation may occur, air must be cooled below the dew point. The only process in nature which is capable of giving rise to sufficient condensation to produce appreciable rainfall is that involved in the cooling caused by a transfer of air from low to high levels, to which reference has been made on p. 18. If an air current consisting of unsaturated air be directed from a low to a high level, we have seen that the temperature of the moving air will be lowered by 1° F. for every 180 feet of ascent, in consequence of the expansion which it undergoes during the process. If the ascent be sufficiently great, the air may be cooled to the dew point. If the ascent be continued still farther, the cooling continues, though now at a diminished rate of 1° for a rise of 300 feet, and results in the formation of cloud. As the process goes on, more water condenses, and in consequence the water droplets in the cloud grow, and ultimately they become large enough to fall to the ground as rain. We have an excellent example of this process of cooling by ascent of air in the heavy rainfall of the Scottish Highlands, or of the English Lake district. The moisture-laden westerly winds from the Atlantic are forced up the sides of the mountains, and during the process they are so much cooled, that they deposit a great part of their water contents. A still more instructive example is afforded by the heavy rainfall which the South-west monsoon gives up as it is forced up the slopes of the highlands on the West coast of India, where the strip of country along the coast receives on the average over 100 inches of rain during the rainy season from June to October.

Though the effects of the cooling or warming of air in consequence of change of level are most easily identified in mountainous regions, it must not be supposed that the presence of rising ground is necessary to set them up. We shall see in Chapters II and III many examples of upward or downward motion taking place in the atmosphere quite independently of orographical features.

The formation of cloud by the expansion of air may be demonstrated by means of the simple apparatus illustrated in Fig. 1. A is an inverted flask partially filled with water; it is connected with a reservoir B, also containing water by means of flexible tubing. If B be lowered, some water will flow from A to B, and the volume of the air imprisoned in A will increase. The cooling inseparable from the expansion will cause a cloud to form in A, which can be easily rendered visible by concentrating a beam of light on it with a lens. If the water level in A and B be identical at the beginning

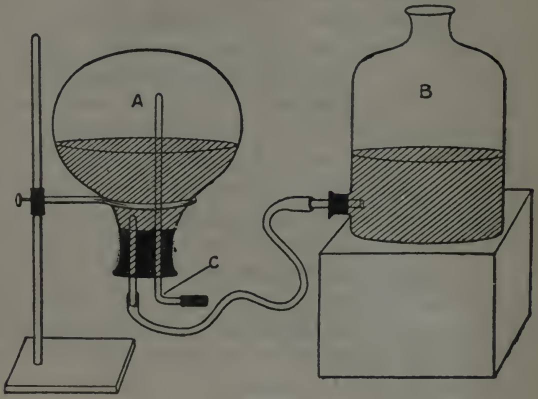

Fig. 1.

of the experiment, and the difference of level be about 13 inches at its close, the expansion which the air in A will have undergone, will correspond approximately with that due to a lift through 1000 feet. It is essential for the success of the experiment that there should be dust particles present in the air. Aitken has shown that if the air be free from dust nuclei, it can be cooled considerably below the dew point without condensation taking place. Air in this abnormal state is said to be super-saturated. As prolonged standing over water will serve to remove dust nuclei from the air, it is essential for the success of the experiment to have some simple method of introducing fresh nuclei into the imprisoned air; this may be conveniently done by passing a tube C through the cork of A, through which smoke from a smouldering match can be drawn into the flask. While an experiment is being made, the end of C is closed with a stopper.

Cloud-Bursts and Hail.—The rate at which a drop of water suspended in the air falls, depends on its size. A very small drop, one-thousandth of an inch in diameter, falls at the rate of less than 1 inch per second or 5 feet per minute relatively to the air surrounding it. A cloud of such small drops one mile above the surface would take over 17 hours to sink to the surface. Such very small drops practically remain suspended indefinitely if the air be still. If the air have an upward motion exceeding the downward motion of the drop, so far from falling, the drop will be carried upwards with the air. Now we have seen that ascent of air is always associated with cooling and, if the air be saturated, with condensation. The drop can only persist in saturated air. It will therefore increase in size in an ascending current in consequence of condensation. Its downward motion relative to the air will consequently increase, and ultimately it may become so great that the drop falls to the ground as rain.

As a general rule, the upward motion of air currents is gradual, *i.e.* the air moves up a gradual incline. Occasionally, however, it is rapid, and under such circumstances the drops soon grow to large sizes. Careful laboratory experiments have shown that drops of diameter about two-tenths of an inch fall at the rate of about

25 feet per second through the air in which they are suspended. Larger drops should fall still more rapidly, but it is found that such drops are not stable. The forces at work within the drop, in consequence of its rapid motion through the air, cause it to break up into smaller drops. It follows that no rain can fall to the ground through an air current in which the upward motion exceeds the limiting value of 25 feet per second, a speed which is comparable with that of a fresh wind. We have good reason to believe that air currents in which the upward motion reaches this magnitude occur in our atmosphere. Small drops are carried upward because their rate of fall relative to the air is less than the upward motion of the air, while large drops which might acquire sufficient falling velocity to escape being carried upwards, are broken up. A vast accumulation of water in the liquid state may thus take place in an ascending current if the upward velocity be sufficiently great. If, for any reason, the upward movement of the air is checked, the suspended water falls to the ground. This process must be taking place on occasions of very heavy rainfalls of short duration to which the name cloud-burst is sometimes applied.

The cooling consequent on the uprush of air may be so great that the temperature falls far below the freezing point, and in such circumstances the drops may be frozen to hailstones. If they are small, these stones will be carried upwards by the ascending air, and grow by condensation of more water or ice upon them. Ultimately they become so large that they fall to the ground. Hailstones often exhibit peculiar concentric markings suggesting that they have been alternately whirled up aloft in a rapidly ascending air stream, and then allowed to fall through a region of less vigorous upward motion.

The essential condition for the formation of hail is a very rapid, almost explosive, uprush of air.

Cloud Formation by Mixture—Fog.—Cooling by expansion due to change of level is not the only cause of the formation of cloud. It can also be produced by the mixture of two portions of air at different temperatures. The condensation of the moisture of our breath in the form of a transitory cloud on a cold damp day, is a familiar example of the process on a small scale. Most fogs are produced in this way. We may picture to ourselves the process involved in the formation of a valley fog on a calm night somewhat as follows: A clear sky after sunset favours the rapid cooling of the ground by radiation, and the air near the surface is chilled by contact with the cold ground. In the absence of wind, the air which has been most strongly cooled, being now heavier than the surrounding air, will drain down towards the bottom of the valley. Here it may come in contact with air containing much moisture from evaporation from damp ground or from the surface of a lake or river, and the mixing of these two supplies of air may give rise to a thick surface cloud or fog. If the air be still, the process is not confined to valleys. Even slight differences of level are sufficient to cause the coldest air to drain down towards the bottom of hollows, where it produces wreaths of mist or fog as it mixes with warmer moist air. The process may often be watched towards evening even in country which is almost flat.

Mixture of air at different temperatures may produce a thick cloud or fog; but a simple calculation will show that we cannot expect to derive appreciable rainfall from the process. A cubic foot of saturated air at the freezing point (32°) contains 2·1 grains of water vapour, while a cubic foot at 68° contains 7·5 grains, if it be saturated. If we allow these 2 cubic feet of saturated air to mix so as to form a uniform mixture, if no condensation occurred each cubic foot of air would contain 4·8 grains of water vapour, and the final temperature would be 50°. As a matter of fact, a cubic foot of air at 50° is saturated when it contains only 4·1 grains of water; 0·7 grain of water would therefore be condensed from each of our 2 cubic feet of air. Actually, the amount condensed would be even less, for the final temperature would be slightly above 50° in consequence of the latent heat of the condensed water. Let us suppose that a column of saturated air at 32°, 1000 feet high and standing on a base of 1 square foot, becomes mixed with a similar column of saturated air at 68°. There would be condensed altogether rather less than 1400 grains of water, and this amount, if distributed as rain over our 2 square feet of base, would give a rainfall of less than two-hundredths of an inch. The conditions we have assumed are far more favourable to rain production than anything we are likely to meet with in the atmosphere, and we may conclude that the mixing of two supplies of air cannot yield more than a very slight fall of rain.

If we put the case of rainfall derived from ascent of air into figures, we arrive at a very different result. Saturated air is cooled from 68° to 32° by raising it through 15,000 feet, about half the height of Mount Everest. A cubic foot of air at 68° raised to this level would therefore give up 5·4 grains of water. If we imagine 1000 cubic feet of such air carried through this process, there would be condensed 5400 grains of water, an amount which would yield about 0·15 inch of rainfall when distributed over a base of 1 square foot.

Wind.—As all processes of weather depend ultimately on air motion, an important part of the work of a meteorological station is devoted to the direct observation of that motion, *i.e.* to the observation of wind. At most stations no special apparatus is used for observing wind. The direction from which the wind is blowing can be determined with sufficient precision from such indications as the drift of smoke or the set of flags, if not from one's own sensations. The force is estimated on what is known as Beaufort's Scale, introduced by Admiral Beaufort in 1805. The observer is called upon to assign to the force of the wind numbers ranging from 1, a light air, to 12, a hurricane which causes widespread havoc. In forming his estimate he takes into account such points as the motion of trees, the rate of progress and list of sailing boats and similar criteria, as well as his own sensations. The method is obviously somewhat crude, but in practice it is found to give satisfactory results when the observers have acquired the necessary experience.

If the exposure be sufficiently open, a station may be equipped with an anemometer for obtaining actual measurements of the speed of the wind in miles per hour. A wind of gale force—*i.e.* of such strength that we may expect it to do damage—is found to have a velocity of about 40 miles per hour, or more. Winds of velocity exceeding 70 miles per hour are rarely recorded on the British coasts even in most exposed situations. The highest wind speed recorded at any anemometer station in the British Isles is 106 miles per hour, attained in a specially strong gust during a gale experienced at Pendennis Castle, Falmouth, on March 14, 1905.

A certain amount of information may be gleaned regarding the motion taking place in the air above us, by watching the motion of clouds. Accordingly, observation of the direction of drift of clouds should form part of the work of a meteorological station. Not infrequently we find that the direction of drift of high clouds makes a considerable angle with the surface wind, or it may even be directly opposed to it.

