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AIR MINISTRY.

METEOROLOGICAL OFFICE.

METEOROLOGY
IN RELATION TO
AIR PILOTAGE

(REPRINT OF CHAPTER XI OF THE "MANUAL OF AIR PILOTAGE".)

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CHAPTER XI.—METEOROLOGY.

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CHAPTER XI—METEOROLOGY.

1. *General Remarks.*—As the element in which an aircraft moves and by which it is supported is the air, a knowledge of the movements and behaviour of the air forms an essential part of the equipment of air pilots. The subject which treats of this behaviour of the atmosphere is called *Meteorology*. In this book the treatment of the subject is confined mainly to general meteorological conditions as affecting aviation in the British Isles. For information regarding the special conditions prevailing in the Mediterranean and the East, reference should be made to Chapter IX of the *R.A.F. Pocket Book.*

2. *The Weather Map.*—One of the best aids to the study of weather phenomena and the inter-relation of the different meteorological elements is the weather map. This consists of a chart on which are plotted simultaneous observations from a network of stations covering a wide area. The weather map is the basis of modern forecasting, the construction of daily maps forming part of the routine of every meteorological service. The construction of such charts is made possible by an international organization which has fixed the times of regular observations, the nature of the observations, the form in which they are collected and the method of exchange of information between different countries. In Europe the standard times of observation are 01.00, 07.00, 13.00 and 18.00 G.M.T., which is, approximately, every six hours. The observations made at the different stations include pressure, temperature, humidity, wind direction and speed, weather and state of sky, height of lowest cloud and visibility. The observations are transmitted to a central office (the Air Ministry in this country) by telephone, telegraph or wireless telegraphy, the messages being sent in a simple code which has also been agreed upon internationally. After the information has been received, each country broadcasts a collective message containing a selection of the observations from its own stations. The times of issue of the national broadcast messages are fixed by international agreement and they are so arranged that, within less than two hours from the time of observation, it is possible for the various meteorological services to have received information extending from well within the Polar Circle on the north to North Africa on the south, and from Russia on the east to the Azores on the west. For forecasting purposes in this country information from the Atlantic is of vital importance and the weather reporting organisation includes a special system of reports from ships in the North Atlantic.

For the purpose of weather reports and forecasts for aviation the four main charts are supplemented by subsidiary charts based on observations at 10.00 and 16.00 G.M.T. from certain stations in the British Isles and the neighbouring areas of the continent. Also during the summer months a similar chart is prepared based on observations at 04.00 G.M.T. A new chart is available, thus, every three hours during the day in addition to the chart at 01.00 G.M.T.

A section of a typical weather map is shown in Fig. 99. For the sake of clearness, only the wind speed and direction,

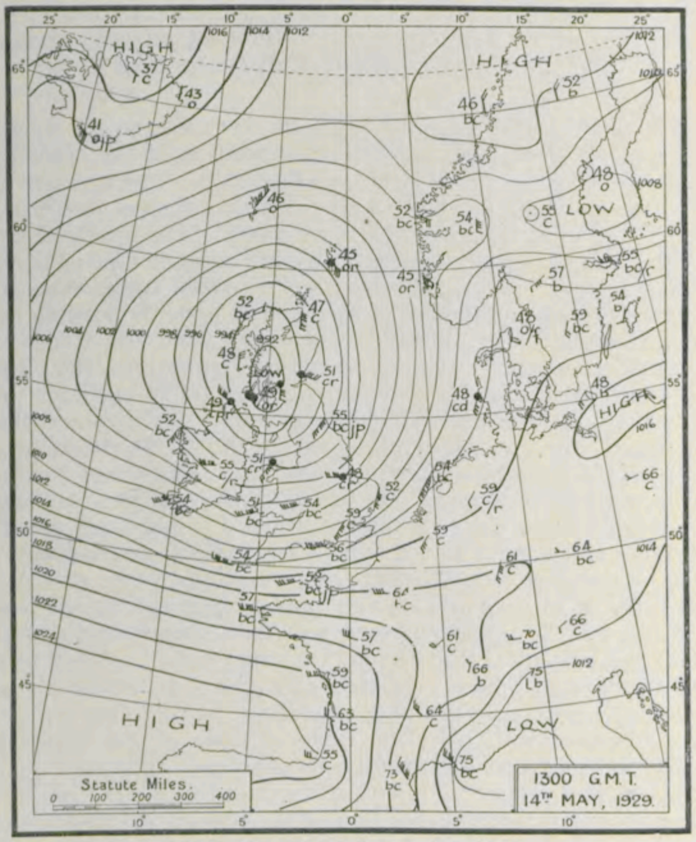


FIG. 99. Synoptic weather chart.

temperature and weather are indicated for each station. The pressures at individual stations have not been represented, but the distribution of pressure is shown by the series of lines called *isobars* along any one of which the mean-sea-level pressure at each place has the same value. The pressures as read at the

stations are corrected and reduced to mean sea level before the observations are despatched, so that the pressures plotted on the charts are comparable with one another. For a description of the methods of observation and the instruments in use at meteorological stations reference may be made to *The Meteorological Observer's Handbook*.

In the weather maps in Figs. 99, 103 and 105 the wind direction is indicated by arrows flying with the wind, and the wind force on the Beaufort scale (see Appendix IX) is indicated by the number of feathers. The weather is indicated by the Beaufort letters, *b* representing clear sky, *bc* sky about half clouded, *c* cloudy sky, *o* overcast sky, *r* rain, *d* drizzle, *s* snow, *p* showers and *jp* showers in neighbourhood of station. In the case of precipitation capital letters denote intensity; thus, R means heavy rain. A solidus divides actual weather from preceding conditions; thus, *c/r* means cloudy sky after rain.

3. *Pressure.*—The pressure of the atmosphere at any point is due to the weight of overlying air. Pressure is usually measured by means of a mercury barometer and for this reason it is frequently expressed in inches of mercury. This really means the length of the column of mercury, the weight of which will balance the weight of a column of air extending from the ground to the top of the atmosphere. Pressure, however, is a force and in meteorological work it is usual to employ a C.G.S. unit, the *millibar*, a millibar being a pressure of 1,000 dynes per square centimetre. 30 mercury inches are equivalent to 1015.9 millibars.

From the definition of pressure it will be obvious that it diminishes gradually with height. The average rate of diminution in the lower levels is 1 millibar for every 30 feet. The rate of decrease depends, however, on the temperature of the air; the higher the temperature, the slower will be the rate of decrease and consequently the higher will be the pressure at any given height. Pressure also varies with time and place, the variations, which are irregular, being associated with weather changes which are due to the movements of high and low pressure systems.

4. *Effect of Variation of Pressure and Temperature on Altimeter Readings.*—The effect of temperature on the variation of pressure with height, and the variation of pressure with place have an important bearing on the readings of an altimeter.

(*a*) Since the rate of decrease of pressure with height depends on temperature, and most altimeters are graduated on the assumption that the temperature at all heights is 50° F., any variation from this standard temperature will produce an error in the altimeter reading. Thus, if the altimeter of an aircraft in flight reads 5,000 feet, and the mean air temperature from the ground to 5,000 feet is 30° F. the true height will be less than 5,000 feet. An approximate rule for allowing for the effect of temperature is to subtract 1/500th of the height for every degree Fahrenheit by which the mean temperature is below 50°, and vice versa. In the example cited the true height would be $5{,}000 - \frac{5{,}000}{500}(50\text{–}30)$ or 4,800 feet.

