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WEATHER FORECASTING

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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.

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11.1 INTRODUCTION

Compared with work in some other countries there has been a relative absence of systematic application of the characteristics of air masses to day-to-day forecasting in the British Isles. However, for several decades there has been a recognition of the importance of the sources of the air masses and of the zones or fronts separating airstreams which are brought into juxtaposition by the flow patterns of the major synoptic systems. It is also true that the general characteristics of the various air masses are widely recognized and used in the United Kingdom by many forecasters in a qualitative way. Nevertheless a systematic application of quantitative values of various relevant properties of the air masses has not found favour amongst forecasters in this country. Perhaps the geographical position of the British Isles, leading to a predominantly maritime type of weather which tends to be changeable throughout the year, is the primary reason for the absence of the use of quantitative air-mass parameters for forecasting in the British Isles. In earlier decades, when there was a complete absence of routine upper air information, expenditure of effort in evaluating suitable air-mass parameters for application to forecasting might have paid good dividends. However, the current geographical and temporal distribution of routine observations of both surface and upper air conditions around and over the British Isles is such that no air mass which is extensive horizontally and vertically can reach the British Isles without there being some fairly recent direct observations of its temperature, humidity and wind structure. For shorter-period forecasting recent actual observations are nearly always preferable to statistical values so that there is now less direct incentive to expend great efforts to develop and evaluate a set of suitable parameters and quantitative data for the direct systematic application of air-mass techniques to day-to-day forecasting. However, for the interpretation of prebaratics 48 hours or more ahead, some knowledge of air-mass weather is essential. No attempt is made in this chapter to provide quantitative values for practical use: the chapter is primarily descriptive. In view of the close association between the general synoptic weather and the air masses involved in some commonly occurring synoptic situations, the qualitative and descriptive account should be of value particularly to the relatively inexperienced forecaster.

The concept of an air mass implies a broad-scale homogeneity within individual air masses. It is only when air masses are in their source regions that the actual conditions observed in air masses approximate closely to uniformity. Once an air mass moves from its source region under the influence of the large-scale flow patterns, it moves into an environment and across a part of the surface of the earth with which it is not in long-term near-equilibrium. Accordingly the air-mass characteristics are not then static but are changing under the influence of the many atmospheric processes which are occurring. The British Isles is not very close to any substantial region of the earth where the primary air masses are generated and it follows that all air masses which affect the British Isles are in a state of flux and transition. It is very important that forecasters should bear this constantly in mind. The physical causes of the changes in the characteristics of air masses away from their source regions are many and various and the combinations of these effects are numerous. At the current time any attempt to draw up a balance sheet between the initial state of an air mass, its state when over the forecast area and the contributions of the various factors which have caused those changes during the epoch between the times of the air mass leaving its source region and arriving over the forecast area, can usually only be done as a research project long after the event and, even then, the balance sheet is unlikely to be very precise. This lack of precision arises partly from a lack of full understanding of all the processes involved and partly from a lack of observations, sufficient in detail, quality and quantity, to enable the various effects to be evaluated with sufficient accuracy. Some of the processes operative in modifying air masses when away from their source regions are cooling or heating by contact with the underlying surface, cooling or heating due to vertical motion (such vertical motion may be due to dynamic causes, or orography) and changes in the radiative regime. On a smaller scale, cooling of layers of air by evaporative cooling from falling precipitation modifies the structure of the air. This is often vitally important for short-period, accurate and detailed forecasting. It follows that air masses when away or moving away from their source region should be regarded not as homogeneous masses of air of unchanging uniform characteristics but as masses of air of rather similar general characteristics which are in process of modification. These processes of modification will generally vary both spatially and temporally. Some of these variations are relatively small; nevertheless they are often of a subtle nature, difficult to estimate in detail on the forecast bench. Since such small variations may contain the key to accurate short-period forecasting problems, they present a formidable problem to the practising forecaster.

In theory, an air mass in its source region is homogeneous and barotropic and, in practice, stagnant air masses bred over long periods in the source regions approximate to a barotropic atmosphere. However, the modifications which are undergone as an air mass moves from its source region introduce a degree of baroclinity, and accordingly when a forecaster identifies an air mass in the neighbourhood of the British Isles on his analysed charts there will generally be displayed some degree of baroclinity, often easily recognized from the thickness pattern. When the synoptic conditions combine in such a way to concentrate the baroclinity into an elongated but relatively narrow band, frontogenesis occurs. Thus when dealing with air masses the practical forecaster will have to cope with situations varying from a state of approximate barotropy to a state of pronounced baroclinity. Although in the latter case it may often prove possible, profitable and practicable to insert a front on the analysed and forecast charts, in some cases there may be a strongly baroclinic zone without there being a recognizable front. Where an air mass displays baroclinity, forecasters should pay great attention both to the broad-scale features and to the detail reported in all observations from that area so that they are on the alert to recognize the first confirmatory observational evidence that cyclonic or frontal developments are occurring within the air mass. When such developments occur the associated weather is more analogous to that associated with cyclones or fronts and many of the remarks in the following sections on air masses would be inapplicable.