CHAPTER II

SYNOPTIC METEOROLOGY

In Chapter I we passed under review the principal observations made at a meteorological station, and considered them in relation to the changes going on in the atmosphere. We have now to see what we can learn by combining the results of observations taken at a number of stations.

Isobars.—We begin again with the observation of pressure. As the reading of a barometer varies with the height of the instrument above sea level, we can make a fair comparison between the uncorrected readings of the barometer at two stations only if they be at the same level. Fortunately, it is not a difficult matter to allow for differences of level by calculation. For the purpose of comparison, it is customary to reduce all barometer readings to a common level, viz. the mean level of the surface of the sea. Tables have been constructed showing the amount of the correction for all altitudes likely to be met with in practice. If we plot on an outline map all the observations of pressure taken at a particular time by marking on the map the positions of the stations and then writing against each position the corrected reading of the barometer as in Fig. 2, we find that the observations group themselves more or less regularly. We can distinguish regions of high barometer and regions of low barometer with transitional areas between them. The distribution of pressure may be rendered apparent by drawing lines on the map through places where the barometric pressure has the same value. Such lines are called isobars. The method of drawing the lines will become clear from an examination of Fig. 2. It will be seen that the lines marked respec-

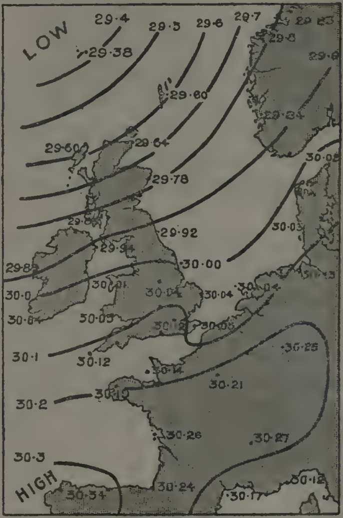

FIG. 2.

tively 30·0 and 30·1 are so drawn that all observations made at stations in the region between them are between 30·00 and 30·10 inches, and similarly for the other lines. The picture presented by the isobars is undergoing continual change. Weather maps have been drawn for Europe day by day for the past fifty years, but in all this long time it may safely be said that no two maps have been identical.

Synoptic Charts.—We may complete our map on which we have shown the distribution of pressure by means of isobars by plotting on it also the observations of other elements. The direction of the winds may be indicated by means of arrows placed alongside the stations, and their forces by using arrows of different types. The temperatures can be indicated by numbers and the "weather" by letters or symbols, B for blue sky, C for cloudy, O for overcast, a black dot for rain, a star for snow, a triangle for hail, three parallel lines for fog, and so on. A graphic representation of the distribution of weather phenomena based on observations taken at a specified time is called a "synoptic chart."

Wind and Pressure—The study of such synoptic charts has done much to enable us to understand the processes underlying the phenomena of weather. The grouping of the other elements is found to be closely dependent on the distribution of pressure as revealed by the isobars, and for that reason we have considered the observations of pressure first. The connection is most intimate in the case of wind. At first sight we might expect the wind to blow directly from regions of high pressure to regions of low, *i.e.* at right angles to the isobars, but this is not the case. The direction of the wind is found to be more nearly parallel with the isobars than at right angles to them, but it is generally inclined slightly towards the side of lower pressure. In the Northern hemisphere the relation between wind direction and distribution of pressure is expressed by the following rule: "Stand with your back to the wind, and the region of lowest pressure will be on your left-hand side, and slightly in front of you." It is illustrated in Fig. 3, in which the lines marked 29·9, 30·0, &c., represent isobars along which the pressure has the values specified, and the arrows indicate the direction of the wind. Numerous other illustrations will be found in Figs. 6 to 12, which are reproductions of actual synoptic charts. In the Southern hemisphere we must read "right" for "left" in the above statement. The statement of the relation between wind direction and pressure distribution is known as Buys Ballot's law, after the Dutch meteorologist who first enunciated it.

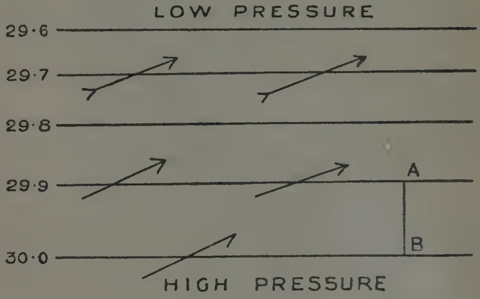

Fig. 3.

A close connection exists also between the force of the wind and the pressure distribution, in that we find that the closer together the isobars, the stronger the wind. In Fig. 3, the isobars are decidedly more crowded on the side of the low pressure than on that of the high, and we should therefore look for the strongest wind in the region where the pressure is low.

Gradient Wind.—The relation between the distribution of pressure and the associated wind has been approached also from the theoretical side by various investigators. They have shown that if we neglect the effects of friction between the earth and the moving air, and make various other assumptions which are only partially realised in practice, then the velocity of the air is proportional to the "gradient." This term is used to denote the rate at which pressure varies along the earth surface, in a direction at right angles to the isobars. For example, if we wish to determine the gradient over any part of the region shown in Fig. 3, we select two points, A and B, so situated that a line joining them is at right angles to the isobars, determine the difference of pressure between them, and divide this by the distance between them. For convenience we select our points A and B on consecutive isobars, so that the difference of pressure between them is exactly 0·1 inch. If the perpendicular distance between the isobars on the scale of the diagram be 50 miles, the gradient might be expressed as 0·1 inch per 50 miles. We see that the gradient is inversely proportional to the perpendicular distance between the isobars. It follows that so long as our assumptions do not depart too greatly from the truth, we should expect the wind velocity to be inversely proportional to the distance between the isobars. In other words, if the distance between consecutive isobars on one map be half what it is on another, we should expect the wind velocity on the first map to be double that shown on the second.

Theory also shows that the direction of the wind should be along the isobars with the low pressure on the left of the path in the Northern hemisphere, so long as friction effects are negligible. This so-called "gradient wind," corresponding with theoretical deductions from the distribution of pressure, is never realised in practice at the surface, but observations made with kites have shown that the winds encountered at altitudes of about half a mile above the surface are usually in close agreement with the gradient wind both as regards direction and velocity.

Steady Current.—We see, then, that the connection between wind and pressure is a very close one, so close indeed that a map of isobars conveys the general features of the arrangement of the winds, though not a single wind be marked on the map. A system of approximately straight isobars, such as that of Fig. 3, represents a steady wind current, the direction being indicated by the run of the isobars. If, as in this case, the lowest pressure is to the North, the wind will blow from West or slightly South of West.

Interaction of Currents—Line-Squalls.—Occasionally we find on a synoptic chart two systems of parallel isobars indicating two wind currents from different directions. Fig. 4 shows an example of such an occurrence. It represents the distribution of pressure over the British Isles at 1 P.M. on February 8, 1906. Over the Northern half of the country the isobars run from North-west to South-east with the lowest pressure to the North-east, indicating a wind from North-west or West-north-west, while to the South of a line running from the Bristol Channel to the Wash, the isobars run from West to East, indicating a wind from a direction slightly South of West, approximately South-west. Fig. 5 shows the position occupied by the line of separation between these two currents at different hours during the day. In order to avoid confusion between forenoon and afternoon, the hours are numbered consecutively from 1 to 24, 13 standing for 1 P.M., 14 for 2 P.M., and so on. Originally the South-west wind, represented by the isobars which run from West to East, covered the whole country, but at 1 A.M. the North-west wind had made its appearance in the Hebrides. By about 8 A.M. it had advanced to the border between Scotland and England, and by 4 P.M. (16 hours) it covered the whole of the British Isles.

Let us examine this case of the interaction of two wind currents rather more closely. We may ask ourselves

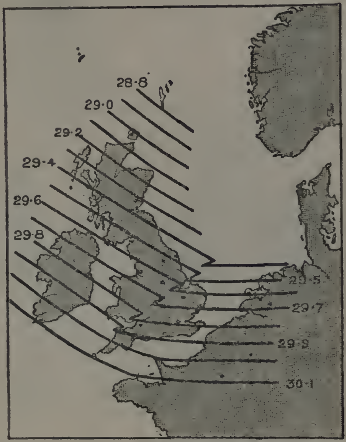

FIG. 4.—February 8, 1906, 1 P.M.

what has become of the current from South-west. Has it been carried away to the South-east as part of the North-west wind? Hardly. The South-west wind was decidedly warmer than that from the North-west, and therefore the air in it was specifically lighter. What has happened is, that the cold North-west wind has flowed under the South-west wind and forced the latter to rise. We have here an obvious case of ascent of air in the free atmosphere quite independently of mountain ranges (see p. 25). The ascent gives rise to cooling, and hence to condensation of water. Rapid cloud formation and heavy rain were reported from all stations at the time of change of wind from South-west to North-west. South-eastward of the dotted line of Fig. 5, the

FIG. 5.—Isochronous Lines showing the advance of the Line-squall of February 8, 1906. Severe Thunder and Hail Storms occurred to the East of the dotted line.

upward motion of the air was sufficiently violent to give rise to severe thunder and hail storms (see p. 28). Throughout this area the changes took place with almost explosive violence, in most cases a severe squall occurred as the wind changed; at Kew Observatory the wind increased suddenly from about 20 to 46 miles per hour, and then died away equally suddenly. The temperature fell from 44° to 37° in a few minutes. These weather changes, a sudden squall accompanied by a change of wind direction and heavy rain or hail, with a fall of temperature, are very characteristic of the phenomena occurring along the line of separation of two currents, to which the name "line-squall" is often applied. The barometer also rises almost instantaneously by a few hundredths of an inch as the places pass out of the régime of displaced wind into that of the displacing wind.

