M.O.637

HANDBOOK

OF

WEATHER FORECASTING

METEOROLOGICAL OFFICE

1964

U.D.C.
551.509.3(02)

PREFACE

The Handbook of Weather Forecasting was written mainly for distribution within the Meteorological Office to provide forecasters with a comprehensive and up-to-date reference book on techniques of forecasting and closely related aspects of meteorology. The work, which appeared originally as twenty separate chapters, is now re-issued in three volumes in loose-leaf form to facilitate revision.

Certain amendments of an essential nature have been incorporated in this edition but, in some chapters, temperature values still appear in degrees Fahrenheit. These will be changed to degrees Celsius when the chapters concerned are completely revised.

CHAPTER 8

CYCLONES AND TROUGHS AFFECTING THE BRITISH ISLES

CONTENTS

CHAPTER 8

CYCLONES AND TROUGHS AFFECTING THE BRITISH ISLES

LIST OF DIAGRAMS

CHAPTER 8

CYCLONES AND TROUGHS AFFECTING THE BRITISH ISLES

8.1 GENERAL INTRODUCTION TO CHAPTERS 8 TO 12 INCLUSIVE

When a forecast is being prepared for a few hours ahead it is possible to consider individually the various physical processes which are expected to occur and to lead to particular states of the various weather elements. This detailed approach to the short-period forecasting of the weather elements, primarily on the basis of physical principles, is dealt with in Chapters 13 to 20. However, the various physical processes at work are so inter-related that, when the forecast is for a longer period ahead, it is impractical to consider separately the effects of radiation, turbulence and so on, and the forecaster is led to base his predictions upon his experience of the weather which has accompanied synoptic situations similar to that expected. In Chapters 8 to 11 an attempt is made to describe in general terms the weather which usually accompanies some of the more common synoptic features. The discussion is divided as follows:

Chapter 8 - Cyclones and troughs
Chapter 9 - Anticyclones and ridges
Chapter 10 - Fronts
Chapter 11 - Air masses

This material is supplemented in Chapter 12 by some statistics of the occurrence of particular synoptic features etc. It is hoped that the statistical and synoptic climatological data will provide a useful back-cloth against which the forecaster, practising his craft in the neighbourhood of the British Isles, can take a correctly balanced view of the current synoptic situation. It is difficult to assess the direct value of a knowledge of the "normal" in day-to-day forecasting. Nevertheless, although the climatological normal will not necessarily be a good forecast on any individual occasion, the forecaster who is unaware of the synoptic climatology of the forecast area must be at a disadvantage compared with very experienced colleagues, and individual forecasts made with a knowledge of climatology ought, in the long run, to be better than those reached purely from a consideration of the current situation and with scant regard for climatology.

A number of notable attempts [1,2,3*] have been made in the past to describe the weather which accompanies various weather maps. The basis has been the division of the weather maps into arbitrary synoptic types. The types used have varied and the selection and recognition of these types has not been without difficulty. Furthermore the number of sub-types required tends to become large so that any comprehensive account, based on these classifications, is likely to become so complex that the probability of practical forecasters making direct use of it is much reduced. Consequently this approach has not been adopted here.

---

*The superscript figures refer to the bibliography at the end of this chapter.

Moreover the classifications[1, 2, 3] and others like them date from the period before a satisfactory aerological network of observations became available and no such classification could be satisfactory now without some recognition of the importance of the long-wave features of the flow in the middle and upper troposphere. Few studies of weather in the British Isles in relation to the upper flow have yet been made although the relationships for the European continent have been examined fairly extensively in the German literature. Having regard to current knowledge of features of tropospheric flow patterns it seems likely that the basic types of the early (surface) classifications, which depended to a greater or lesser degree on the location of the major high-pressure area and the orientation of its major axis, are related to the presence near the British Isles of some sections of preferred long wave patterns of tropospheric flow. Chapters 5 and 6 of this handbook contain some general ideas on the movement, evolution and persistence of some of these patterns and also on the variations likely to be experienced as short wave features move through the predominant and relatively slowly changing long wave pattern. If forecasters can make a reasonable estimate of the long wave features for a day or two and can also identify the major baroclinic or frontal regions, they should then be able to estimate the general type of weather likely to be experienced over some areas of the chart. Thus, to some extent, recent advances in the use and interpretation of upper air data should have provided the well equipped forecaster with means whereby estimates can sometimes be made of the general weather which is likely to occur for one or two days (and occasionally for longer periods), as the embroidery of the smaller synoptic patterns moves through or around the long wave patterns. Periods of change of type are very difficult to predict and constitute one of the major problems which confront the practical forecaster.

In the absence of much synoptic research on the relation of weather to the synoptic situation, Chapters 8 to 11 are necessarily written from the author's practical experience without any attempt at statistical verification. Some personal bias in selection of topics and interpretation is therefore inevitable but it is hoped that any bias will be gradually eliminated by revision in future editions of this handbook.

Forecasters should be aware of the series of aviation meteorological reports which are available within the Meteorological Office. Those particular reports dealing with areas of or near the British Isles are detailed in the bibliography.[4, 5] Some other unpublished reports[6] refer to various areas of Europe. These various reports are valuable and should be read and consulted by forecasters from time to time.