(*b*) The effect of the variation of sea-level pressure from place to place may be important in a long cross-country flight. Consider, for example, the case of a flight from Leuchars to Gosport on the day to which the weather chart in Fig. 99 applies. The sea-level pressure at Leuchars is 994 mb., and if the altimeter was set to read zero at the start of the flight, it would have read zero when near Gosport at the height at which the pressure was also 994 mb. But the sea-level pressure at Gosport was 1,010 mb., a difference of 16 millibars, and since pressure decreases at the rate of 1 millibar in 30 feet, the pressure would have been 994 mb. at 30 × 16 or 480 feet. In other words, the altimeter would have underestimated the true height by 480 feet. Similarly in flying from high to low pressure an altimeter would register in excess of the true height. The latter case is the more important in practice, particularly when flying in bad weather on a day when there is a large horizontal variation of pressure.

In the example cited it was assumed that the pressure did not change during flight. Actually there would usually be a slight change from the conditions given by the latest weather chart, but allowance can be made for this, and a close estimate of the pressure at the aerodrome of destination at the time of arrival obtained from the charts.

5. *Temperature.*—The variation of temperature over the earth's surface is of considerable importance in meteorology since it is the key to many of the physical processes which form part of the atmospheric machinery. The main source of atmospheric heat is the earth's surface, which absorbs *radiation* received from the sun, the energy absorbed being converted into heat. The air in contact with the earth becomes heated by *conduction*, and the heat thus acquired is transferred from lower to higher levels mainly by the process of *convection*, or the actual ascent of air which has been warmed by contact with the ground. Temperature, therefore, diminishes normally with height above the ground. The average rate of decrease or *lapse rate* is 3° F. per 1,000 feet, although the actual lapse rate on a particular day may differ considerably from the average value, particularly in the lower layers near the ground. In certain conditions, temperature may actually increase with increasing height forming an *inversion*. Near the ground an

inversion is most readily produced during a clear night in winter when the earth's surface becomes cooled by radiation and cools the air in contact with it so that this air becomes colder than the air at some distance above the earth.

If a mass of air becomes warmer than the surrounding air, it expands and, becoming lighter than its environment tends to rise. In rising it becomes cooled by expansion owing to the fact that pressure diminishes with increasing height. If there is no gain or loss of heat from outside the mass of air, the change is said to be *adiabatic* and the rate of fall of temperature in these conditions for dry air is 5·4° F. per 1,000 feet. This is called the *dry adiabatic lapse rate.* If the lapse rate in the surrounding air is greater than the dry adiabatic lapse rate the air will go on rising, for at any height it will be warmer, and therefore lighter, than its environment. The atmosphere is then said to be *unstable.* If, on the other hand, the lapse rate is less than the dry adiabatic lapse rate, the air instead of rising will tend to fall back, for it will be colder, and therefore heavier, than its environment; the atmosphere is then said to be *stable.* The smaller the lapse rate the more stable will be the air. An inversion is, thus, a very stable condition.

6. *Humidity.*—The air contains a certain quantity of water vapour, the amount being subject to wide variation with both time and place. The maximum amount of water vapour which the air can take up depends on its temperature; the warmer it is the more water vapour it can hold. When the air contains as much water vapour as it can hold it is said to be *saturated.* The temperature to which unsaturated air has to be reduced before it becomes saturated is termed the *dew-point.* Any further cooling results in some of the water vapour being condensed into water drops. The actual amount of water vapour which a given sample of air contains is called the *absolute humidity.* It is more usual, however, to express the amount as a percentage of the amount which the air would contain if saturated at the same temperature. This percentage is termed the *relative humidity*.

Air which contains water vapour but which is unsaturated behaves under pressure changes as if it were dry air; on rising it cools at the rate of 5·4° F. per 1,000 feet. When saturated air rises, however, the expansion and cooling produce condensation which is accompanied by the liberation of heat. The result of this is to practically halve the rate of cooling which unsaturated air undergoes on rising. The rate for ascending saturated air, which depends on the temperature of the air is only 2·6° F. per 1,000 feet at 50° F. This is called the *saturated adiabatic lapse rate.*

7. *Wind.*—An examination of the weather chart in Fig. 99 will show that the wind arrows tend to follow the run of the isobars, but that they are inclined towards the side of lower pressure. Further, the closer the isobars are together, the stronger is the wind. The relation between the direction of the wind and the distribution of pressure is expressed by *Buys Ballot's law* which states that if you stand with your back to the wind in the northern hemisphere the lower pressure is on your left. In the southern hemisphere the reverse will hold.

At a certain height above the ground the wind actually blows along the isobars and the wind speed is proportional to the pressure gradient, that is, the rate of change of pressure horizontally in a direction perpendicular to the isobars. In practice, the wind calculated from the pressure gradient agrees with the observed wind at a height of about 1,500 feet. Thus, if from a weather chart the direction of the isobars and the pressure gradient at a certain point are measured, a close approximation to the direction and speed of the wind at 1,500 feet is obtained. In practice, a scale is used which, when placed on the map across the isobars gives directly the actual speed of the wind in miles per hour.

The deviation of the surface wind from the direction of the isobars is due to friction between the lower layer of air and the earth's surface, which acts as a retarding force reducing the wind speed. The effect of the friction is to produce eddies which result in *gustiness* in the wind near the ground. The existence of these eddies, or *turbulence,* is made visible by the smoke from a chimney. If there were no friction, and consequently no turbulence, the wind would blow as a steady current with uniform speed and direction, whereas actually it blows in a succession of gusts and lulls of the order of a fraction of a minute. The gustiness which occurs in the wind is evident from Fig. 100 which is a reproduction of a trace from a recording anemometer, the upper trace giving the wind speed during the course of a day and the lower trace the direction. Turbulence varies with the nature of the surface over which the wind is blowing, increases as the wind speed increases and decreases with height. It is also affected by temperature and extends to a greater height in summer than in winter, and also to a greater height in the day than at night.

8. *Variation of Wind with Height.*—It will be evident from the preceding paragraph that there must be an increase in wind speed from the surface, where the effect of friction is greatest, up to a height of 1,500 feet where the wind current is relatively undisturbed, and also that the wind direction must at the same time *veer,* that is, change in a clockwise direction. While this is usually true of all winds, no general