Cyclones.—The isobars may assume many varied shapes representing different kinds of air motion and therefore of weather. A most important type is that in which the lines of equal pressure form concentric curves approximately circular or oval in shape with the lowest pressure at the centre of the system. To such a system the name "cyclone" or "depression" has been applied. Fig. 6 shows a typical example. It is a reproduction of the synoptic chart for 6 P.M. on March 24, 1902. As is usual in a cyclone, the isobars are crowded together more closely than is the case on most weather maps, and hence we should expect to find strong winds or gales recorded on the map. We actually find winds of gale force in the Bristol Channel, the mouth of the English Channel, on the north coast of Ireland, and at Spurn Head. As regards direction the wind is everywhere in accordance with Buys Ballot's law—it blows nearly along the isobars with the low pressure on the left of its path, but it is generally deflected slightly inwards towards the centre of low pressure. We have the general impression that the air is rotating about the centre of the system in a direction opposed to that of rotation of the hands of a clock, with a gradual inflow towards the centre. This inflow might be expected to result in a rapid increase of pressure in the central region of the cyclone—in other words, in its destruction—and the system can only persist if there is removal of air from the central regions to balance the inflow. Such removal can only take place by upward motion of the air which we know is the main source of rainfall. We therefore

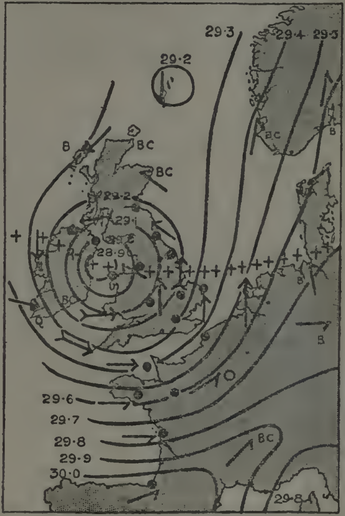

Fig. 6.—Cyclone of March 24, 1902, 6 p.m. (For explanation of symbols used, see p. 35.)

expect a cyclone to be a region where rain is falling. In Fig. 6 the black dots indicate the positions of the stations from which rain was reported at 6 p.m. on March 24, 1902. It will be noticed that the rain is by no means uniformly distributed over the whole area; no rain is falling in the South of Ireland or South-west of England, and in places the weather is represented by the letters B C (blue sky with broken cloud). The behaviour of cyclones and the distribution of wind and weather in them have been the subject of much study. Particular attention was devoted to the subject in this country by Abercromby, and the results which he arrived at, though they have been amplified in many ways, have generally been confirmed by further investigation. A most important property of cyclones is their travel. The whole system of isobars is found to move forward and to carry along with it its appropriate distribution of wind and weather. Abercromby referred the properties of a cyclone to the "path" along which the centre of the system moves. In the example which we have selected the path lay from West to East across the British Isles from the North-west of Ireland to the Wash. It is marked by a line of crosses. Abercromby distinguished the line through the centre approximately at right angles to the path as the "trough" of the cyclone. During the passage of a cyclone over an observing station the barometer continues to fall until the place comes on the line of the trough, whereupon it begins to rise again.

Sequence of Wind and Weather in a Cyclone.—It is evident that the sequence of winds which a place will experience as a cyclone passes over it, will be quite different according as the place lies to the right or to the left of the path. In our example, the wind is Westerly or South-westerly over Germany and Sweden in the region not yet affected by the depression. If we consider a place to the North or left side of the path the wind will "back"—*i.e.* shift in a direction opposite to the motion of the sun—to South and South-east as the depression approaches. It will be approximately Easterly at the time of passage of the trough, and then continues to back through North-east to North and even to North-west. On the other hand, a place to the South or right of the path will experience first a backing of the wind to South, and then a "veering" (movement with the sun) through West to North-west or North.

The variations of weather which occur as a cyclone passes are equally characteristic. In the region not yet affected by the depression, the weather is fine. In our example we find B (blue sky) over Germany and Denmark. Frequently the earliest indication of the approach of the cyclone is the development of a halo round the sun or moon. The most usual form of halo is a white luminous ring round the luminary, having an angular radius of about 22°. Soon high cirrus clouds, so-called mares' tails, begin to form. Gradually the clouds become more dense as the wind backs and increases in force. As the process continues, the air becomes damp and muggy. Presently rain sets in, and generally continues for several hours. After the passage of the trough, the weather improves. The rear of the cyclone is usually a region of squally, showery weather, indicated on synoptic charts by the letters Q (squalls) and P (passing showers), the showers alternating with fair intervals. The temperature is generally several degrees lower than that in front of the trough.

On the Southern or right-hand side of the path the passage of the trough is often marked by a sudden change of wind. The trough in this part of the system marks the line of separation between two air currents of different directions. In our example, it is obviously a line of separation between a current of Southerly or South-westerly wind and a current of Westerly wind. We should therefore expect to find the phenomena with which we have become familiar in the case of line-squalls to occur as it passes, and, in fact, this is exactly what takes place. There is a sudden change of wind and fall of temperature, and a marked increase in the rainfall, the so-called clearing shower. On the Northern or left-hand side of the path, sudden changes do not occur as the trough passes. The transition from rainy to fair weather is more gradual.

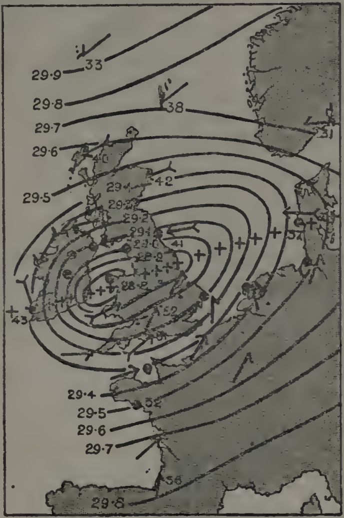

FIG. 7.—Cyclone of November 12, 1901, 6 P.M. (For explanation of symbols used, see p. 35.)

Production of Rainfall in a Cyclone.—Fig. 7 shows us another example of a cyclone, which differs in many respects from that just considered. Though the path followed by the centre was approximately the same, the rate of advance was much slower, and the shape of the isobars more oval. We have included this depression because it shows us another example of rainfall due to the interaction of two air currents, but in this case the cold current does not force its way under the warm one, driving it before it, but merely places itself across its path, and so forces it to ascend as up a mountain slope. The map, which is a reproduction of the synoptic chart for 6 P.M. on November 12, 1902, shows Easterly winds to the North of the path, which is indicated by a line of crosses, running from the South of Ireland to the mouth of the Humber, while to the South of it there are South-westerly winds over England. A glance at the temperatures shows that the east wind is about ten degrees colder than the South-westerly one—in other words, the density of the Easterly wind was considerably greater than that of the South-westerly one. The latter thus finds its farther advance along the surface barred as it comes up to the line of the path. It is therefore forced to ascend, and cooling and precipitation result, for the air of the South-west wind is saturated. The condensed water is carried farther to the North, and ultimately falls to the ground through the surface East wind. The rainfall deposited by this depression on the Northern side of its path was phenomenally heavy. More than four inches fell over a large area in the North of Ireland, and more than three inches in the North of England. We have here the explanation of an often observed fact, viz. that the region of heaviest rainfall lies on the left hand, in this case Northern side of the path. We see also why under certain circumstances East winds may be very rainy, but it would be a mistake to regard the East wind as the carrier which brings the water. That part is played by the South-west wind. Our East winds are generally dry, and even in this case there was no departure from the general rule, for in the North of Scotland there was practically no rain.

The interaction between two air currents at different temperatures is not the only cause of rainfall in cyclones. Upward motion and consequent expansion, with formation of cloud and rain, must occur whenever the paths along which the air is moving converge and there is not sufficient increase of velocity to compensate for the diminished cross-section of the current. The motion of the air in such circumstances may be likened to the flow of water in a river which is gradually narrowing. In the narrow places either the water must be deeper or its speed must increase, or we may find a combination of both these occurrences. In the case of an air current increase of depth can only be attained by an increase of vertical thickness—in other words, by ascent of a portion of the air. In the example which we have just considered, steady rain fell during several hours in the region covered by the South-west wind. Over half an inch was measured in the part of England lying to the South of the path.

The Motion of Cyclones.—The paths followed by the centres of depressions may be very erratic, and a chart on which are plotted all paths of cyclones experienced during a fairly long period such as a year, presents at first sight a hopelessly confused and tangled appearance. The general motion is, however, very decidedly towards the East. Motion from East to West, though by no means unknown, is uncommon. The many attempts which have been made to classify the tracks of depressions have not led to very definite results, though undoubtedly some paths are more frequented than others.

Equally variable is the rate at which depressions move. Twenty to thirty miles per hour is a very usual rate but this speed may be considerably exceeded, while on the other hand at times a cyclone may remain almost stationary for long periods.

Anticyclones.—Having considered some of the main characteristics of cyclones, we turn now to the type of pressure distribution to which the term anticyclone has been applied. In this type the isobars again form closed curves, generally circular or oval in shape, but at the centre of the system the pressure now has a maximum instead of a minimum value.

In the central region we find calms or light variable airs. Nearer the periphery there is more definite air movement. In accordance with Buys Ballot's law, that the low pressure lies to the left of an observer with his back to the wind, the arrangement of air currents is such as to give an impression of circulation round the centre, the direction of rotation in the northern hemisphere being the same as that of the hands of a clock. The winds are generally light, for the isobars are usually considerably farther apart than is the case in cyclones.

The anticyclone is generally regarded as the pressure distribution typical of fine weather, and, if by fine weather we mean absence of rainfall, the statement is generally, but not invariably, correct. Anticyclones are distinguished from cyclones by their greater stability. Frequently they remain stationary for days together, so that our long spells of dry weather are often associated with their occurrence. At other times they travel like cyclones, the direction of motion being in general from West towards some Easterly point, but the rate of progress is usually slow compared with that of cyclones.

As regards the appearance of the sky, we may distinguish two types. In the one the sky is cloudless or nearly so, while in the other it is covered by a uniform layer of cloud. So persistent may this layer be that at times the whole country is covered by it for days in succession, with hardly a gleam of sunshine anywhere. The appearance is then gloomy, and even threatening, but rain seldom results. The temperatures experienced with the two types of conditions are very different. During the prevalence of the cloudy type, the direct radiation of heat from the sun is practically cut off, and the temperature remains strangely uniform, the day and night readings differing by no more than a degree or two. In winter the temperature under such circumstances is often considerably above the normal. On the other hand, in the cloud-free type conditions are very different. The effects of radiation have free play, and the contrasts between day and night are great in consequence of the heating of the earth's surface by day and its cooling by night (see p. 14). In winter when the nights are long the cooling by night is the more important factor. The heat received by day is insufficient to make good the loss by night. Some of our severest and most prolonged frosts have occurred under such conditions. In summer, on the other hand, the warming of the earth's surface can go on throughout the long summer day, and the comparative absence of air motion in the shape of strong winds affords opportunity for the strong heating of the surface layers, so that we may get very high temperatures.

