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METEOROLOGY

in relation to

AIR NAVIGATION



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REPRINT OF CHAPTER XVII OF THE
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VOL. I

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CHAPTER XVII.—METEOROLOGY

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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*. Details concerning the method of plotting observations are given in *Instructions for the Preparation of Weather Maps with Tables of the Specifications and Symbols (Form 2459)*.

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, wireless telegraphy or teleprinter, 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 Berlin, and the countries of the U.S.S.R. forward their observations to Moscow. On receipt of the observations in Paris, Berlin 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; collective messages are also received twice daily from Washington containing observations at a large number of stations in Canada and the United States.

(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, 112 and 114 the wind direction is indicated by arrows flying with the wind. The number of feathers on the arrows corresponds to the wind force on the Beaufort scale (see Appendix XIV), two steps on the

Beaufort scale being denoted by one feather; thus force 5 is 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

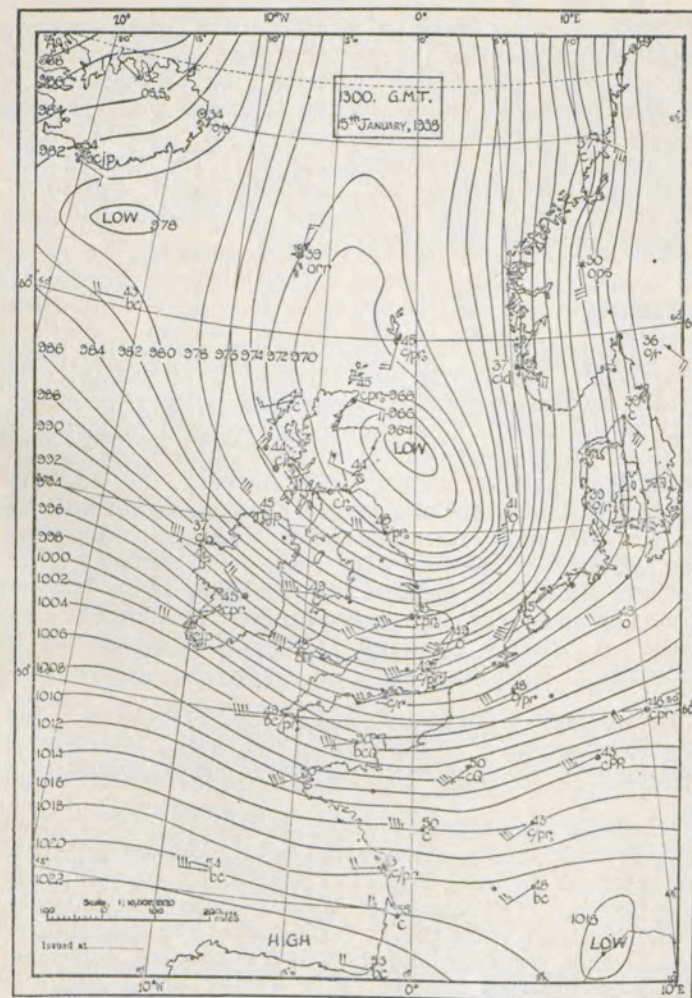


FIG. 107.—Synoptic weather chart.

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 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. (See Form 2459 referred to in para. 1.)

(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 approximately 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 is the rate of decrease of pressure upwards; consequently, for the same pressure at sea-level, the warmer the air from the ground to a given height the higher is the pressure at that height. 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. The correction due to temperature is usually very small and is only of importance when altitudes are required very exactly.

(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 Calshot on the day to which the weather chart in Fig. 107 applied. The sea-level pressure at Leuchars was 967 mb., and if the altimeter was set to read zero at the start of the flight, it would have read zero when near Calshot at the height at which the pressure was also 967 mb. But the sea-level pressure at Calshot was 996 mb., a difference of 29 millibars, and since pressure decreases at the rate of 1 millibar in 30 feet, the pressure would have been 967 mb. at 30×29 or 870 feet above sea-level. In other words, the altimeter at Calshot would have underestimated the true height by 870 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* (*starboard* in the

Southern Hemisphere) 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. An aircraft in flight may obtain, on request, information enabling him to correct his altimeter; 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 over the earth's surface.

(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 practically along the isobars and that the wind speed is proportional to the pressure gradient, which 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 very closely 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 (known as the geostrophic wind 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.

(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 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 in duration. 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

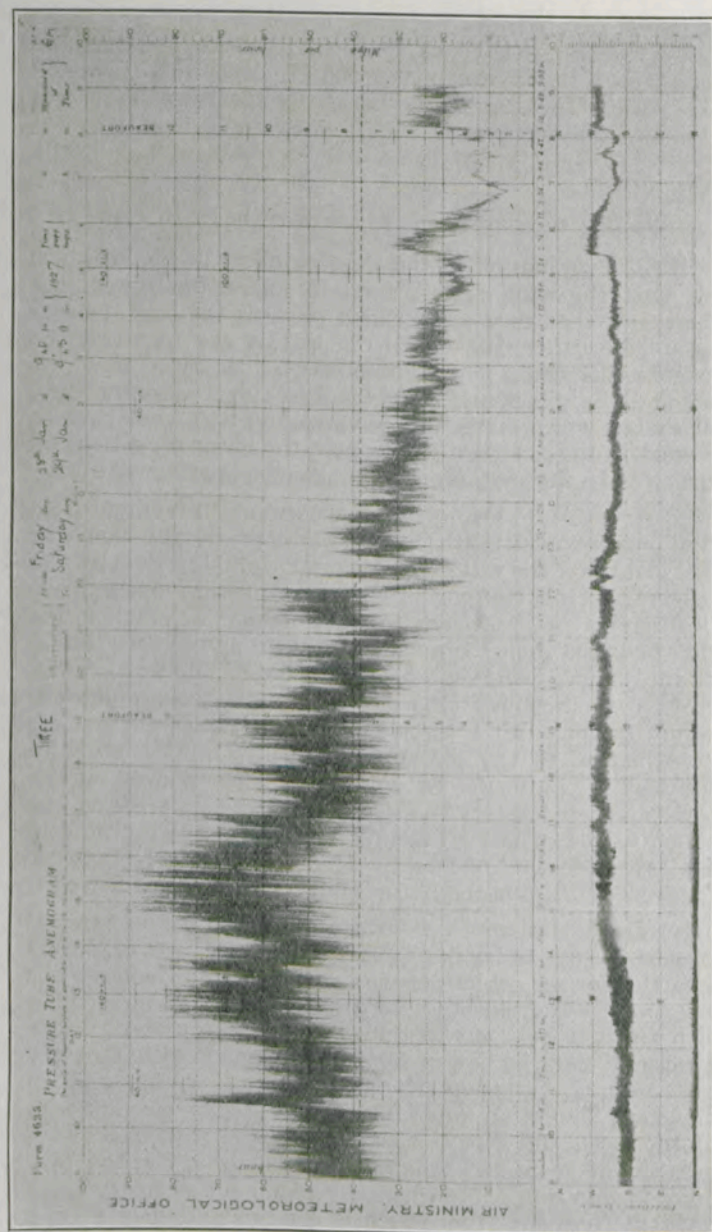


Fig. 108.—Record from Dine's pressure tube anemometer.

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 (the opposite in the Southern Hemisphere). While this is usually true, no general rule can be laid down for the increase of wind with height, for it depends on a number of factors.

(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 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. The variation of the wind is controlled mainly 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. Upper winds may also be measured by observing the movement of shell-bursts or smoke-puffs from aeroplanes. When such 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, the season of the year and topography. 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. In general, it may be stated that the veer and increase of wind with height in the first 1,500 feet, which was noted in para. 7, is more marked at night than in the middle of the day.