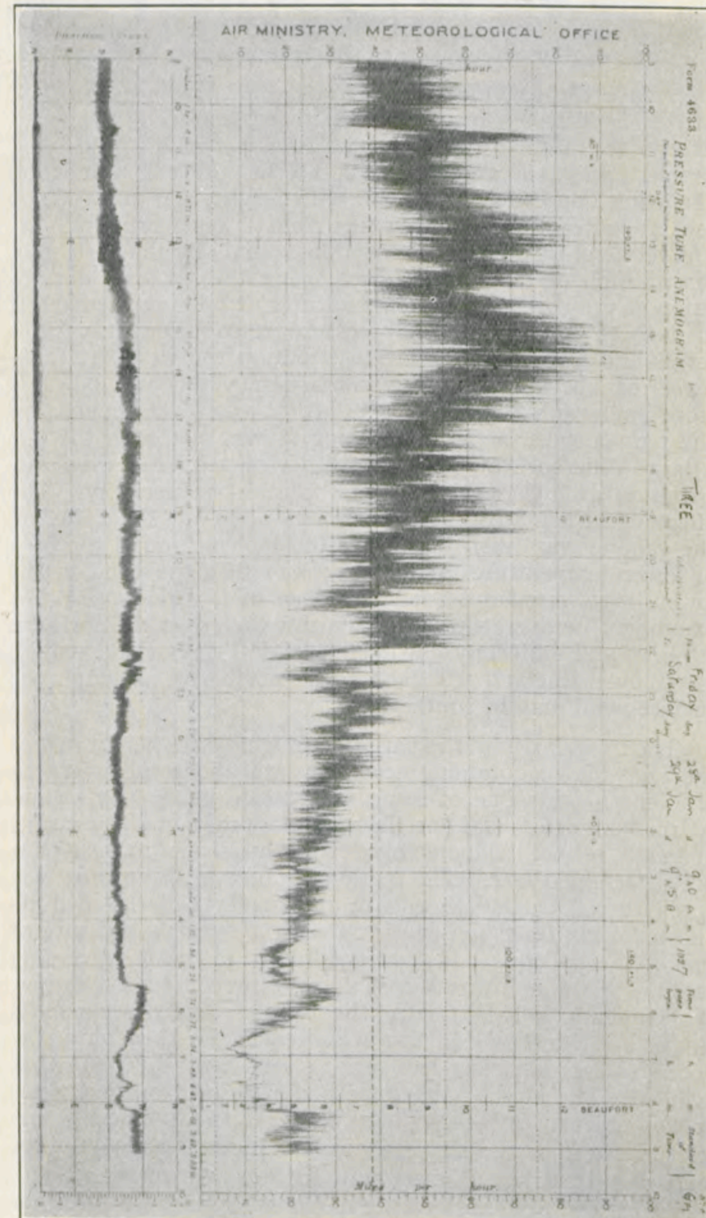


FIG. 100. Record from Dine's Pressure Tube Anemometer.

rule can be laid down for the increase of wind with height, for it depends on the actual direction and speed of the wind, the time of day, the season of the year and local topography.

Above the 1,500 feet level, the change in wind speed and direction with height varies with the direction of the wind. Thus, winds from a westerly point usually continue to increase in speed and veer with increasing height. Easterly winds, on the other hand, tend to fall off with height, and above 3,000 feet are often replaced by winds from a westerly point. At greater heights, the wind is controlled partly by the horizontal distribution of temperature. Knowing the sea-level distribution of pressure and the temperatures at different heights, it is possible to compute the pressure distribution at various levels and from the pressure distribution the winds at those levels can be obtained with fair accuracy. It will be clear from paragraph **3** that the pressure at any level depends on the temperature in the intervening layers, so that if there is a large difference of temperature horizontally the wind distribution at high levels must be affected appreciably. The effect of such a variation of temperature is to superpose on the general wind distribution a wind blowing round the area of lower temperature in the same way that the wind in the lower levels circulates round an area of low pressure. For example, if temperatures are uniformly high over the northern Atlantic and uniformly low over the Continent, winds at high levels over England will tend to be northerly, although the surface wind may be southerly.

The irregularity in the variation of wind with height makes the question of obtaining accurate data about the winds at different heights one of some importance in air navigation. At meteorological stations the winds are measured by means of small rubber balloons filled with hydrogen to rise at a pre-determined rate. The motion is observed by means of a specially constructed theodolite and readings of the altitude and azimuth are taken every minute. Assuming the rate of rise of the balloon, it is then possible to calculate by a slide rule the speed and direction of the wind in consecutive layers. By attaching a long tail to the balloon, and observing its length on a graticule in the eye-piece of the theodolite, the necessity for assuming the rate of ascent of the balloon is avoided. The most accurate method is to use two theodolites at the end of a measured base line, but this method is less convenient than the single theodolite method as it requires more personnel and a longer time for working up the results. When balloon observations are not possible owing to weather conditions, useful information can be obtained from the movements of clouds and from synoptic weather charts.

9. *Diurnal Variation of Wind.*—The turbulence in the lower layers of air is responsible for a diurnal change in the wind speed and direction in these layers. During the day, turbulence is active and the lower layers of the atmosphere become well mixed. The wind at, say, 1,000 feet gives up some of its momentum to the wind near the ground which, consequently, increases in speed reaching a maximum usually in the early afternoon. At the same time the direction of the wind near the ground tends to veer towards the direction of the wind at 1,000 feet. At night turbulence practically ceases, and the wind near the ground backs and lulls. At 1,000 feet the reverse takes place, the wind backing and decreasing during the day and reaching its maximum speed at night. A height of 1,000 feet has been taken as an example, but the actual upper limit of the height at which these changes take place depends on the strength of the wind and the season of the year. In general, it may be stated that the veer and increase of wind in the first 1,500 feet, which was noted in paragraph **8**, is more marked at night than in the middle of the day. The changes outlined may be completely masked, however, by temporary variations in weather conditions. They would be most in evidence, normally, on a fine, relatively quiet, day in summer.

10. *Local Winds Independent of General Pressure Distribution.*—There are two important exceptions to the general rule stated in paragraph **7** regarding the relation between wind direction and the general pressure distribution.

(*a*) *Katabatic Winds.*—On a clear night the ground becomes cooled by radiation to the sky and the air in contact with the ground consequently becomes cooled. In undulating country the air on the surface of a hill, being colder than the air at some distance from the surface, tends to flow down the slope under gravity causing a local wind. The direction of this wind, which is called *Katabatic,* is determined by the slope of the hill and may bear no relation to the pressure distribution. Under favourable conditions the speed of the wind may exceed that of the gradient wind.

(*b*) *Land and Sea Breezes.*—In summer during the day the land surface near the coast becomes much hotter than the surface of the sea. The air over the land consequently becomes warmed and expands and at some distance above the surface the pressure is therefore higher than that at the same level over the neighbouring sea. Consequently air flows at this higher level from land to sea until the pressure at the surface over the sea becomes higher than that at the surface over the land. A return surface wind therefore blows from sea to land and this circulation continues throughout the day. This wind is called a *sea breeze*. Sea breezes are usually less than 500 feet in vertical extent, but may extend occasionally to 1,000 feet or even over. As in the case of katabatic winds, they may bear no relation to the pressure distribution. At night conditions are reversed, the land surface becoming colder than the sea. The surface wind then tends to blow from land to sea, and in quiet weather persists till the morning.

11. *Vertical Currents.*—Ascending and descending currents in the atmosphere constitute the chief cause of *bumpiness* in flying. They may be caused by irregularities in the ground, by the unequal heating of the earth's surface, or, more generally, whenever conditions are favourable for a steep temperature lapse rate at low levels. In the first class the most persistent upward currents are found on the windward side of a ridge of high ground, while corresponding down-currents occur on the lee side. Disturbances of this kind may extend up to a height of 3,000 feet. Minor irregularities, such as belts of trees, produce vertical currents on a smaller scale. Upward currents produced by local heating are found on a hot day over roads, chalk-pits and other places of similar contrast to surrounding areas, while downward currents are to be found over lakes, rivers and forests. On a larger scale, ascending currents occur along the coast on a hot summer day with a sea breeze; these are indicated by long lines of cumulus cloud frequently seen along the coast line (*see* para. **14**). Corresponding downward currents are to be found over the sea.

Vertical currents over a large area occur on days when there is a steep temperature lapse rate and the atmosphere is unstable. Such conditions may occur on a hot day in summer when there is strong convection, as evidenced by the formation of cumulus clouds; a sky covered with such cloud produces alternations of ascending and descending currents. Another example is that of a cold air current of polar origin which, having reached this country by flowing southward over warmer water, has become unstable. In such conditions squally winds, accompanied by severe bumps may be experienced. There is very little information available regarding the magnitude of vertical currents which occur in the conditions described, but it is probable that, even in this country, upward currents of the order of 1,000 feet per minute are experienced occasionally, while in hot countries upward currents of twice this speed may occur. The strongest upward currents, however, which may be far in excess of these values, occur in line-squalls, and more particularly in thunderstorms, which are described in paras. **20** and **21**.