As an illustration of anticyclonic conditions we have selected the synoptic chart for 7 A.M. on September 4, 1911 (Fig. 8). Over the Continent the cloudless type prevails. The highest temperatures were experienced along the shores of the Bay of Biscay where the wind was Easterly, so that the moderating effect of the sea was eliminated. The temperature rose to 99° in the shade at many stations in this region in the course of the day. Over the British Isles, conditions are more variable. The cloudy type has established itself temporarily over a considerable area in the West and South of England, and in the St. George's Channel region we even find very light rain.

The fine weather of a clear anticyclone is often marred

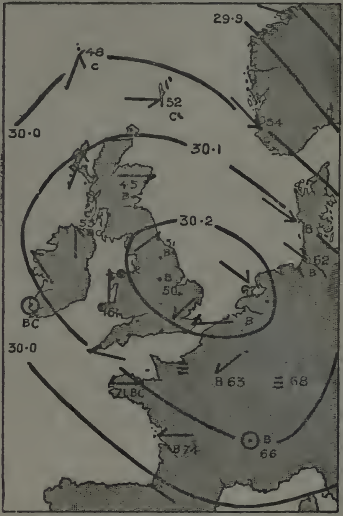

FIG. 8.—Anticyclone of September 4, 1911, 7 A.M. (For explanation of symbols, see p. 35.)

by much fog, especially in autumn and winter. The cooling of the surface by night, and consequent drainage of cooled air towards low-lying regions where it may mix with warmer air moistened by evaporation from rivers or marshes, often give rise to fogs by the process described on p. 29. In our example, fog is shown at the French stations Belfort and Havre. As a rule, the warming which takes place after sunrise is sufficient to dispel the fog, but occasionally this is not so. In our large towns, where the atmosphere is polluted by smoke, the persistence is often very marked, for the evaporation of the water particles which compose the fog is much delayed by the soot and tarry matters thus artifici lly added to them.

The air of an anticyclone is usually distinctly dry, much drier than that of a cyclone at corresponding temperatures. It must, however, be remembered that anticyclones are characterised by slight air motion. The air near the surface has therefore good opportunity for absorbing moisture by evaporation from the ground, especially if there has been recent rainfall. The air near the surface may thus be nearly saturated so that condensation is easily induced. We may under such circumstances get a development of fog on a large scale, and other causes besides nocturnal radiation may be at work in aiding the process. In some anticyclones the tendency for fog formation is so strongly developed, that almost the whole country is covered by a layer from which only the hills project.

CHAPTER III

FORECASTING FROM SYNOPTIC CHARTS

The International Weather Service.—The recognition of the phenomena of the travel of weather immediately suggested the possibility of foretelling future meteorological conditions by the regular collection of information regarding the present. Attention was very forcibly drawn to the subject by a severe gale which swept along the South of Europe on November 14, 1854, and did great damage to the English and French fleets in the Crimea. Shortly after this occurrence, the French astronomer, Leverrier, succeeded in establishing in Paris an organisation for collecting weather reports on an international basis. In this country, a similar organisation was established soon after, under the direction of Admiral Fitzroy. At the present day, arrangements are made in almost all countries for collecting by telegraph the information necessary for the construction of daily synoptic charts with a view to forecasting the weather.

In the West European area, with which we are more directly concerned, observations are taken daily at 7 A.M. of the mean time of the meridian of Greenwich. By about 9 A.M. the information has been exchanged between the central offices in the various European capitals and the synoptic charts have been drawn, so that the work of preparing forecasts can proceed. A Daily

Report, embodying the observations and containing a copy of the synoptic chart, is issued the same day. Observations are also taken in the evening, and are similarly treated. In this country the *Times* newspaper has for many years published the synoptic charts in its daily issues.

The area embraced in the Daily Weather Reports of this country includes, in addition to the British Isles, the whole of Scandinavia, the West of Germany, France, and a part of Spain. Some years ago arrangements were made to receive regular reports by cable from the Azores in mid-Atlantic, and more recently the laying of the cable to Iceland has made it possible to obtain regular information from Iceland and Faroe. Wireless telegraphy has also extended the area to the Westward of the Irish coast. The importance of this extension will be apparent when we reflect that the general direction of travel of cyclones and indeed of all weather phenomena is from the West in the latitude of Europe.

Weather Types.—The general principles on which forecasts are based will be evident from the account we have given above of the behaviour of cyclones and anticyclones. Well-defined cyclones and anticyclones do not form the only types of pressure distribution to be found on our synoptic charts. They are, in fact, of rather rare occurrence, but as they are the most definite types with which we have to deal, they have been more closely studied than any others. In order to make this sketch of the system of forecasting from synoptic charts more complete, we will consider briefly some of the sub-types most frequently mentioned in weather reports.

Secondary Depressions.—The map may show us a principal depression with one or perhaps several smaller depressions on its periphery. These small satellites are spoken of as "secondaries" to the primary. The most usual effect of a secondary is to reduce the gradient between secondary and primary, and to steepen it on the side of the secondary remote from the primary. As an example, we give in Fig. 9 the synoptic chart for the

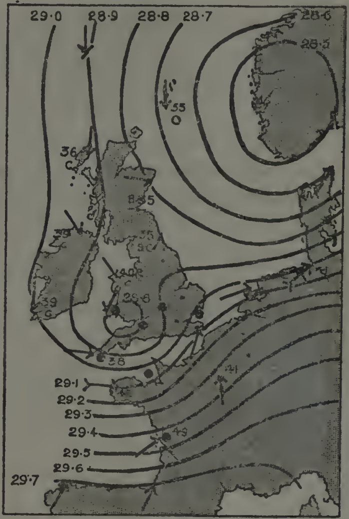

FIG. 9.—Secondary Depression, December 4, 1909, 7 A.M. (For explanation of symbols, see p. 35.)

morning of December 4, 1909. It shows as a primary depression over the South of Norway, with a clearly defined secondary over South Wales. Along the line joining the centres of a primary and secondary situated as these two are, there must be a point where the gradient for North-westerly wind due to the primary is exactly equal and opposite to the gradient for South-easterly wind, due to the secondary. This point of zero pressure gradient should be a point of calm. On our map, we find very light and variable breezes in the region of slight gradient over the North of England. To the South of the secondary there is a very steep gradient over the English Channel, France, and Germany, and gales prevail in many places. The secondary moved rapidly North-eastward. On the following morning, the primary was still in much the same position; it had moved very slightly Westward, its centre being just off the Norwegian coast, instead of over Norway. The secondary had advanced to Denmark. It was the cause of severe gales and heavy rain as it passed over the South of England.

Sometimes secondaries appear merely as a bulge in the isobars on one side of the primary. In other cases the secondary may become so fully developed that the terms primary and secondary are no longer applicable. In fact, cases are not uncommon in which a secondary develops rapidly and assumes larger dimensions and greater intensity than the original primary.

V-shaped Depressions.—We pass on to the so-called V-shaped depression. As the name implies, the isobars are V-shaped, the point of the V being generally directed towards the South. The central line of the V is called the trough, for its passage over a place marks the lowest value of the barometer. Fig. 10, a reproduction of the synoptic chart for 8 A.M. on January 7, 1900, shows a typical V. There are Southerly winds on the Eastern or front side of the trough, and winds from between West and North, on its Western or rearward side. A V-shaped depression may be looked upon as coming within the general case of the interaction of two air currents of different direction, to which reference has already been made on p. 38. The transition from Southerly to North-westerly wind as the trough passes is often very sudden, and it is then accompanied by the phenomena of a line-squall, including the heavy "clearing shower." The interaction of the two currents is not the only cause

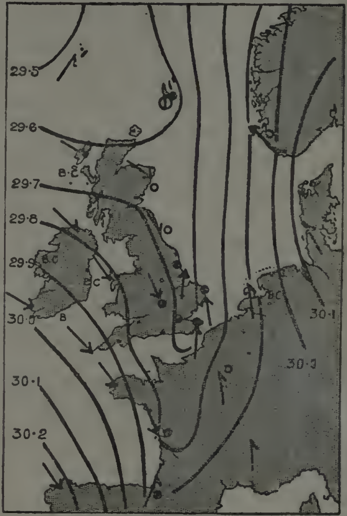

FIG. 10.—V-shaped Depression, January 7, 1900, 8 A.M. (For explanation of symbols, see p. 35.)

of rainfall in the typical V-shaped depression. There is usually also a good deal of rainfall of the type referred to on p. 47, associated with the Southerly wind in front of the trough. The North-westerly wind is characterised by squally and showery weather alternating with fair intervals, like the North-westerly wind in the rear of a circular depression.

Wedge Isobars.—Cyclonic depressions frequently follow one another along very similar paths. Special weather conditions prevail in the region between two such cyclones. The isobars are V-shaped, but the V is inverted, *i.e.* its point is directed towards the North

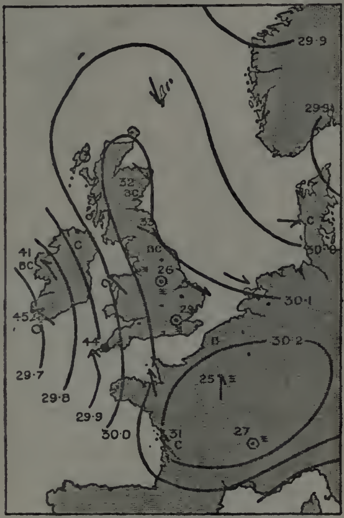

FIG. 11.—Wedge, February 22, 1906, 8 A.M.

and its central line or axis is a line of maximum pressure. In our example, Fig. 11, the synoptic chart for February 22, 1906, the "wedge"-like arrangement of isobars over England forms a Northward extension of an anticyclone over France. The axis which lies over the centre of England is a region of calms or light variable airs; it forms a neutral area between the North-westerly wind, of the depression which has passed by, and the South-easterly wind in front of the advancing one. A wedge is usually a region of fine weather, especially on the Eastern side of the axis, though often there is a good deal of radiation fog as in this case. To the West of the

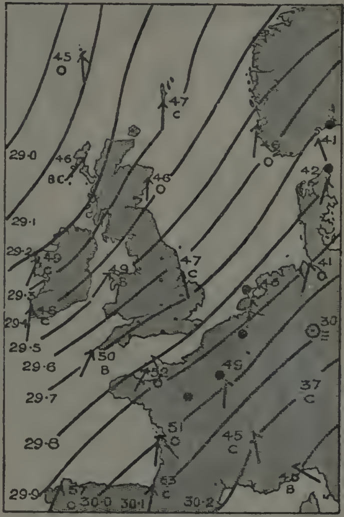

FIG. 12.—South-westerly type, December 19, 1911, 7 A.M. (For explanation of symbols, see p. 35.)

ridge or axis, the cloud development of the advancing cyclone is apparent, in places rain has already set in in our example.