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 clear day the air on hills, being warmed more than the air over the valleys at the same height, tends to rise. Air flows up the valleys to take the place of the rising air. Such an airflow is called an *anabatic wind*.

(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 side of a hill, being colder than the free air at the same height above the valley, 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 general 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*.—During the day the land surface near the coast becomes hotter than the surface of the sea. The air over the land consequently becomes warmer than that over the sea and, as warm air is lighter than cold air, the pressure over the land becomes relatively low. There is therefore a tendency for air to flow from sea to land. This wind is called the sea breeze. Since there cannot be an accumulation of air over the land there must be some compensating return current at higher levels. In the British Isles the sea breeze does not normally exceed 10 to 15 m.p.h. and is mainly a feature of quiet summer weather. The strength of the sea breeze decreases rapidly above 500 feet and is inappreciable above 1,000 feet. The return current is not sufficiently strong to have any importance to aviation. In low latitudes the development of the sea breeze is much more pronounced. It may extend to several thousand feet reaching a strength of 30 m.p.h. and may penetrate a long way inland. As in the case of a katabatic wind, a sea-breeze may bear no relation to the general 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, but with a relatively small velocity.

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.

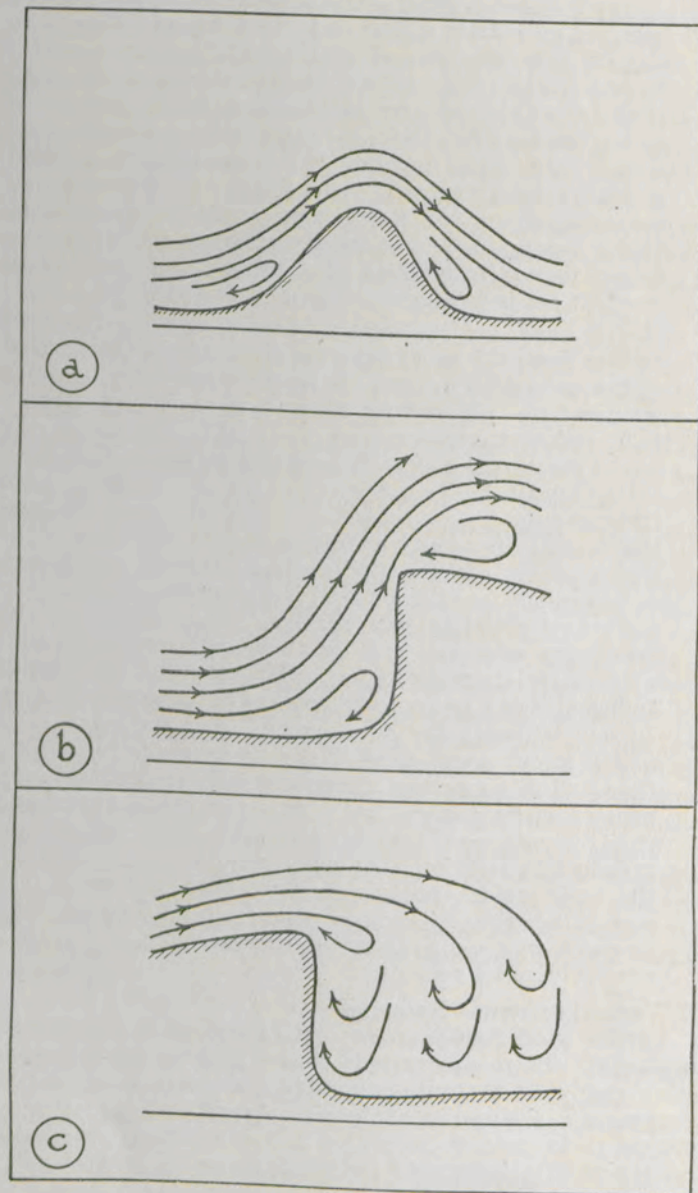


FIG. 109.—(a) Air flow over hill with steep slopes
 (b) Air flow over cliff facing to windward.
 (c) Air flow over cliff facing to leeward.

If the latter is at right angles to the wind direction some of 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. The actual height to which the disturbance extends depends on the temperature lapse rate, being greater when the latter is large. When a temperature inversion exists at some height above the hill little vertical motion is possible if the cold air resting on the earth is almost stationary and the warm air above moves alone. 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) *Thermal up-currents.*—Considerable vertical currents are produced owing to the 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.

In thunderstorms ascending currents of the order of 30 m.p.h. are not uncommon and it is known that the speed required to sustain a hailstone of 1 inch diameter is about 50 m.p.h.

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.

(iv) *Frontal up-currents*.—The most powerful up-currents experienced are due to causes which are, in the main, independent of the nature of the surface below. These up-currents are due to the inter-action 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, in northern latitudes, 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 vertical currents occur in line-squalls and more particularly in thunderstorms which are described in paras. 21 and 22.

(v) *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 often producing noticeable bumpiness. The upward current is reinforced if there is high ground bordering the coast.

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 on minute hygroscopic particles which act as nuclei. The actual amount of water vapour which a given sample of air contains is called the *absolute humidity*. It may be given by the mass of vapour per unit mass of air. It is more usual, however, to express the amount of water vapour as a percentage of the amount which the air would contain if saturated at the same temperature. This percentage is termed the *relative humidity*. Saturated air has 100 per cent. relative humidity, half-saturated 50 per cent. and completely dry air 0 per cent.

(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°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 practically to halve the rate of cooling which unsaturated air undergoes on rising. The rate for ascending saturated air, which depends on the temperature of the air, is only 2.6°F. per 1,000 feet at 50°F. This is called the *saturated or wet adiabatic lapse rate*. The limit between stability and instability (see para. 5 (ii)) in the case of saturated air is a lapse-rate equal to the wet adiabatic.

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. The term "fog" is limited 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 (a) to the cooling of the surface of the ground or sea which is communicated to the air above it, (b) by the drift of air over a surface which is colder than itself, or, more rarely, (c) 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 bodily, but mixing due to slight turbulence may convey the cooling and condensation upwards through the surface layers. 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.

13. Visibility

Visibility is defined by the maximum distance at which objects can be clearly discerned. It is measured at meteorological stations by selecting a number of well-defined objects at certain specified distances and by observing the most distant of these objects which is visible. Apart from the bad visibility associated with such phenomena as fog, heavy rain and snow, one of the most important factors in determining visibility is the position of industrial areas and large towns. The visibility in a certain area may thus vary considerably with different wind directions. In general, good visibility near the ground is associated with a high temperature lapse rate, when atmospheric pollution is carried upwards by convection, and

bad visibility with a low lapse rate, especially with an inversion. At higher levels, however, visibility may be different from that near the ground. For example, on a hot day in summer convection currents may carry smoke upwards to 5,000 or 6,000 ft. 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. 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. 110. 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 ft.)*

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

2. *Cirrocumulus (Cicu.)*—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. *Cirrostratus (Cist.)*—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.).

*It should be noted that the heights given are for temperate latitudes and refer, not to sea-level, but to the general level of the land in the region. In certain cases there may be large departures from the given heights, especially as regards cirrus, the upper level of which may be 50,000 ft. or more in the tropics but the lower level of which may be as little as 10,000 ft. in temperate latitudes, and in polar regions almost as low as the surface.

1. *Alto cumulus* (*Acu.*)—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. *Allostratus* (*Ast.*)—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. *Stratocumulus* (*Stcu.*)—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. Sometimes as low as 500 ft.; or as high as 8,000 ft.

2. *Stratus* (*St.*)—A uniform layer of cloud, resembling fog, but not resting on the ground, but sometimes practically down to the surface; sometimes as high as 4,000 ft.