8.2. FRONTAL CYCLONES

8.2.1. Open-wave cyclone

The distribution of clouds and precipitation associated with an open-wave cyclone during its development from a shallow wave to a deep depression is given in many texts. In addition most textbooks contain schematic vertical cross-sections along lines across various parts of the depression in various stages of development and these sections convey a clear idea of conditions in a model wave depression. However, in every wave depression the pattern of clouds and precipitation differs to a greater or lesser extent from that depicted in the model. For example, there may be considerable clear lanes between layers of cloud associated with the warm front, or perhaps two zones of continuous precipitation separated by a zone almost devoid of precipitation, or there may be fairly extensive rain occurring in the warm sector. These differences are confusing to inexperienced forecasters and at times so irritating, even to experienced forecasters, that some tend to take too cynical a view and regard the model as valueless. This is certainly a too extreme and unbalanced view. There is little doubt that, for practical forecasting, the picture of the model distribution to be expected is a very valuable concept. It has simplicity, is readily committed to memory and it serves as a basis from which to determine or estimate the extent of variations of the actual weather from that depicted in the model. In short-period forecasting some reliance can be placed on the persistence and extrapolation of observed differences but this calls for great care particularly when active development is occurring. For interpreting wave depressions on 24-hour prebaratics some broad modifications to the model may be justified. For example if the wave is moving round the periphery of a large anticyclone where isobars are generally anticyclonically curved a forecast of rather less rain and thinner clouds with some clear lanes may be appropriate. Similarly, less rain is to be expected if the wave is moving through an area of the chart favourable for anticyclogenesis rather than cyclogenesis (for example, along a band of thickness lines to the rear of a large thermal trough). If the tephigrams indicate pronounced dryness in the warm air aloft, thinner clouds and little rain may be a good forecast for a few hours but care should be taken in extending such a forecast for longer periods since the shape and appearance of tephigrams can be radically changed by prolonged and steady ascent of air. On the other hand, where there is clearly an ample supply of moisture and where vigorous development, with attendant ascent of air, is expected, a forecast of thick extensive and almost unbroken cloud to great heights would be appropriate.

Most of the rainfall associated with a typical wave depression (of the order of 10 millimetres over the British Isles) occurs in a fairly narrow band some 300 miles or so wide along the track of the tip of the warm sector. Further from the track the rain at fronts is often quite light. Figure 8.1 shows schematically a typical distribution of precipitation associated with a young wave depression.

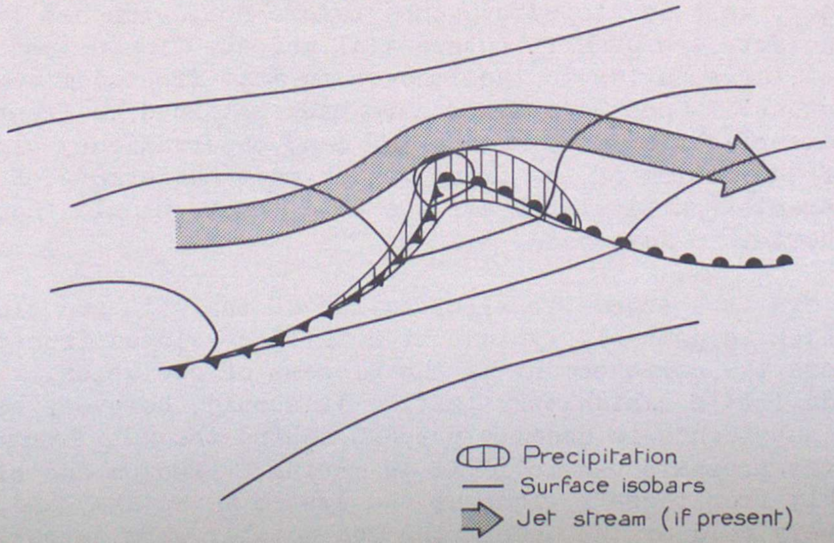


FIGURE 8.1 SCHEMATIC DISTRIBUTION OF PRECIPITATION ASSOCIATED WITH A YOUNG WAVE DEPRESSION

A successful forecast of the track of the depression is very important for accurate forecasting. In winter-time, when temperatures at low levels to northward of a depression are near or just below 0°C. whilst those to southward are, at least initially, well above 0°C., the track of the depression may determine to a large extent whether precipitation in an area reaches the ground in the liquid or solid state. An example of extensive snow to northward of a centre is illustrated in Chapter 17, Section 17.9.4.3.