Straight Isobars.—On many occasions the isobars show no definite arrangement which can be classed under any of the types which we have considered so far. In Fig. 12 we have an example of what we may call a "South-westerly" type in which this is the case. The isobars are approximately parallel, and run from South-west to North-east, and consequently winds from between South and South-west are general throughout the area. The weather under such circumstances may vary from fine to showery, and we may even come across regions in which there occur several hours of steady rainfall. Much must depend on the moisture content of the air, and on the distribution of temperature. If the air is nearly saturated, there is likely to be steady rain in regions where it has to ascend over high ground. In our example it is generally fine. Note, however, the line of rain dots extending from Central France to the North of Holland, and reappearing in the North of Denmark and South of Norway. East and West of the line, the weather is fair or fine. Such a linear distribution of showers in a South-westerly or Westerly current is very common. It may be attributed to differences of temperature or moisture content in adjoining parts of the current, which give rise to convection currents, and so cause showers. In our example, the temperature is distinctly lower on the Eastern than on the Western side of the rain line.

Over North-western Europe, South-westerly conditions are more common than any other type of pressure distribution. They often continue for several weeks without interruption. Frequently, we find in the general South-westerly current small depressions which move rapidly towards East or North-east. The centres of these depressions generally keep to the North of the British Isles, or cross our Northern districts. Thus the direction of the wind over our Southern counties is persistently from between South and West. At other times, we notice that a decided fall of the barometer spreads in from the West without the appearance of any definite centre of low pressure on the map, even though the area under observation be extended far to the Westward, by means of ships' observations. The map simply shows a bulge in the isobars similar to that which marks some types of secondary depression. As the barometer falls in the West the isobars assume a more South to North direction, while the gradient becomes steeper. The wind accordingly backs towards South or even South-east, and increases, frequently attaining gale force. There may also be rainfall of several hours' duration. Presently the fall of the barometer ceases, and gives place to a rise, the wind veers towards West, and the weather improves. "Secondaries" of this nature may follow one another rapidly during South-westerly weather.

During winter, South-westerly conditions are always accompanied by mild weather, and generally by much rain and frequent gales. In summer, moderate temperatures prevail during a spell of South-westerly conditions.

Parallel isobars favourable for winds from other directions also occur, but we do not propose to give examples for all directions. We content ourselves with an example showing the distribution of pressure during a period of persistent March East wind (Fig. 13). The chart for March 22, 1883, when extended to include the Eastern part of the North Atlantic Ocean, shows a deep depression off the coast of Spain, with an anticyclonic region of high pressure between Scotland and Iceland. Over the British Isles, France, and Germany the pressure distributions favour strong East or North-east winds, bringing us cold dry air from Northern Russia.

Meteorological Development and Travel.—It will be obvious from this brief sketch that the art of forecasting consists in forming an estimate of the probable displacement of the various systems shown on the map, and of the developments that are likely to take place in them. The observations of pressure are to the forecaster the most important. If he can foresee the changes which are

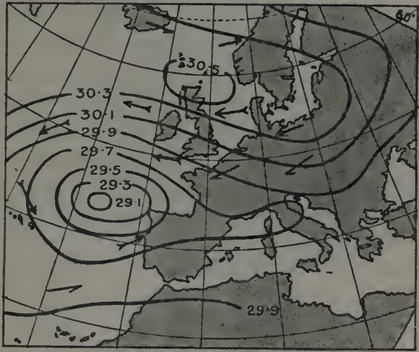

Fig. 13.—Easterly type, March 22, 1883.

likely to ensue in the configuration of the isobars, he can foretell the winds with a high degree of precision. The distributions of weather and temperature are less directly related to the isobaric distribution, for it is possible to get two maps on which the isobars are very similar but with very different distributions of rain and sunshine, but even here we have seen that a certain regularity is apparent.

Developments are always in progress in the meteorological situation, and the principle of travel, which is the most obvious one on which to base forecasts, will not by itself give satisfactory results. It is for this reason that the suggestion to give warning of the approach of gales towards the coasts of Europe by communicating by cable information regarding the eastward progress of severe cyclones experienced in America has led to no practical result. By compiling the observations made by ships during their passage across the ocean, it has been possible in a few instances to trace the advance of a cyclone from one side of the Atlantic to the other, but such cases are rare. The suggestion was put to the test of experiment for a number of years, but it was found that the changes which occur in the configuration of cyclones are so considerable, and their paths so erratic, that no satisfactory warnings can be based on information cabled from America, until our knowledge of the principles underlying meteorological changes is more complete.

CHAPTER IV

AVERAGE VALUES

Average Values.—Hitherto we have approached the problem of how to deal with meteorological observations by considering together the records obtained from different places at one particular instant. Much valuable information may also be obtained by considering the records for longer periods—that is, by dealing with average values. For example, we may take all the observations of pressure for successive days of a month, and take their average, and if we repeat the process for all our stations and enter the results on a map, we can construct a map of mean pressure for the month, and again we can bring out the general features of the distribution by drawing isobars of equal mean pressure. We can go still further, and take out the means for a particular month for a series of years, and, by taking their average, determine the long period average or normal value for that month. By repeating the process for many stations, we get the material for constructing a map of average pressure for the month. Figs. 14 and 15 show the distribution of average pressure over the globe for January and July. In a similar manner, we can prepare maps of the distribution of average temperature or average rainfall.

Average Pressure for January.—On the map for January, one of the most conspicuous features is a region of high pressure over Siberia. In its central region, the average pressure is as high as 30·6 inches. From the point of highest pressure, the system extends both Eastward and Westward. To the West, a belt in which pressure is above 30·1 inches, covers Southern Europe and connects with a region over the Atlantic Ocean, just off the coast of Spain, in which pressure exceeds

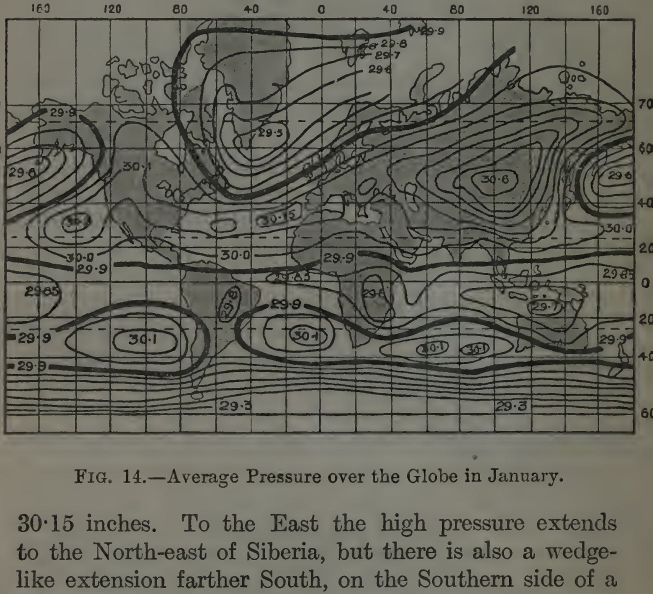

FIG. 14.—Average Pressure over the Globe in January.

30·15 inches. To the East the high pressure extends to the North-east of Siberia, but there is also a wedge-like extension farther South, on the Southern side of a large area of low pressure over the North Pacific Ocean. This wedge extends towards an area of high pressure, with readings of about 30·2 inches over the North Pacific Ocean off the coast of California. This is connected in turn by a ridge of high pressure, extending across the American continent with an area of "high," with pressures above 30·15 inches in mid-Atlantic, situated at no great distance from the "high" off the coast of Spain, to which reference was made in tracing the Westward extension of the Siberian system. In the Southern hemisphere we notice well-defined regions of high pressure over the three oceans. They are oval in shape, and the longer axes of the ovals lie in the East to West direction. We have thus in each hemisphere a belt of high average pressure encircling the globe almost completely. The belts may be identified by tracing out in the Northern hemisphere the course of the isobar marked 30·1 inches, and in the Southern hemisphere that marked 29·9 inches. The latter have been thickened, as representing approximately the average pressure for the whole globe. The central lines of the belts lie about 30° to 40° distant from the equator.

On the equatorial side of these belts, pressure falls off to a minimum in a belt of low pressure, encircling the earth in the neighbourhood of the equator. Its position may be identified by tracing out the course of the isobar for 29·85 inches. The actual line of lowest pressure lies somewhat to the South of the equator. The lowest pressures in the belt appear over the continents. Over Africa there is shown an isobar 29·8 inches, and over Australia the isobar 29·7 inches appears. The value 29·8 inches is also shown over South America.

On the polar side of the high pressure belt, we find in the Southern hemisphere a steady decrease of pressure, with the isobar of 29·4 inches encircling the globe between latitudes 50° and 60° South. In the Northern hemisphere, conditions are rather more complex. There are two well-defined regions of low pressure, one over the North Pacific Ocean, the other over the North Atlantic, with its lowest pressure value in the area between Iceland and Greenland. From this region, low pressure extends North-eastward into the Arctic Ocean.

On the Northern side of the low pressure area of the Northern hemisphere, our map shows us an increase of pressure towards the pole. Recent Antarctic expeditions have brought to light a certain amount of evidence which tends to show that a similar increase of pressure may also be expected as we approach the South pole. It has been impossible to obtain direct confirmation of this suggestion, as all observations of pressure which we possess from the plateau of the Antarctic continent have of necessity been taken at considerable altitudes above sea level. They therefore require to be reduced to sea level before they can be plotted on our maps for comparison with readings from other parts of the world, and for this purpose we need to know accurately the height of the positions where the observations were made. This information can only be obtained from a detailed survey of the country, and this has not yet been possible for reasons which are not far to seek.

The consideration of the pressure distribution in January leads us to the following generalised scheme. In each hemisphere there is a belt of high pressure encircling the globe at about 30° or 40° from the equator, and a polar cap of high pressure. On the equatorial sides of the belt of "high," pressure falls off and reaches a minimum in a belt encircling the globe in the neighbourhood of the equator. On the polar side of the belt of "high," pressure likewise decreases and reaches a minimum at a distance of about 60° from the equator.