There have been several classifications of air masses of quite an elaborate nature, designed to assist the recognition of variations in the process of modification undergone by the air mass as it moved from its source to the area under consideration. As explained earlier these elaborate schemes have not been developed or systematically applied by the Meteorological Office to forecasting in the neighbourhood of the British Isles. In this chapter two broad divisions will be made, namely, warm air and cold air and the more subtle nuances in warm and cold air masses will be described in the text without giving that sub-type of air mass a generic name. Broadly speaking, an air mass will be regarded as warm if it had its ultimate origin in southerly latitudes and is travelling or lying over a cooler surface (but including "warm air" of maritime origin in summer being carried across and heated over a warmer land surface). Air will be regarded as cold if it had its ultimate origin in northern latitudes and is travelling or lying over a warmer surface (but including "cold air" of northern origin travelling in winter over a very cold land surface).

Most of the material of this chapter relates to precipitation and clouds associated with air masses. Some remarks on visibilities and air masses are included in Chapter 17, Section 17.6.2.

11.2 WARM AIR

When warm air is mentioned, one of the first thoughts to come to mind is of the warm sector of a depression and it is convenient to start this section with a few remarks on weather associated with warm sectors.

Outbreaks of rain in warm sectors are often associated with the process of occlusion and also with the approach of the cold front. outbreaks are not particularly extensive horizontally (perhaps with linear dimensions of not more than a few tens of miles) but, at times, a band of precipitation may break out. When such a band occurs well in advance of the cold front and is orientated across the general flow in both the warm sector and the lower troposphere, the rain band tends to be carried forward with the flow at about 700 millibars and may even overtake the preceding warm front. These processes are more likely to occur near the central parts of the disturbance. Further from the centre and toward the flanks of an anticyclone the air may be substantially drier, particularly in the lower troposphere, and this renders outbreaks of rain in those localities much less likely.

Outbreaks of precipitation which sometimes occur in a warm sector just in advance of the cold front tend to be in a band which is often orientated more or less along the thickness lines associated with the cold front, that is, often more or less parallel to the cold front. In such cases the component of wind at 700 millibars across the belt of precipitation is relatively small so that the lateral translation of the rain belt away from the front tends also to be small. However, patterns of varying intensities of precipitation sometimes show translation longitudinally along the band in the general direction of the 700-millibar flow.

It should not be construed from the above that precipitation will break out in every warm sector. Many, in fact, are actually rainless and any precipitation (other than immediate pre-cold frontal precipitation which is clearly of frontal origin) that does occur is often limited to quite slight drizzle. In the present state of knowledge it is not possible, in advance of an actual outbreak, to indicate the conditions which are necessary or sufficient to justify a confident forecast of warm-sector precipitation. Clearly an adequate supply of moisture in a substantial stratum of the warm air and an indication from the wind field or the tendency distribution that convergence was likely would enhance the chances. Further there may, on some occasions, be the remnants of an old frontal system indicating a double frontal structure. This too might be a contributory factor but much discretion is needed when resurrecting old and previously dropped fronts and reinserting them in a warm sector - sometimes done to explain an actual outbreak of rain which has already occurred. Warm-sector rain may also be more likely if the warm-sector isobars display cyclonic rather than anti-cyclonic curvature. Judgement is clearly needed and, on 24-hour pre-baratics, the chances of precipitation breaking out in a warm sector can seldom be estimated with any great confidence. In the very short term, a detailed network of observations should be carefully scrutinized for any outbreaks of precipitation. Once a coherent band of precipitation has broken out and been located at a relatively early stage in its life, some reliance can often be placed on its persistence for a few hours. Extrapolation of observed movements are then useful for short-period forecasting. However, some outbreaks of precipitation in warm sectors present no coherent picture and have a random spatial and temporal distribution akin to that of showers. Such outbreaks may occur when conditional instability, which sometimes occurs at upper levels, is released sporadically. In such cases persistence of the current pattern of the outbreak is usually unreliable as a guide even for the very short term. It is relevant to remark that observations of precipitation patterns by means of suitable radar sets constitute a powerful tool for the forecaster. A direct viewing of the radar display will enable the forecaster to determine the instantaneous distribution of precipitation. The movement of precipitation can be estimated by noting the movements of the radar echoes between successive inspections of the radar display. (See Chapter 16 for further comments on the use of radar weather echoes.)

