

AIR MINISTRY  
METEOROLOGICAL OFFICE  
M.O. 327 (1937 Edition)

METEOROLOGY  
*in relation to*  
AIR NAVIGATION



LONDON  
HIS MAJESTY'S STATIONERY OFFICE  
Price 1s. 6d. net

M.O. 327

## OFFICIAL PUBLICATIONS ON METEOROLOGY

MEASUREMENT OF UPPER WINDS by means of  
Pilot Balloons. (No. 396, 1936). 1s.

METEOROLOGICAL GLOSSARY (continuation of the  
Weather Map, q.v.). (No. 225 ii. 2nd edition. Entirely  
rewritten, 1930). 4s. 6d.

METEOROLOGICAL OBSERVER'S HANDBOOK.  
Instructions in the care and manipulation of meteoro-  
logical instruments, and in the making of observations  
both instrumental and non-instrumental. (No. 191. 1934  
edition). 5s.

WEATHER MAP. An introduction to Modern Meteor-  
ology. (No. 225 i. 2nd edition, 1930. Reprinted 1935).  
(See also Meteorological Glossary, in continuation of the  
Weather Map). 3s.

*All prices are net. Postage extra.*

### HIS MAJESTY'S STATIONERY OFFICE

LONDON: Adastral House, Kingsway, W.C.2.

EDINBURGH 2: 120 George Street; MANCHESTER 1: 26 York Street;  
CARDIFF 1: 1, St. Andrew's Crescent; BELFAST: 80, Chichester Street;

*or through any bookseller.*

net 2/11/3/149/6

Copy for Official Use

AIR MINISTRY  
METEOROLOGICAL OFFICE  
M.O. 327 (1937 Edition)

# METEOROLOGY

*in relation to*

## AIR NAVIGATION

REPRINT OF CHAPTER XVII OF THE  
"MANUAL OF AIR NAVIGATION"  
VOL. I

*Crown Copyright Reserved*



LONDON

PRINTED AND PUBLISHED BY HIS MAJESTY'S STATIONERY OFFICE  
To be purchased directly from H.M. STATIONERY OFFICE at the following addresses:  
Adastral House, Kingsway, London, W.C.2; 120 George Street, Edinburgh 2;  
26 York Street, Manchester 1; 1 St. Andrew's Crescent, Cardiff;  
80 Chichester Street, Belfast;  
or through any bookseller

1937

Price 1s. 0d. net

## CHAPTER XVII.—METEOROLOGY

	Para.
General remarks .. .. .	1
The weather map .. .. .	2
Pressure .. .. .	3
Effect of variation of pressure and temperature on altimeter readings .. .. .	4
Temperature .. .. .	5
Wind .. .. .	6
Variation of wind with height .. .. .	7
Diurnal variation of wind .. .. .	8
Local winds independent of general pressure distribution ..	9
Vertical currents. Bumpiness .. .. .	10
Humidity .. .. .	11
Fog .. .. .	12
Visibility .. .. .	13
Clouds .. .. .	14
Precipitation .. .. .	15
Ice accretion on aircraft .. .. .	16
Weather in relation to wind currents .. .. .	17
The depression .. .. .	18
The anticyclone .. .. .	19
Other types of pressure distribution .. .. .	20
Line squalls .. .. .	21
Thunderstorms .. .. .	22
Lightning and aircraft .. .. .	23
Instructions for preparing weather reports .. .. .	24

### Appendices

- XIV. The Beaufort scale of wind force.
- XV. Code for abbreviated weather reports.

## CHAPTER XVII.—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 branch of knowledge is called *Meteorology*. In this chapter the treatment of the subject is confined mainly to general meteorological conditions as affecting aviation in the British Isles. For further reading in Meteorology *The Weather Map* (M.O.225i) and *The Meteorological Glossary* (M.O.225ii) may be consulted. For a description of the methods of making weather observations, and the instruments in use at meteorological stations, reference should be made to *The Meteorological Observer's Handbook*. Information concerning the organisation of the meteorological services for service aviation will be found in *K.R. and A.C.I., para. 728*, and in *Air Ministry Orders*, while the organisation for civil aviation is detailed in *The Air Pilot of Great Britain and Ireland, Parts I and II*.

### 2. The weather map

(i) 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 several maps daily forming part of the routine of meteorological services.

(ii) The construction of such charts is made possible by an international organisation 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 0100, 0700, 1300 and 1800 G.M.T., which is, approximately, every six hours. (In Middle East, Iraq, India and Singapore the times are slightly different.) The observations made at the different stations include pressure and its changes, temperature, humidity, wind direction and speed, weather and state of sky, height of lowest cloud and visibility. The observations are transmitted from individual observing stations to a central office in each country (the Air Ministry in the British Isles) by telephone, telegraph or wireless telegraphy, the messages being sent in a simple figure code which has also been agreed upon internationally. For the purpose of disseminating the information collected in this way in the

countries of Europe, the Continent is divided into three main groups, the Western group, the Central group and the Russian group. As soon as each country has collected the observations from its own stations, those in the Western group communicate their observations, according to a pre-arranged time table, to Paris, while all those in the Central group forward theirs to Hamburg, and the countries of the U.S.S.R. forward their observations to Moscow. On receipt of the observations in Paris, Hamburg or Moscow, they are re-issued from high-power wireless stations so that they can be received in all parts of Europe. This arrangement ensures that, within less than two hours from the time of observation, it is possible for the various meteorological services in Europe to have received information extending from well within the Polar Circle in the north to North Africa in the south, and from the Levant in the east to the Azores and Greenland in 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.

(iii) For the purpose of weather reports and forecasts for aviation in the British Isles the four main charts constructed from the observations made at 0100, 0700, 1300 and 1800 G.M.T. are supplemented by subsidiary charts based on observations at 0400, 1000, 1600 and 2200 hrs. G.M.T. from certain stations in this country and the neighbouring areas of the Continent. A new chart is thus available approximately every three hours.

(iv) A section of a typical weather map is shown in Fig. 107. For the sake of clearness, only the wind speed and direction, 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 a 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 observing stations are corrected and reduced to mean sea level before the weather messages are despatched, so that the pressures plotted on the charts are comparable with one another.

(v) In the weather maps in Figs. 107, 113 and 114 the wind direction is indicated by arrows flying with the wind, and the number of feathers on the arrows denotes the wind force on the Beaufort scale (*see* Appendix XIV). As from March, 1936, it has been the practice to denote two steps on the Beaufort scale by one feather; thus force 5 is now indicated by two whole feathers and one half feather. 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. This method of plotting weather reports is used here for clarity of representation on a small-scale map. In actual practice at the meteorological offices

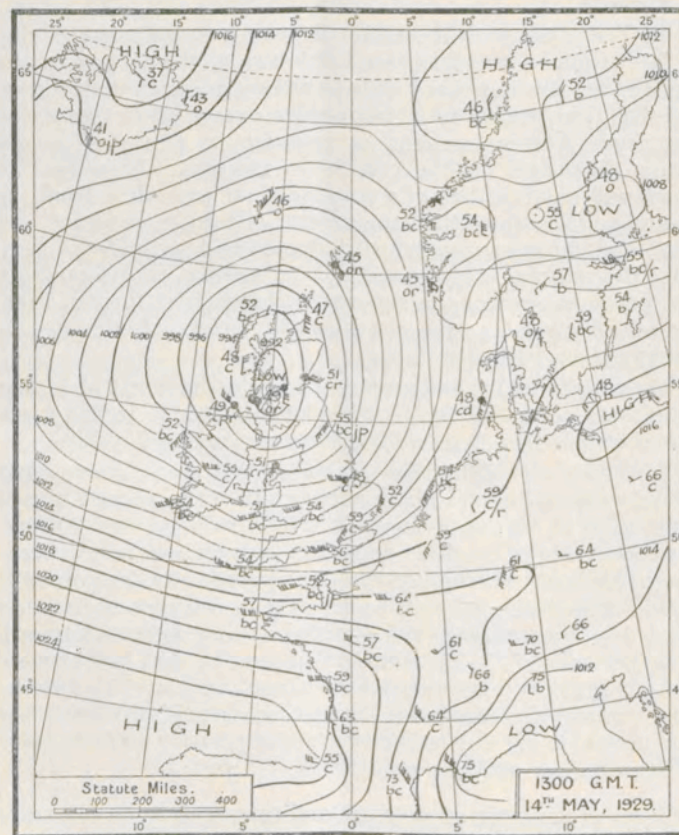


FIG. 107.—Synoptic weather chart.

in this country, all the weather elements observed and reported are plotted on the chart in a uniform manner, as each of these is of great importance in preparing reports and forecasts for aviation purposes.

(vi) The isobars drawn on weather maps do not run in a featureless manner over the chart, but show one or a combination of easily recognisable patterns, the arrangement of

pressure distribution falling generally into areas where pressure is lower than in the surrounding parts, and into regions where it is higher than in the adjacent localities. The areas of comparatively low pressure are variously called *depressions*, *cyclones* or *lows*, while the regions of comparatively high pressure are called *anticyclones* or *highs*.

### 3. Pressure

(i) The pressure of the atmosphere at any point in it is due to the weight of overlying air. Pressure at the surface of the earth is usually measured by means of a mercury barometer, and for this reason it is frequently expressed in inches of mercury. A measurement of pressure so expressed really means the length of the column of mercury, the weight of which will balance that 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*, to measure it: a millibar is the pressure exerted on an area of one square centimetre by a force of 1,000 dynes. A pressure expressed as 30 inches of mercury is equivalent to 1015.9 millibars.

On weather maps isobars are drawn for intervals of 1, 2 or 4 millibars according to the scale of the chart. In the maps reproduced in this chapter the interval is one of 2 millibars.