West Wind Belts.—We have next to consider the distribution of pressure in connection with the wind circulation. We have seen that on a synoptic chart there is a very close connection between the direction and force of the wind and the course of the isobars. A similar connection exists between the distribution of average pressure and the so-called prevailing wind. A map of average pressure gives us, in fact, a representation of the average flow of air over the earth's surface. If we regard our map for January in this light, we should expect to find the prevailing wind over Northern Europe and the adjoining parts of the Atlantic Ocean, and also over Western Siberia, to be from the South-west. In the East of Siberia and on its Pacific coast we may expect North-westerly to Northerly winds ; but on the Southern side of the North Pacific low pressure system we again find an average gradient for South-westerly wind. Over North America, the distribution of pressure favours South-westerly wind over the Western part of the Continent, North-westerly wind on its Eastern side. This scheme of winds, deduced from the distribution of average pressure, is found to be in close agreement with the actual prevailing winds as deduced from observations of wind.

In the Southern hemisphere, we must remember that Buys Ballot's law of the relation of wind direction to pressure distribution needs modification. An observer with his back to the wind there has the region of low pressure on his right, instead of on his left as in the Northern hemisphere. On the Southern side of the high pressure belt, Westerly winds are therefore to be expected over the region in which pressure decreases as we go polewards. We have here, in fact, the sailor's well-known "roaring forties."

We see, then, that in both hemispheres we have, on the polar side of the high pressure belts, broad belts of prevailing Westerly winds, extending from about latitude

40° to 60° North. In the Southern hemisphere, where the smaller land surface introduces fewer complications due to the unequal heating of land and sea, the circulation is particularly conspicuous. Here the oscillation between North-westerly and South-westerly directions, which are so conspicuous in the Northern hemisphere, are relatively unimportant.

We should be wrong if we regarded the flow of air in the West wind belt of the Northern hemisphere as a steady flow from West to East. During the prevalence of Westerly or South-westerly conditions, the actual conditions may approximate very closely to the average ones, and we may regard our cyclones, secondaries, and V-shaped depressions as mere incidents in the general drift from West towards East. At other times, the Westerly current is entirely interrupted or displaced from its normal position. Such displacements or interruptions occur with Northerly or Easterly weather. Fig. 13, on p. 61, represents an instance. The high pressure belt is displaced far to the South of its normal position. It is well to the South of latitude 30° North. The Westerly belt on its Northern side scarcely stretches as far North as Spain, while over the region North of latitude 40° we find the easterly current normally shown some 20° farther North, on the polar side of the Atlantic low pressure system in the region between Greenland and Spitzbergen. In the Southern hemisphere the Westerly current of the " roaring forties " is much more constant, such big displacements from its normal course do not occur.

Trade Winds.—On the equatorial side of the high pressure belts there is a flow of air towards the equator in both hemispheres. The equator itself, or rather the line of minimum pressure in the equatorial low pressure belt, which in January is several degrees South of the equator, is a region of calms or light variable breezes. As there is convergence of air towards it from both sides, it must be a region of ascent of air, and hence of cloud formation and rainfall. In the Northern hemisphere, the flow towards the equator is from North-east, in the Southern it is from South-east. These winds constitute the so-called Trade Winds. Over the oceans they blow with most remarkable persistence. In the region of the South-east Trade of the South Atlantic, the current is particularly steady, interruptions similar to those which occur in the West wind belt of the Northern hemisphere being unknown. At St. Helena, which lies in the centre of the South-east Trade Wind region, the South-east wind blows day after day with no more variation than a point or two in direction, and a few miles per hour in velocity. Over the continents the course of events is rather less regular.

The central line of the high pressure belts which mark the lines of separation between the Westerly winds on the polar side, and the Trade Winds on the equatorial side, are regions of variable wind direction. Usually the wind here is also very light, and calms are of frequent occurrence.

Polar Easterly Winds.—On the Northern side of the minimum of pressure, approximately in 60° North latitude, we should expect Easterly winds to predominate, a supposition which is borne out by the winds observed in the Behring Sea neighbourhood, and on the West coast of Greenland. In the Southern hemisphere, recent Antarctic expeditions have also met with Easterly wind after the West wind belt of the "roaring forties" had been left behind. The evidence in favour of the view that pressure increases as we approach the pole is indeed largely based on the occurrence of these East winds.

Conditions in July.—If we turn now to the normal pressure for July (Fig. 15), we can identify similar general features on the map. In the Southern hemisphere, the high pressure systems over the oceans have moved further Northward, and pressure has increased in them.

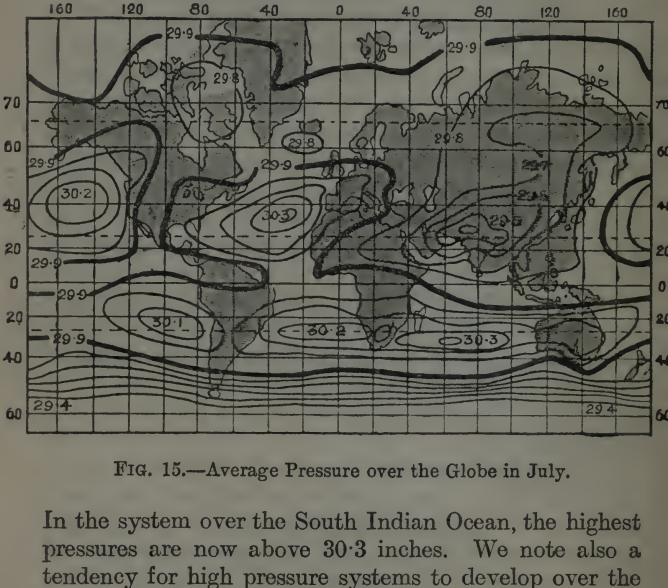

FIG. 15.—Average Pressure over the Globe in July.

In the system over the South Indian Ocean, the highest pressures are now above 30·3 inches. We note also a tendency for high pressure systems to develop over the continents, particularly in South Africa and Australia. In short, the high pressure belt of the Southern hemisphere has become much more definitely developed in the course of its Northward displacement. In the Northern hemisphere, the high pressure systems over the oceans in latitude 40°, have become more developed, but the ridges connecting them across the continents have become broken up. We can still, however, recognise the region of Westerly wind on the Northern side of the systems over the oceans and over Northern Europe. The equatorial belt of low pressure, the line of separation between the North-east and South-east trade winds, has also moved Northward. Over the Atlantic and Pacific Oceans, it is shown somewhat to the North of the equator. Over Siberia, the high pressure system has disappeared. In its place we find a low pressure area centred to the North of India. This system, which is much elongated in the West to East direction, may be regarded as the representative of the equatorial low pressure belt in this part of the world.

Monsoons.—The fundamental seasonal changes in the pressure distribution are associated with seasonal changes in the winds, known as Monsoons, which are of enormous importance in modifying the climates of the regions in which they occur. Thus in January, the wind in the Northern part of the Indian Ocean is from North-east. India enjoys its dry season. On the other hand, in July, the North-east wind is displaced by a South-west wind, the South-west Monsoon, which deposits copious moisture over the Indian continent (see p. 25). Similar typical seasonal changes of wind occur on the coast of China. During our Northern winter cold, very dry North-westerly winds prevail, but when once the heating up of the vast Asiatic continent has taken place and led to the establishment of the low pressure system in the interior, Southerly winds bring copious rainfall.

Seasonal changes of wind of this nature are not confined to the Asiatic continent. They are very conspicuous also along the North coast of Australia, which during our winter is exposed to damp North-westerly winds, while during our summer it enjoys a South-easterly wind, a branch of the South-east Trade Wind.

Again, on the West Coast of Africa, in the neighbourhood of the Gambia, the prevailing wind during our winter is the Harmattan, an intensely dry North-east wind which comes from the North African desert and feeds the North-east Trade Wind of the North Atlantic. In summer, the equatorial belt of low pressure where the two Trade Winds meet, has advanced Northwards to near the latitude of Bathurst (14° North), and the climate is intensely damp and rainy. Local causes deflect the Trade Winds, and the prevailing winds are from West to South-west.

Seasonal Changes of Rainfall.—If we compare the maps of mean pressure for January and July, we notice that the two high pressure belts and the equatorial low pressure belt move backwards and forwards in the course of the year, between extreme Northern and extreme Southern positions. The whole system is farthest North in our Northern summer when the sun has its greatest Northern declination, and farthest South in our Northern winter when the sun has its greatest Southern declination. This annual movement has a most important influence on the seasonal variations of climate in different zones on the globe.

The equatorial belt of low pressure passes over a place situated on or very near the equator twice in the course of each year. Seeing that both Trade Winds give a steady flow of air towards the low pressure belt, the belt must be a region where ascent of air predominates, and therefore also a region of much cloud and rain. Places in tropical latitudes must therefore experience two rainy periods in the course of the year, one at the time when the equatorial low pressure belt passes over the place on its Northward excursion, the other during its passage Southward. The year is, in fact, divided into four seasons—two rainy, and two relatively dry. The regular alternation of winter and summer experienced in Temperate latitudes is absent.

At some distance from the equator, the two rainy seasons coalesce, and there is a single rainy season at the time of maximum declination of the sun, in what we should call summer. We saw an example of this in the seasonal variation of rainfall at Bathurst on the Gambia. At a somewhat greater distance from the equator beyond the tropics, we find a zone with definite winter rains. During our summer, the high pressure system centred between Spain and Florida is well developed—in other words, anticyclonic dry conditions predominate in the area under its sway. Thus practically no rain falls in the North of Africa and the Southern part of the Mediterranean during this part of the year. In the Northern winter, on the other hand, occasions arise on which the Westerly winds associated with cyclonic depressions on the Northern side of the high pressure belt can affect the Mediterranean region. Thus Morocco receives practically all its rain during the winter months. In Capetown, similar conditions prevail. During January, the Southern summer, anticyclonic conditions predominate, and there is a dry season. In winter (July) the high pressure belt is farther Northward, and occasions arise when the Westerly wind on its Southern side can affect the extreme tip of the African continent and bring it rain.