Orographic uplift often plays an important role in the release of precipitation in a warm sector. The greater tendency for precipitation to occur when warm air currents cross the larger masses of high ground (for example, Scottish and Welsh mountains, Dartmoor and the Pennines) is well known and often allowed for in a qualitative way. It should also be recognized that even low hills may also exert an effect on warm-sector rainfall. For example, the south coast of England may experience substantial rainfall whereas rainfall may be much less in the London area and perhaps negligible in East Anglia. It is possible that coastal convergence may also be a factor at times in causing the increased rainfall.

The cloud in warm air may be extensive horizontally and thick vertically; on the other hand there may be practically no cloud as, for example, in summer with anticyclonic conditions. The occurrence of extensive low cloud, often with at least patches (if not greater amounts) with a very low base, is usually associated with the cooling of warm moist air by contact with a cooler underlying surface, but adiabatic cooling due to any ascent of warm air near the ground and evaporative cooling from falling rain may also be factors. A long over-water fetch from the region of (or even beyond) the Azores, particularly in spring and early summer when the sea near the British Isles is cold, is a typical well known case leading to the formation of extensive stratus and/or sea fog. If the fetch is from the south or perhaps somewhat south of east, the land masses of Spain, Portugal and France provide some shelter for the British Isles - more particularly for the eastern parts of the country. With such isobaric distributions there is a tendency for the low cloud neither to have an exceptionally low base nor to exist in large amounts. If the general fetch is well round to west and the surface air has travelled across much of the North Atlantic, again cloud bases may well not be exceptionally low, presumably because the surface air will acquire only a moderate initial dew-point over the lower sea temperatures in those latitudes in the western Atlantic. It should be noted, however, that air which, in the western Atlantic, flows as a south-west current from subtropical latitudes and later turns as a westerly or even as a north-westerly before approaching the United Kingdom may be heavily laden with extensive low stratus on reaching western coastal districts.

With very moist air, cloud bases on coasts and on hills near coasts are very low - often on the surface or below 300 feet. As the air moves inland, cloud bases are usually somewhat higher and amounts less - particularly if there is some insolation over land. At times, however, with very wet air, low hills well inland may have their tops shrouded in stratus but cloud over lower-lying ground will usually have a base of at least a few hundred feet. Low-lying gaps in the hills often exert an important effect on amounts and heights of low cloud downwind. The gaps in association with the configuration of the nearby hills sometimes lead to a sort of funnelling effect for some wind directions and this enhances the penetration and advection of low cloud. For other wind directions the range of hills may provide some shelter for areas to the lee. For example, the Cotswolds lie in a general north-east to south-west direction and low stratus occurring in a south-westerly flow can penetrate readily into the Midlands through the Severn valley; and the North and South Downs, lying approximately west to east, provide some shelter to the lower Thames valley and estuary when a warm southerly current brings extensive low stratus to the Channel coasts.

Cloud bases associated with low stratus in warm air are not always higher with increasing distance inland. If the ground is exceptionally cold and there is an extensive snow cover, the continued cooling of warm air as it moves across the ground may be sufficient to cause cloud bases to become lower - even down to the surface at times if the winds are light. Such occurrences are not very common even in winter. They are most likely to occur when a prolonged cold spell, during which there has been extensive snowfall, breaks down and the cold air is replaced by a very mild moist current. However, not all such occurrences are accompanied by very low stratus or extensive fog but its possible occurrence should always be carefully considered when such a change of type takes place.

In contrast to the extensive cloud sheets in moist maritime warm air, dry warm air which has subsided in anticyclonic regions may have but little cloud and what low cloud there is probably has a base near or somewhat above 2,000 feet. For example, when an anticyclone is situated over continental Europe with its western edge near France, a current of warm air may reach the British Isles as a southerly and relatively dry stream. With such currents the weather is often bright and sunny and sometimes very warm for the time of the year.

Synoptic examples of warm air with and without extensive sheets of low cloud are included in Chapter 16, Section 16.9.1.1 and Chapter 14, Section 14.12.3 respectively. An example of extensive fog and very low stratus, which occurred when warm air moved across a snow-covered ground, is given in Chapter 16, Section 16.9.5.

Little has been said so far of cloud conditions above the lower layers. In a very moist warm air mass in which general convergence and bodily ascent of air is occurring there may well be deep and horizontally extensive masses of medium and high clouds. In contrast, near the fringe of an extensive anticyclone where subsidence is taking or has recently taken place through much of the lower and middle troposphere, there is often little upper cloud. In many cases there is often only a little wispy cirrus above the tops of any low clouds which do not generally exceed about 4,000 or 5,000 feet. When considering the probable cloud conditions in warm air in a region which is intermediate between relatively large cyclones and anticyclones, attention should be given to the probable air trajectories. There should certainly be no slavish advection of the current cloud conditions as a forecast of tomorrow's weather. This is particularly true when warm subsided air (with only small amounts of low cloud and wispy cirrus) is likely to move towards and become involved in the circulation of a large and active depression. If the warm subsided air undergoes a small but steady ascent for 24 hours or more, which is not unreasonable in the circulation of an active depression, the cooling due to expansion on ascent may radically alter the temperature distribution and, if widespread precipitation should also fall from a higher level through the ascending air mass, the dew-point distribution may be greatly modified and lead to the formation of extensive sheets of low cloud.