12. *Fog* is probably the most important meteorological element from the point of view of aviation in these latitudes. It may be caused by the condensation of water vapour in the surface layers of the atmosphere or it may be due to smoke or dust held in suspension in the air. It is usual to limit the term "fog" to a condition of atmospheric obscurity in which objects at a distance of one kilometre (approximately 1,000 yards) are not visible. When the visibility exceeds one kilometre, but is less than two kilometres, the obscuration is called "*mist*" or "*haze*" according to whether it is produced by condensed water particles or by solid matter such as dust or smoke. Condensation of water vapour in the surface layers of the atmosphere is brought about by the cooling of the air below its dew point. The cooling may be due to the cooling of the surface of the ground which is communicated to the air above it, by the drift of air over a surface which is colder than itself, or, more rarely, by the mixing of two currents of air of different temperatures and humidities. In the first two cases an inversion is formed in the lower layers of air, which effectively prevents the air from rising. The turbulent mixing of the moist air within the layer of the inversion causes condensation. For the effective formation of fog the wind must be light in order to allow the air near the ground to become sufficiently cooled; also there must be sufficient moisture in the air for the cooling to produce condensation.

Fogs over land occur chiefly in autumn and winter. They are formed most frequently on calm, clear nights. They reach their maximum intensity, normally, in the early morning, from one to two hours after sunrise, and usually disperse before mid-day. In winter, however, they may cover a wide area and persist for some days. Fogs at sea, on the other hand, are characteristic of spring and summer, and are usually formed by the passage of a current of air from a large land mass, or from tropical or sub-tropical regions, over the sea which, at this season, is relatively cold. Over the English Channel they usually occur with warm south-west winds. In undulating country fog may occur at all seasons due to the drifting of low cloud over the high ground. High ground near the sea suffers the most in this respect.

Near large towns and industrial areas where there is a continuous output of smoke from factory chimneys, &c., smoke fogs are frequent. Their formation is most favoured by similar conditions to those which give rise to water fogs, since an inversion and a light wind prevent the smoke from dispersing quickly either vertically or horizontally. Such fogs may be carried a considerable distance to leeward of the source of pollution. The worst fog occurs when conditions are also favourable for condensation and a mixture of the two kinds of fog produces considerable obscurity.

The height to which an ordinary fog extends varies considerably. It is usually less than 1,000 feet and frequently less than

FOG PREDICTION DIAGRAM FOR ENGLAND.

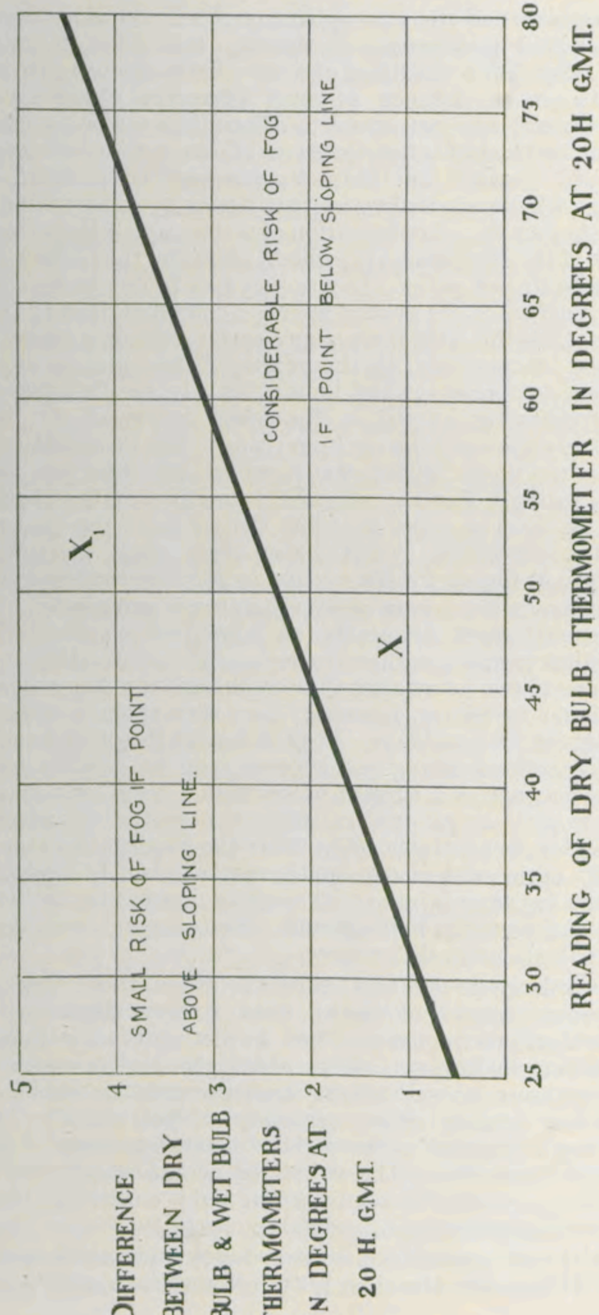


FIG. 101.

500 feet. In certain conditions a fog has no clearly defined upper boundary but merges into cloud which may extend to a considerable height.

In the case of a fog formed at an inland station at night by radiation cooling, it is frequently possible to make an accurate forecast of the probability of fog based entirely on local readings of wet and dry bulb thermometers, which form a convenient method of measuring the humidity of the air. The thermometers should be exposed in a standard Stevenson Screen, and should be sufficiently remote from buildings or other obstacles to prevent the latter from influencing the readings. The following rules are used in conjunction with the diagram in Fig. 101 which connects the readings of the dry bulb thermometer at 20.00 G.M.T. with the difference between the readings of the dry and wet bulbs. The diagram should apply with little modification to any inland aerodrome in a flat situation in England :

(i) The diagram can only be used if the sky is clear or not more than half-clouded.

(ii) If the wind at 20.00 G.M.T. is above 8 m.p.h. at 5 feet above the ground, there is little risk of fog or mist.

(iii) If the wind at 20.00 G.M.T. is calm, there is considerable risk of fog or mist whatever may be the thermometer readings.

(iv) If the wind at 20.00 G.M.T. is less than 8 m.p.h. the risk of fog is considerable if the temperature readings give in the diagram a point which comes below the sloping line.

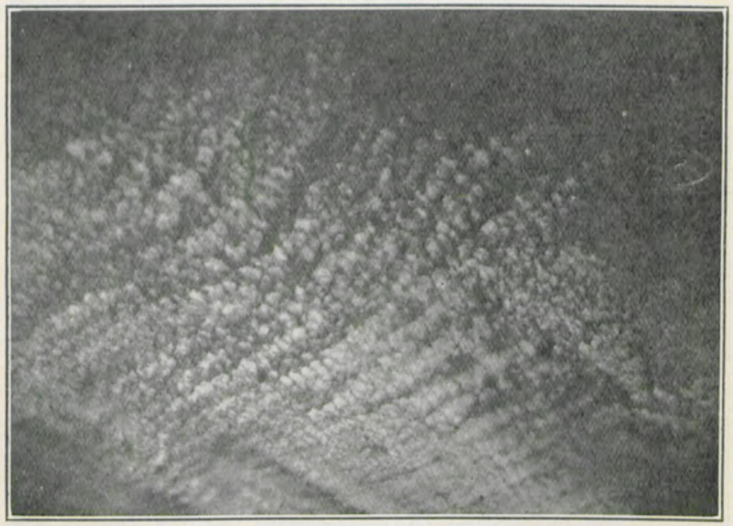
13. *Visibility* is defined by the maximum distance at which an object can be seen and the clearness with which its details can be discerned. It is measured at meteorological stations by selecting a number of well-defined objects at certain specified distances and by observing the most distant of these objects which is visible. Apart from the bad visibility associated with such phenomena as fog, heavy rain and snow, one of the most important factors in determining visibility is the position of industrial areas and large towns. The visibility in a certain area may thus vary considerably with different wind directions. In general, good visibility near the ground is associated with a high temperature lapse rate, when atmospheric pollution is carried upwards by convection, and bad visibility with a low lapse rate, especially with an inversion. At higher levels, however, visibility may be different from that near the ground. For example, on a hot day in summer convection currents may carry smoke upwards to 5,000 or 6,000 feet forming a layer of haze. Smoke haze is

(1) Cirrus (**Ci.**). Mares' tails with tufted ends, often at about 30,000 ft.