(ii) From the definition given, it will be obvious that pressure diminishes gradually with height. The *average* rate of diminution in the lower levels is 1 millibar for every 30 feet. The *actual* rate of decrease depends, however, on the temperature of the air: the higher the temperature, the less dense is the air, and the slower will be the rate of decrease of pressure upwards; consequently the pressure at any given height will be higher than if the air from the ground to that height were colder. Pressure also varies with time and place, the variations, which are irregular, being associated with weather changes which are due to the changes in position and intensity of high and low pressure systems.

### 4. Effect of variation of pressure and temperature on altimeter readings

(i) The effects of temperature on the variation of pressure with height, and the variation of pressure with place, have an important bearing on the readings of the altimeter.

(ii) The altimeter is a special form of aneroid barometer which expresses changes in pressure in terms of height. To graduate the altimeter it is necessary to assume an ideal atmosphere, and, in most of the altimeters in current use, the temperature of this atmosphere is taken to be 50° F. (10° C.). Since the rate of decrease of pressure with height depends on

temperature, any variation from this standard temperature of 50° F. will produce an error in the altimeter reading. Thus, if the altimeter of an aircraft in flight reads 5,000 feet, the true height will be 5,000 feet only if the temperature of the air from the ground to the aeroplane is 50° F., but if the mean air temperature is below 50° F., say 30° F., the true height will be less than 5,000 feet, because the air below the altimeter is denser than the standard atmosphere. An approximate rule for allowing for this effect of temperature is to subtract 1 per cent. of the height for each 5 degrees Fahrenheit by which the mean temperature from the aircraft to the ground is below 50°, and vice versa. In the example cited the true height would be less than 5,000 feet by 1 per cent. of  $5,000 \times \frac{(50-30)}{5}$  or 200 feet.

(iii) 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. 107 applied. The sea-level pressure at Leuchars was 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  $30 \times 16$  or 480 feet above sea-level. In other words, the altimeter at Gosport 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. From considerations dealt with in para. 7, it will be seen that if a pilot is flying with a *strong wind* on his *port* beam he is flying into an area where pressure is considerably lower than at his starting point, and his altimeter is overestimating, perhaps dangerously.

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

(i) 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 not the direct rays of the sun, but the earth's surface, which absorbs *radiation* received from the sun, the energy absorbed being converted into *heat*. The air in contact with the heated earth becomes itself 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, at least for the first 7 miles or so. The average rate of decrease or *lapse rate* in this layer of air is  $3^{\circ}\text{F. per } 1,000 \text{ feet}$ , 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 radiates its heat to the sky and becomes cooled, thus cooling the air in contact with it. This air becomes colder, therefore, than the air at some distance above the earth, and an inversion is established.

(ii) 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  $5.4^{\circ}\text{F. per } 1,000 \text{ feet}$ . 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. Wind

(i) Wind is the movement of air necessary to balance two forces acting upon the air: namely, horizontal changes of pressure, and the rotating motion of the earth.

(ii) An examination of the weather chart in Fig. 107 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.

(iii) At a certain height above the ground it is found from actual measurement that the wind blows along the isobars and that 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 speed of the wind in miles per hour at 1,500 feet. The mean-sea-level pressure isobars therefore give the lines of flow of the air at 1,500 feet, and are of great assistance in allowing for wind in air navigation.

(iv) 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. 108, 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.

## 7. Variation of wind with height

(i) 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 rule can be laid down for the increase

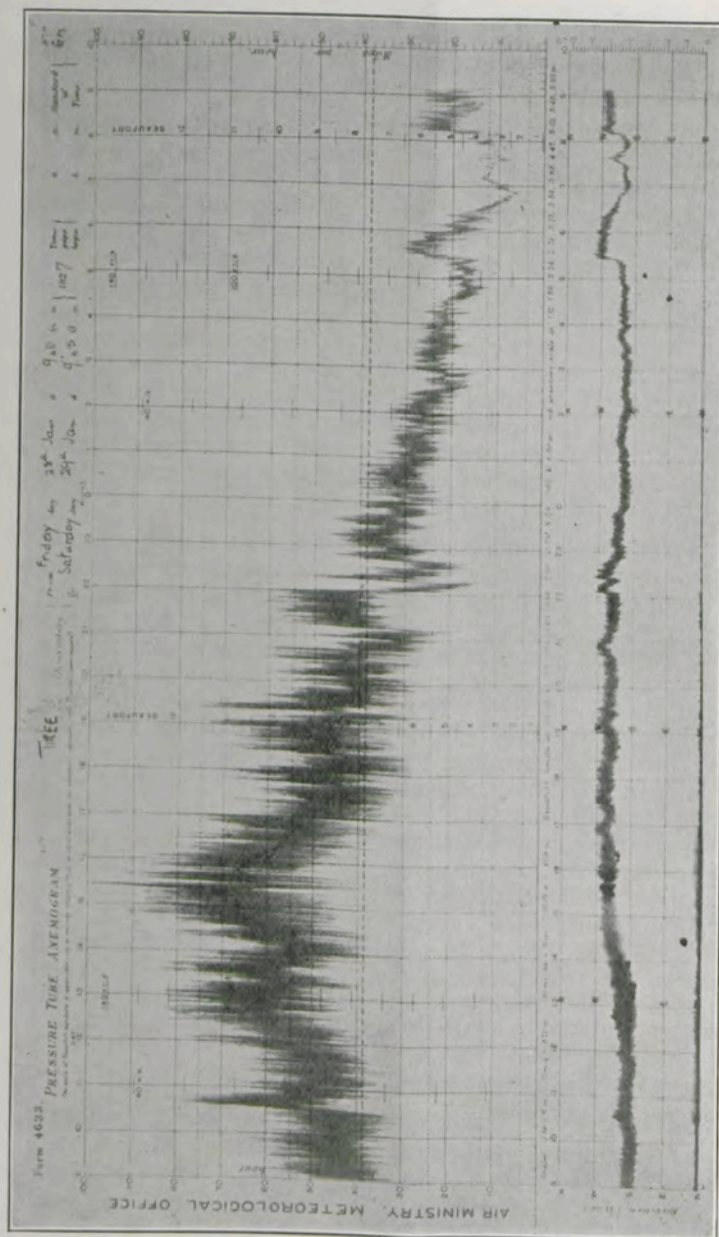


Fig. 108.—Record from Dine's pressure tube anemometer.

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.

(ii) 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.

(iii) The irregularity in the variation of wind with height makes the question of obtaining accurate data about the winds at different heights one of importance in air navigation. At meteorological stations the winds are measured by means of small rubber balloons filled with hydrogen to rise at a predetermined 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.

### 8. 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 almost 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 para. 7, 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, and much less marked in winter.

### 9. Local winds independent of general pressure distribution

There are certain important exceptions to the general rule stated in para. 6 regarding the relation between wind direction and the general pressure distribution. Of these the following may be noted:—

(i) *Anabatic winds*.—On a hot day the air in valleys is warmed and, owing to its decreased density, tends to rise, flowing up the valley and up the slopes of hills. Such a wind is called *Anabatic*.

(ii) *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, especially if the pressure gradient tends to augment the influence of the hill.

(iii) *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 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.

### 10. Vertical currents—Bumpiness

(i) The wind flow over the earth's surface is not entirely horizontal. There are various causes present which, acting either singly or in conjunction tend to produce a vertical component in the motion of the air. Apart from the gustiness referred to in para. 6, ascending and descending currents in the atmosphere constitute the chief cause of bumpiness in flying.

(ii) *Dynamic up-currents*.—The most obvious way in which deviation from the regular horizontal wind flow may be produced is by means of an obstruction such as a ridge of hills. If the latter is at right angles to the wind direction the air must, of necessity, pass over the summit, producing an upward current on the windward side and a downward current on the lee side. In such a case the vertical motion extends to an average height above the summit equal, approximately, to four times the height of the ridge. The actual height to which the disturbance extends depends, however, on the temperature lapse rate, being greater when the latter is large. If, on the other hand, a temperature inversion exists at some height above the hill no vertical motion is possible above the level of the inversion and no bumps are experienced when flying over the hill above this level. These conditions occur most frequently in winter in the relatively quiet conditions associated with an anticyclone (see para. 19).

In the case of a hill with steep slopes, there is a tendency for stationary eddies to be formed on both the windward and leeward sides, the wind blowing down the hill near the bottom of the slope on the windward side and up the hill on the leeward side (see fig. 109 (a)). Between the main upward or

downward current and the return current close to the hill, a shadow area, or region of dead air will be found to exist. Such eddies persist so long as the lapse rate is less than the dry adiabatic and the wind speed is less than about 20 m.p.h. If the lapse rate or wind speed exceeds these values, the wind flow over the hill becomes generally turbulent and the more definite larger eddies are difficult to distinguish.

The wind flow over a cliff with a steep face is more turbulent than in the case of a hill. Fig. 109 (b) and (c) illustrates the types of disturbance produced when the cliff faces to windward and to leeward respectively. In the latter case the eddies may persist for a considerable distance to leeward causing dangerous flying conditions. An example of a disturbance of this kind is found in the wind currents over the Rock of Gibraltar.

(iii) *Frictional up-currents.*—In a coastal region when the wind blows from the sea up-currents are produced by surface friction. Owing to the increased friction which occurs in the transition from sea to land, the wind experiences a strong retardation or decrease in velocity. This decrease is compensated by a corresponding ascending current over the coast.

Ascending currents along the coasts, due to this cause, occur more particularly in summer with a sea breeze. Evidence of the upward current is seen in the long line of cumulus cloud (see para. 14) which persists along the coast line. The upward current is reinforced if there is high ground bordering the coast.

(iv) *Thermal up-currents.*—Considerable vertical currents are produced owing to the irregular heating of the earth's surface by the sun. On a fine day in summer, particularly if there is little wind, the ground rapidly becomes heated, causing the air at lower levels to approach the unstable adiabatic state. Streams of air then flow upwards from the ground and, if the air is sufficiently moist, a cumulus cloud forms at the top of each rising column. As the cloud grows, a powerful circulation develops within it, drawing in air from lower levels. A sky covered with such cloud produces alternating ascending and descending currents with correspondingly disturbed flying conditions.