A characteristic feature of many warm air masses near the British Isles is their stable stratification throughout much of the troposphere. However, some warm air masses do contain layers which are unstable. For example, in the summer half of the year instability in warm air is sometimes present at mid-tropospheric levels - instability in the layer from 700 (or perhaps as low as 800 millibars) to 500 millibars or above might be typical. If this instability can be realized then any cloud or precipitation which is formed will be of typical instability type. When upper instability is present in warm air the lower layers may contain an inversion or exhibit a stable lapse rate. There are two common ways in which the upper instability is sometimes realized. One method is due to a rise of temperature in the lower layers which is sufficiently large to surmount the lower stable layer so that convection currents from the ground can rise until they enter the unstable layer. The other method is by general upper convergence and ascent of air within the unstable layer due to dynamical causes. Clouds formed in this way are of comvective type and, although they often have a high base (perhaps 5,000 feet or more), they are sometimes of deep vertical extent. With the large amount of moisture sometimes present in the lower levels of these warm air masses heavy convectional precipitation is released. Sometimes the storms are very heavy. A typical synoptic situation favourable for this type of weather is one with a flow from somewhere around south, from France or the Low Countries, towards the British Isles. Two features often present in such a situation are an anticyclonic cell centred over Europe, somewhat to the east of the Greenwich Meridian, and a cold trough or cold pool with its axis lying in an approximately north to south direction near the west of the British Isles. In a typical case the cold front or trough would extend at least across the zone between 50° and 45°N. (and often rather further to the south) and would be located between about 15° and 5°W. The flow between such a western trough and eastern anticyclonic cell often shows a marked inversion or stable layer in the lowest few thousand feet and marked instability in mid-tropospheric levels. The lower-level flow is usually from the south or a point somewhat to east of south. The flow at mid-tropospheric levels is often from south-south-west or south-west and the wind speed usually increases with height between about 800 and 600 millibars or somewhat above. The problem on the forecast bench is to assess whether the instability at upper levels will be released either by convection from below and/or by convergence and ascent in the unstable layer. If the upper instability is not released, the weather over the British Isles is then frequently sunny and very warm. Only relatively small amounts of cumulus cloud, which are often quite shallow, develop and exist for just a few hours after midday. On some occasions however, there seems to be a combination of intense heating with the consequent release of convection from below over France coupled with an area of upper convergence often in north France or the Low Countries. This convergence causes the formation of an extensive area of upper clouds at the medium unstable levels. Such areas of unstable upper cloud are often orientated approximately east - west and are advected forward with the component of flow at about 700 millibars. These areas of convective activity seem to show a preference to form in the evening over France. Sometimes the weather over the southern British Isles on that same day has been generally hot or very hot, with any small amounts of cloud which formed dispersing about sunset. The disturbed cloudy zone over France moves with a northward component and is often accompanied by an outbreak of thundery rain which is sometimes very heavy. The rain sometimes continues for several hours, but at decreased intensity, after the thunderstorms have moved away northwards. Any thunderstorms which occur are often extensive but within the thundery zone it is sometimes possible to identify areas, perhaps 10 or 20 miles in horizontal extent, within which the severity of the thunderstorms is noticeably greater than in surrounding districts. On some occasions a squall line is associated with the thundery precipitation. Such squall lines often move with the speed and direction of the upper wind at about 700 millibars. This relationship is probably due primarily to the fact that the descending chilled air of the squall, originating at upper levels, carries its momentum down to ground level. These thundery outbreaks spreading northward from France tend to reach the Channel coasts or south-eastern regions of England shortly after dark and usually continue to move with a northward component. During the ensuing day most outbreaks gradually lose their intensity but can usually be followed on a sequence of charts as an identifiable and readily recognizable system, often for as long as 12 or 18 hours by which time they have usually progressed up to or beyond the Scottish - English border. After such an outbreak the cold trough to westward usually moves eastward across the country, but there is then seldom much precipitation associated with the cold front. Indeed it is often almost rainless.