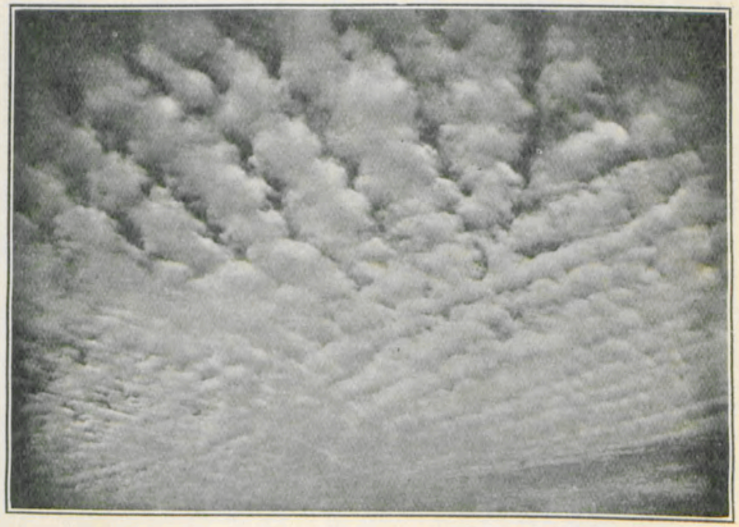
(2) Cirro-Stratus (**Ci.-St.**) uniform sheet of very high cloud, 30,000 ft.; about 25,000 beneath is Fracto-cumulus (**Fr. Cu.**) a string of ragged cumulus at about 6,000 ft.

FIG. 102. CLOUD FORMS.

(Photographs selected from the collection of MR. G. A. CLARKE of the Observatory, Aberdeen.)



(3) Cirro-Cumulus (**Ci.-Cu.**). The Mackerel Sky. The highest form of Cloudlets in waves: 20,000 to 25,000 ft.



(4) Alto-Cumulus (**A.-Cu.**). Layer of large Cloudlets in waves at middle height.

FIG. 102. CLOUD FORMS—*continued.*

(Photographs selected from the collection of MR. G. A. CLARKE of the Observatory, Aberdeen.)

(5) Alto-Stratus (**A.-St.**). Sheet at middle height, between 10,000 and 25,000 ft.

(6) Strato-Cumulus (**St.-Cu.**). Layer of clouds in irregular order below 7,000 ft.

FIG. 102.—CLOUD FORMS—*continued.*

(Photographs selected from the collection of MR. G. A. CLARKE of the Observatory, Aberdeen.)

(7) Nimbus (**Nb.**). Shapeless cloud-base below 7,000 ft., rain falling.

(8) Cumulus (**Cu.**). Detached cloud with flat base at mean height 4,500 ft., and domed top at mean height 6,000 ft.

FIG. 102.—CLOUD FORMS—*continued.*

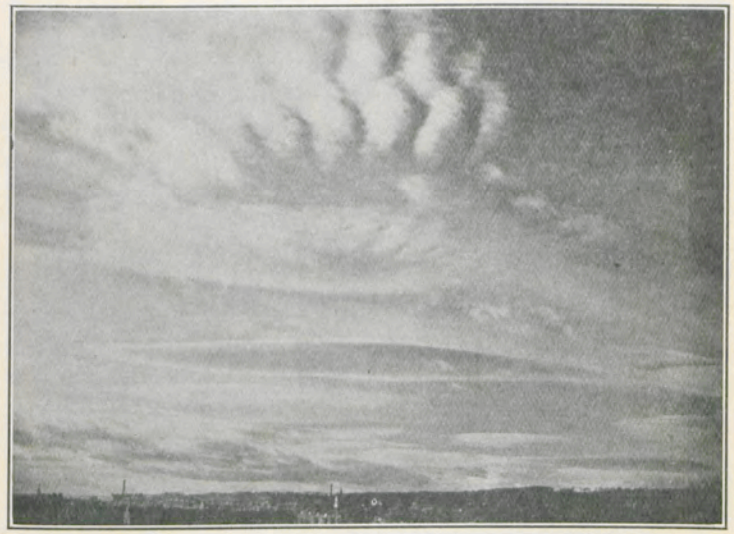
(Photographs selected from the collection of MR. G. A. CLARKE of the Observatory, Aberdeen.)

(9) Cumulo-Nimbus (**Cu.-Nb.**). A thunder-cloud with "anvil" finely developed

(10) Stratus (**St.**). Level sheet of low cloud: below 3,000 ft.

FIG. 102.—CLOUD FORMS—*continued.*

(Photographs selected from the collection of MR. G. A. CLARKE of the Observatory, Aberdeen.)

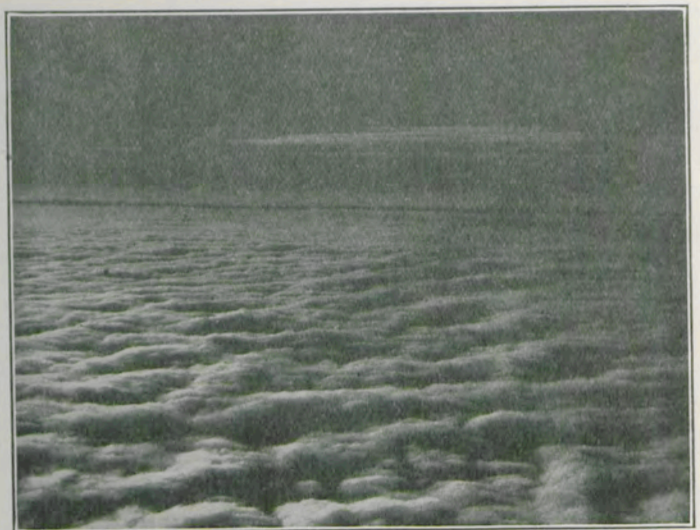


(11) Alto-Cumulus-lenticularis (**A.-Cu.-Lent.**). Almond-shaped banks of cloudlets at the alto-cumulus level.

(12) Alto-Cumulus-Castellatus. Little miniature cumulus rising in many heads from a more or less compact layer of alto-cumulus.

FIG. 102.—CLOUD FORMS—*continued.*

(Photographs selected from the collection of MR. G. A. CLARKE of the Observatory, Aberdeen.)

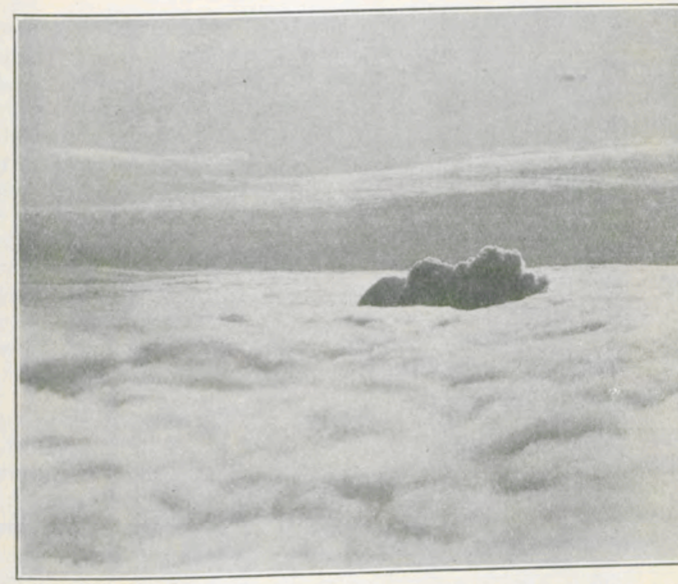


(13) A typical horizontal sheet of Strato-Cumulus (height 1,000 to 2,500 feet).