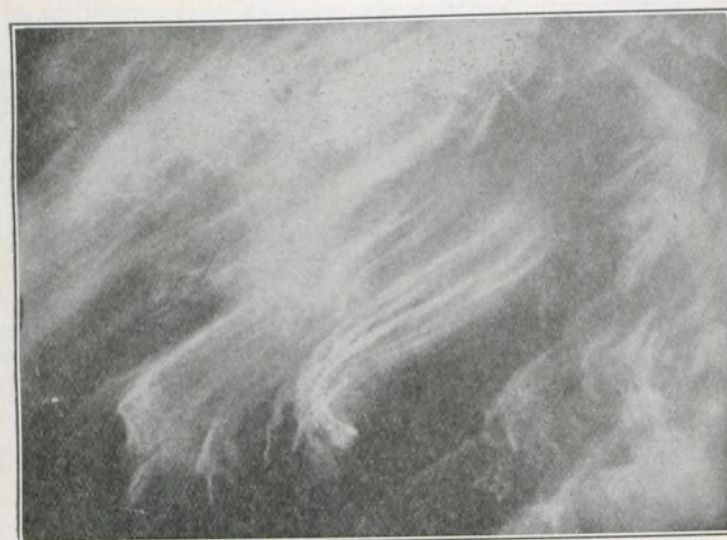
3. *Nimbostratus* (*Nbst.*)—A low, amorphous and rainy layer of dark grey colour and nearly uniform. Sometimes practically down to the surface; sometimes as high as 4,000 ft.

(d) *Clouds with vertical development.* (Mean upper level that of the cirrus, mean lower level 1,600 ft.)

1. *Cumulus* (*Cu.*)—Thick clouds with vertical development; the upper surface is dome-shaped and exhibits protuberances, while the base is nearly horizontal. Sometimes as low as 1,000 ft.; or as high as 8,000 ft.

2. *Cumulonimbus* (*Cunb.*)—Heavy masses of cloud with great vertical development, whose cumuliform 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. Sometimes as low as 1,000 ft.; or as high as 8,000 ft. (The "top" of *Cunb.* frequently extends to heights of over 10,000 ft. and may reach 25,000 ft. or more.

(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



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



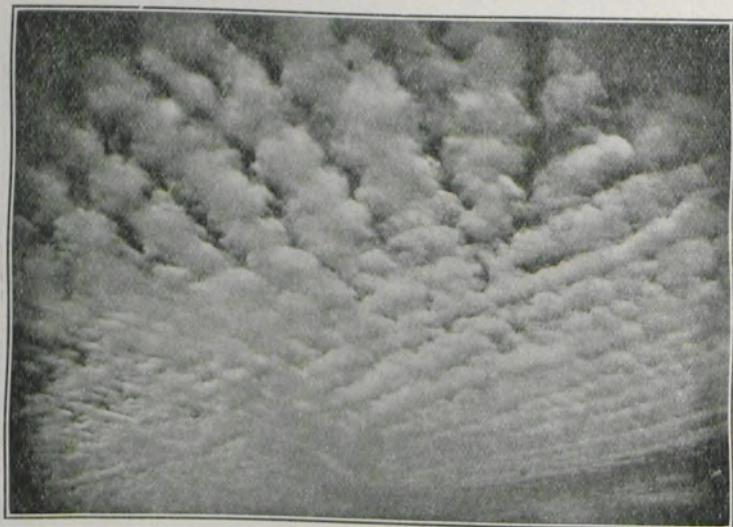
(2) Cirrostratus (*Cist.*) uniform sheet of very high cloud, 30,000 ft.; about 25,000 ft. beneath is Fractocumulus (*Frcu.*) a string of ragged cumulus at about 6,000 ft.

FIG. 110.—CLOUD FORMS.

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



(3) Cirrocumulus (**Cicu.**). The Mackerel Sky. The highest form of cloudlets in waves: 20,000 to 25,000 ft.



(4) Altocumulus (**Acu.**). Layer of large cloudlets in waves at middle height.

FIG. 110.—CLOUD FORMS—*continued*.

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



(5) Altostratus (**Ast.**). Sheet at middle height, between 10,000 and 25,000 ft.



(6) Stratocumulus (**Stcu.**). Layer of clouds in irregular order below 7,000 ft.

FIG. 110.—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. 110.—CLOUD FORMS—*continued*.

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



(9) *Cumulonimbus (Cunb.)*. A thunder-cloud with "anvil" finely developed.



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

FIG. 110.—CLOUD FORMS—*continued*.

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



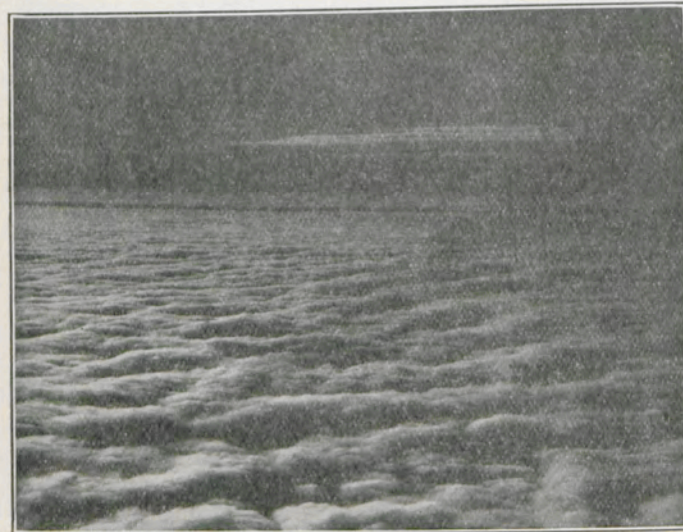
(11) *Altocumulus lenticularis*. Almond-shaped banks of cloudlets at the altocumulus level.



(12) *Altocumulus Castellatus*. Little miniature cumulus rising in many heads from a more or less compact layer of altocumulus.

FIG. 110.—CLOUD FORMS—*continued*.

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



(13) A typical horizontal sheet of *Stratocumulus* (height 1,000 to 2,500 ft.).



(14) A turbulent layer of *Stratocumulus*. The raggedness shows extreme bumpiness.

FIG. 110.—CLOUD FORMS—*continued*.

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



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



(16) Fractocumulus.

FIG. 110.—CLOUD FORMS—*continued*.

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

of rising air. Speaking broadly, the methods of formation of clouds may be classified as follows :—

(a) *Orography*.—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.

(b) *Convection*.—Owing to the 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, cumulonimbus clouds are formed and thunderstorms may develop. In a similar way, cumuliform cloud and even thunderstorms may form in a mass of air as the result of heating from below during its passage over a relatively warm sea surface. Temperature falls with increasing height throughout such clouds which are usually very bumpy. (See also para. 16 on ice accretion.)

Conditions favourable for the development of cumulus or cumulonimbus clouds also occur in the rear of a depression when a current of cold air meets a current of warmer air at the "cold front."

(c) *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). As the result of convergence the warm air rises over the colder air along a gently sloping surface. The warm air may ascend to the Cirrus level and give rise to the cloud sequence shown in Fig. 111, ranging from high Cirrus cloud through altostratus to low nimbostratus.

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 altostratus may be above 10,000 ft., the nimbostratus may fall to 300 ft. or lower. Altostratus is comparatively free from bumps but nimbostratus may be very bumpy.