A variant of this type of synoptic situation is one in which the cold trough or pool extends well southward of 45°N. - usually to about 40°N. and occasionally farther south. The trough is orientated between about south-west and south-south-west and is located between the Azores and Portugal or north-west Spain. Cold pools in this area often show a tendency in summer to persist over the relatively cold water to westwards of Portugal and north-west Spain. In this situation there exists a belt of south to south-west thermal winds over Spain and Portugal and north-western France. Any convective activity bred by strong heating over Spain would tend to be carried towards the Bay of Biscay. Although each individual convective cell of any thundery outbreak is usually quite short-lived, conglomerate areas of thundery activity sometimes exhibit a tendency to persist for several hours. In this type of situation the early morning sferic reports sometimes indicate areas of activity in the Bay of Biscay to northward of Spain. Presumably these are due to a continuance of activity bred the previous day over Spain, a continuance achieved by a complex of factors not yet fully understood. Whether the activity continues to persist and to move towards and affect south-western districts depends on the thermal structure and other developments. In quite a large number of cases the disturbed weather does not persist and/or move to affect the United Kingdom but this can seldom be forecast with confidence at the time the early morning sferic reports reveal its existence. If there are concomitant signs of the development of only a slight baroclinic disturbance or pressure trough in close proximity to the outbreak, it would be wise to include in the forecast some mention of the movement (and possible intensification) of the storms from the Bay of Biscay. Subsequent reports in that general area and direction received from all sources (for example, ground and upper air reports, aircraft observations, sferic and radar reports) should be very carefully scrutinized so that the earliest and best-possible positive indication of the development (or lack of it) and movement may be obtained, thereby enabling the forecaster confidently to make the shorter-period forecasts more precise and accurate.

Many of these storm areas in the Bay of Biscay are located fairly near the baroclinic region between the colder air to westward and the warmer air to eastward. In some respects the storms are more a feature of the cold than the warm air mass. However, in view of the broad similarity of this synoptic situation to that in which storms move northward to the British Isles from northern France it seemed preferable to include the treatment in this section.

Maritime warm air is stable at low levels until it has been strongly heated at the surface and usually more than one day's heating over land is required to release instability. With some summer cold fronts, especially in the south, there is a tendency for troughs or small lows to develop ahead of them (these nearly always seem to form when summer cold fronts approach north Spain and western France and their formation and behaviour have already been discussed). Another type of pre-frontal outbreak of precipitation sometimes occurs ahead of these cold fronts. The relatively narrow band of precipitation is aligned with the front but the rear edge is clearly in advance of the surface front. Sometimes a well marked squall occurs in the rain belt. These pre-frontal outbreaks seem to be particularly well marked in the United States of America where sometimes the squall line may be 100 miles or so ahead of the cold front. Pre-frontal squall lines occasionally occur in the neighbourhood of the British Isles. It is generally difficult to forecast confidently a pre-frontal belt of precipitation or squall line in advance of its occurrence but, once formed, there is a tendency for the system to be self-maintaining so that the movement of the weather can be reasonably extrapolated from a series of recent observations and from the forecast movement of the cold front. In some actual cases it may seem preferable on later chart analyses to jump the cold front forward and locate it with the belt of precipitation and any squall - even though this is incorrect historically. Whether this should be done or not is largely a matter of personal preference.

Although no detailed classification of air masses has been attempted in this handbook it may be useful to describe a few typical situations in which warm air reaches the British Isles. A common and widely recognized type is that in which warm air reaches windward shores as a broad relatively straight current - often from a direction lying between about 200 and 260 degrees. If this maritime warm air has recently travelled from regions well to south of the latitude of the Azores, dew-points are likely to be very high. When the Azores anticyclone extends to northward of its usual location warm air may reach the British Isles from directions to north of west. From the point of view of general synoptic weather it is important to determine the earlier history of the warm air. If it has travelled mainly across the cooler waters of the North Atlantic, perhaps as a south-westerly or westerly current before veering to north of west near the British Isles, the air is unlikely to have a very high dew-point. If, however, in the western Atlantic the air had travelled as a southerly current from quite low latitudes prior to veering to west in mid-Atlantic and later to west of north near the British Isles then dew-points are often very high. In such cases low stratus and sea fog may be extensive. When an anticyclone in warm air is situated near the western regions of the British Isles, warm air may travel well to northward before turning and approaching the British Isles from the north. When the anticyclone is large and stationary the arrival of warm air from the north is unlikely to catch the forecaster unawares. At times, however, when a surface anticyclone of relatively small dimensions is centred near or somewhat to westward of Scotland, warm air in the low levels may circulate from the Atlantic Ocean, around the north of Scotland and enter the North Sea between Scotland and Norway. It may then reach the eastern shores of England and Scotland as a relatively moist easterly current, often laden with low stratus or fog. The increased humidity in this air mass is sometimes a factor which causes a persistent north-easterly current, which was previously virtually free from cloud, to become laden with low stratus or fog.