(14) A turbulent layer of Strato-Cumulus. The raggedness shows extreme bumpiness.

FIG. 102. CLOUD FORMS—*continued.*

(Photographs taken from the air by Captain C. K. M. DOUGLAS).



(15) Top of large Cumulus protruding 2000 feet through a cloud-sheet. The height of the upper surface of the cloud-sheet was 8,000 feet.

(16) Fracto-Cumulus.

FIG. 102. CLOUD FORMS—*continued.*

(Photographs taken from the air by Captain C. K. M. DOUGLAS.)

often carried by the upper winds to a considerable distance from the source of pollution in a gradually widening belt. Thus, in spring when east winds are relatively frequent and the lapse rate is high, thick haze from the industrial districts of Belgium and Germany may be encountered over England. Similarly north-west winds often bring thick smoke-haze from the Midlands to south-east England. In winter haze at high levels usually occurs with north-west winds which are more frequently characterised at this season by a high lapse rate than winds from other directions. Visibility is also dependent partly on optical considerations ; on a hot day, the shimmer of the air over hot ground makes objects indistinct, while in the air cloud shadows and light reflected from clouds may make observation difficult.

14. *Clouds*, like fog are caused by the condensation of water vapour in the air when it is cooled below its dew point, but whereas fogs are formed by the cooling of air without any change of level, the cooling, in the case of cloud formation, is brought about almost invariably by the adiabatic expansion of rising air. There are four main types of cloud : cirrus, stratus, cumulus and nimbus ; but there are several subsidiary types depending upon the heights at which the clouds occur and the meteorological conditions giving rise to their formation. Some of the more commonly occurring cloud forms are shown in figure 102. Several forms may, of course, occur at the same time.

Speaking broadly, the methods of formation of cloud by the cooling of rising air may be divided into three main groups. In the first group there is the gradual ascending movement of air over large areas giving rise to continuously overcast skies. This group is referred to later in paragraph **18.** In the second group are the more localised but stronger vertical movements associated with a steep temperature lapse rate and giving rise to broken skies with cumulus and cumulo-nimbus clouds. Cumulus clouds occur on fine summer days due to the heating of the ground, and usually dissolve towards evening. Under favourable conditions, however, such clouds may attain great vertical structure, extending to 20,000 feet. The third group includes clouds of the strato-cumulus type which occur in horizontal sheets and which are produced by smaller eddies causing turbulent mixing between successive layers of air, which extends gradually upwards from the surface. Such clouds are frequently formed by the passage of a current of cold air over a surface which is warmer than itself. The eddy motion set up at the surface tends to establish an adiabatic lapse rate and the cooling may extend sufficiently for condensation to occur and a layer of cloud to form. The air above the cloud, being unaffected by the turbulent mixing is warmer than the air lower down which has been cooled by the process. In other words, there is an inversion above the cloud layer. The turbulent mixing, when sufficiently vigorous, causes the clouds to assume the roll form characteristic of strato-cumulus. The air in and below such clouds is usually bumpy, while above them there is steady flying. Cloud of this type usually tends to break up in summer, but in winter it may last for days. Most cloud sheets are characterised by an inversion above them. Pronounced inversions are sometimes formed by the arrival of a current of warm air at a height of a few thousand feet. In such cases there is a marked change of wind above the cloud.

15. *Precipitation.*—In the first two methods of cloud formation considered in the preceding paragraph, if the ascending movement of the air continues after condensation has commenced, the process of cooling is carried still further, and the cloud particles grow in size until *rain* falls. The nature of the rainfall depends on the magnitude of the ascending current of air and, therefore, on the lapse rate. In the case of a gradual ascending movement over a wide area continuous steady rain occurs, the rain drops falling through the air as soon as they are formed. If the temperature conditions in the air are such that condensation takes place near the freezing point *snow* occurs. It is not uncommon for snow to occur in the upper air and to change to rain lower down, the precipitation reaching the ground in this form.

In the case of a steep lapse rate and strong ascending currents, the process of rain formation is more complicated. The rate at which rain drops fall through the air depends on the size of the drops, so that the stronger the ascending current the larger is the size of the drops that can be supported by it, and consequently the heavier is the rainfall. There is, however, a certain limiting speed to the ascending current which can support a rain drop, and if the upward motion exceeds this speed, which is about 1,600 feet per minute, the larger drops become unstable and break up into smaller drops which are carried upwards. In this way large accumulations of water can occur, and if the ascending currents suddenly cease very heavy rain results. If the ascending current is strong and reaches a considerable height *hail* may occur. The drops are carried upwards to the snow level when they are frozen into clear ice and gather a coating of snow outside the ice. Violent ascending currents are rarely steady but occur in gusts and lulls. A water drop may be carried up and down several times before finally falling to the ground. Each time it falls it gathers a coating of water over the snow and when it is carried up again the water covering freezes and a further coating of snow accumulates. In this way hailstones are formed. The stronger the ascending current, the longer the water drops remain in the air, going through the process outlined, and the larger are the hailstones.

16. *Ice Formation on Aircraft.*—Under certain meteorological conditions, ice may be formed on aeroplanes in flight. The amount of ice formed increases with the length of time during which the aeroplane is subjected to those conditions ; cases are on record where machines have been forced down in a comparatively short space of time on account of ice loading. There are two sets of circumstances in which the phenomenon may occur.

(*a*) When rain falls into a region of the atmosphere which is below freezing point the water immediately freezes on everything on to which it falls, leaving a crust of transparent ice, which, on occasions, may be very thick. This ice formation is known as *glazed frost*.

(*b*) Clouds may be below freezing point and yet consist of small particles in the liquid state. Any relative motion between the air in such clouds and any obstacle leads to a deposition of ice mainly on the windward side of the obstacle. A typical case is the formation of rime during fogs at ground level. Ice formed in this way is generally of a light feathery nature, and is easily shaken from the obstacle to which it attaches.

From these considerations, the following action suggests itself as desirable when a pilot observes ice forming on his aircraft :—

(*a*) When a pilot, flying in air at or below freezing point, notes that rain is falling from a higher level and that ice is forming on the machine, he should immediately ascend. The fact that rain is falling shows that there is a warmer layer at no great height above him, and he should rise until this layer is reached, when the conditions for ice formation on the aeroplane will no longer obtain. It should be noted that, in this case, descending with a view to continuing the flight at a lower level is generally of no avail, since the cold layer nearly always extends right down to the surface.

(*b* All the evidence points to rime forming only in clouds in which the temperature is at or round about the freezing point. If, therefore, a pilot sees rime forming on the machine, he should, if possible, get out of the cloud either by ascending or descending. If the cloud is so low that he cannot fly below it, he should then ascend, and even if he does not reach the upper surface of the cloud he will soon get into a region where the temperature is sufficiently low to prevent dangerous accumulation of rime.

17. *Weather in Relation to Wind Currents.*—The variability of the weather in this country is largely due to its position, lying as it does in a transition zone. From north to south there is a transition from polar to sub-tropical conditions, while from west to east there is a transition from maritime to continental conditions. The result is that while the general air circulation in these latitudes is from west to east, many and frequent variations from this circulation take place, the pressure distribution rarely remaining unchanged for very long. The weather at any given place depends on the direction and past history of the prevailing currents at different levels with certain modifications depending on the season of the year, the time of day and the local topographical features. The wind circulation over a particular area at any time may be in the nature of a homogeneous current or may consist of two or more currents of different origin, and consequently of different temperatures and humidities, in juxtaposition. Speaking very generally, good flying weather is to be found in a homogeneous current, although exceptions to this are to be found. For example, if a current of cold air from high latitudes reaches this country after passing over a stretch of warm sea, the air becomes unstable owing to surface heating and showers readily develop. If such a current strikes high ground, the ascending movement may be increased and considerable rain may occur locally. Bad flying weather, however, is to be found more commonly at or near a discontinuity between two currents. The most important examples of such discontinuities occur in the type of pressure distribution known as a *depression*.