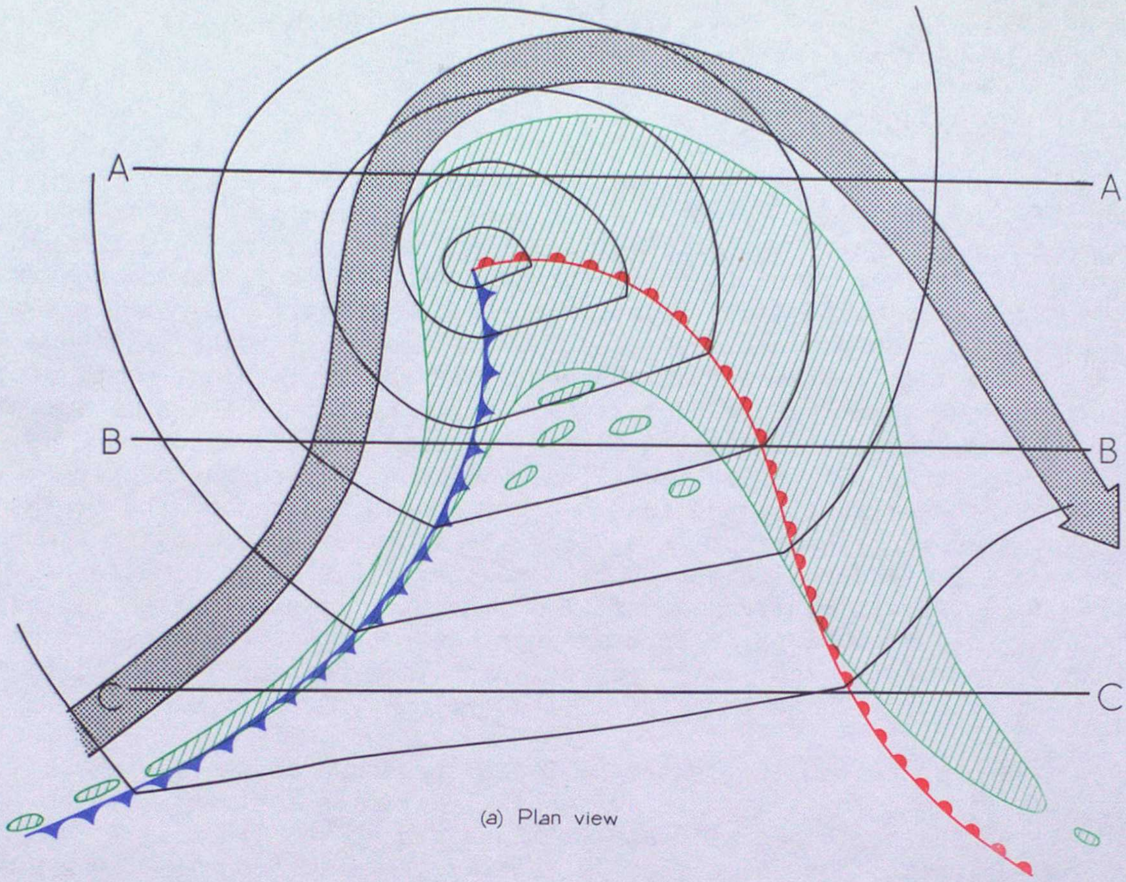
When a wave is developing on a cold front visibilities in the cold air mass are seldom poor. In some cases there may be hill and coastal fog in the warm air, more particularly close to the warm front. Continued development of the wave depression causes increased surface winds in its circulation and there is a tendency for any fog patches in the warm air to be lifted to low stratus. If the base of the low stratus remains very low (perhaps below 300 feet) then horizontal visibility beneath it will usually remain poor. If there should be any fog patches in the cold air due to night radiation ahead of the system, the freshening wind and formation or advection of cloud will usually lead to a fairly rapid clearance.

8.2.2. Fully developed cyclones

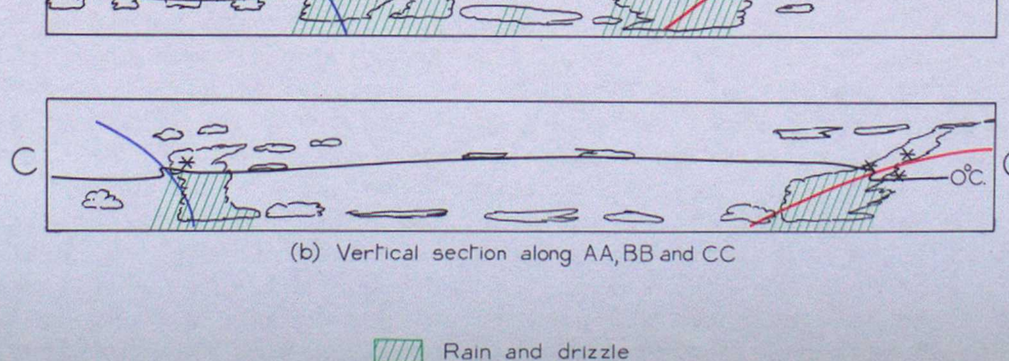
In fully developed cyclones, which are often destined to form a feature of the long wave pattern for a few days, the isobars usually have considerably greater curvature than in open waves and the wind regime is of very well marked cyclonic type not only at the surface but often through much of the lower and middle troposphere. At about the time of maximum development the warm and cold fronts usually show pronounced curvature - particularly in the central parts of the cyclone. The precipitation is often quite extensive as are also the areas of cloud, both in horizontal and vertical extent. Around the time of maximum development, the process of occlusion usually commences. After commencement, occlusion often proceeds rapidly and may well be virtually complete within about 24 hours of onset. An example of fairly rapid occlusion of a deep depression is contained in Chapter 13, Section 13.13.4.

In a deep, well developed cyclone, before occlusion has commenced, pressure gradients are usually substantial and the fronts tend to be orientated at large angles to the isobars so that frontal movements are usually vigorous. Once good fixes have been obtained on frontal positions (for example by a dense network of land observations) close estimates of the motion of the front can be made and errors of timing frontal movements (particularly for the cold front) should then be small for short-term forecasts.