When warm maritime air reaches the British Isles on a trajectory from between 200° eastward to about 160° its traverse across Portugal, Spain or France introduces some modifications. It is not possible to indicate in general terms the extent of modification, but it is reasonable to expect an increasing degree of continental influence on maritime air with decrease in azimuth of the wind direction. Air which is primarily of continental origin may also reach the British Isles from these or more easterly directions. In summer, when warm continental or Mediterranean air leaves the European mainland and has a substantial fetch across the relatively cold North Sea before reaching the eastern shores of Britain, it is often difficult for forecasters to decide when and where low stratus will occur in the airstream. It is not possible to give general and reliable guidance and each such synoptic situation must be assessed individually from the available data. The modifications to the low-level distributions of temperature and humidity of warm airstreams when crossing cold water surfaces are discussed in Chapter 14, Section 14.10.2 and Chapter 15, Section 15.6.1.1. Some remarks on low stratus clouds are contained in Chapter 16, Section 16.6.3.

11.3 COLD AIR

As with warm air the type of weather associated with cold air may range between wide extremes. For example, there may be brilliantly fine cloudless weather with exceptional visibility and light winds leading to a particularly fine exhilarating day. Towards the other extreme, a cyclonic day in high summer may have strong winds, large amounts of cloud with frequent showers or outbreaks of rain, and temperatures which are cool or very cool for the time of the year. In combination these features produce a cold depressing day which is least summery in character. The following example indicates one way in which weather in a cold air mass may vary with time. Shortly after the initial arrival of cold air, the weather may be bright and sunny with only a little low cloud. Visibility is usually good. Some hours later the cold air may be sufficiently deep for fairly large cumulus clouds to form and there may be cumulonimbus cloud and showers. These conditions may be subject to considerable diurnal variation. If, at a still later stage, an anticyclone develops in the cold air, showers will be suppressed and in the central regions, with light winds and clear skies at night, intense outgoing radiation will set up a very stable layer near the ground. In some cases fogs may form - particularly if the ground is still wet from preceding precipitation. Near heavy industrial areas there may be a noticeable increase in atmospheric pollution and decrease in visibility due to smoke during a single night with very stable lower layers. If the anticyclone stagnates and the layer near the ground becomes very cold and the low-level inversion cannot be broken down by weak winter insolation, the continued accumulation of the products of combustion leads to a highly polluted atmosphere near the ground. In extreme cases this leads to smog conditions.

These examples of some of the differing weather conditions which can occur in cold air masses make it clear that the accompanying synoptic situation must also be considered when describing general synoptic weather which occurs in cold air masses.

In cold air masses the lapse rate of temperature through substantial layers often lies between the dry and wet adiabatic lapse rates and any cloud or precipitation which occurs is then usually of a convective character. Consideration of the possibility of the formation of clouds or precipitation in cold air on any one occasion involves detailed assessments of many parameters. Examples are distributions of temperature and humidity, the extent of surface heating, the presence of cyclonic or anticyclonic vorticity etc. These detailed assessments are appropriate to other chapters of the handbook and are not included here.

Heating from below is a common mechanism leading to the formation of cloud or precipitation in cold air masses. Forecasters should note that, near the British Isles, there is a seasonal variation of the importance of heat supplied to cold air masses from the sea and land surfaces. In the summer half of the year diurnal heating of the land surface is of greater importance for the formation of showers and thunderstorms in cold air. In the winter half of the year the majority of showers and thunderstorms, bred by heating from below, owe their origin to convection currents set up in the cold air over the relatively warm adjacent sea areas. At no season of the year is either of these sources of heat the sole cause of the development of showers. For example, heating over land in winter may be important in some situations and orographic effects may trigger off instability showers. Nevertheless it is useful to bear in mind the greater importance of heat supplied by the land and sea surfaces in summer and winter respectively.

In high summer many cold air masses reach the British Isles along tracks with anticyclonic curvature, and appreciable subsidence occurs in the air masses. The weather is then fine or, at most, there are a few scattered showers. On the other hand, when an active depression is centred near the British Isles and isobars are cyclonically curved, there may be a general convergence in the cold air resulting in widespread moderate showers or periods of rain, much low cloud and notably low day temperatures. Cold air masses which become stagnant or slow-moving over the British Isles in "col" areas, in weakly cyclonic areas or in filling depressions often give rise to deep convection in the afternoon. The resulting showers are often heavy and accompanied by thunder but are often separated by areas of generally fine weather and substantial areas may escape precipitation altogether.