18. *The Depression.*—On a weather map a depression appears as a system of closed isobars with the lowest pressure in the centre and the surface winds blowing counter-clockwise round the centre (in the northern hemisphere) with the usual deviation across the isobars from high to low pressure. Depressions usually move from south of west to north of east in western Europe and are frequently associated with strong south-westerly winds on their southern sides. Depressions moving in other directions are, however, by no means uncommon. The weather chart in Fig. 103 shows a depression centred over Northern Ireland and moving north-eastwards. The two broken lines emanating from the centre of the depression mark the boundaries between warm and cold air currents. On the south-east side of the depression, between the two lines, is an area of relatively warm air, the surface temperatures being of the order of 50° F. This area is called the *warm sector*, and it will be observed that in this area the isobars are close together and the winds strong. A depression usually moves in a direction parallel to the isobars in the warm sector. On the other sides of the two broken lines are colder currents, the surface temperatures being about 10° lower than those in the warm sector. Remembering that the depression is moving north-eastwards, it is seen that the warm air is overtaking the cold air to the north of the broken line which extends eastwards from the centre of the depression. This line is called the *warm front*. The warm air being lighter, ascends over the retreating cold air forming a sloping surface. A typical section through a warm front is shown in Fig. 104. The slope of the surface between the two air currents varies according to the conditions existing, but is of the order of

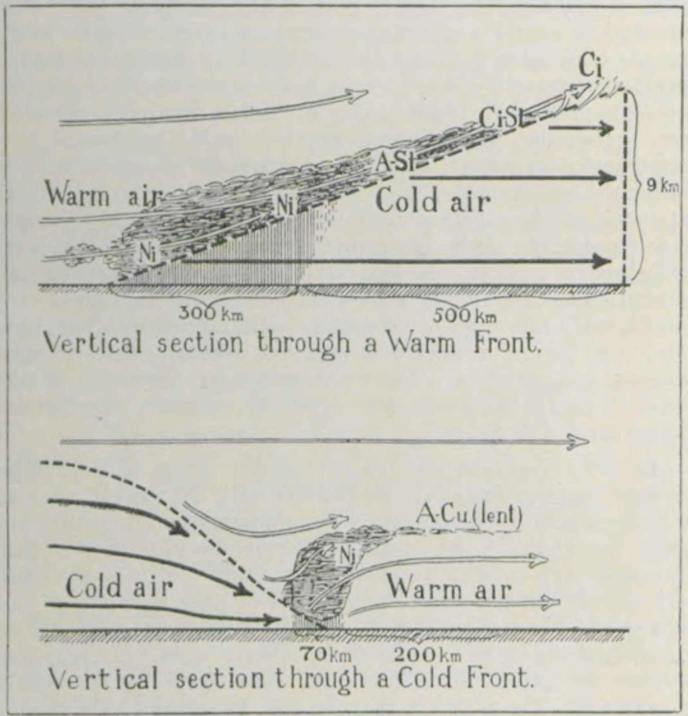


FIG. 104. Rain and Cloud formation.

1 : 100. The ascent of the warm air gives rise to the cloud sequence shown and as the front approaches rain begins to fall, increasing in intensity as the clouds become lower. In advance of the warm front there is, thus, a wide belt of low cloud and continuous rain. The area over which rain is falling is shaded in the map in Fig. 103. After the warm front has passed the cloud lifts and tends to break, although since the air current

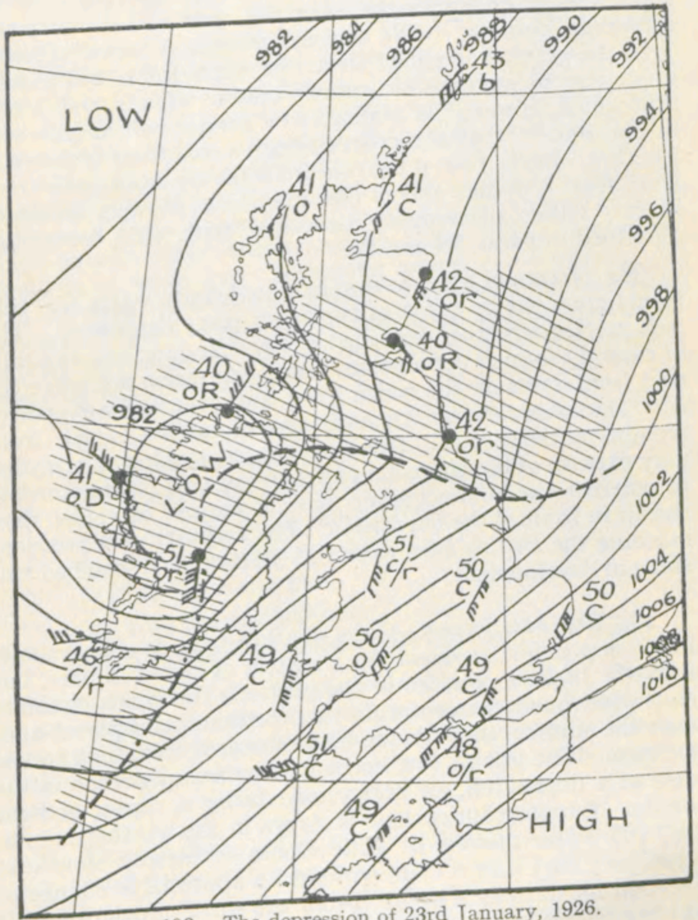


FIG. 103. The depression of 23rd January, 1926.

in the warm sector is warm and moist, the weather usually remains cloudy and if there is any high ground, local rain may occur owing to the consequent ascent of the warm air. Along the broken line extending southwards from the centre of the depression the cold air is overtaking the warm air. This line is called the *cold front*. In this case the cold air being heavier undercuts the warm air, causing instability and ascending currents. The upward motion is more vigorous than the gradual ascent of air at the warm front, and usually gives rise to cumulus or cumulo-nimbus clouds and heavy rain which, however, is confined to a narrow belt as indicated in Fig. 103. A typical section through a cold front is shown in Fig. 104. In the rear of the cold front the air has usually come from high latitudes and is unstable, local showers occurring in it. Other phenomena associated with cold fronts are described in paras. **20** and **21.**

The picture of a depression having definite warm and cold fronts must not be taken as typical of every depression. The well-marked structure described is only characteristic, as a rule, of recently formed depressions. As a depression advances the cold front gains on the warm front, and eventually overtakes it. The warm sector then disappears and a single front remains on the surface. This front, which is called an *occlusion* may partake of the character of a warm or cold front according to whether the advancing air mass is warmer or colder than the air in front of the depression. The majority of depressions reaching the British Isles from the Atlantic have reached this stage of development.