The extent to which the ground becomes heated depends on the nature of the surface. Thus, thermal up-currents are more pronounced over some kinds of terrain than over others. Bare rocky or sandy soil becomes heated much more readily than land covered with grass or vegetation. Upward currents are experienced on a hot day over such areas which contrast with their surroundings while downward currents are found over lakes, rivers and forests.

Another example of thermal up-currents is seen in the case of a cold current of polar origin which, having reached England by flowing southward over warmer water, has become unstable. In such conditions squally winds accompanied by severe bumps may be experienced. These conditions occur most frequently in spring when the ground is becoming warmer and the upper air is still relatively cold.

(v) *Frontal up-currents.*—The vertical currents considered hitherto have been the effect, either directly or indirectly, of the topography of the earth's surface. The most powerful up-currents experienced, however, are due to purely meteorological causes which are, in the main, independent of the nature of the surface below. These up-currents are due to the interaction of air masses which, being of different thermal structure, produce disturbed conditions along the boundaries where they meet. The most important type of disturbance is the cold front of a depression, along which the cold northerly or north-westerly winds of polar origin in the rear of the depression undercut the warmer south-westerly winds on the southern side (see para. 18). The most intense upward currents occur in line-squalls and more particularly in thunderstorms which are described in paras. 21 and 22.

## 11. Humidity

(i) 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*. Any mass of air containing water vapour can therefore be cooled down until it is 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*.

(ii) 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  $5.4^{\circ}\text{F.}$  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

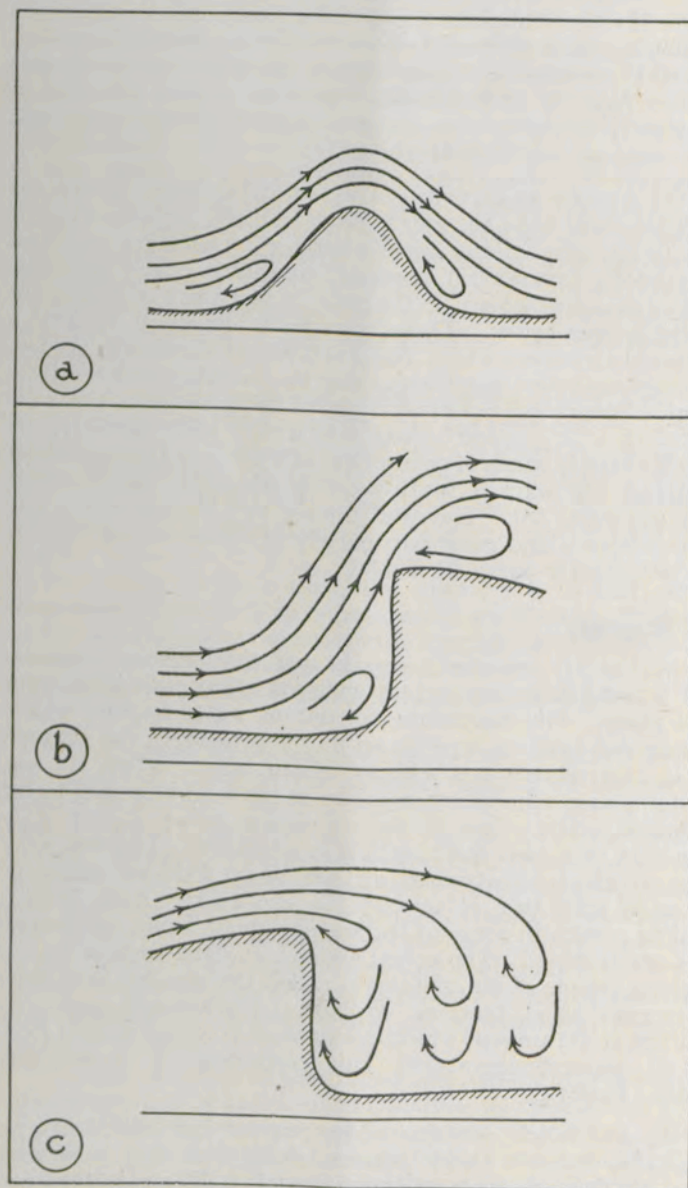


FIG. 109.—(a) Air flow over hill with steep slopes.  
 (b) Air flow over cliff facing to windward.  
 (c) Air flow over cliff facing to leeward.

cooling which unsaturated air undergoes on rising. The rate for ascending saturated air, which depends on the temperature of the air, is only  $2.6^{\circ}\text{F.}$  per 1,000 feet at  $50^{\circ}\text{F.}$  This is called the *saturated adiabatic lapse rate*.

## 12. Fog

(i) *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, or a combination of water vapour and smoke. 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. The wetness of the ground therefore has a bearing on the likelihood of occurrence of fog.

(ii) 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.

(iii) Near large towns and industrial areas where there is a continuous output of smoke from factory chimneys, etc., 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.

(iv) The height to which an ordinary fog extends varies considerably. It is usually less than 1,000 feet and frequently less than 500 feet. In certain conditions a fog has no clearly defined upper boundary but merges into cloud which may extend to a considerable height.

(v) 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. 110 which connects the readings of the dry bulb thermometer at 2000 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:

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

(b) If the wind at 2000 G.M.T. is above 8 m.p.h. at 5 feet above the ground, there is little risk of fog or mist.

(c) If the wind at 2000 G.M.T. is calm, there is considerable risk of fog or mist whatever may be the thermometer readings.

(d) If the wind at 2000 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

*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

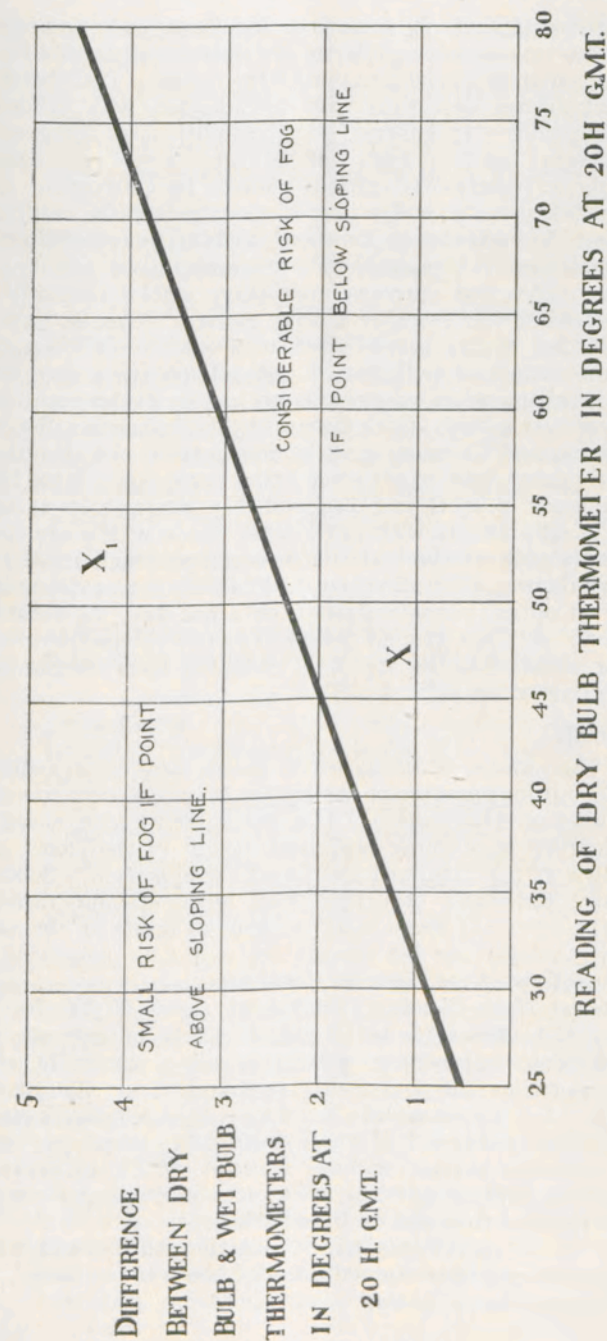


Fig. 110.—Fog prediction diagram for England.

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 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

(i) The number of forms which clouds may take is almost infinite, but for purposes of description it is necessary to adopt some kind of classification. The system adopted is based on the observed appearance and mean height of the cloud, and is known as the International Cloud Classification. Some of the more commonly occurring cloud forms are illustrated in Fig. 111. Several forms may, of course, occur at the same time.

The following are the main cloud types:—

(a) *High Clouds*. (Mean lower level 20,000 feet.)

1. *Cirrus (Ci.)*—Detached clouds of delicate and fibrous appearance, without shading, generally white in colour, often of a silky appearance.

2. *Cirro-cumulus (Ci.-Cu.)*—A cirriform layer or patch composed of small white flakes or of very small globular masses, without shadows, which are arranged in groups or lines, or more often in ripples resembling those of the sand on the sea-shore.

3. *Cirro-stratus (Ci.-St.)*—A thin whitish veil, which does not blur the outlines of the sun or moon, but gives rise to halos.

(b) *Middle Clouds*. (Mean upper level 20,000 ft., mean lower level, 6,500 ft.).

1. *Alto-cumulus (A.-Cu.)*—A layer, or patches composed of laminae or rather flattened globular masses, the smallest elements of the regular arranged layer being fairly small and thin, with or without shading.

2. *Alto-stratus (A.-St.)* Striated or fibrous veil, more or less grey or bluish in colour. (This cloud is like thick cirro-stratus but without halo phenomena.)

(c) *Low Clouds*. (Mean upper level 6,500 ft., mean lower level close to the ground.)

1. *Strato-cumulus (St.-Cu.)*—A layer of patches composed of laminae or globular masses; the smallest of the regularly arranged elements are fairly large; they are often soft and grey, with darker parts.

2. *Stratus (St.)*—A uniform layer of cloud, resembling fog, but not resting on the ground.