Figure 8.2 is a schematic illustration of the rain and cloud distribution which is probably typical of a fully developed frontal cyclone shortly before the commencement of the process of occlusion. The diagram needs little explanatory text. It should, however, be remarked that strong subsidence is usually present behind the cold frontal trough and behind the pressure centre if it is moving. Medium and high cloud clears quickly from these regions as the system moves away and, unless the air is very cold or the underlying sea notably warm, a period without showers may follow - the heavy and frequent showers occurring later as the cold air becomes deeper and is less modified by subsidence. The axis of the thermal trough in the rear of a depression is a useful indication of the region of maximum development of showers; this region is often located at and to the forward side of the axis. Showers often decrease abruptly to the rear of the axis of the thermal trough. Any cold pool which exists in the rear of a depression is a centre of maximum



(a) Plan view



(b) Vertical section along AA, BB and CC

FIGURE 8.2 SCHEMATIC DISTRIBUTION OF PRECIPITATION AND CLOUD IN A WELL DEVELOPED FRONTAL CYCLONE shower activity. Cold pools are further discussed in Chapter 11, Section 11.3 and Chapter 12, Section 12.5.3.

8.2.3. Occluding cyclones

After occlusion commences many cyclones tend to slow down, some gradually, others quite abruptly. In some cases the orientation and shape of the occlusion are fairly simple and the front may be followed systematically from chart to chart for many hours with little change in shape superposed on the pure translation of the front. In other cases the occlusion soon becomes distorted. Sometimes, under the influence of strong winds some distance from the centre of the depression, parts of the occlusion move quickly forward well in advance of both the centre and the triple point, where the gradient along the front may be weaker. Continuation of this sort of movement leads to an occlusion which spirals out from the centre, circumscribes a considerable section of the depression and then trails more or less along the isobars (contours) to the triple point. After a further period of distortion it is sometimes extremely difficult to track and follow consistently the movement of such relatively old occlusions. In some such cases better forecasts may be obtained by dropping the distorted occlusion from both analyses and forecasts and treating those portions of the cyclone as non-frontal.

On some occasions the centre of lowest pressure moves in sympathy with the triple point leaving a substantial air-mass contrast between cold air to the north and mild air to the south of the track. A "back-bent" occlusion is then swept rapidly towards the cold front by the gradient winds in the rear or left-hand sector of the cyclone. Such occlusions then move quite close to and take a curvature similar to that of the cold front. It will generally be found that they are active for a limited distance from the triple point - perhaps 200 miles would be typical and 300 would be classed fairly long, and any temptation to draw longer back-bent occlusions should be resisted.

When deep cyclones slow down and retain substantial pressure gradients some distance from their centres, the geometry of any occlusion often becomes complicated and the front distorted. It is clearly impossible to describe all generic shapes, but one effect, which is generally noticeable in the associated weather, is the spread of precipitation and cloud to the rear quadrants of the cyclone - notably that quadrant to the left of the track of the centre and, at times, also to those parts of the right rear quadrant which are nearer the centre. Over sea areas it is often difficult from the sparse observations to delineate such rainy areas accurately. The spread back of rain and low cloud is particularly noteworthy along the east coast of the British Isles on those occasions when depressions, after crossing the British Isles, slow down and stagnate in the North Sea and cause persistent gradient winds between north and east in eastern districts. The rain associated with such spread back is generally slight (but not invariably so) but it is usually prolonged and may aggregate to a substantial total amount. The pick-up of moisture from the North Sea may be an important feature leading to these persistent rains and also to the prevalence of extensive sheets of low cloud which frequently persist for a few hours after the cessation of rain. It is noteworthy that such periods of rain and extensive low cloud can persist even with sustained rises of pressure and several notable floods near the east coast of Britain have occurred under such conditions. When such an occluded depression is slowing down, it is sound practice to defer a clearance beyond the straightforward estimate of clearance based on the movement of the cyclone, the extent of occlusion, or rising tendencies. Clearances almost never come sooner than such estimates and are generally delayed.

When the lowest pressure remains at the end of the occlusion remote from the triple point and occlusion proceeds rapidly, the warm air in the cyclone is rapidly evicted from the surface to the upper air in the central regions and surface warm air is restricted to a peripheral region of the cyclone. At times, a secondary depression may also form at the triple point - this will be discussed in Section 8.2.6. However, even when an actual centre cannot be detected at the triple point, even over a dense land network, there sometimes appears to be a tendency for the formation of at least a marked trough. Gales become particularly intense near the triple point but there may perhaps be a temporary phase of lighter winds between the triple point and the main centre.

Experience indicates that the period of heaviest rain often occurs at the time occlusion takes place. The heaviest rain tends to be located near the triple point and to occur at about the time of the passage in quick succession of both warm and cold fronts. In an unpublished monograph Douglas[7] has commented on an association between the occlusion process and outbreaks of rain in the depression. He remarked that

"Rain in the warm sector is generally associated with the occlusion process, and the approach of a cold front greatly increases the chance of rain not only in the warm sector but also ahead of the warm front, unless the cold front trough develops at the expense of the warm front trough with excessive backing of the warm sector isobars."