(d) *Turbulence*.—When a current of air flows over the earth's surface turbulence, in other words *eddy-motion*, is set-up. This motion consists of irregular up and down currents. The air in the upward currents cools at the adiabatic lapse-rate and, if sufficient moisture is available and the turbulence is sufficiently vigorous, condensation may take place in the upper part of the turbulent layer. This results in the layer type of cloud such as stratus and

stratocumulus. The air in and below such clouds is usually rather bumpy, while above them there is steady flying. Cloud of this type usually tends to break up during the day in summer, but in winter it may last for days. Most cloud sheets are characterised by an inversion above them. In some cases there is a marked change of wind above the cloud.

It should be noted that cumulus or cumulonimbus may develop in isolated patches in or below a layer of stratocumulus giving rise to areas of severe bumpiness. This phenomenon is illustrated in plate (15) of Fig. 110.

Stratus cloud 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 drops grow in size until they are too heavy to remain suspended in the air, and rain falls.

The formation of rain may be classified in the same way as the formation of cloud.

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

An air current striking a mountain slope is deflected upwards, and the consequent dynamical cooling which produces cloud, if the air is moist enough, may also produce rain. 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) *Convective rain* is associated with 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 from water surfaces. This type of rainfall is associated with a steep temperature lapse rate and strong ascending currents.

(c) *Cyclonic rain* is the rainfall associated with the passage of depressions. It is caused by a *gradual ascending movement over a wide area* as at a warm or cold front, 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.

(d) *Turbulent rain*.—The clouds formed as the result of *eddy-motion* are undergoing a continual process of formation and dissipation. It is not possible, therefore, for large drops to form. Precipitation from stratocumulus is very rare but slight drizzle, that is very small rain-drops, may fall from stratus.

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 below 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 cumulonimbus 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.

Water drops formed in a rising current of air may not change to ice immediately when they are lifted to a height where the temperature is below the freezing point. In fact, super-cooled drops, as they are then called, may be carried upwards into the higher part of the cloud where ice crystals are present. Here pellets of snow or soft hail are formed which may eventually become large enough to fall through the ascending currents. The supercooled drops encountered will freeze on these pellets. The process is in fact, similar to that of the accumulation of ice on an aircraft in flight (*see para. 16*). The pellets 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. 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. The four main types of ice accretion may be summarised as follows in order of increasing danger :—

(a) A white semicrystalline coating of ice which covers the surface of the aircraft, has little effect on flying but may obscure vision if it forms on the wind screen and interferes with radio communication by coating the aerial with ice. It generally forms in clear air when a cold aircraft enters warmer and damper air during a rapid descent and is due to the condensation of the invisible water vapour in the atmosphere direct into ice crystals without passing through the intermediate water stage.

Surface equivalent : hoar frost on grass and shrubs during a clear frosty night.

(b) A light white opaque deposit of ice which accumulates on the leading edges of wings, struts and wires of an aircraft. It forms when flying in filmy clouds consisting of small supercooled (temperature below freezing point) water drops. The deposit has no great weight, but its danger lies in an alteration of the aerodynamic characteristic of the wings and in the choking of the orifices of the carburettor and flying instruments.

Surface equivalent : rime, the deposit formed from freezing fogs.

(c) A transparent or translucent coating of ice which has a glassy surface appearance. It forms within dense cloud consisting of large supercooled water drops. In addition to the dangers enumerated in (b) there is the weight of the accumulation and the vibration set up by the unequal loading of wings, struts and especially the blades of the propellers. When appreciable blocks of ice break off the vibration may become so intense that there is danger of fracture of the aircraft structure.

Surface equivalent : intermediate between rime and glazed frost.

(d) A heavy coating of clear ice which forms all over an aircraft when rain falls on it whilst flying in a layer with temperature below the freezing point. The danger is great owing to the decrease of lift because of the altered wing curvature, the increase of drag on account of the enlarged area of the wings and finally the weight of the large mass of ice which may accumulate in a short time.

Surface equivalent : glazed frost due to rain turning to ice after it has fallen on to frozen ground.

(ii) The physics of "ice accretion" indicate that when a supercooled water drop impinges on an aircraft part of the drop freezes immediately at the leading edge whilst the remaining part of the drop freezes subsequently. In the case of a small drop the final freezing occurs quickly giving opaque ice on and near the leading edge. For a large drop the final freezing is not quite so rapid and the drop has opportunity to spread over the wing. This leads to the more dangerous type of clear ice which not only builds up outwards from the leading edge but also spreads back over the wings. For ice accumulation to become dangerous, it is necessary that there should be abundance of large water drops in the liquid state at air temperatures below the freezing point. These conditions are met with only in clouds, rain, sleet or rain and hail.

(iii) Observations made in England show that ice accretion may occur in any type of cloud, except perhaps members of the cirrus group, provided the temperature in the cloud

lies within the range 10° F. to 32° F. It is occasionally met with at temperatures below 10° F. but is usually not then heavy. The cloud in which it is most frequently encountered in winter is stratocumulus but the heaviest deposits occur in cumulus and cumulonimbus. Owing to the large vertical currents known to exist in the latter clouds and the resulting great upward diffusion of water drops, no part of these clouds where the temperature is below freezing can be said to be immune from the possibility of icing. Ice accretion is comparatively rare in altostratus clouds.

The worst type of ice formation, glazed frost, described in (d) above is comparatively rare in this country but more frequent in winter on the Continent and in North America. The average height of the freezing point level in the British Isles varies from about 1,800 feet in winter to 10,000 feet in summer, although there may be large variations from these figures on any one day. These heights, therefore, represent the average lowest levels according to the season where ice formation may be expected. If clouds or precipitation are present then the upper limit of the ice zone as a rough approximation may be taken as 7,000 feet above these heights. On a few occasions during every winter in this country the ice zone extends down to ground level.

(iv) When ice accretion is observed in flight there is only one certain method of escaping its dangers and that is to get out of the ice forming layer at the first possible moment. This may be done by ascending or descending, but in many cases the reciprocal course is the wisest. The appropriate action will obviously depend on the thickness of the cloud, conditions below the cloud as regards visibility and hills in cloud and the performance of the aircraft, but the following points should be noted :—

(a) *Heap Clouds*.—Normally cumulus and cumulonimbus clouds are isolated and of limited extent and can be avoided by slight alterations in course (exception at cold front given below under (c)).

(b) *Layer Clouds*.—The base of stratocumulus is usually at about 2,000 feet and the top of the layer at 4,000–5,000 feet. Any ice that may have formed in the cloud can usually be cleared quickly in the relatively warm air either above or below the cloud layer. If temperatures are everywhere below the freezing point the ice will evaporate without melting, particularly in the bright sunshine above the cloud. This would normally be the case with altocumulus which usually forms at a height in the atmosphere where temperatures are everywhere below the freezing point. Stratus cloud on the other

hand has a low cloud base and frequently envelops high ground so that if high ground lies along the route it is best to go above the cloud.