3. *Nimbo-stratus (Nb.-St.)*—A low, amorphous and rainy layer of dark grey colour and nearly uniform.

(d) *Clouds with vertical development*. (Mean upper level that of the cirrus, mean lower level 500 m.)

1. *Cumulus (Cu.)*—Thick clouds with vertical development; the upper surface is dome-shaped and exhibits protuberances, while the base is nearly horizontal.

2. *Cumulo-nimbus (Cu.-Nb.)*—Heavy masses of cloud with great vertical development, whose cumuloform summits rise in the form of mountains or towers, the upper parts having a fibrous texture and often spreading out in the shape of an anvil.

(ii) 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. Speaking broadly, the methods of formation of clouds may be classified as follows:—

(a) *By direct ascent of air*.

1. *Topography*.—Wind blowing against a range of hills or mountains is forced to rise and a long bank of cloud, more or less continuous, forms on the upper part of the mountains or above the hills. Temperature falls with increasing height throughout the cloud.



(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. 111.—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. 111.—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. 111.—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. 111.—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.



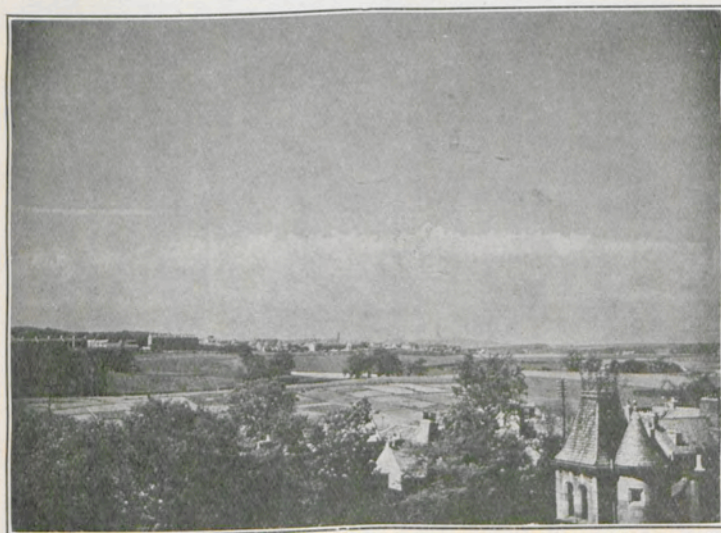
(10) Stratus (**St.**). Level sheet of low cloud : below 3,000 ft.

FIG. 111.—CLOUD FORMS—*continued*.

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



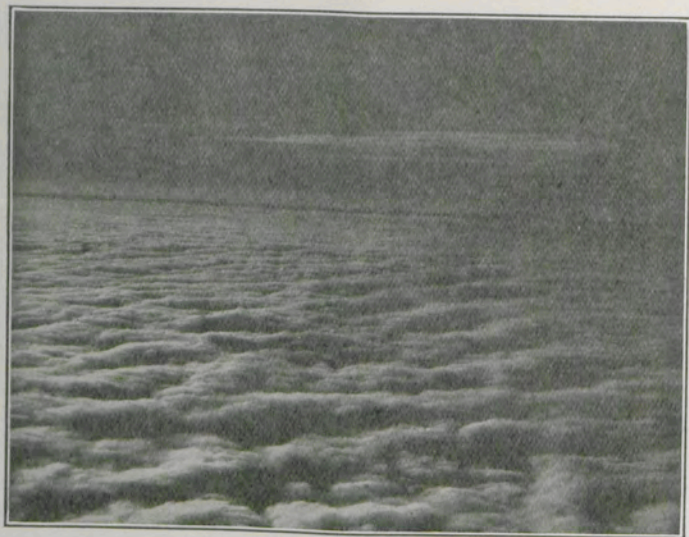
(11) Alto-Cumulus-lenticularis (**A.-Cu.-Lent.**). Almond-shaped banks of cloudlets at the alto-cumulus level.



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

FIG. 111.—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. 111.—CLOUD FORMS—*continued*.

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



(15) Top of large Cumulus protruding 2,000 feet through a cloud-sheet.  
The height of the upper surface of the cloud-sheet was 8,000 feet.



(16) Fracto-Cumulus.

FIG. 111.—CLOUD FORMS—*continued*

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

2. *Convection*.—Owing to the irregular heating of the ground by the sun large vertical movements of air occur and a cumulus cloud forms at the top of each rising column. Between the clouds descending currents and clear sky occur. Such clouds usually form during the day and dissolve at night. On a very hot day, with moist air, cumulo-nimbus clouds are formed and thunderstorms may develop. Temperature falls with increasing height throughout the cloud. Such clouds are usually very bumpy.

Conditions favourable for the development of cumulus or cumulo-nimbus clouds also occur in the rear of a depression when a current of cold air meets a current of warmer air (the "cold front") and undercuts the latter causing large-scale convective movement (see para. 18).

3. *Gradual ascent of air over large area*.—This occurs in advance of a depression when a warm air current is advancing on a colder current (the "warm front") (see para. 18). The warm air rises over the denser, colder air forming a sloping surface. The warm air may ascend to the Cirrus level and give rise to the cloud sequence shown in Fig. 112, ranging from high Cirrus cloud through alto-stratus to low nimbo-stratus. There is usually a temperature inversion at the boundary of separation.

It should be noted that, when flying towards the warm front, the base of the cloud becomes progressively lower. Although initially the base of the alto-stratus may be above 10,000 feet, the nimbo-stratus may fall to 300 feet or lower. Also the pilot is flying in a direction opposite to that of the movement of the front, and if the latter is travelling rapidly, the change from high to low cloud will take place in a relatively short interval of time. Alto-stratus is comparatively free from bumps but nimbo-stratus may be very bumpy.

(b) *By eddies*.—When a current of cold air flows over a warmer surface, eddy motion is set up which causes mixing between successive layers of air. The mixing and consequent cooling may extend sufficiently far upwards for condensation to occur and a layer of strato-cumulus 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 cases there is a marked change of wind above the cloud. It should be noted that in a layer of strato-cumulus, cumulus or cumulo-nimbus may develop in isolated patches giving rise to areas of severe bumpiness. This phenomenon is illustrated in plate (15) of Fig. 111.

(c) *By mixing*.—If two air currents of different temperatures flow parallel to each other, mixing may occur at the boundary and a belt of cloud form. In such cases the cloud usually extends right down to the ground.

Stratus cloud is formed by the turbulent mixing of moist air in a layer above the surface of the ground. It frequently occurs in the early morning as a transition stage between night fog and clear day conditions. Such cloud usually has a very low base and frequently envelops high ground.

## 15. Precipitation

(i) *Rain* is produced by the condensation of the water vapour in the atmosphere. It has been seen that when the temperature of a mass of air containing water vapour falls sufficiently, a point is reached where the water vapour is condensed into fine particles of water, and a cloud is formed. If the process of cooling is carried still further by the ascending motion of the air continuing after condensation has commenced, the cloud particles grow in size until they are too heavy to remain suspended in the air, and rain falls. The nature of the rain-fall depends on the magnitude of the ascending currents of air, and, therefore, on the lapse rate.

Rain may be classified, according to the manner in which cooling is brought about, into three types:—orographic, cyclonic, and convective.

(a) *Orographic rain* is caused by the interference of rising land in the path of moisture-laden wind.

A horizontal air current striking a mountain slope is deflected upwards, and the consequent dynamical cooling produces rain if the air is moist enough. Mountain ranges at right angles to the direction of the wind offer greater obstruction to the wind, and therefore are more likely to produce rain than mountain ranges which lie in the direction of the

wind. In the case of isolated mountain peaks, the wind is often able to go round, and the amount of rain produced may be trifling. The prevailing wind of the British Isles is from the south-west and as this damp wind passes across the country the aqueous content decreases. A mountain range of a given height along the west coast would therefore produce a greater rainfall than a range of similar height and position relative to the wind in the east.

These orographic rains are typically persistent and usually widespread. Their great importance lies in the fact that the main controlling factor, namely the rising ground, is always operative, and naturally always in the same place. Thus a station on a hill is not only usually wetter year by year than a neighbouring station in a valley, but the proportion remains fairly constant. Some valleys, if they are surrounded by mountains on all sides, receive nearly as large a rainfall as the surrounding mountains, since air is generally rising as it passes across these valleys.

(b) *Cyclonic rain* is the rainfall associated with the passage of depressions. It is caused by a gradual ascending movement over a wide area, and is therefore a continuous steady rain, the rain drops falling through the air as soon as they are formed owing to the absence of any large vertical air currents.

(c) *Convective rain* is caused by the heating of the surface layers of the air. The warm air is frequently heavily charged with moisture taken up from the ground, from vegetation, or water surfaces. This type of rainfall is associated with a steep temperature lapse rate and strong ascending currents, and the process of rain formation is more complicated.

The rate at which raindrops fall through the air depends on the size of the drops. When first released their speed will increase until the air resistance is exactly equal to their weight, when they will continue to move at that steady speed, which is known as the *terminal velocity*. The stronger the ascending current, therefore, 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 size of raindrop which can be generated: above this size the drop will break up into smaller drops. In consequence, if the speed of the ascending current is greater than a certain amount (about 1,600 feet per minute), no water drops can fall through it, but all will be carried upwards. In this way large accumulations of water can occur in a cloud, and if the ascending air currents suddenly cease, very heavy rainfall results.

(ii) *Snow* is precipitation in the form of ice-crystals of feathery or needle-like structure. The crystals may fall singly or a large number of them may be matted together in the form of large flakes.

Snow occurs when the temperature conditions in the air are such that condensation is taking place near the freezing point. 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. Snow will therefore frequently be encountered while flying during the winter when it is raining at ground level.

(iii) The term *hail* properly denotes the hard pellets of ice of various shapes and sizes which fall from cumulo-nimbus clouds and are often associated with thunderstorms. A variety known as soft hail is small, white, opaque and soft, resembling little snow pellets.