8.2.4. Secondaries on cold fronts

The general characteristics of secondaries on cold fronts cover a wide spectrum. The least definite is the very shallow minor wave which is barely detectable in the isobaric distribution, even on a large open-scale surface chart with a dense network of plotted observations, and is quite imperceptible on routine upper air charts. In many cases the net effect on weather of such a shallow wave which does not develop is to delay the movement of the cold front in the rear of the primary depression (sometimes causing little more than a hesitation in the movement of the cold front) and to cause a corresponding delay in the clearance of the frontal high clouds. On some occasions, there is a slight spread back of cloud over areas which had previously cleared after the passage of the cold front of the previous depression. For these non-developing waves such spread back would seldom exceed about 100 nautical miles normal to the rear edge of the frontal cloud sheet prior to the wave development (the orientation of the edge of such cloud sheets is often approximately that of the surface cold front or the mid-tropospheric winds). This type of weak wave development usually causes little spread back of precipitation and any precipitation that does occur, in areas which had previously cleared, tends to be slight or intermittent. The shallow wave development is associated with a slower movement of the cold front so that frontal precipitation is prolonged near those parts of the front and is also often intensified, even when the isobars are little distorted. Such shallow waves usually ripple along the cold front and become absorbed in the circulation of the primary depression. When the waves are very shallow, and the isobaric pattern feeble and indefinite, it is sometimes difficult to track them consistently - even on detailed hourly charts - and any particular wave may well become undetectable as a definite entity after an existence of only a few hours.

In marked contrast to the shallow non-developing wave some secondaries on cold fronts develop quite rapidly, deepen markedly and produce extensive and clear-cut isobaric patterns. In some cases the secondaries distort the contour patterns, up to say 500 millibars or above, after a few hours existence. Such strongly developing waves have an associated cloud and precipitation structure, both in horizontal and vertical extent, which is little different from that of a developing primary cyclone. These secondaries persist for many hours, perhaps one to three days at times, and on some occasions attain such a depth and horizontal and vertical extent that they later become of greater significance than the primary depression. With such very vigorous secondary depressions the surface winds often reach gale force. The strongest surface winds tend to occur shortly after the passage of the cold front and usually within 100 miles (or perhaps 200 miles at times) of the tip of the warm sector.

Secondaries on cold fronts may develop to any extent lying between these two extreme types. Some problems of forecasting them on prebaratic and prontour charts have been dealt with in Chapter 6. As shallow non-developing waves tend to move along the front, with little change in frontal position, the movements of cloud and precipitation are in the same general direction. Deepening waves tend to move more towards the colder air. This movement, coupled with the wind fields they establish, causes a retrograde motion of the initial cold front (that is, it returns as a warm front). There is a corresponding movement of cloud and precipitation across the orientation of the initial cold front. Thus cloud and precipitation return to those areas which had cleared previously after the passage of the initial cold front. A further clearance usually subsequently reaches those areas as the colder air mass arrives again in the rear of the secondary depression.

Occasionally, near the col between the primary depression and the cold-front wave, visibility may deteriorate below fog limits in limited areas which are quite close to the cloudy rainy areas, provided that synoptic events occur to a fairly strict time-table. In the col there will be a fairly restricted area of light winds in a general area which is otherwise characterized by moderate (or even strong) winds in the circulations of primary and secondary depressions. In the hours preceding the wave formation there may well have been rain from warm, and/or cold fronts or from general convergence in the primary cyclone. If such rain has occurred the ground is often wet. If, shortly afterwards, the sky clears, sometimes in a narrow belt just to the rear of the cold-type front in the late afternoon (notably in winter), the strong outgoing radiation coupled with light winds and wet ground may be sufficient to cause fog to form there. Nearer the secondary depression, the medium and high cloud will usually be sufficient to limit outgoing radiation so that fog does not form. If such cloud subsequently moves or forms over the foggy area, the change in the radiation balance is often sufficient to disperse the belt of fog, even if there is little surface wind. The region where this type of sequence is likely to occur is restricted; and the occurrence of a narrow belt of radiation fog, within an area affected by a primary and secondary depression, is not common since it requires a fairly strict time-table of occurrences. However, when it does occur, it may surprise the forecaster, since the (usually brief and very restricted) foggy interlude tends to occur after a day of mainly cyclonic activity, often with rain, low cloud and sometimes substantial surface winds. In such circumstances it is relatively easy to overlook the rapid effects on visibility which can be caused by clearing skies and light winds - which may be quite transient since, if the wave moves and deepens, the combination of a freshening wind and cloud cover are usually sufficient to clear the fog or at least cause it to thin considerably.

8.2.5. Secondaries on warm fronts

These are less common than those on cold fronts and they exhibit quite different characteristics. They seldom develop appreciably and usually ripple along the warm front until they finally fill up as they move into an anticyclogenetic area which usually exists in a location down the thermal wind and somewhat to the right of the track of the wave. Some remarks on the thermal patterns and behaviour of warm-front waves are contained in Chapter 5, Section 5.14.2.1 and Chapter 6, Section 6.5.2. Warm-front waves do not occur on the great majority of warm fronts in the region of the British Isles. When a wave does appear there is usually only one wave of any substance, but occasionally two successive waves may appear on the same warm front.