(c) *Frontal conditions*.—In the case of the clouds nimbostratus and altostratus the pilot is confronted with an extensive layer usually several thousands of feet in thickness. These clouds are associated with the passage of warm fronts and occlusions and the avoiding of the ice zone will depend on the movement of the front relative to the track of the aircraft and also to the activity of the front. In an active front the ice zone may be said to extend from the region below the clouds where rain or sleet is falling at a temperature of about 32° F. up into the cloud until the temperature has fallen to about 10° F. So there again two alternatives, either an ascent in the cloud to the 10° F. level or a descent through the rain region to a level where the temperature is above the freezing point. In practice, however, it may be impossible owing to the accumulation of ice to reach the former level and if, in addition, the lower level extends below the level of any high ground that has to be traversed, or extends down to sea level as it frequently does on the Continent in winter, there appears no alternative but to land at the nearest aerodrome, or return to the point of departure, if this has not in the meantime been similarly affected. On some occasions the relatively warmer air, in which these clouds have formed, has a layer with a temperature above the freezing point and the flight can then be made in this layer without ice formation. If the front is not active, i.e., no rain is falling, the flight can be made below the altostratus or nimbostratus provided the nimbostratus which frequently lowers to 2,000 feet does not envelop any high ground along the route. The production of rain due to forced convection on the windward side of any high ground being traversed by a front must also be kept in mind. Fortunately, altostratus cloud does not usually give rise to ice formation in this country so that if the flight is being made at some distance from the active part of the front it can usually be continued, if need be, in this type of cloud. At the cold front the cloud types are normally nimbostratus and cumulonimbus and as stated above no part of the latter cloud where the temperature is below the freezing point is immune from ice formation. Avoidance, therefore, consists in either (a) flight in rain below the cloud or in the cloud base provided temperatures are above the freezing point or (b) flight above clouds which would probably mean an altitude of 10,000 to 25,000 feet. The latter alternative would be advisable if the frontal clouds are down on the high ground with temperature below the freezing point.

The above remarks concerning fronts apply to the colder half of the year in this country. In the summer there is little danger in navigating fronts from the ice formation viewpoint because the layer with temperatures below the freezing point is sufficiently high to leave plenty of room for navigation.

(v) Warnings of ice accretion are broadcast from the Borough Hill Meteorological Wireless station and are given when appropriate in all weather forecasts. The forecaster is usually in a position to give considerable assistance to the pilot in determining the probable ice-forming zones.

(vi) For more detailed information on this subject reference should be made to *Ice Accretion on Aircraft* (M.O. 420b).

17. Weather in relation to wind currents and air masses

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. 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, fog and low cloud may be associated with a homogeneous air mass. Bad flying weather, however, is to be found more commonly at or near the boundary between two distinct air masses. The most important examples of such conditions occur in the type of pressure distribution known as a *depression*.

18. The depression or "low"

(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. They may vary in size from a diameter of a few hundred to more than a thousand miles. Some are very deep, that is, the pressure is considerably less at the centre than at the periphery (see, for example Fig. 107); others are shallow. Some travel as much as 1,000 miles in a day, others remain practically stationary. The life of a depression varies from one or two days to five days or more. The weather chart in Fig. 112 shows a depression

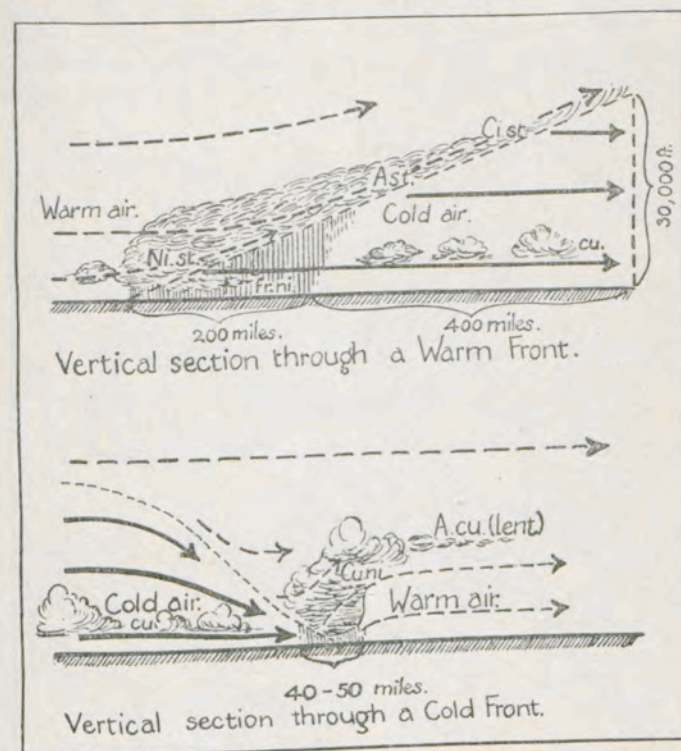


FIG. 111.—Rain and cloud formation.

centred over Northern Ireland and moving north-eastwards. The line CLW going through the centre of the depression marks the boundary between the warm and cold air currents. On the south-east side of the depression, 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 side of the line are colder

currents, the surface temperatures being about 10° lower than those in the warm sector.

(ii) At the line LW the warm air is overtaking the cold. This line is called the *warm front*. The warm air ascends over the retreating cold air along a gently sloping surface. A typical section through a warm front is shown in Fig. 111. The slope of the frontal surface between the two

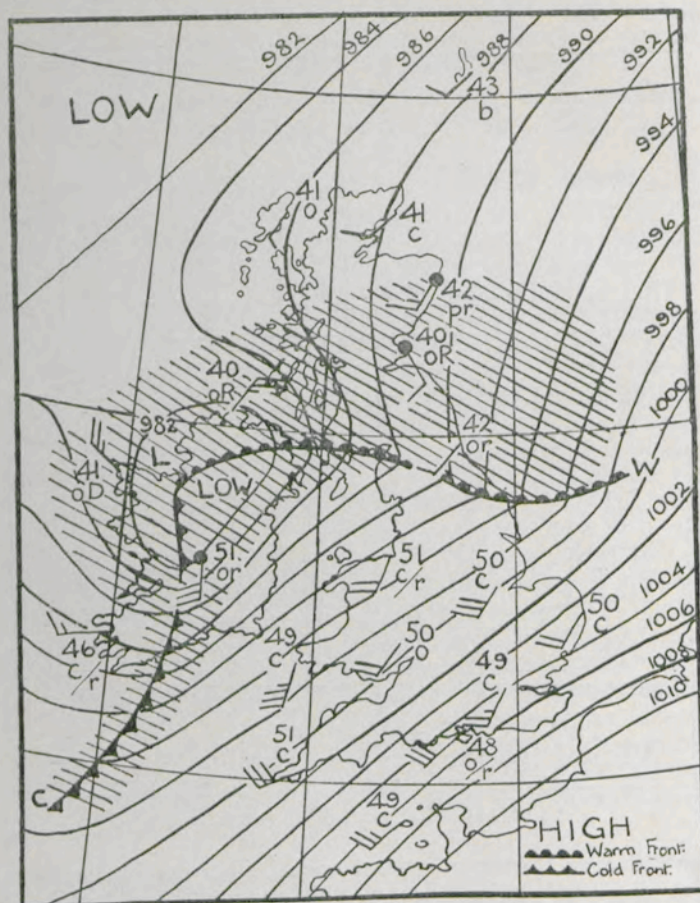
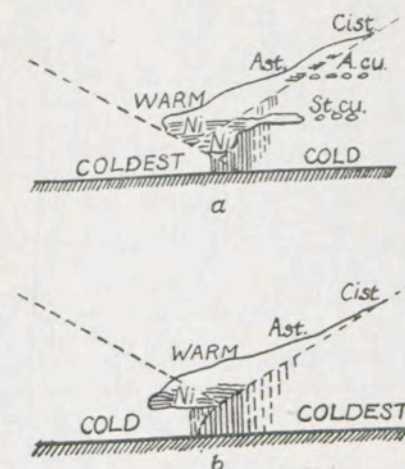


FIG. 112.—A depression.

air masses varies, but is of the order of 1 : 100 to 1 : 200; owing to the effect of friction, however, and the consequent retardation of the lower layers, the slope of the frontal surface near the ground may be very small. The ascent of the warm air gives rise to the cloud sequence as shown in Fig. 111.