Hailstones may attain a great size, stones as large as golf balls having been observed in Europe, and the recorded weights range up to 2 lbs.

Hail is formed in the same way as convective rain already described, being raindrops which have been carried upwards in strong ascending currents of air to levels where the temperature is well below freezing point, and thus become frozen. They frequently make several upward and downward journeys in the cloud before becoming heavy enough to overcome the resistance of the rising air and finally falling to the ground. This accounts for the laminated structure of many hailstones. The stronger the upward currents the larger are the hailstones, so that large hailstones are evidence of dangerous flying conditions.

## 16. Ice accretion on aircraft

(i) In certain conditions ice may form on the wings and other parts of an aircraft in flight. When the rate of deposition is slow the formation is mostly crystalline and opaque and forms mainly on the leading edges with little change of aerodynamic shape. When, however, the deposition is rapid, mainly clear ice forms and adheres firmly to the surfaces. The leading edges then acquire a mushroom-shaped growth and the aerodynamic shape of the surfaces changes, causing rapid loss of lift. Danger also arises from pieces of ice becoming detached from the airscrew; this causes loss of balance and vibration, apart from the risk of pieces of ice striking the fuselage, cockpit, etc.

(ii) Ice deposition may occur in the following ways:—

(a) By direct change from water vapour to the solid state. This occurs when condensation takes place below freezing point, but more frequently below 25° F. A white crystalline deposit then forms on exposed surfaces (hoar frost). Deposition is slow and there is little adhesion.

(b) When flying in clouds in which supercooled water drops occur below 32° F. These drops solidify immediately

on striking the surface of the aircraft, forming a deposit of feathery ice crystals (rime). Such deposition may occur at any temperature from 32° F. to below 10° F.

(c) When rain is falling through air having a temperature below the freezing point, it freezes immediately on striking the surface of the aircraft causing a rapid deposition of clear ice (glazed frost). Such deposition occurs in or below clouds with temperatures 1° to 3° F. below the freezing point. These conditions frequently occur at the end of a cold period in advance of the warm front of a depression (see para. 18), the temperature above the boundary of separation being above 32° F. while the temperature below it is lower than 32° F. The area in which glazed frost is formed may extend up to 100 miles in advance of the lowest part of the front.

(iii) Observations made in England show that ice accretion may occur in any type of cloud, but that deposits are heaviest in strato-cumulus, stratus, cumulus and cumulo-nimbus. It is likely to be encountered :—

(a) in any cloud with a temperature below 32° F. ;

(b) in any area where the ground temperature is below 40° F., particularly if there is rising ground to be crossed ;

(c) with rain at or near the ground and temperatures only a little above 32° F. In these conditions sleet and snow will be encountered at no great height ;

(d) at the end of a cold period as described in (ii) (c) above.

(iv) The conditions in which glazed frost forms (see (ii) (c) above) may be encountered at any level below the inversion between the two air currents. Consequently the deposition of ice can only be checked by climbing into the warmer air above the inversion. In other cases deposition can be checked by getting out of the cloud. When flying in strato-cumulus or stratus, there is less risk of ice formation when flying near the upper boundary of the cloud. If ice commences to form it is then possible to climb above the cloud where the air is warmer.

## 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

(i) 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. 113 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 within it 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. 112. The slope of the surface between the two air currents varies according to the conditions existing, but is of the order of 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

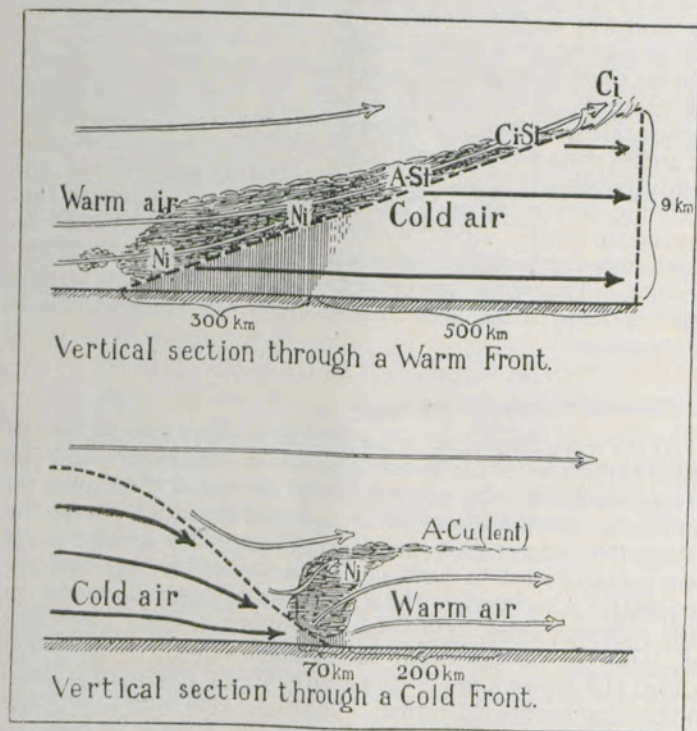


FIG. 112.—Rain and cloud formation.

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. 113. After the warm front has passed the cloud lifts and tends to break, although since the air current 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. 113. A typical section through a cold front is shown in Fig. 112. 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. 21 and 22.

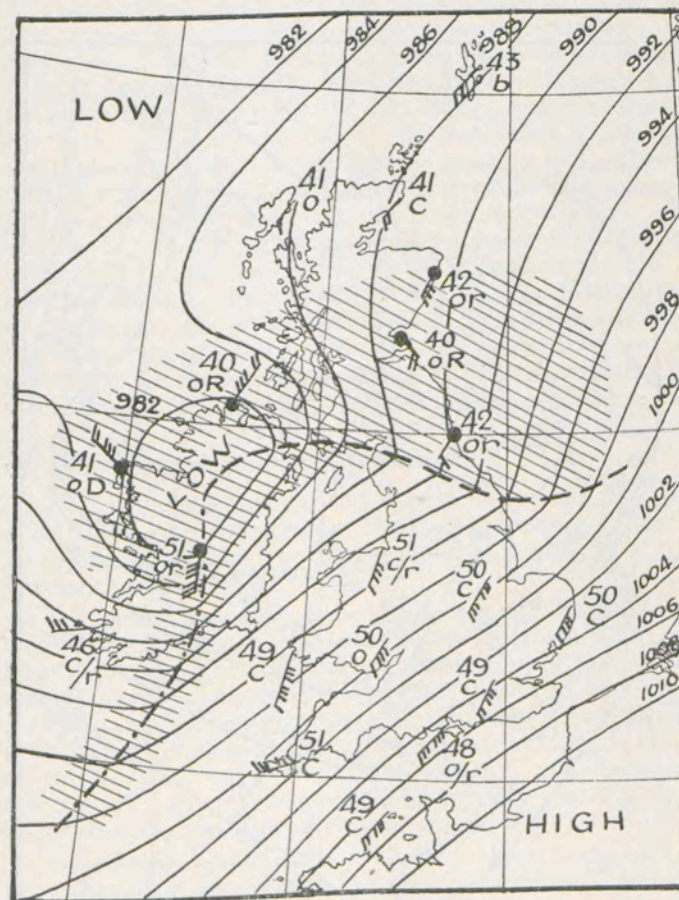
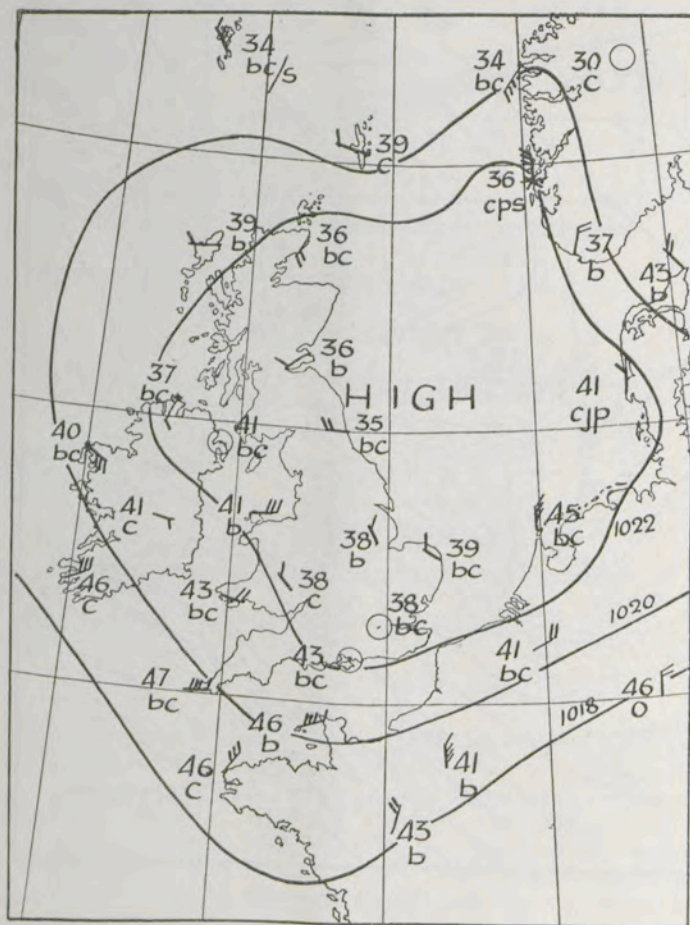


FIG. 113.—A depression.

(ii) 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.



THE ANTICYCLONE OF 1<sup>ST</sup> MAY, 1927.

FIG. 114.—An anticyclone.

## 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. 114. 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. Other types of pressure distribution

The depression and the anticyclone form the two main types of pressure distribution, but it is usual to describe the arrangement of isobars on any weather map with the help of four more acknowledged types.

The subsidiary type most commonly mentioned is the *secondary depression*. Sometimes in the neighbourhood of a large depression, usually on its southern side, the isobars take a bend outwards, marking the position of a small area of low pressure. Such a secondary depression usually travels forward in the same direction as the main low, but outstrips it in rate of travel. It usually produces much rain and frequently much wind. In the summer secondary depressions are normally shallow, and cause thunderstorms.