In the cold air ahead of the waving warm front the surface pressure gradient is sometimes quite strong and there is usually a noticeable ageostrophic motion towards the front. Thus the surface winds in the cold air tend to be strong and noticeably backed from the isobars. The associated cloud and precipitation patterns ripple along the front in phase with the wave. They seldom extend far from the front in the direction of the cold air - perhaps 100 to 150 miles would be typical. Cloud bases may, of course, be quite low in the warm air but, particularly with the slower-moving warm-front wave, cloud bases may also be very low ahead of the warm front where continuous precipitation falls through the cold air. General precipitation is often slight. However, moderate precipitation usually occurs for a time in an elongated area, which is generally aligned with and close to the front; this area is of a length usually not exceeding 50 to 100 miles and is centred somewhat ahead of the tip of the wave.

8.2.6. Secondaries at points of occlusion

Sawyer[8] has described the characteristic thickness patterns associated with the formation of secondary depressions at the triple points of both warm and cold occlusions, and an account of this has been given in Chapters 5 and 6. The weather associated with a secondary at the triple point of the warm-type occlusion resembles that of the warm-front breakaway depression but there is sometimes a noteworthy penetration of rain into the ridge ahead of it. Little can be said of the weather associated with a secondary at the triple point of a cold occlusion which is not a glimpse of the obvious. It does seem, however, that some of the heaviest rains tend to occur with the inception of the formation of secondaries (or larger falling tendencies) at points of occlusion.

8.3. NON-FRONTAL CYCLONES

8.3.1. Old frontal cyclones

Large occluded depressions sometimes remain features of the synoptic chart long after they have lost all frontal structure; sometimes they remain for several days. They are then associated with a cold pool or flat trough in the thickness pattern and the air in them is unstable. Coupled with the slow frictional convergence towards the centre in the lowest few thousand feet of the atmosphere, this leads to irregular outbreaks of showers in the absence of any special heating from below. Such showers often amalgamate into rain areas 50 or 100 miles in extent but the distribution and timing of such precipitation is almost impossible to predict with any accuracy, except by extrapolation of the rain areas already on the chart or inferred from radar weather echoes.

8.3.2. Polar lows

The term polar low is here taken as referring to fairly small-scale cyclones or troughs (sometimes the surface isobars show only a very minor ripple) embedded in a deep cold current which has recently left northerly latitudes. These small polar lows generally move in the direction of the general lower tropospheric flow which is usually left substantially unchanged after their passage. At times, however, air which is both colder and deeper may arrive behind a larger and more vigorous polar low. The approach of a polar low is heralded by falling tendencies (which may be only very slight), a backing and sometimes a decrease of the surface winds and a pronounced change in type, and increase in amount, of medium and high clouds. These changes in upper clouds are usually very noticeable because the preceding cold air is often virtually free from upper clouds apart from anvil cirrus clouds which are either the residue of or blown off from the tops of shower clouds. At localities near upwind coasts, the warning given by these forerunners of the approach of a polar low may be little more than one or two hours. At inland stations, in polar outbreaks with strong tropospheric winds and even with moderate winds, the warning given by upwind coastal stations may amount to but a few hours. At times when the polar low has formed well to the north of the British Isles, observations on the west coast of Iceland, at the Faeroes, or on the Norwegian coasts enable the existence of polar lows to be inferred, although these observations may well show only the weather on the extreme periphery of such polar lows which are likely to move towards and affect the British Isles. Thus the precise location of a polar low at sea is often in doubt. Even when its position is known fairly accurately, the timing of movement for periods of say 12 to 24 hours often introduces considerable uncertainty in the forecast position. When a polar low moves or forms over a relatively dense observational network some of these uncertainties are removed. Although showers, which may be both severe at times and frequent, are often features of a typical polar outbreak a polar low causes either a period of continuous precipitation or such extensive and frequent showers that for most practical purposes it is little different from continuous precipitation. The sky is usually almost completely covered by upper clouds and the cold dull weather, with precipitation in the polar low, contrasts unpleasantly with the bright, showery, but at times exhilarating, weather of the pure polar outbreak. In winter, and even in spring, polar lows may bring considerable falls of snow, particularly on high ground and at times on low ground also. The falls of snow from a polar low, being of longer duration and of greater horizontal extent than those from the showers of a simple polar outbreak, may disrupt transport and cause considerable difficulties both to the general public and to some special sections of the nation, notably farmers maintaining livestock out of doors, particularly in hilly country where there may be deep drifts.

Clearance of the sky after the passage of the polar low is often rapid and complete. Incoming solar radiation during the day may melt wholly or partially any frozen precipitation which is lying. Strong outgoing radiation may produce hard frost at night. Any subsequent hard freezing of partially melted snow often causes very great difficulties for transport.

Not all polar lows in winter cause solid precipitation, but the current temperatures in the lower troposphere should always be carefully considered. In polar lows, cooling by evaporation of precipitation may occasionally be an important factor in determining the nature of precipitation at the ground. This cooling should generally be considered when indicating the level of the 0°C. isotherm for aircraft flying at relatively low levels near or through a polar low. As the 0°C. isotherm is often within 2,000 or 3,000 feet of mean sea level in winter or early spring, any lowering of the 0°C. isotherm may leave little or no room for manoeuvre between flight at a level with temperatures above 0°C. and the ground. As the precipitation and cloud system of a polar low might extend horizontally over a distance of about 100 or 150 miles, and vertically to at least 700 millibars, an aircraft may have to traverse a substantial extent of cloud in a search for a path free from the risk of ice accretion.