At still greater distances from the equator, the seasonal variation of rainfall is less marked. In North-west Europe, Brittany, the British Isles, and Norway, autumn and winter have the heaviest rainfall in consequence of the greater intensity of the South-westerly current, which manifests itself in more frequent cyclonic depressions. Over Central Europe and Western Siberia most rain is experienced in summer, for in winter, in consequence of the low temperature over the Continent, the air there can contain comparatively little moisture, even when it is saturated, and hence precipitation during this season must be comparatively low.

The following results, in which the average rainfall appropriate to each season is expressed as a percentage of the year's fall, illustrate these points for various regions:—

	Dec.-Feb.	March-May.	June-August.	Sept.-Nov.
Equatorial Africa (Coastal regions)	26	36	2	36
Equatorial Africa (Lakes and Nile Plateau)	22	36	15	27
French Sudan, Lat. 13° N.	...	10	63	27
North Coast of Africa, 32° N.	65	10	...	25
South Italy, 36° N.	42	19	3	36
North of Scotland, 58° N.	31	19	20	30
Central Europe, 51° N.	18	24	35	23
North Asia, 55° N.	7	13	58	22
Cape Town, 34° S.	8	27	46	19
Shanghai, 31° N.	13	24	41	22

The considerations which we have brought forward here, in discussing the seasonal variation of rainfall, must not be regarded as of universal application. Local circumstances depending on the distribution of land and sea may modify them profoundly. Thus we have seen that on the coast of China, in about the same latitude as Morocco, the normal variation of the seasons gives a dry winter and a very moist rainy summer. Figures for Shanghai have been added to the table.

CHAPTER V

DEPARTURES FROM AVERAGE VALUES—CORRELATION

MUCH study has been devoted to the question of the departure of the mean values for individual months, seasons, or years, from the corresponding averages for long periods. The practical importance of the question is great, for if once the laws which regulate these divergences can be determined, we shall be well on the road towards the preparation of forecasts of the general character of the weather for long periods ahead. The problem has been approached from two distinct points of view. Either the records from a single place or district have been examined with the object of tracing in them the regular recurrence of similar conditions at fixed intervals, or consideration has been given to the divergences from average recorded at one place in connection with those recorded elsewhere, or even with quantities such as, for example, the activity of the sun as represented by the extent of his spots, and endeavours have then been made to trace out relations between the two. It cannot be claimed that either method has as yet led to many results which can be regarded as more than "suggestive"; but if we remember the complexity of the problems which have to be solved, this need not cause surprise or induce pessimistic views regarding future progress.

Periodic Phenomena.—If we are looking for evidence of periodic recurrence in meteorological phenomena, it must be remembered that weather, as we experience it, may be the resultant of many influences, some of which may recur at regular intervals, while others may be what we call accidental. Obviously the longer the period over which our records extend, the better our chance of successfully eliminating the effects of such accidental variations. Very few existing records extend back over one hundred years, and even those which cover fifty years are not always suitable for the determination of periodicities owing to uncertainties regarding the conditions under which the early observations were made, or changes in environment at the stations. The gradual growth of buildings near a station might, for example, influence the temperature readings appreciably, and might lead an investigator to attribute to Nature what is really the result of man's handiwork.

A good deal of evidence has been accumulated in favour of the view that the meteorological conditions of our globe exhibit a periodicity of thirty-five years—in other words, that there is a tendency for a similarity in the general run of the seasons to recur after the lapse of this interval of time. Bruckner's study of the information available regarding the variations of the water level in the Caspian Sea, first suggested this period. Russian records also contain a good deal of information regarding floods or unusual shallowness of the rivers, and the dates of their opening and closing to navigation, and a close examination of this material tended to confirm the view. Subsequently, the investigation was extended to the water levels of lakes in other parts of the world, having inland drainage, and the results were again in many instances broadly confirmatory of Bruckner's cycle. Records of the advance and recession of Alpine glaciers also supplied a certain amount of confirmation. The evidence in favour of the existence of a periodicity of thirty-five years has had to be culled, often with great labour, from historical documents in which references to meteorological phenomena are only incidental. Only by using such sources of information has it been possible to extend the inquiry over the greater part of the last two centuries. Such indirect evidence is not as satisfactory as we could wish, but the number of meteorological records which are of sufficient length to be of service in an inquiry of this sort is very small. Hann's examination of the rainfall records from Padua, Milan, and Klagenfurt, which cover the years from 1726–1900, has shown some indications of the reality of a period of average length about thirty-five years.

In the Meteorology of the Southern hemisphere, different authors have found indications of the existence of a period of nineteen years. The records of Australia, South Africa, and South America all show suggestions of such a period, but as yet the evidence cannot be regarded as conclusive.

Mathematical Analysis.—The process of determining periodicities from short records is unsatisfactory, as we can only measure the interval from one group of abnormal years to the next group in which the abnormality is of a similar nature. At best the results of the observations can be represented by a curve, and the supposed periodicity be determined from its inspection. Accidental variations may easily prove misleading. When longer records are available, we may call in the aid of mathematical analysis. Such analysis has been applied to the long rainfall record from Padua, which was mentioned above, and has resulted in the discovery of periodicities of 592 days and 148 days hidden away among the accidental variations. Unfortunately, this method of investigation is very laborious, so that as yet it has not found wide application in meteorological investigations.

Correlation.—The second method of investigation, which may be described as that of looking for indications of correlation between phenomena in different parts of the world, leads us into the problems of what may be called "world meteorology." Observations of pressure are specially suitable for discussion from this point of view, as the remaining elements may be conveniently grouped around the variations of pressure. One of the earliest relations of this kind to attract attention was that between the pressure values observed respectively in Iceland and the Azores. It has been found that if for a given month the mean pressure in Iceland be above the average, then the chances are in favour of the corresponding value for the Azores being below the average, and *vice versa*. Now a glance at the maps of average pressure distribution over the globe for January and July (Figs. 14 and 15) will show that Iceland is in the low pressure area which covers the North Atlantic Ocean, while the Azores lie in the high pressure system off the coast of Spain. Pressure below the average in Iceland and above it in the Azores means an increase in the steepness of the gradient favourable for South-westerly wind over the Eastern part of the North Atlantic Ocean, which cannot be without effect on the weather conditions of North-west Europe. Expressed in terms of synoptic charts it means unusual frequency or unusual intensity of cyclones passing over this part of the ocean towards the British Isles and Norway. If this state of things occurs in winter, we experience mild rainy weather with frequent gales. On the other hand, a weakening of the normal gradient over the ocean is associated with rainfall and temperature below the average, over our islands. On rare occasions, the conditions may depart so far from the average, that the mean pressure in Iceland is actually higher than that at the Azores for the corresponding period. The normal gradient is then reversed, and we get North-easterly or Northerly winds over the Eastern part of the Atlantic, and abnormal weather conditions over North-west Europe. In view of their forming an index of the state of development of the anticyclonic and cyclonic systems of the North-east Atlantic, which exert so profound an influence over the weather conditions of Europe, Iceland and the Azores have been referred to by the appropriate name of "centres of action." Naturally we look for centres of action, in this sense of the term, in those regions which appear as regions of "high" or "low" on the maps of average pressure, such as, in the Northern hemisphere, the high pressure system over Siberia, the North Pacific low pressure system, and the "high" to the South-east of it. In the Southern hemisphere, the high pressure regions over the three oceans suggest themselves for investigation. Unfortunately, these regions in many cases present few attractions to traders, despite their meteorological interest, so that regular observations in them can only be organised with difficulty. The gaps are, however, gradually being filled up by the establishment of stations in outlying islands. Suggestions are not wanting that oppositions similar to that found between Iceland and the Azores exist also between Tahiti in the South Pacific "high" and Terra de Fuego in the Southern low pressure belt, and between Siberia and Alaska.

The method of correlation has been extended by considering the departures from average observed at one place during a given month or season, in relation with those observed elsewhere at some subsequent period, the underlying idea being that a knowledge of the conditions prevailing in the present may enable us to form an opinion of those to be expected in the future. Special attention has been given in this connection to the conditions over the North Atlantic, and many endeavours have been made to determine the influence of the ice conditions in the Iceland-Greenland region on the subsequent weather of North-west Europe. Careful examination of the available records has led Meinardus to put forward tentatively the suggestion that the following phenomena are closely and intimately connected :—

A.—(1) Weak Atlantic circulation during the period from August to February, *i.e.* pressure difference between Europe and Iceland or between Iceland and the Azores less than the normal, as a consequence of which the South-westerly winds over the region between Europe and Iceland must be less strong or less persistent than is normally the case.

(2) Low water temperatures on the coasts of Europe from November to April.

(3) Low air temperature over Central Europe from February to April.

(4) Little ice off Newfoundland in spring.

(5) Much ice off Iceland in spring.

(6) Bad wheat and rye harvest in Western Europe and North Germany.

B.—(1) Strong Atlantic circulation from August to February.

(2) High water temperature on the coast of Europe from November to April.

(3) High air temperature in Central Europe from February to April.

(4) Much ice off Newfoundland in spring.

(5) Little ice off Iceland in spring.

(6) Good wheat and rye harvest in Western Europe and North Germany.

The curves of Fig. 16 show the variations of some of

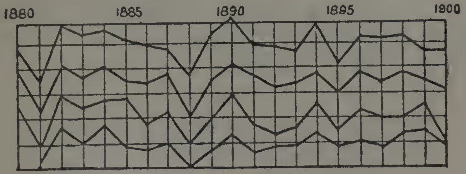

Fig. 16.

First Curve, Pressure Difference, Azores—Iceland (August to February)
Second Curve, Pressure Difference, Copenhagen—Iceland (August to February)
Third Curve, Amount of Ice off Newfoundland in Spring
Fourth Curve, Warmth of Water in the North Sea (November to April)

these quantities from year to year on which this generalisation is based. It will be admitted that they show close similarities though the variations in the various elements are not in all cases parallel. The results will serve to show the direction in which we may look for progress in the solution of the problems of this nature which confront the meteorologist.

The conditions which prevail in our atmosphere are so complex, that a complete solution of the problems cannot be hoped for, if a restricted area only is reviewed. Each restricted area is subject to influences from without, and in turn reacts upon more distant regions, and we must aim at including the whole globe in our investigations. Evidence is not wanting of meteorological connections existing between widely separated regions. Thus a comparison of the monthly means of pressure observed at the Argentine Observatory at Cordoba, with corresponding values from India, shows that these two regions are, as it were, in opposition to one another. When pressure in India is in excess of the normal pressure, the Argentine is in defect of its normal, and *vice versa*. There is, in fact, an oscillation between these two widely separated regions which has been described, not inaptly, as a barometric see-saw.