In late spring (that is, about May) when the ground is warming up rapidly there are, in most years, some outbreaks of cold air in association with northerly winds which sweep across much of the British Isles. Heating over the sea which is rather cold in late spring, is, however, often still sufficient to set up convection in the cold air and maritime showers of at least moderate intensity occur. Day-time heating over the land may be sufficient to maintain the convection originating over the sea. In some cases the additional impetus to convection from heating over the land may increase the severity of the showers and enhance the chance of thunder. Any air-mass thunderstorms which do occur, either at sea or overland, tend to be sporadic and short-lived. The relatively low water content of cold northerly outbreaks is a factor which tends to inhibit the formation of large long-lived thunderstorms. The height of the 0°C. isotherm is usually low in these springtime northerlies and some of the showery precipitation may reach the ground as hail or snow.

By far the greater majority of showers and thunderstorms in cold air masses in winter are bred over the relatively warm seas. When the cold air is fairly deep and convection from the sea surface can penetrate easily up to 600 or 400 millibars showers will be frequent and often heavy, particularly near windward coasts, and there may be a few thunderstorms. However, the majority of deep cold outbreaks occur near the centres of cold pools or pronounced cold troughs and the low temperatures of the upper air restrict the maximum total water content to a fairly low limit which will tend usually to place a curb on the severity of thunderstorms. Once the winter type of shower moves inland over relatively low-lying ground it usually tends to decrease in activity but it may penetrate some tens of miles before decaying completely. For example, showers bred over the Irish Sea in a north-westerly current may penetrate through the Cheshire gap and survive long enough, by day or by night, to reach the Midlands (for example, the Birmingham area). By night they would seldom survive long enough to reach London but, by day, diurnal convection from the land might maintain the shower (or generate another) so that showers would occur in south-eastern parts of the country. The orientation of hills sometimes has an important effect on the extent and direction of the penetration inland of showers. When the wind blows along a range of hills, the high ground does not impede the penetration inland to any substantial degree and some configurations of quite small ranges of hills appear at times to assist penetration. However, when the wind blows across the longer horizontal dimension of the hills many of the showers which reach the hills, or are triggered off by forced ascent when air ascends the windwards slopes, deposit much of their precipitation over the hills, on the lee slope or on adjacent lee ground. Consequently, many areas well to the lee are effectively in a "shadow" which is characterized by an almost complete absence of showers and, possibly, by quite small amounts of cloud if there is a well marked Föhn.

Some winter thunderstorms in cold air may be regarded as purely barotropic storms. The storms are usually short-lived and quite isolated - but the shower activity may be very widespread. With very deep cold air masses any thunderstorms near windward coasts may be rather more extensive. However, surface observations plotted on synoptic charts will generally indicate that isolated storms appear here and there at one synoptic hour. At the next hour it is often impossible to identify with any certainty any storms existing at the previous hour. In marginal cases some storms appear to give only one or, at most, a few claps of thunder. It is clearly impossible to forecast the location of any particular short-lived storm in advance of its initial occurrence. Radar observations of any existing storms are very valuable for very short-period forecasting but, in view of the short life of this type of storm, any tendency to extrapolate forward beyond one hour would be unwise in general. The majority of isolated winter thunderstorms occur near windward coasts, perhaps within 50 miles, and there is a maximum frequency in the early morning. The extent of penetration inland is a difficult problem. Although winter insolation is weak, convection from day-time heating over land must be a factor at times in maintaining an existing thunderstorm. A synoptic example illustrating winter barotropic thunderstorms in cold air is included in Chapter 16, Section 16.9.3.1.

In a number of cases, particularly in strong flows from between about west and north, some winter thunderstorms are associated with weak baroclinic features. These thunderstorms tend to be more widespread and severe than the air-mass storms. They also persist for longer periods and move farther inland before decaying completely. In some cases a line of storms develop local circulations which exert a self-maintaining effect on the storms. Once the baroclinic type of storm areas have been identified on detailed synoptic charts, their movements can be determined and extrapolated with reasonable accuracy. However, when they are upwind to seaward, their presence is often difficult to detect with much accuracy.

When cold air leaves a source region near Greenland or over the North American continent and travels across almost the whole of the North Atlantic Ocean before reaching the British Isles, the air-mass characteristics are considerably modified by the sea passage. The air has usually lost some of its intense instability although it is generally still unstable. The water content of the air has increased considerably, particularly when the air penetrates well south over the warmer regions of the Atlantic Ocean before approaching the British Isles from an approximately south-westerly direction. In such cold airstreams there are often local outbreaks of heavy rain. These outbreaks tend to occur in belts, often more or less parallel to the thermal wind. The rain is usually continuous, but of the instability type, and persists for several hours. The duration of the heavier rain is usually limited to a few hours. In some cases the precipitation is intermittent rather than continuous.