8.3.2. Heat lows

When heat lows over the British Isles appear on the surface chart, they usually do so in the late afternoon or evening after a day of intense solar heating. The preceding pressure distribution is usually slack although the upper winds in the lower or middle troposphere may be relatively steady in direction and light in speed (but occasionally moderate). The heat lows show up as quite shallow isobaric features on the surface chart. The weather which accompanies or immediately follows these can vary from case to case. With dry and relatively stable conditions in the troposphere, only small amounts of shallow cumuliform cloud with high bases (perhaps 4,000 feet or more) will form during the day and these will disperse in the evening. In such cases the shallow heat lows usually fill up during the night and do not disturb the continuance of fine weather. When the troposphere contains a fair amount of moisture and the surface temperatures likely to be reached under the influence of day-time heating are expected to make the air unstable up to considerable heights (say 400- or 300-millibar levels), some thundery activity is likely to break out by about mid-afternoon. The storms are often clearly associated geographically with the surface heat lows which seem to form preferentially over the Midlands, East Anglia and the Lincolnshire and Yorkshire plains. The storms usually retain their separate identities, but occasionally a group may amalgamate to form one large storm area which may then persist as a more or less self-maintaining system for a few hours. More generally, the storms drift separately north or north-east in the light upper winds which, at about 700 millibars, are often from a south or south-westerly point. These storms form over the British Isles: they are not the type which drift up from France. It would seem reasonable to expect a greater liability to these storms when the preceding morning situation indicates cyclonic vorticity over the British Isles than when there is anticyclonic vorticity, but the writer has been unable to trace any useful quantitative relationships or empirical rules.

It should be emphasized that the thunderstorms associated with the surface heating leading to the formation of heat lows behave rather differently as to movement from those assoicated with convection in a cold unstable outbreak in the rear of a depression. In the latter case there is often considerable cyclonic curvature and vorticity, a substantial wind throughout much of the troposphere with a clear and fairly definite flow pattern which will tend to carry any storms with it, and there are probably widespread showers. The heat low is usually associated with rather weak and irregular upper winds and the showers or thunderstorms tend to be large and slow-moving so that many areas between are unaffected and enjoy fine, hot, sunny weather.

At times when a pronounced warm spell, often with light south-east or south surface winds, breaks down, it does so as a cold front or cold trough moves slowly eastwards across western districts of the British Isles, the Bay of Biscay, France and Spain. Sporadic thunderstorms of the type described above may well occur in the afternoon and evening in association with heat lows over the British Isles, but the first break in the general weather often occurs in association with the northward movement from France or the western Low Countries of a trough in the isobars. This trough usually lies ahead of an upper trough, orientated approximately north-west to south-east, which moves into France and Britain from the Bay of Biscay, bringing substantially cooler air in the upper troposphere. The leading surface trough is often orientated approximately east-west and is usually accompanied by a fairly extensive belt of thick, upper, unstable cloud and an area of continuous rain, some of this being very heavy and with violent and prolonged thunderstorms at times. Although there may have been a few isolated storms during the afternoon or early evening from heat lows formed over England and Wales, the skies in southern areas of England are often almost cloudless for a few hours during the late evening and earlier part of the night. This fine period is followed by an outbreak of thunderstorms, which are often extensive. After the thunderstorms have moved away, continuous rain tends to persist in the area for some hours. The intensity of this rain is usually at least moderate just to the rear of the thunderstorms, but it tends to become less intense as the thundery trough moves farther away to the north. This type of sequence, following a hot spell, is typically a summer phenomenon, but it may occasionally occur after a hot spell quite early in spring. The generation of the troughs over France and the speed of the upper winds often seem to combine to cause these storms to reach southern districts of England towards or a little after midnight. Once they have been detected by the dense observing network over England, their movement can be deduced and the timing of their subsequent advance across other districts is not usually particularly difficult. Variations in the intensity of the rain and the outbreak of new large areas of thunderstorms within the general cloud mass and rain area are rather difficult to forecast. For very short-term forecasting, radar weather echoes can be exceedingly valuable (see Chapter 16). Some other remarks on northward-moving troughs from France are included in Section 8.5.

8.4. OROGRAPHIC LOWS

In the British Isles the height and extent of high ground are relatively small and orographic lows formed to the lee of high ground are usually insignificant on the synoptic scale when compared with those formed in the Gulfs of Lions and Genoa and to the south of the Atlas mountains. Nevertheless, on some detailed charts it may be possible to detect vestigial traces of orographic lows or troughs, for example, in the lee of the Welsh hills or the Scottish highlands. Such pressure systems cannot be forecast with much accuracy and their effect on general synoptic weather in the British Isles is almost negligible. When such features are likely to occur, some allowance may perhaps be made in forecasts of the surface wind in the regions affected. Marshall[9] has found that with a strong north-westerly flow across the Scottish highlands, surface winds at Bell Rock are, in the mean, further backed from the geostrophic than with winds in other quadrants (see Chapter 13, Section 13.5.1). This effect could be explained by an orographic low or trough occurring on the lee side of the Scottish highlands.