A *V-shaped depression* is a further extension of the secondary; and the isobars extend out a long way in the form of a letter V. The central line of the V obviously marks a region of abrupt change in the wind direction. It is really a well-marked cold front, and produces a rapid change in the weather from heavy rain to clear skies, and a large fall in temperature.

A *wedge or ridge of high pressure* is the region between two depressions where the isobars are shaped like an inverted V.

The wedge usually extends polewards between the two lows which are skirting the northern edge of an anticyclone, and moves eastward with them. The front of the wedge is therefore a region of fine weather with north-westerly winds, rapidly becoming light in force as the axis of the wedge approaches; then the wind backs to south-west or south as the new depression comes along, and rain usually follows. A wedge represents the interval of fine weather between two rainy periods.

A *col* is a region between two anticyclones, like a mountain pass between two higher peaks. Since the wind is blowing round the two highs in a clockwise direction, the *col* is a region of light airs from very different directions which are being brought into close proximity. A *col* gives conditions for fog in cold weather and thunderstorms in hot weather.

## 21. Line squalls

(i) In para. 6 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.

(ii) When a cold front travels across the country, the friction at the surface retards the cold air in contact with it, while the cold air at some height above the ground moves forward unimpeded. The result is that the cold air assumes the form of a wedge with its point some distance above the ground.

When the tip of the wedge comes overhead at a station the barometer commences to rise rapidly and continues to do so as the vertical thickness of the denser cold air above the station increases. The abrupt pressure changes cause a rapid veer of wind, usually from a southerly point to north-west, and a short sudden increase of wind speed, these phenomena constituting the squall. Under the overhanging portion of the wedge of cold air there is warm air so that the overhanging portion is unstable. The breakdown of this unstable arrangement gives rise to intense vertical currents as the warm air rises over the front edge of the cold wedge. The squall cloud forms near this front edge, the well-known roll form being imparted owing to a compensating downward current just behind the edge. If the warm air mass in advance of the cold front is initially unstable, the ascent of air will not be confined to the lower layers but will continue to considerable heights forming towering cumulus clouds with the possibility of heavy rain or hail and thunder and lightning.

(iii) Line-squalls usually travel from a direction between north-west and south-west. Occasionally they move from north to south or from south to north. There is very rarely an easterly component in the motion. Rates of travel of 30 m.p.h. are quite common and speeds of 60 m.p.h. are not unknown. A line-squall does not usually advance at a uniform rate along its whole length.

(iv) Since there are cold fronts associated with all active depressions of temperate latitudes the frequency of occurrence of line-squalls of varying degrees of intensity is high, but for every severe squall there may be many of only moderate or slight intensity. The horizontal length of a line-squall may be anything up to 1,000 miles. The length of life is often at least twenty-four hours. A line-squall would usually become less intense, or die out altogether, when an occlusion is formed, but even afterwards the occlusion may have the character of a cold front and the line-squall persist for a further considerable period before dying out. It is important to note that, just as there is a considerable variation of speed of advance along the front so the intensity of the associated phenomena may vary at different points.

(v) Although line-squalls are associated with the cold fronts of moving depressions of temperate latitudes, line-squall phenomena are also encountered in the Tropics, often in an intense form. In many tropical countries the daily sea breeze often sets in as a line-squall. The "Nor'-westers" of Bengal, the "Sumatras" of the Malacca Straits, the "Pampero's" of the Argentine and the "Southerly Bursters" in south and south-east Australia are all line-squall phenomena.

## 22. Thunderstorms

(i) 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. A fully developed thunderstorm may be described as one in which heavy rain or hail, lightning and thunder occur. The lightning flashes are evidence of the vast quantity of electrical energy released in a thunderstorm and the question naturally arises as to the origin of this energy.

(ii) There is always some electrical force in the earth's atmosphere, especially near the surface, but in fine weather this is relatively small and for most practical purposes may be neglected. The electrical field which exists in all regions during fine weather is called the normal field.

(iii) As soon as the weather becomes disturbed more intense electrical forces make their appearance. During fog the normal electrical field becomes greatly intensified and in some cases may become so strong that some electrical discharge takes place from the ends of pointed metallic conductors connected to the earth. If, however, the fog is not accompanied by precipitation the electrical fields never become sufficiently strong for disruptive discharges to take place and therefore fogs in themselves do not produce dangerous conditions.

(iv) As soon as precipitation in any form—rain, snow, sleet or hail—commences, an entirely new set of electrical conditions is introduced. It was pointed out in para. 15 that the largest raindrops which can persist in the air require an upward current of 1,600 feet per minute to support them and that, above this speed, the drops become unstable and break up into smaller drops.

Laboratory experiments have proved that when a water drop suddenly breaks up in the air into a number of smaller drops considerable electrical separation takes place. The water becomes positively charged while the air becomes negatively charged. When the drops break in an ascending current of air the positively charged water-drops, on account of their weight, lag behind the ascending air which carries the negative charge. This results in the negative charge being removed from the positive charge, the former being carried into the upper part of the cloud and the latter remaining in the lower part or falling to earth as rain. The separation of electricity into different parts of the cloud will set up large electrical fields.

It is important to note that the electrical effect is produced after the precipitation is formed and has commenced to fall relatively to the air in which it is supported. Further, the air

must be moving upwards if any large quantity of electricity is to be developed; generally speaking, the more violent the ascending currents the more efficient they will be in producing electrical effects.

(v) With these considerations in mind it is easy to understand the efficiency of different kinds of weather in producing electrical effects. Commencing with fine weather we have only the normal electrical field which is small and for most purposes unimportant. When fog or cloud are formed, no new electricity is produced and all that they can do is to modify the existing normal field; but the electrical fields produced in this way are not strong enough to be of much practical interest. As soon as some of the cloud particles become sufficiently large to fall through their neighbours, the possibility of the production of electricity and its separation arises. If the rain or snowfall is slow and steady, as in the case of the precipitation associated with a warm front when the whole sky is covered with cloud which has a very slow and regular ascent, the production of electricity is slow and the electrical field does not rise to high values although it may be higher than during fine weather.

(vi) When the atmosphere becomes unstable, as at a cold front, or in polar air, or during a hot summer day, the ascent of the air no longer takes place slowly and steadily over a vast area, but tends to rise in local ascending currents each one of which is marked out by a cap of cloud surrounded by clear air. As the ascent progresses and becomes more violent showers of rain or snow are formed. The conditions are then suitable for efficient separation of electricity. As the ascending currents, and with them the precipitation, become more extensive and more intense so the electrical separation increases. The accumulation of large electrical charges results in strong electrical fields, and as soon as these fields become large enough electrical discharges commence. The discharges are at first probably small and local, but as the field increases still further the large disruptive discharges which we call lightning take place and we have a thunderstorm.

With still greater increase in the ascending currents hail is formed and the lightning becomes more frequent and violent. The presence of hail is proof that rapid ascending currents exist and violent electrical effects may be expected.

(vii) 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 anti-cyclonic 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 frequently accompanying line-squalls. Storms of this type occur at any time of year.

(d) In unstable polar currents in which the development of showers is often accompanied by thunder. These conditions occur more particularly near the western seaboard in winter.

(viii) Thunderstorms are neither so numerous nor so severe in the British Isles as in the Tropics. They are most frequent in the eastern and midland districts and a large majority occur in the summer half year, especially from May to August. In the western coastal districts the storms are of types (c) and (d) above and occur with nearly equal frequency in the summer and winter seasons. There are many hot summer days, especially in anti-cyclones, when the necessary conditions for the formation of a thunderstorm, viz., an adequate supply of moisture and a steep temperature lapse rate, are not fulfilled so that the hottest summers are not necessarily the most thundery. The requisite conditions exist most frequently at this season in shallow depressions or in cols. With conditions in the upper air favourable, it is possible for severe storms to occur at night, provided there is some initial impulse to start the cloud formation, e.g. the convergence along a cold front.

### 23. Lightning and aircraft

(i) It has been seen that in a thundercloud the breaking-up of the water drops results in a separation of electricity, the water after breaking-up having a positive charge while the cloud particles become negatively charged. The electricity is attached to the cloud or rain particles and as each of these particles is surrounded by non-conducting air, the charge cannot leave its carrier but must travel wherever that carrier goes. The electricity thus becomes localised and bound in definite regions of the cloud. Each concentration of electricity is the origin of an electrical field of force which is most intense at the edge of the region containing the charge. As the electrical strength of the air breaks down where the field is the most intense and from this point a lightning flash starts, it is clear that a flash may start within the cloud and pass from

a region of positive to a region of negative charge all within the cloud; or it may start under one charge—but well within the cloud—and pass from there to the ground.

(ii) The presence of an aeroplane may affect an electrical discharge in two ways. Before an electrical discharge can start the electrical force must reach that intensity which breaks down the air. If into a part of the electrical field which is near but slightly below the sparking value an electrical conductor is introduced, the conductor concentrates the field and may raise the intensity above the sparking value. A discharge then starts at the conductor which may develop into a lightning discharge. If, therefore, an aeroplane flies near to that part of a cloud which carries a high charge it may initiate a lightning discharge.

The second way in which an aeroplane may influence a lightning discharge is to be by chance near to the path of a discharge which has started elsewhere. When a discharge starts at any point it progresses by building for itself a conducting channel through the air. The general direction of propagation of a discharge is towards the electricity of the opposite sign to that which caused the breakdown. Thus, if a discharge starts in a region of the cloud which has a positive charge the channel will grow either towards the negative electricity in another part of the cloud or to the negative electricity induced on the surface of the ground. If there is a high conducting path—such as the metal in an aeroplane—within striking distance of the channel as it lengthens, the channel will be attracted to this and pass into it at one end and out at the other. As the majority of flashes below a cloud strike downwards to the earth the air path may be appreciably shortened by a trailing aerial. Generally speaking, the greater the linear length of a conductor the more risk there is of its providing a short circuit for a lightning flash. Thus the long wire used in towing targets by aeroplanes may provide an attractive path for a discharge even though it lies in a horizontal direction; for the electrical field is by no means always vertical.