19. *The Anticyclone.*—On a weather map an anticyclone, like a depression, is shown by a system of closed isobars, but with the highest pressure in the centre. The winds circulate clockwise round the centre (in the Northern hemisphere) and, near the surface, they tend to blow outwards from high to low pressure. The isobars are, normally, farther apart than in the case of a depression, an anticyclone being a region of light winds. A typical anticyclone is shown in the weather map in fig. 105. The motion of anticyclones is usually slow and irregular ; they may remain without an appreciable change of position for days at a time. From the wind circulation it is evident that an anticyclone is a region of descending currents, although the rate of descent of the air is very slow. Conditions are therefore stable. In summer the weather is usually fine, but in winter, although the weather is quiet, and persistent rain is exceptional, conditions are much more varied. The weather is frequently cloudy, extensive sheets of stratus, and particularly strato-cumulus, formed as described in para. **14,** covering the sky. Such cloud layers occur most frequently on

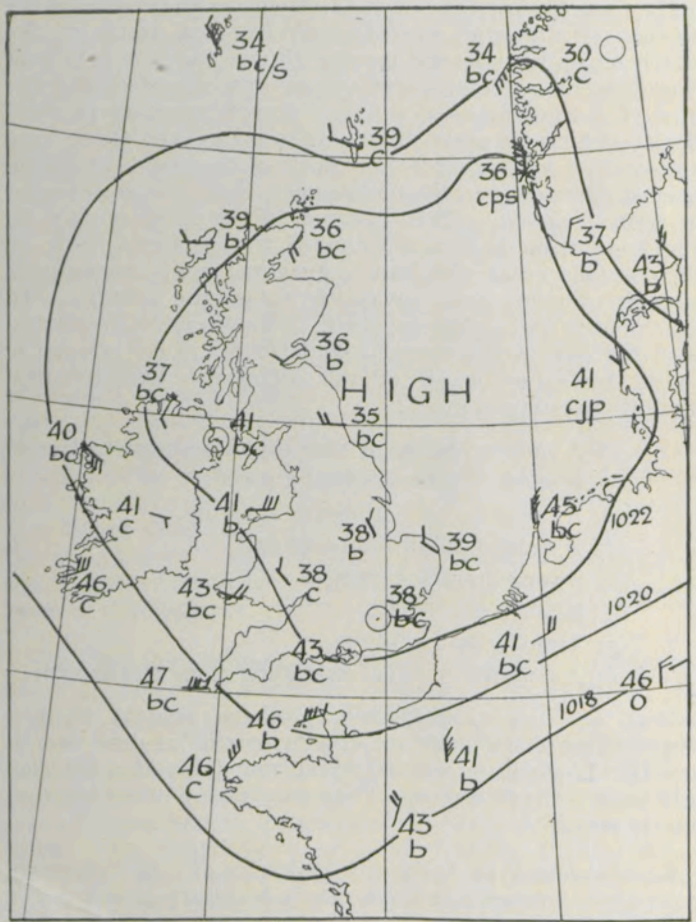
the north-east side of the anticyclone. The absence of strong winds and the stable condition of the atmosphere are very favourable for the formation of fog. In fact, most of the fogs in autumn and winter occur in anticyclonic conditions.

20. *Line Squalls.*—In para. **7** reference was made to the gustiness of the wind near the surface as a result of the friction set up between the moving air and the ground, a gust being defined as a temporary increase in wind velocity of the order of a fraction of a minute. Rapid increases of wind velocity lasting for some minutes also occur, and these may be associated with a temporary shift of the wind, and with heavy showers or even thunderstorms. Such changes of wind are termed *squalls.* Their method of occurrence may be understood from a consideration of the particular case in which squalls occur simultaneously along a line, sometimes hundreds of miles long, advancing across the country. To such the term *line-squall* is applied. A line-squall is invariably associated with a well-marked cold front and its passage is marked by some or all of the following characteristics, according to circumstances :

(*a*) A sudden change of wind direction, usually a veer.
(*b*) A sudden increase of wind speed.
(*c*) A rapid rise of barometric pressure.
(*d*) A sudden fall of temperature.
(*e*) Strong upward currents.
(*f*) Heavy rain or hail.
(*g*) Thunder and lightning.
(*h*) A long roll of cloud extending along the front.

Most of these characteristics will be evident from a consideration of the structure of a depression as described in para. **18.** Line-squalls usually travel from a direction between north-west and south-west. They very rarely move from an easterly point.

21. *Thunderstorms.*—For the formation of a thunderstorm a very steep temperature lapse rate is necessary giving rise to strong vertical currents. Thunderstorms are associated with heavy cumulus or cumulo-nimbus clouds with strong ascending currents in the region of the front of the cloud, and are frequently accompanied by hail. In para. **15** it was pointed out that the largest rain drops which can persist in the air require an upward current of 1,600 feet per minute and that above this speed, the drops become unstable and break up into smaller drops. It has been shown that this breaking-up of drops results in a separation of positive and negative



THE ANTICYCLONE OF 1ST MAY, 1927.

FIG. 105.

electricity, the water after breaking having a positive charge while the cloud becomes negatively charged. In the cloud where the ascending currents are greatest, an accumulation of water occurs. The larger drops only can penetrate to the lower part of the region of maximum vertical velocity where they are broken up into smaller drops, the water becoming positively charged and the cloud negatively charged. Owing to the motion of the cloud, the negatively charged cloud particles are rapidly separated from the water, so that in the region of separation there is an accumulation of positive electricity, while the remainder of the cloud has a volume charge of negative electricity. From the region of separation heavy rain falls, carrying its positive charge with it so that the ground also becomes positively charged. Lightning discharges may occur from the region of separation towards the main cloud or downwards or, occasionally, from the ground to the negatively charged cloud.

The necessary conditions as regards instability for the formation of a thunderstorm may occur in the following ways :—

(*a*) Strong surface heating of the ground on clear days. Thunderstorms formed in this way usually occur in the afternoon. They are most frequent in early summer when the upper air is relatively cold.

(*b*) The setting in of a cold upper current of air over a warm surface current. Such conditions are produced over England when a cool south-westerly wind sets in above a warm current from the south-east. They frequently occur in summer when a fine spell of anticyclonic weather is breaking down, and unsettled conditions are commencing to spread from the Atlantic.

(*c*) The undercutting of warm moist air by a cold current. These conditions are associated with a cold front. Thunderstorms, thus, frequently accompany line-squalls. Storms of this type may occur at any time of year.

APPENDIX IX.

THE BEAUFORT SCALE OF WIND FORCE WITH SPECIFICATIONS AND EQUIVALENTS.

Beaufort Number.	General Description of Wind.	Specification of Beaufort Scale.		Limits of Velocity in Miles per Hour at about 30 feet above level ground.
		For Coast use.*	For use Inland.	
0	Calm	Calm	Smoke rises vertically	Less than 1
1	Light air	Fishing smack just has steerage way.	Wind direction shown by smoke drift but not by wind vanes.	1–3
2	Slight breeze.	Wind fills the sails of smacks, which then move at about 1–2 miles per hour.	Wind felt on face; leaves rustle; ordinary vane moved by wind.	4–7
3	Gentle breeze.	Smacks begin to careen and travel about 3–4 miles per hour.	Leaves and small twigs in constant motion; wind extends light flag.	8–12
4	Moderate breeze.	Good working breeze; smacks carry all canvas with good list.	Raises dust and loose paper; small branches are moved.	13–18
5	Fresh breeze.	Smacks shorten sail	Small trees in leaf begin to sway.	19–24
6	Strong breeze.	Smacks have double reef in main sail.	Large branches in motion; whistling in telegraph wires.	25–31
7	High wind	Smacks at sea lie to	Whole trees in motion	32–38
8	Gale	All smacks make for harbour.	Breaks twigs off trees; generally impedes progress.	39–46
9	Strong gale	.. .. ..	Slight structural damage occurs; chimney pots removed.	47–54
10	Whole gale	.. .. ..	Trees uprooted; considerable structural damage.	55–63
11	Storm	.. .. ..	Very rarely experienced; widespread damage.	64–75
12	Hurricane	.. .. ..	.. .. ..	Above 75

* The fishing smack in this column may be taken as representing a trawler of average type and trim.