Precipitation may commence from the higher layers of altostratus but it often evaporates before reaching the ground. The intensity of the precipitation at the ground gradually increases as the cloud base lowers and eventually becomes continuous and almost steady until the front has passed. In advance of a warm front, therefore, there is a comparatively wide belt of low cloud and continuous rain (or snow). In Fig. 112, the shaded area indicates where rain is falling. After the warm front has passed, the cloud slowly lifts and tends to break, but since the air in the warm sector is generally moist as well as warm, the weather often remains cloudy. As the result of turbulence or the effect of high ground, the warm air may be lifted sufficiently to cause local rain or drizzle.



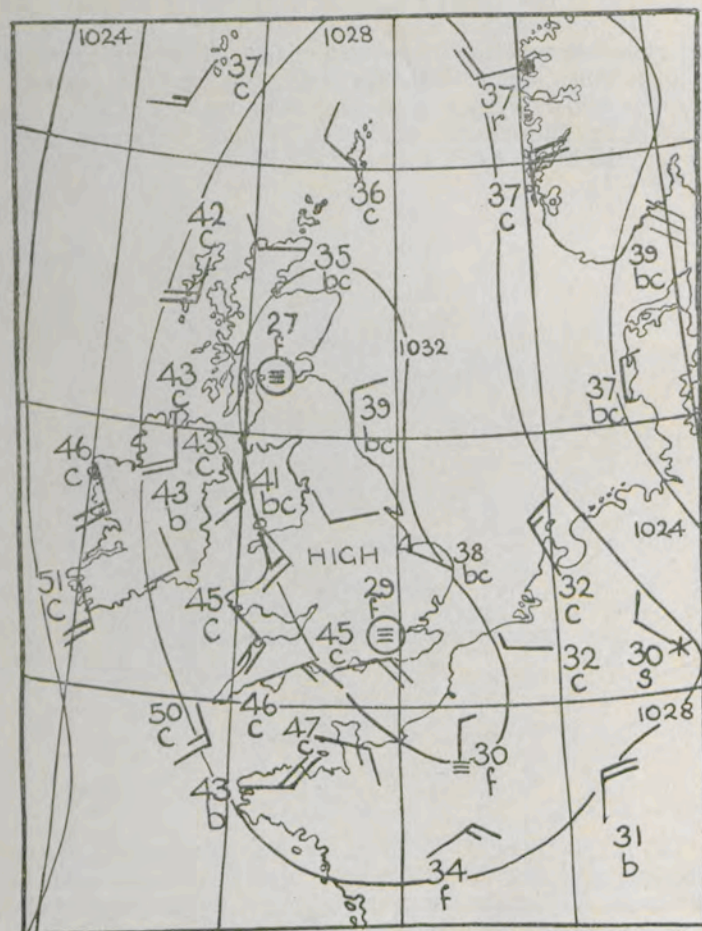
Types of Occlusion.

FIG. 113.

(iii) At the line LC the cold air is overtaking the warm. This line is called the *cold front*. In this case, the cold air thrusts its way under the warm air, the normal slope of the frontal surface being about 1 : 50. The vertical motion may be decidedly more pronounced at a cold front than at a warm front and may lead to the development of cumulo-nimbus cloud, thunderstorms and line-squall phenomena (see para. 21). The low cloud and heavy rain are, however, generally confined to a relatively narrow belt. A typical section through a cold front is shown in Fig. 111. In the rear of the cold front the air, which has often come from high latitudes, may have been

warmed considerably in its lower layers with resulting instability and the occurrence of local showers. Other phenomena associated with cold fronts are described in paras. 21 and 22.

(iv) The picture of a depression having definite warm and cold fronts must not be taken as typical of every depression.



THE ANTICYCLONE OF 28TH NOVEMBER, 1937.

FIG. 114.—An anticyclone.

The well-marked structure described is only characteristic, as a rule, of recently formed depressions. As a depression advances, the rising of the warm air along LW and the undercutting of the warm air along LC tend to narrow down the tongue of

warm air and ultimately the warm air leaves the surface altogether. With the disappearance of the warm sector a single front only 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 behind LC is warmer or colder than the air in front of LW. Fig. 113 illustrates these two cases in vertical section. It should be noted that the warm air is still present in the upper layers and that the cloud and rain associated with the original fronts may exist for some time after the warm air has left the earth's surface. The majority of depressions reaching the British Isles from the Atlantic are *occluded*. At this stage a depression tends to slow down and begins to fill up.

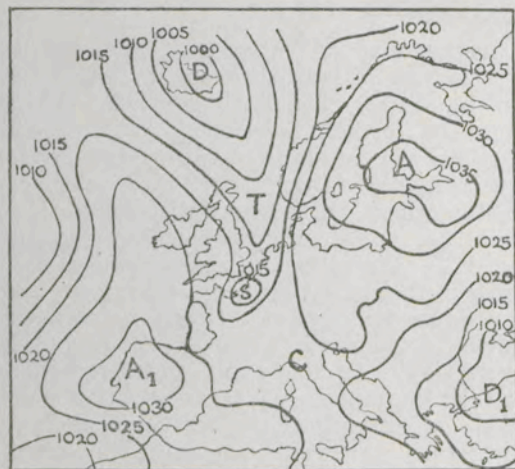
19. The anticyclone or "high"

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, the central part of 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. An anticyclone is a region of descending currents, although the rate of descent of the air is very slow. As clouds and rainfall require ascending motion for their formation, anticyclonic weather is not usually accompanied by precipitation and is generally fair. In summer the weather is usually fine and clear although much cloud may occur with some rain in its outer portions. In winter, although the weather is quiet, and persistent rain is exceptional, conditions are much more varied. The weather may be dull and gloomy, extensive sheets of stratus, and particularly strato-cumulus, formed as described in para. 14, covering the sky. On the other hand, the sky may be almost cloudless with frosty nights. 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. (See Fig. 115.)

(i) *Secondary depression.*—The isobars round a depression are not always symmetrical; sometimes they show bulges or distortions which are accompanied by a deviation of the wind from the general circulation in the depression itself. Such a distortion may enclose a small area of low pressure which is known as a secondary depression. A secondary depression is usually carried along in the circulation of the main depression, that is, it tends to rotate about the latter in a counter-clockwise direction (in the northern hemisphere). If a secondary develops considerably it may ultimately absorb the primary depression. An intense secondary depression gives rise to copious precipitation and severe gales. In the summer, secondary depressions are generally shallow and are associated with thunderstorms.



AA₁, Anticyclones. DD₁, Depressions.
T, Trough. S, Secondary, W, Wedge.
C, Coll.

FIG. 115.—Types of pressure distribution.

(ii) *Trough of low pressure.*—This is a type of pressure distribution in which the isobars extend outwards from a low-pressure area in the form of the letter V. On this account a trough of low pressure is sometimes referred to as a *V-shaped depression*. The central line of the V marks a region of a rapid or even an abrupt change in the wind direction and is generally the line of a well-defined front. Actually, however, a trough of low pressure is not always associated with a front. In the case of the cold front with which a line-squall is associated the bend in the isobars is very sharp.

(iii) *Wedge, or ridge, of high pressure.*—This type of pressure distribution appears as an extension of a high-pressure area. The isobars are again V-shaped but without the sharp bend characteristic of the trough of low pressure. The wedge usually extends between the two lows which are skirting the edge of an anticyclone, and moves forward with them. In advance of the wedge there is often a region of fine weather with north-westerly winds, rapidly becoming light in force as the axis of the wedge approaches; the wind then backs as the new depression comes along, and rain usually follows. Thus a wedge represents the interval of dry weather between two rainy periods.

(iv) *Col.*—This is a region between two anticyclones, analogous to 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 different directions and gives conditions favourable for the formation of fog in winter and thunderstorms in summer.

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 lasting for a fraction of a minute or so. 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; possibly ice-accretion.
- (e) Severe bumpiness.
- (f) Heavy rain or hail.
- (g) Thunder and lightning.
- (h) A heavy bank of low cloud towering to great heights.