(iii) The conclusion to be drawn from these considerations is clear; the aircraft should, if possible, avoid the regions where there is great electrical activity. As already explained, these regions are the parts of the cloud where the most violent ascending currents occur and are generally situated some distance within the cloud itself. If therefore an aeroplane is caught in a thunderstorm it is best both from the point of view of dangerous electrical discharges and dangerous vertical air currents to fly well below the cloud and never through it, if that can be avoided.

(iv) If an aeroplane, without an aerial, is near to a lightning discharge it has not a very great attractive power because its linear dimensions are not great. If, however, it is struck the discharge will enter and leave at those points which give the longest path in the direction in which the discharge is travelling. The actual direction of the field will determine the exact points in each individual case, but experience shows that they are most commonly the tips of the wings, the nose of the plane and the end of the tail. If all these points are connected together by one or more metallic paths, the total cross section of which is of the order of half a square inch, the flash can enter and leave the plane without doing any damage. In most planes there is sufficient metal paths to satisfy this condition, but in machines largely built on wooden frameworks there may be some section in which the metal paths are only meagre and a structural wire or a control wire has to take a heavy load, and there is then danger that this member may be burnt out. The more metal there is in the framework of the machine the less the danger of this occurring. It is clearly desirable that the current should have open to it every possible path between the point where it enters and the point where it leaves so as to decrease the resistance and to increase the effective cross-section of the conducting path. This will only be attained if every piece of metal in the aeroplane is bonded *at both ends* to other metal conductors.

(v) On machines without aerials there is practically no danger to the personnel, for the cockpit is generally situated within such a mass of metal that there is little chance of any part attaining a high electrical potential relatively to any other part, so that there is little tendency of the discharge to pass into the human occupant.

The position, however, is much more serious if the machine has a trailing aerial. In the first place the aerial extends the linear dimensions of the conductor and generally in the direction which the flash wishes to take. Thus a machine with an aerial is more likely to be struck than one without. Further, the aerial goes directly into the cockpit and is not directly connected to the main mass of bonded metal of the aeroplane which takes the place of a normal "earth". This will conduct the high potential current of the flash right into the interior of the plane and through the numerous "leads" of the wireless set into dangerous proximity of the wireless operator, and of anyone wearing headphones. The most important thing therefore to be done when it is known that the plane is in a danger area, or is about to enter a danger area, is to wind in the aerial. It is not sufficient just to "earth" the aerial, for this does not reduce the attraction which the aerial exerts on a near discharge, or the tendency to initiate a discharge. Also

an earthed aerial is almost certainly to be melted if the plane is struck. The aerial should always be earthed before the operator commences to wind it in, otherwise he will be in considerable personal danger if the plane is struck while he is handling the winch.

(vi) The wireless operator can assist the pilot in deciding when dangerous conditions exist by noting any considerable increase in the number or strength of atmospheric discharges. He should inform the pilot who will consider this information together with the weather conditions in the region towards which he intends to fly. If the pilot considers it desirable, he will order the wireless operator to earth and wind in the aerial. The pilot should endeavour to issue this instruction in plenty of time for the aerial to be wound in before the real danger zone is reached. If the danger zone—characterised by heavy rain, hail, snow or lightning—is reached before the aerial can be wound in, the aerial should be immediately earthed and the aircraft flown out of the storm as quickly as possible, even if that necessitates flying back on its course. As soon as conditions allow the aerial should then be wound in when the pilot will be in a position to consider whether or not he should proceed on his course through the storm.

(vii) *Static charges.*—When an aeroplane is flying through a region where there is an intense electrical field different parts of the machine will be in regions at very different potentials. If the machine were completely of metal this would lead to no differences of potential within the machine itself for a metallic conductor must have the same potential everywhere. If, however, there are a number of metal pieces not all bound together these will take up different potentials and shocks may be experienced when these metals are touched.

In a similar way the aeroplane as a whole may become charged when flying through an intense electrical field, owing to the induced charges escaping through local brush discharges or even through the exhaust gases of the engine. Any such charges are rapidly dissipated as soon as the machine flies out of the electrical field; for the engine exhaust then acts as efficiently as a charge dissipater as it had previously acted as a charge collector. If however the machine lands while still in the intense field it may cause a spark on landing.

#### 24. Instructions for preparing weather reports

(i) Weather reports for aviation purposes are transmitted in the abbreviated form of the International Code (Copenhagen, 1929). They include observations of the following elements which do not require the use of instruments:—weather, cloud, visibility and ground wind.

The standard form of the code is :

IIIC<sub>L</sub>C<sub>M</sub>      wwVhN<sub>h</sub>      DDFWN

The meanings of the symbols and the specifications of the different scales are given in appendix XV. The index figures (III) are fixed for each station. Each of the other letters is represented by one of the figures 0 to 9, the appropriate figure being selected from the table in appendix XV. Two figures are given for present weather (ww) on the scale 00 to 99 while wind direction (DD) is also represented by two figures on the scale 01 to 32. The following instructions are given for the guidance of Duty Pilots and others charged with the preparation of weather reports. In the case of requested weather reports it is only necessary to give the second and third groups of the code (see K.R. & A.C.I., para. 728).

(ii) *Forms of low and medium cloud (C<sub>L</sub>C<sub>M</sub>)*—First examine the sky and note what types of clouds can be seen. Illustrations of the different cloud forms are given in Fig. 111. Select from the code for C<sub>L</sub> the code figure which most nearly represents the state of the sky as regards the type or types of low cloud observed. *This will give the figure for C<sub>L</sub>.* Then select from the code for C<sub>M</sub> the code figure which most nearly represents the state of the sky as regards the type or types of medium cloud observed. *This will give the figure for C<sub>M</sub>.* If it is impossible to decide which code figure should be used for the form of low or medium cloud, replace the corresponding letter C<sub>L</sub> or C<sub>M</sub> by a hyphen. If there are no low or medium clouds present, then the appropriate letter C<sub>L</sub> or C<sub>M</sub> should be coded as 0.

(iii) *Amount of cloud whose height is reported as h.*—Next it is necessary to decide what cloud shall be adopted for determining h (see para. 24 (vi) below) and to estimate the number of tenths of sky covered by this cloud. From the code for N<sub>h</sub> select the code figure which represents this amount of cloud. *This will give the figure for N<sub>h</sub>.* It should be noted that the code figure is usually different from the number of tenths of sky covered with cloud. For example, special code numbers are allotted to a "trace" of cloud, that is, when there is less than one-tenth of cloud present; to the case in which there are more than nine-tenths of cloud but the sky is not entirely covered, small openings being visible; and to the case in which the sky is completely obscured by fog, duststorm or other phenomenon.

(iv) *Total amount of cloud.*—Finally, estimate the number of tenths of sky covered by all types of cloud (low, medium and high) and select from the code the code figure representing this amount. *This will give the figure for N.* Note carefully that this number (N) is the total amount and not the amount of the

medium cloud as reported by C<sub>M</sub>. For example, if there were two types of cloud present, Strato-cumulus and Alto-cumulus, the amount of Strato-cumulus being 5 and the apparent amount of Alto-cumulus being 3, then two-tenths of the sky would be blue sky with no cloud on it and eight-tenths would be covered with cloud. The figure to be reported for N would be, therefore, 5 (seven to eight-tenths).

(v) *Procedure in case of fog.*—If the sky is obscured by fog, then C<sub>L</sub> will be reported by a hyphen, C<sub>M</sub> will also be a hyphen and N<sub>h</sub> and N will be 9 (sky obscured by fog). If the sun or stars can be seen through fog or mist and there is no evidence of cloud above the fog or mist, the amount of cloud N should be taken as 0, and C<sub>L</sub>, C<sub>M</sub> should each also be reported by the figure 0. If cloud can be seen through the fog or mist the amount of cloud should be estimated as well as possible and the form or forms noted to the best of the observer's ability. The cloud forms and cloud amount should then be reported in the ordinary way as if fog or mist were not present.

(vi) *Height of base of cloud.*—The fourth figure of the second group (h) is to be used for reporting the height of the base of the cloud above the level of the ground at the station. A table giving the relation between the figures to be telegraphed and the actual height of the cloud is given in the code for h. Particulars of the cloud whose height has to be determined are set out at the foot of columns 2 and 3 in Appendix XV.

The height of the cloud should be estimated to the best of the observer's ability but, whenever possible, a report should be obtained from a pilot who has been to the cloud level. Where the height of the cloud base is estimated to be approximately at one of the 100 feet or 1,000 feet levels which separate consecutive code numbers (e.g. 600 feet), the larger code number should be chosen if the cloud is judged to be above the level and the lower number if it is judged to be below the level. If the cloud is judged to be exactly at the level the lower code number should be selected. For example, if the base of the cloud is estimated to be exactly at 3,000 feet, h should be 5 and not 6.

(vii) *Present weather.*—A table showing the figures corresponding with the different weather conditions is given in the code for ww.

As a general rule, the largest number in the table which describes appropriately the present weather and the general character of the weather must be selected.

One of the numbers 50–99 must be used if precipitation is occurring at the time of observation or has occurred within ten minutes or less of the time of observation.

Whenever a figure corresponding to the description "intermittent" is used the fog or precipitation must not have continued without break during the last hour.

Figures 20-29 must never be used when precipitation is actually occurring at the time of observation or within ten minutes of that time.

Figures 30-49 must be used only when the visibility is less than 1,100 yards, and there is no precipitation at the time of observation or within ten minutes of that time.