8.5. TROUGHS

Some comments on the weather accompanying frontal troughs are included in Chapter 10. So far as non-frontal troughs are concerned, if a trough line is moving faster than the wind speed through it there must be convergence in the lower layers ahead of it and divergence behind. However, where the wind blows through a stationary or slow-moving trough, the reverse must be true - divergence downstream (ahead) and convergence upstream (behind). Additionally there will be some frictional convergence. Most troughs approaching the British Isles from the west move roughly with the wind speed, and convergence occurs mainly near and ahead of the trough line. However, there are occasional troughs, mainly moving west from the continent, with convergence and bad weather in the rear. Thus it is not sound practice invariably to associate an expected improvement of weather with a surface trough line. (The surface trough line is, however, a useful device for timing the changes in the winds.) Although there may be only a belt of showers associated with some troughs, in many cases there is an area of continuous precipitation and this often seems to cease some distance ahead of the surface pressure trough - in some cases in the British Isles this distance may amount to 50 to 100 miles and occasionally may be rather more. Where the current weather can be seen to be conforming to this pattern and the winds in the lower troposphere (say around 700 millibars) seem likely to shear the rain forward of a slower-moving surface trough, some reliance may be placed on a continuation of the trend in the short term. It would, however, be unwise generally to forecast such a pattern from a set of 24-hour forecast charts, except perhaps when the forecast wind distribution seemed likely to be very reliable and to be favourable for any rain to be sheared forward of the trough line.

The area of precipitation, when forward of the trough line, is not always approximately parallel to that line, although in many cases it tends to be so. In southerly situations, when thundery weather moves northward from France, the areas of cloud and precipitation tend to be orientated approximately east-west and well ahead of the main cold trough on the chart, which often lies in a broadly north-south direction off south-western coasts and across the Bay of Biscay to Spain. This major trough may be cold-frontal and can be clearly and readily identified on both surface and upper charts (say at 700 and even 500 millibars at times). Whereas at the onset and outbreak of precipitation it may be difficult initially to detect the rather weak isobaric trough associated with the east-west belt of precipitation, a well marked trough usually appears later.

On some occasions, thermal troughs show a tendency to relax, leading generally to improved weather in the trough, but sometimes they extend in a south or south-easterly direction. Miles[10] has described some features associated with this so-called meridional extension of thermal troughs. With regard to the weather associated with meridional extension, Miles found that there was a good deal of variety but that the distribution shown schematically in Figure 8.3 applied fairly generally.

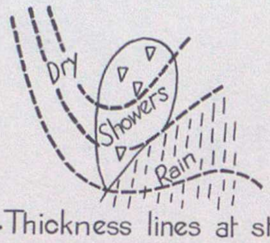


FIGURE 8.3 IDEALIZED DISTRIBUTION OF WEATHER WITH EXTENDING THERMAL TROUGHS

The area of rain (or snow) to the south-east of the thickness trough usually moved south-east as the process went on. This precipitation might be associated with the cold front but, if this had already moved away to the east, the rain might occur ahead of a post-frontal trough. In those cases, it sometimes appeared to result from an amalgamation of shower clouds into a continuous belt of cloud, and might be of a rather intermittent nature. In the northerly current, showers were usually restricted to an area near the axis of the thermal trough and stabilization came in, quite quickly as a rule, from the north-west.

It is important that the available upper air charts should be carefully examined for evidence of the existence of upper troughs. The advection of an upper cold trough may increase upper instability to such an extent that there is a marked increase in the depth of convection, and this may lead to an increase in the frequency and/or severity of showers or thunderstorms. On some occasions the arrival of an upper trough may cause a baroclinic disturbance to form, or a nearby depression to deepen markedly, leading to a period of disturbed weather.

BIBLIOGRAPHY

1. GOLD, E; Aids to forecasting: types of pressure distribution. Geophys. Mem., London, 2, No. 16, 1920.

2. NEWNHAM, E.V.; Classification of synoptic charts for the North Atlantic for 1896-1910. Geophys. Mem., London, 3, No. 26, 1925.

3. JONES, F.M.; Classification of daily weather charts, 1930-1941, persistence and movement of the main high pressure systems. Met. Res. Pap., London, No. 80, 1943.

4. Aviation meteorological reports on regions of the United Kingdom Nos. 9, 13, 15, 16 and 26, 1942-45. Unpublished. Copies available in Meteorological Office Library, London.

5. Aviation meteorology of eastern England. 1951. Unpublished. Copy available in Meteorological Office Library, London.

6. Aviation meteorological reports on regions of Europe. Nos. 6, 7, 8, 11, 12, 18, 19, 20, 21, 22, 23 and 25, 1939-45. Unpublished. Copies available in Meteorological Office Library, London.

7. DOUGLAS, C.K.M.; Preliminary monograph on forecasting rainfall and thunderstorms. Unpublished. Copy available in Meteorological Office Library, London.

8. SAWYER, J.S.; Formation of secondary depressions in relation to the thickness pattern. Met. Mag., London, 79, 1950, p.1.

9. MARSHALL, W.A.L.; Comparison of the wind recorded by anemograph with the geostrophic wind. Prof. Notes met. Off., London, 7, No. 108, 1954.

10. MILES, M.K.; Factors leading to the meridional extension of thermal troughs and some forecasting criteria derived from them. Met. Mag., London, 88, 1959, p. 193.