(ii) When a cold front travels across the country, the friction at the surface retards the lower layers of the cold air, while the cold air at some height above the ground moves forward unimpeded. The result is that the cold air assumes the form of an overhanging tongue with its point some distance above the ground. Under the overhanging portion of the cold air there is warm air so that conditions are unstable. The breakdown of this unstable arrangement gives rise to intense vertical currents. The squall cloud forms near the front of the tongue of cold air and develops the well-known roll form. This roll cloud, however, is generally detached from the main cloud system of towering cumulonimbus, which is the real hazard to aviation—because of the violent bumpiness, electrical effects and possible ice-accretion.

(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. In this country 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 cold fronts are associated with the active depressions of temperate latitudes the frequency of occurrence of line-squalls of varying degrees of intensity is rather 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. Its length of life is often at least twenty-four hours. A line-squall usually becomes less intense, or dies out altogether, when an occlusion is formed, but even afterwards the occlusion may have the character of a cold front and the line-squall may 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 Busters" 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 cumulonimbus clouds with strong ascending currents 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) One of the most widely accepted theories which has been advanced to explain the cause of lightning is that based upon the fact that when a raindrop breaks up (*see para 15 (i)*) into smaller drops, the water becomes positively charged and the air negatively charged. The negative charges are carried upwards in the ascending currents of air and the positively charged drops lag behind. As a result of this separation of electricity different parts of the cloud acquire different electrical charges. It is probable that the collision of ice-crystals in the upper part of the cloud also contributes to the separation of electrical charges. The accumulation of large, localised charges in a thunder-cloud may lead to a discharge taking place from one part of a cloud to another part or between cloud and ground. The flash of the discharge is known as lightning. A distinction is sometimes drawn between "forked" lightning in which the path of the actual discharge is visible, and "sheet" lightning in which all that is seen is the flash of illuminated clouds which obscure the actual path. Generally speaking, the more violent the ascending currents the greater the production of electrical effects.

(iii) The necessary conditions for the formation of a thunderstorm are an adequate supply of moisture and a lapse-rate of temperature in excess of the saturated adiabatic (*see para. 11*) through a considerable height. There are three cases which may be considered :—

(a) *Surface heating.*—Thunderstorms produced by this cause alone occur over the land during the heat of the day, mainly in summer; when once formed they may actually persist until long after sunset. They may also occur over the sea at any hour of the day or night, chiefly in autumn and winter, in cold air masses moving over a warm sea surface.

(b) *Instability due to the over-running of colder air.*—When the direction of the wind changes with height the upper air may have a very different origin from that of the lower air. For example, a cool southwesterly wind may be found above a relatively warm current from the southeast. This sometimes happens in summer when a spell of fine anticyclonic weather is breaking down and

unsettled conditions are coming in from the Atlantic. Such storms may be started by some kind of initial impulse or "trigger action" examples of which are:—

Surface heating. In this case the storms develop in much the same way as those mentioned in (a) above.

Orography, which gives thunderstorms in mountainous districts.

Convergence and consequent ascent of air in shallow depressions.

(c) *Instability at a cold front or line squall*.—The formation of thunderstorms in this case has already been discussed in paras. 18 (iii) and 21 (ii).

(iv) 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 (a) and (c) 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. Atmospheric electricity

(i) The electrical effects accompanying various types of weather may be summarised as follows:—

(a) *Clear sky*.—Normal fine weather electricity, which is relatively small. For most practical purposes it may be neglected although it is not insignificant when kite balloons are under consideration. The electrical field which exists in fine weather is called the normal field.

(b) *Some cloud or fog, but no precipitation*.—Outside the cloud there is no marked effect on the normal field; within the cloud or fog there are local increases of the normal field, but not to any dangerous extent.

(c) *Steady light rain*.—The normal field may be increased but no large electrical forces are produced either within or without the cloud.

(d) *Showery rain from detached clouds*.—Electrical generation takes place within the cloud and the electrical force may be strong near to the cloud. Electrical discharges are not likely from small detached clouds, but they are not impossible.

(e) *Heavy showery rain*.—The electrical conditions become more marked and culminate in thunderstorms.

(f) *Hail or soft hail*.—Seldom occur without electrical discharges and the most violent thunderstorms are generally hailstorms.

(g) *Snow*.—Snow is similar to rain in that if it is light and steady there is little electrical effect, while if it falls from shower clouds there may be much electrical activity. The lightning from snow showers is usually infrequent but very intense. In addition, drift snow can give rise to strong electrical fields near the ground.

(h) *Dust storms*.—The mere raising of a cloud of dust produces strong electrical fields, but it is not certain whether the lightning discharges which occasionally accompany duststorms are due to the dust or to rain in the upper part of the cloud which fails to reach the ground.

(ii) *Lightning* is by no means so serious a hazard to aviation as fog, ice-accretion and violent vertical current. Nevertheless, it does present a real danger, for two reasons. The first is, that an aircraft (which acts as a conductor) may, when flying near to some part of a cloud which carries a high charge, initiate a lightning discharge by concentrating the electric field and thus raising the intensity of the latter above its sparking value. The second is, that an aeroplane, by providing a highly conducting path, may actually "short-circuit" a lightning discharge. It is obvious, therefore, that an aircraft should not, if possible, fly in the immediate vicinity of thunder-clouds; if a machine is actually caught in a thunderstorm it is best both from the point of view of dangerous electrical discharges and dangerous vertical currents to fly well below the cloud and never through it, if that can be avoided.

Apart from the aerial, the metal parts of a modern machine, which are always bonded together are of dimensions sufficiently large to provide an adequate path for a flash to enter or leave the plane without doing any damage. The greater the linear length of a conductor, however, the greater the risk of its providing a short circuit for a lightning flash. Hence, although there is practically no danger to personnel on a machine without an aerial, the position is much more serious when

a machine has a trailing aerial, or is towing a target or sky-sign by means of a long wire. The aerial is normally not directly connected to the main mass of bonded metal of the aeroplane which takes the place of the usual "earth." *When an aircraft carrying an aerial is in, or about to enter, a danger area, it is important, therefore, 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. A wireless operator can assist the pilot in deciding when dangerous conditions exist by noting any considerable increase in the number or strength of atmospherics. If such is the case, he should inform the pilot who should consider this information in relation to the weather conditions in the region towards which he intends to fly. If the pilot considers it desirable, he should 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 be wound in; the pilot will then be in a position to consider whether to proceed on his course through the storm or not.*

(iii) An aeroplane as a whole may become charged when flying through an intense electrical field as, for example in a duststorm or snowstorm, owing to induced charges. Any such charges are rapidly dissipated as soon as the machine flies out of the electrical field; but if the machine lands while still in the intense field it may cause a spark on landing.

(iv) For more detailed information on this subject reference should be made to *Lightning and Aircraft* (M.O. 336 f).

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_LC_M

wwVhN_h

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. Details are given in Form 2612 *Abbreviated Weather Reports for Aviation*. 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_LC_M)*—First examine the sky and note what types of clouds can be seen. Illustrations of the different cloud forms are given in Fig. 110. Select from the code for C_L 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_L*. Then select from the code for C_M 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_M*. 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_L or C_M by a hyphen. If there are no low or medium clouds present, then the appropriate letter C_L or C_M 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. The method of the determination of h is given at the foot of columns 2 and 3 of appendix XV. The method of obtaining N_h is as follows. Estimate the number of tenths of sky covered by cloud of the types to be reported by N_h; 0 representing a sky which is entirely free from low cloud and 10 a sky which is completely covered with low cloud. From the code for N_h select the code figure which represents this amount of cloud. *This will give the figure for N_h*. 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_M . For example, if there were two types of cloud present, stratocumulus being 5 and the amount of altocumulus 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_L will be reported by a hyphen, C_M will also be a hyphen and N_h 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_L , C_M 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.