N.B.—Figures 35-39 refer to storms of drifting snow caused by the wind *raising* the snow from the ground, when it is not snowing in the ordinary sense of the term, i.e., when no more snow is coming down to the ground than is raised from the ground by the wind. When it is snowing in the ordinary sense of the term figures 35-39 must not be used even if the snow is also drifting in the wind.

Figures 80-89 must only be used when the precipitation is of the shower type, and when precipitation is actually falling at the time of observation. The clouds which give showers are isolated clouds, and the showers are therefore always of short duration. Between the showers there is a definite clearance unless stratiform clouds are filling the interstices between the shower clouds.

The figures 20, 30, 40, 50, 60, 70, 80 and 90 should not be used unless the observer is unable to describe the phenomenon by one of the other code figures or is in doubt as to the exact description of the weather phenomenon observed.

(viii) *Past weather*.—One figure is used in reporting past weather. A table giving the relation between the numbers and the past weather is given in the code for W.

In using this code the number is taken which describes the most important feature of the past weather not already reported by the two figures for "present weather". In any case in which the two figures for "present weather" describe fully the past weather also, then the appropriate single past weather figure is reported in confirmation, e.g. :—in the case of heavy continuous rain without fog or mist the present weather figures would be 66 and the past weather figure would be 6.

For stations making regular reports at fixed hours the period covered by the figure for past weather will be 7 hours in the case of observations made at 0100, 6 hours at 0700, 6 hours at 1300 and 5 hours at 1800 G.M.T.

In the case of observations made at 0400, 1000 and 1600 G.M.T. the period will be 3 hours, while at 2200 G.M.T. it will be 4 hours.

For reports intermediate between the hours stated above, whether they be routine observations or special reports of sudden changes in the weather, the figure for past weather will refer to the period since the last report, but this period must never exceed 6 hours. In the case of the first report of the day, if this is made at an hour other than one of those enumerated above, the period covered by the figure for past weather will be 1 hour.

In the case of requested weather reports the period covered by the figure for past weather will be 1 hour.

(ix) *Visibility*.—The horizontal visibility, or approximate distance at which objects can be distinguished, is reported by one figure. Select a number of objects at the distances given in the table for V in appendix XV. Take the most distant object which is visible, then use the table to obtain the figure to be reported. For example, if the object at 2,200 yards is the most distant object visible, then objects at 4,400 yards are *not* visible and the figure to be reported is 5.

An object is regarded as being visible if the nature of the object can be determined by its appearance, e.g., if the object is a tree and it can be distinguished as a tree.

The distances of the objects should be as nearly as possible those given in the table; but a variation of 10 per cent. on either side is allowed so that the most suitable objects available may be used.

(x) *Wind direction*.—33 is added to the Code number for wind direction if the gustiness of the wind has been unusually marked during the last hour, 67 is added to the Code number if a definite squall or line squall has occurred during the past hour.

(Revised April, 1935)

## APPENDIX XIV

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	Light 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	Moderate gale.	Smacks at sea lie to.	Whole trees in motion	32-38
8	Fresh 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.

S.O. Code No. 40-99-0-37

CODE FOR ABBREVIATED WEATHER REPORTS FOR AVIATION

1st Group. IIIC <sub>L</sub> C <sub>M</sub>	2nd Group. wwVhN <sub>h</sub>	3rd Group. DDFWN	Code for Weather at actual time of observation and general character of weather (ww).	
III = Index number of station.	ww = Weather at time of observation.	DD = Direction of wind at surface in points of compass. Scale 01-32. (00 = Calm, 08 = E, 16 = S, etc.)	00-19 <i>Abbreviated description of sky and special phenomena.</i>	
C <sub>L</sub> = Form of low cloud.	V = Horizontal visibility.	F = Force of wind at surface on Beaufort Scale (0-12). (Forces above 9 are reported as 9 in telegrams, with the actual force in a word at the end, e.g., force 10 is reported at the end as "Storm ten", force 11 as "Storm eleven".)	00 Cloudless.	
C <sub>M</sub> = Form of medium cloud.	h = Height of base of cloud.	W = Weather during the period preceding the observation.	01 Partly cloudy.	
	N <sub>h</sub> = Amount of cloud whose height is reported by h.	N = Total amount of sky covered by cloud.	02 Cloudy.	
			03 Overcast.	
			04 Low fog whether on land or at sea.	
			05 Haze (but visibility greater than 2,200 yards).	
			06 Dust devils seen.	
			07 Distant lightning.	
			08 Mist (visibility between 1,100 and 2,200 yards).	
			09 Fog at a distance but not at the station or ship.	
			10 Precipitation within sight.	
			11 Thunder, without precipitation at the station.	
			12 Duststorm visible but not at the station.	
			13 Ugly, threatening sky.	
			14 Squally weather.	
			15 Heavy squalls } in last	
			16 Waterspouts seen } 3 hours.	
			17—	
			18—	
			19—	
			20-29 <i>Precipitation in last hour but not at time of observation.</i>	
			20 Precipitation (rain, drizzle, hail, snow or sleet)	
			21 Drizzle } other in last hour but not at time.	
			22 Rain } other	
			23 Snow } than	
			24 Sleet } showers	
			25 Rain shower(s)	
			26 Snow shower(s)	
			27 Hail or rain and hail shower(s)	
			28 Slight thunderstorm	
			29 Heavy "	
			30-39 <i>Duststorms and storms of drifting snow (visibility less than 1,100 yards).</i>	
			30 Dust or sandstorm.	
			31 Dust or sandstorm has decreased.	
			32 Dust or sandstorm no appreciable change.	
			33 Dust or sandstorm has increased.	
			34 Line of duststorms.	
			35 Storm of drifting snow.	
			36 Slight storm of drifting snow } generally low.	
			37 Heavy storm of drifting snow }	
			38 Slight storm of drifting snow } generally high.	
			39 Heavy storm of drifting snow }	
			40-49 <i>Fog or thick dust haze (visibility less than 1,100 yards).</i>	
			40 Fog.	
			41 Moderate fog in last hour.	
			42 Thick fog in last hour.	
			43 Fog, sky discernible } has become thinner during last hour.	
			44 Fog, sky not discernible }	
			45 Fog, sky discernible } no appreciable change during last hour.	
			46 Fog, sky not discernible }	
			47 Fog, sky discernible } has begun or become thicker during last hour.	
			48 Fog, sky not discernible }	
			49 Fog in patches.	
			50-99 <b>PRECIPITATION AT TIME OF OBSERVATION.</b>	
			50-59 <i>Drizzle (precipitation consisting of numerous minute drops).</i>	
			50 Drizzle.	
			51 Intermittent } slight	
			52 Continuous } drizzle.	
			53 Intermittent } moderate	
			54 Continuous } drizzle.	
			55 Intermittent } thick	
			56 Continuous } drizzle.	
			57 Drizzle and fog.	
			58 Slight or moderate } drizzle and rain.	
			59 Thick }	
			60-69 <i>Rain.</i>	
			60 Rain.	
			61 Intermittent } slight	
			62 Continuous } rain.	
			63 Intermittent } moderate	
			64 Continuous } rain.	
			65 Intermittent } heavy	
			66 Continuous } rain.	
			67 Rain and fog.	
			68 Slight or moderate } rain and snow.	
			69 Heavy }	
			70-79 <i>Snow.</i>	
			70 Snow or sleet.	
			71 Intermittent } slight snow	
			72 Continuous } in flakes.	
			73 Intermittent } moderate snow	
			74 Continuous } in flakes.	
			75 Intermittent } heavy snow	
			76 Continuous } in flakes.	
			77 Snow and fog.	
			78 Granular snow (frozen drizzle).	
			79 Ice crystals.	
			80-89 <i>Shower(s).</i>	
			80 Shower(s).	
			81 Shower(s) of slight or moderate } rain.	
			82 Shower(s) of heavy } snow.	
			83 Shower(s) of slight or moderate }	
			84 Shower(s) of heavy } rain and snow.	
			85 Shower(s) of slight or moderate }	
			86 Shower(s) of heavy } snow.	
			87 Shower(s) of granular snow.	
			88 Shower(s) of slight or moderate } hail, or rain and hail.	
			89 Shower(s) of heavy }	
			90-99 <i>Thunderstorm.</i>	
			90 Thunderstorm.	
			91 Rain at time } thunderstorm during last hour, but not at time of observation.	
			92 Snow or sleet } at time	
			93 Thunderstorm, slight without hail or soft hail, but with rain (or snow)	
			94 Thunderstorm, slight with soft hail	
			95 Thunderstorm, moderate without hail, but with rain (or snow)	
			96 Thunderstorm, moderate with soft hail	
			97 Thunderstorm, heavy without hail, but with rain (or snow)	
			98 Thunderstorm, combined with dust-storm	
			99 Thunderstorm, heavy with hail	

# THE METEOROLOGICAL MAGAZINE

The monthly magazine for all who are interested in the weather.

- popular and scientific accounts of weather phenomena.
- abnormal seasons.
- weather of the preceding months in all parts of the world.
- reviews of new books.
- reports of scientific meetings.
- official notices of the Meteorological Office.
- other matters of general interest.

Recent articles were—

Change of climate in the British Isles.

Light Winds in the London Area.

Problems of Forecasting.

The Blizzard of 27 February—1 March, 1937.

Weather of 1936 in the northern Pennines.

Variations of pressure near the British Isles during 1936.

Weather of 1936.

THE METEOROLOGICAL MAGAZINE was founded in 1866 by the late George James Symons, F.R.S., founder of the British Rainfall Organization, under the title of *Symons's Monthly Meteorological Magazine*.

The Meteorological Magazine is published by His Majesty's Stationery Office, and can be purchased directly from

HIS MAJESTY'S STATIONERY OFFICE

at the following addresses:

Adastral House, Kingsway, London, W.C.2

120 George Street, Edinburgh 2

1 St. Andrew's Crescent, Cardiff

26 York Street, Manchester 1

80 Chichester Street, Belfast

or through any bookseller.

Price 6d. net, post free 6½d. Annual Subscription 6s. 6d. post free.