Cold air which reaches this country in winter, in easterly situations which are sometimes persistent, deserves some special mention. In the persistent situation the airstream originates from continental eastern Europe or even farther east. In January or February, if the north German plains are frozen hard, the cold airstream is fairly dry and sometimes cloudless on reaching the continental shore abutting the North Sea. During its passage across the North Sea towards the shores of the British Isles the air is modified by the sea to an extent depending partly on sea temperatures, on the characteristics of the air on leaving the European continent and on the length of sea track. These cold easterly airstreams in winter are predominantly either cloudy or cloudless when they reach the eastern seaboard of the British Isles. The cloudless type usually produces very cold nights but the sunny days may be quite invigorating. The cloudy type produces less extreme temperatures but there are often frequent falls of snow - particularly in eastern coastal districts. When the airstream is cloudy and the low-level relative humidity is high the weather feels particularly raw and colder to the body than the temperature alone would imply.

In some situations there may be extensive low cloud already present in the easterly flow when it leaves the European continental coast and enters the North Sea. The effect of transit over the North Sea will, in general, maintain or even thicken the cloud sheet. Except for the infrequent occurrence of dispersal of cloud due to the dynamic causes, most of these cloudy airstreams will still be cloudy when they reach eastern coastal districts of the British Isles. Some comments on forecasting with such easterly situations are given in Chapter 14, Section 14.10, and Chapter 16, Section 16.6.3. Some synoptic illustrations are included in Chapter 14, Section 14.12.4 and Chapter 16, Section 16.9.4.1.

11.4 COLD POOLS

Sumner[1*] made a statistical and synoptic study of cold pools over the area between 60°W. and 30°E. and south of 80°N. for the five-year period September 1946 to August 1951. Some statistical data from that study are included in Chapter 12, Section 12.4.3. Sumner found that the cold pools in high latitudes showed no tendency to come southwards beyond 65°N. and accordingly they did not directly affect the weather of the British Isles. The weather associated with cold pools southwards of 65°N. was assessed from a careful inspection of synoptic charts. Cold pools may be associated with a variety of surface pressure fields and at times Sumner found it convenient to classify cold pools in terms of the associated surface features. In parts of the following account some reference will be made to associated surface features.

More than half the cold pools were classified as being cloudy (three-quarters cover of cloud), about one quarter as partly cloudy (between a quarter and three-quarters cover of cloud), while there were relatively few cases of overcast or fine (a quarter cover of cloud) - each being just under ten per cent of the total. Cold pools associated with surface lows (L - type) usually had the largest cloud amounts, whilst those associated with a surface col (C - type) or a fairly straight run of isobars between a large depression and a large anticyclone (S - type) had the smallest.

With cold pools situated over the land there was a rather complex (statistical) diurnal variation of cloudiness. The proportion of cases classified as overcast or cloudy increased from 55 per cent at 0300 G.M.T. to 70 per cent at 1500 G.M.T. However, within this

*The superscript figure refers to the bibliography at the end of this chapter.

general trend from lower to higher cloudiness, Sumner noticed that there was an appreciable counter drift since about 15 per cent of the total cases changed from overcast or cloudy at 0300 G.M.T. to partly cloudy or fine at 1500 G.M.T. This diurnal rhythm was present irrespective of the type of associated surface pressure system. Sumner found no discernible diurnal variation in the cloud over the sea but this was more uncertain because of the scantier coverage of observations.

On the whole there were slightly more cases of cold pools with than without precipitation of some sort. Within the cloud groupings referred to above, the proportion with precipitation increased from nil with fine conditions to 100 per cent with completely overcast, the figures for partly cloudy and cloudy being about 45 and 55 per cent respectively. The L - type cold pools had the highest proportion with precipitation (nearly 70 per cent) and the S- and C - type the lowest (about 40 per cent). Cold pools associated with surface highs (H - type) and those with surface ridges (R - type) showed a surprisingly high proportion with precipitation. Sumner commented that this precipitation was invariably slight snow or sleet with the H - type but with the R - type all forms and intensities of precipitation occurred, including one case of widespread moderate rain and another with thunderstorms. General precipitation over the entire area of the cold pool was recorded on about 20 per cent of the total occasions, 30 per cent had only local precipitation and the remainder none at all.

Only six cases of thunderstorms were noted by Sumner but there were many more occasions when "sferics" were reported within the area of the pool. These occurred mostly over Europe in the warmer months and showed a definite diurnal variation with the greater frequency in the afternoon. Owing to the possible positioning errors of sferic observations, Sumner thought that the sferics might often have referred to thunderstorms in the peripheral regions of the cold pools. Although some thunderstorms may not have been observed, Sumner considered that the infrequency of thunderstorms within cold pools was probably real.

Information showing some useful relationships between the 1000 - 500-millibar central thicknesses and the nature of precipitation in cold pools are given in Chapter 16, Section 16.7.6.

BIBLIOGRAPHY

1. SUMNER, E.J.; Cold pools: a statistical and synoptic study. Met. Mag., London, 82, 1953, p. 291.