The simplest method of obtaining the height of the cloud at present is to send up a small balloon rising at a known rate, and take the time until it disappears in the base of the cloud. This requires some care to avoid being misled by cloud drifting over after the balloon has reached a higher level than the cloud.

By night a small candle lantern (paper) is hung beneath the balloon. A quicker and simpler method at night, when a searchlight is available, is to direct the beam vertically to illuminate the base of the cloud. The height, h, may then be determined by observation of the angular elevation of the illuminated patch from a point at a known distance from the searchlight.

At stations where balloons are not available, the height of the cloud must be estimated to the best of the observer's ability. It is not anticipated that observers who have not had experience with balloons will be able to make very close estimates, and unless some definite information is available, such as a report from a pilot who has been to the cloud level, they should not aim at getting nearer than the nearest 1,000 feet, except for clouds below 1,000 feet. It is then frequently

possible to make use of neighbouring hills to obtain a closer estimate. Care is required, however, in estimating cloud height in this manner. An isolated hill or range is often capped by a semi-permanent cloud which is produced by the effect of the hill itself upon the air current. 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.

03 must be used only when sky is completely covered with a layer of thick or heavy cloud.

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 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 (W)*.—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 (V)*.—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 (DD)*.—The figures to be reported for wind direction correspond to the thirty-two points of the compass, N., N. by E., NNE., etc. 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.

(xi) *Wind force (F)*.—This may be estimated by means of the Beaufort Scale in appendix XIV. Forces above 9 should be reported as 9 and the actual force indicated by means of a word at the end of the message, e.g., "Storm ten" for force 10, "Storm eleven" for force 11, etc.

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. 40-99-0-39

CODE FOR ABBREVIATED WEATHER REPORTS FOR AVIATION

1st Group. IIIC _L C _M	2nd Group. wwVhN _h	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 _L = 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".)	50-59 PRECIPITATION AT TIME OF OBSERVATION.	
C _M = Form of medium cloud.	h = Height of base of cloud.	N = Total amount of sky covered by cloud.	50-59 <i>Drizzle (precipitation consisting of numerous minute drops).</i>	
	N _h = Amount of cloud whose height is reported by h.		50 Drizzle.	
Code for C_L.	Code for ww (see Columns 4-5).		51 Intermittent } slight	
0 = No low cloud.	Code for V.		52 Continuous } drizzle.	
1 = Fair weather Cu.	<i>Objects visible at Objects not visible at</i>		53 Intermittent } moderate	
2 = Large Cu. without anvil.	0 — 55 yards.		54 Continuous } drizzle.	
3 = Cb.	1 55 yards. 220 "		55 Intermittent } thick	
4 = Sc. formed by the spreading out of Cu.	2 220 " 550 "		56 Continuous } drizzle.	
5 = Layer of St. or Sc.	3 550 " 1,100 "		57 Drizzle and fog.	
6 = Ragged low clouds of bad weather (or Fractonimbus).	4 1,100 " 2,200 "		58 Slight or moderate } drizzle and rain.	
7 = Fair weather Cu. and Sc.	5 2,200 " 4,400 "		59 Thick }	
8 = Large Cu. (or Cb.) and Sc.	6 4,400 " 6½ miles.			
9 = Large Cu. or Cb. and ragged low clouds of bad weather.	7 6½ miles. 12½ "			
- = Low cloud not discernible.	8 12½ " 31 "			
	9 31 " or above.			
Code for C_M.	Code for h.	Code for F.	60-69 <i>Rain.</i>	
0 = No medium cloud.	0 = 0-150 feet.		60 Rain.	
1 = Typical As. (thin).	1 = 150-300 "		61 Intermittent } slight	
2 = Typical As. (thick)—(sun or moon invisible)—or Nimbostratus.	2 = 300-600 "		62 Continuous } rain.	
3 = Single layer of Ac. or high Sc.	3 = 600-1,000 "		63 Intermittent } moderate	
4 = Ac. in isolated bands. Individually decreasing—(often lenticular).	4 = 1,000-2,000 "		64 Continuous } rain.	
5 = Ac. in bands (increasing).	5 = 2,000-3,000 "		65 Intermittent } heavy	
6 = Ac. formed by the spreading out of Cu.	6 = 3,000-5,000 "		66 Continuous } rain.	
7 = Ac. associated with As. or As. with parts resembling Ac.	7 = 5,000-6,500 "		67 Rain and fog.	
8 = Ac. Castellatus (or Ac. in ragged fragments).	8 = 6,500-8,000 "		68 Slight or moderate } rain and snow.	
9 = Ac. in several layers generally associated with fibrous veils and a chaotic appearance of the sky.	9 = No cloud below 8,000 feet.		69 Heavy }	
	Code for N_h and N.	Code for W.	70-79 <i>Snow.</i>	
	Tenths of sky covered		70 Snow or sleet.	
	0 = 0.		71 Intermittent } slight snow	
	1 = Trace.		72 Continuous } in flakes.	
	2 = 1.		73 Intermittent } moderate snow	
	3 = 2-3.		74 Continuous } in flakes.	
	4 = 4, 5 or 6.		75 Intermittent } heavy snow	
	5 = 7-8.		76 Continuous } in flakes.	
	6 = 9.		77 Snow and fog.	
	7 = More than 9 but not overcast.		78 Granular snow (frozen drizzle).	
	8 = 10.		79 Ice crystals.	
	9 = Sky obscured by fog, dust-storm or other phenomenon.		80-89 <i>Shower(s).</i>	
	<i>Note.</i> —Code figure 0 is to be used only when the sky is completely free from cloud. Code figure 8 is to be used only when the sky is completely covered with cloud so that no blue sky is visible, or, in the case of N _h , so that no higher cloud is visible.		80 Shower(s).	
	<i>Amount of Cloud whose height is reported as h.</i> —First it is necessary to decide what cloud shall be adopted for determining h. The method of the determination of h is treated below.		81 Shower(s) of slight or moderate } rain.	
	<i>Case 1.</i> —If there is cloud of Form C _L , then h will refer to this cloud except in Case 3 below. (The word "Cloud" is here used <i>not</i> to signify a single cloud but in a collective sense. It refers to all the clouds, or the whole layer of cloud reported as Form C _L .)		82 Shower(s) of heavy } snow.	
	<i>Case 2.</i> —If there is no cloud of Form C _L and there is cloud of Form C _M whose base is below 8,000 feet, then h will refer to this cloud. It will usually be Nimbostratus or thick Altostratus.		83 Shower(s) of slight or moderate }	
	<i>Case 3.</i> —If the cloud of Form C _L is only fragments (usually Fractonimbus or Fractostratus) below a more extensive cloud whose base is below 8,000 feet, then h will refer to this more extensive cloud.		84 Shower(s) of heavy } rain and snow.	
	<i>The amount of cloud, N_h, will be estimated to give as well as possible all the cloud of the Form used for determining h. In Case 1, it will be all the cloud reported by C_L; in Case 2, all the cloud of the layer of C_M used for h; this will usually be all the C_M cloud present though, on exceptional occasions, there might be some other C_M cloud at a definitely higher level and this other C_M would then not be included in estimating N_h. In Case 3, the same considerations apply as in Cases 1 and 2.</i>		85 Shower(s) of slight or moderate }	
			86 Shower(s) of heavy } hail, or rain and hail.	
			87 Shower(s) of granular snow.	
			88 Shower(s) of slight } 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	