CHAPTER VI

THE UPPER AIR

UNTIL comparatively recently, the material available for the study of weather phenomena has consisted almost entirely of observations made at ground level. The only exceptions have been observations of cloud drift, and the records from mountain observatories. Our views regarding the distribution of temperature, wind, and other elements in the layers of atmosphere above the ground, and of the changes taking place in them, have been based almost exclusively on inference from the surface observations. Fortunately, considerable progress has been made in the last ten or fifteen years in securing direct observations from the upper air, and in our last chapter we will indicate briefly some of the results obtained.

Instruments.—A few words first as to the method of making the observations. The idea of using balloons for weather study is as old as the invention of the balloon itself, and many of the older scientists made experiments in that direction. In this country, systematic work on an extended scale was carried out by Welsh and Glaisher, about the middle of the last century, for the express purpose of examining weather phenomena. In a famous ascent made in September 1862, Glaisher reached an altitude of about 29,000 feet. After this the work was dropped, and it was not resumed until the last decade of the nineteenth century, when an important series of ascents with manned balloons was carried out in Germany. Work with manned balloons is, however, both expensive and risky, and the greater part of our knowledge of the upper air has been obtained by sending up recording instruments attached to kites or unmanned balloons.

The meteorograph, as the instrument is called, consists in all cases of a combination of barometer and thermometer. In those used with kites, an anemometer for measuring the velocity of the wind and a hair hygrometer for observing changes in the moisture of the air are usually added. All these component instruments are arranged to write a continuous record of their indications on a cardboard disc or other suitable writing surface which is rotated by clockwork. The kite meteorograph is tied inside the kite, which usually takes the form of a large box-kite 8 or 10 feet high. The kite is flown on a thin steel wire. Under favourable circumstances heights of over 20,000 feet, or about 4 miles, can be attained by this means.

In balloon ascents the object is to attain the greatest possible elevation, and therefore great lightness of the meteorograph is essential. The instrument used in this country weighs only about 2 ounces. It records only temperature and pressure. The balloons are generally of thin sheet india-rubber. They are filled with hydrogen gas, and at the start they are about 1 yard in diameter. As the balloon rises, the imprisoned hydrogen expands, and ultimately the balloon bursts, when instrument and the remains of the balloon fall to the ground. A few instruments are not recovered, but the majority of them are picked up sooner or later, and find their way back into the hands of those who liberated them. The method has even been used at sea. By attaching a conspicuous float to the instrument, it has been possible to keep it above water until picked up by those on the lookout for it. By carefully watching the motion of the balloon through a theodolite while it remains in view, information can be obtained regarding the direction and speed of the air currents in the higher regions of the atmosphere. The balloons may reach very great heights. Altitudes of 10 miles are by no means uncommon, and occasionally heights of over 15 miles are reached.

The calculation of the height to which a balloon or kite has risen from the record of the barometer which it carries is a comparatively simple one if we know how the temperature changes during the ascent. The principle involved, which depends on the fact that the pressure of the air is due to the weight of the atmosphere above (see pp. 12, 33), is applied every day in reducing barometer readings to mean sea level before they are plotted on synoptic charts. We may therefore regard the barometer scale as a height scale, and express the results of an ascent by stating how the temperature, wind velocity, and humidity varied with height.

The Stratosphere.—One of the most remarkable facts brought to light by observations made with balloons is the one that our atmosphere may be divided by an approximately horizontal surface into two parts in which the distribution of temperature is very different. All ascents agree in showing a fall of temperature in the lower of these two parts, which expands up to a height of about 6 miles at the rate of about 1° F. for each rise of 300 feet. Above this level no further decrease of temperature occurs—the temperature remains sensibly constant. This upper region is often referred to as the isothermal layer or region, but the name is not particularly well selected, for balloons liberated simultaneously at stations not far apart have brought back records showing very different temperatures in this upper region; and, again, records obtained at one and the same station on consecutive days, or at even shorter intervals, have shown conspicuous differences. The layer is thus by no means a region of constant temperature, as the name isothermal would lead us to imagine, either in horizontal extension or in time. Another name which has been suggested is stratosphere, while the lower region in which temperature decreases with increasing altitude is known as the troposphere.

Since the discovery of the existence of the stratosphere, a vigorous campaign has been conducted with a view to learning more of the phenomenon. Attention has been particularly directed to determining the level at which the transition from troposphere to stratosphere occurs, and the temperature met with in the latter. The transition from one layer to the other is sometimes rather vague, but in most ascents it is sufficiently sharp to enable the height of the boundary to be fixed without difficulty. In the British Isles, the height of the lower surface of the stratosphere varies roughly between 5 and 7 miles, and the temperature encountered in it from $-20°$ to $-80°$ F.

It appears from the observations obtained in different parts of the world, that the level at which the stratosphere is entered is lowest in polar regions, and highest over the equator. The temperature in the stratosphere depends very much on the height of its lower boundary, being lower the greater the height of the dividing layer. Thus it comes about that the lowest temperatures in the upper air are found not at the poles, but over the equatorial regions. In an ascent made from the Victoria Nyanza in Central Africa a temperature as low as −119° F., more than 150° F. below the freezing-point, was met with in the stratosphere. This is probably the lowest temperature ever recorded naturally.

The level of the commencement of the stratosphere varies considerably under different weather conditions. It is found to be low when the barometer is low, and *vice versa*. For the British Isles, Mr. Dines has calculated its average height to be 5·3 miles with a barometer as low as 29·06 inches, the corresponding temperature being −55° F., and 7·7 miles when the barometer is 30·43 inches, the average temperature then being −76° F. Now cyclones and anticyclones are normally regions of high and low barometer respectively, and it follows therefore that the stratosphere is generally low, and therefore relatively warm over cyclonic regions, and high, and therefore relatively cold, over anticyclonic ones.

Cyclones and Anticyclones.—Observations on the upper air have not as yet thrown much light on the all-important question of the ultimate causes which give rise to cyclones and anticyclones, though they have added much to our knowledge of the conditions prevailing in them when once formed. The old view that cyclones consisted of a mass of air with a warm central core, and that the relatively high temperature prevailing in the central region was the cause of the ascent of air there, has been shown to be untenable. The corresponding assumption that an anticyclone consists of a mass of air colder than its surroundings, and that the high pressure prevailing in it at the surface is a direct consequence of the great density of the air by reason of its low temperature, has also had to be abandoned. Doubt was first thrown on these views by observations taken on mountains, and they have been fully confirmed by the observations made with balloons and kites. We now know that the temperature decreases as we ascend more rapidly in a cyclone than in an anticyclone—at any rate, up to a height of about 6 miles. The average rate of decrease is about 14° per mile in cyclones, and only about 12° per mile in anticyclones. Thus if the surface temperatures in a cyclone and a neighbouring anticyclone are the same, we know that at some distance above the surface the temperature in the cyclonic region will be lower than that at the same level in the anticyclone. At the 6 mile level we may expect the cyclone to be colder by 15°. In the region of the stratosphere, the anticyclone will be the colder, for we have seen that the temperature in this region depends greatly on the level at which the stratosphere commences, and this is higher in the anticyclone than in the cyclone.

Even if the temperature in the anticyclone at the surface is considerably below that in the cyclone, it is probable that at heights of from 3 to 6 miles the cyclone will be the colder, for observations have shown that the intense cold of many of our winter anticyclones is, so to speak, only skin deep. It is confined to the surface layers, which are cooled abnormally by contact with the ground, which has been cooled by radiation. Under such conditions, much warmer air is generally found at no great distance above the surface.

Inversions.—The regular fall of temperature with increasing height, which is on the average at the rate of about 1° F. for 300 feet up to the level of the commencement of the stratosphere, is not infrequently interrupted by comparatively thin layers in which the temperature increases with altitude. The name "inversions" is given to these relatively warm layers. They are usually characterised by great dryness, a fact which suggests that they are composed of air which has descended from higher regions in the atmosphere. They are encountered almost invariably under anticyclonic conditions, but their occurrence is by no means confined to this type of weather.

Variation of Wind with Height.—In addition to the distribution of temperature and humidity in the upper air, much attention has been devoted to the variation of the force of the wind with increasing altitude. The motion of the air near the surface, *i.e.* of the air in which we have to make our estimates or measurements of wind velocity, is much influenced by surface conditions. Even in the most exposed situations the motion is much impeded. Observations show that the velocity increases rapidly with increasing elevation above the surface. At the same time the wind becomes much less gusty, a fact which aeroplanists find of great importance. At an elevation of about half a mile, the disturbing influence of the surface is more or less completely eliminated, and the wind velocity takes up a value which agrees closely with that which theory shows us to be appropriate to the distribution of pressure prevailing at the time (see p. 37). When this "gradient velocity" has been reached, the direction of flow of the air is generally along the isobars shown on the map, with the low pressure on the left in the Northern hemisphere. The incurvature towards the side of low pressure, which we are accustomed to find when we compare the direction of the surface winds with the isobars, has become much reduced. At still higher levels, Westerly and Easterly winds exhibit characteristic differences. Westerly winds generally tend to increase in force until the level of the stratosphere is reached. On the other hand, Easterly winds very often show a decrease; sometimes they do not even attain the gradient velocity. In many instances it has been found that Easterly winds are of no great vertical height. At comparatively low levels, balloons are found to enter a region of light and variable wind, above which they meet with a current from the West. It will be remembered that in considering the cyclone of November 11 to 13, 1901, we found reason for thinking that the Easterly wind on the Northern side of the path was of no great thickness (see p. 46). It is interesting to find that balloon observations show that this is a general characteristic of Easterly winds. There are, of course, exceptions—some East winds extend to very great height.

The study of the upper air by means of kites and balloons is as yet in its infancy, and it is not possible to sum up the results obtained in concise generalisations. The separation of the atmosphere into two regions, the stratosphere and the troposphere, stands out so far as the great new fact which the observations have brought to light. The anticipation that the conditions in the upper air would prove to be much more simple than those prevailing near the surface, in consequence of the absence of the disturbing influence of the ground, has not been fulfilled. The changes met with above are quite as great in magnitude and as sudden in their occurrence as those with which we are familiar at ground level.

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