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SURFACE PROGNOSES

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CHAPTER 14

SURFACE PROGNOSES

14.1 INTRODUCTION

Although a number of individual forecasters experimented with the drawing of forecast charts during the 1920s and probably earlier, in 'Construction and use of prebaratic charts' [1] it was indicated that the routine preparation of forecast surface charts did not commence in the Meteorological Office until 1925. This was in the nature of an experiment (the charts were not used at that time for operational forecasting). The experiment was not continued but some individual forecasters continued to prepare occasional forecast charts. The preparation of routine surface and upper-air forecast charts for operational use in the Meteorological Office was commenced in the early 1940s.

Forecast charts prepared in a central office can be transmitted to distant offices either by means of coded messages or by facsimile. By such transmissions, the views of forecasters at meteorological centres can be economically transmitted to a wide clientele. Such transmissions are of great value to outstations without the resources or time to prepare their own forecast charts as routine. Apart from their obvious value in depicting general developments over a substantial area for 24 hours or so ahead, they also contribute to the shorter-period, more local forecasting. For example, experience indicates that it is easy for a forecaster, interested in a relatively small area, to concentrate unduly on that part of the chart without taking due account of movement and development around the fringes of the smaller area. The more general forecast chart over a large area and for a probably longer period ahead assists the outstation forecaster to take a better perspective.

In the Central Forecasting Office of the Meteorological Office, forecast surface charts are prepared for a substantial part of the North Atlantic Ocean, Europe and adjacent areas for a period 24 hours ahead of the time of the chart on which they are based. By the time these forecasts can be issued and displayed at distant stations, the forecasts are valid for a period about 19 hours ahead. The period of validity and time of issue represent a compromise between speed, accuracy and user requirements. For general purposes the 24-hour period seems a good working value but, for specialist use, some variations may be required. For local forecasts, for example, it may be valuable to prepare a skeletal forecast surface chart for a very restricted area for as little as 6 or even 3 hours ahead. In such a short time, very little development on a synoptic scale can occur, and these forecast charts are usually little more than a direct linear extrapolation of current trends as revealed by a recent series of charts. Although the concept of linear extrapolation is simple, short-period forecast charts can be very useful and should not be ignored for very short-term forecasting. Forecasts are also prepared for periods greater than 24 hours ahead: these are discussed in Chapter 15 - Medium- and long-range forecasting.

Although a good deal of reliance is placed on the computer-produced surface chart and on the objectively forecast upper-air patterns as aids in the production of the final surface prognosis, there is still a need for the employment of the more traditional skills of the forecaster. The 'man-machine' mix may change with time, with more emphasis being placed on the computer products, but a knowledge of manual methods will still be required for some considerable time in the future, as a basis for the checking of the numerical model and, if necessary, modification of the output. Much of the extent of this chapter will be taken up by a description of the manual methods, and although there must be much empiricism, at the same time an effort will be made to incorporate results from theoretical concepts, some of which were considered in Chapter 2 - Dynamical ideas in weather forecasting. The techniques described will be those in use in the United Kingdom. There will be some discussion of the development and movement of various types of feature, but a comprehensive account is clearly impossible because there are so many variations. Some further information of this nature will be found in Chapters 4 to 7.

14.2 THE IMPORTANCE OF ANALYSES

Essential prerequisites to the preparation of successful forecast charts are careful analyses and considerations of a series of surface and upper-level charts. It is important to stress, particularly to inexperienced forecasters, that analyses do not end with the construction of suitable isopleths which fit the available observations and are reasonable from the aspect of continuity. This is only the first stage of analysis and is really nothing more than a mapping of scalar or vector quantities. It is most important that the latest charts and the preceding series should be meticuluously examined so that the analyst can obtain a time and space appreciation of movement and development. The analyst should also study the charts so that he obtains an understanding of the situation which is satisfactory from the geometrical, kinematical, statical, dynamical and physical viewpoints. This is an exacting task which can seldom be completed in entirety on the forecast bench, even when a long time can be devoted to analysis. It certainly cannot be reached by a hurried and ill-considered drawing of a few isopleths.

When considering analysed charts with a view to the preparation of forecast charts it is important that contemplation should be concentrated on important things. Contemplation is a time-consuming process and the practising forecaster has usually little time to spare. There is, of course, no invariant rule on how the time available for analysis should be allocated. Nevertheless it will usually be found advantageous to take the broad view first. This will involve a consideration of the major synoptic systems, usually several hundreds of kilometres in horizontal dimension, which form a vital part of the long-wave pattern over the chart area. For the charts drawn at most outstations, this will mean considering generally one or two, but seldom more than three, major features on any one occasion. Within the broad flow pattern associated with these major features there will usually be found a number of smaller features of sufficient size to be important on the synoptic scale, for example, a few hundred kilometres in extent and with a lifetime of at least several hours. In the short term, behaviour of these smaller synoptic systems is often closely controlled by the larger systems so that, when making an assessment and judgement of past events, forecasters must examine both the long- and short-wave patterns and their interrelations.

To achieve a more complete understanding of the charts currently being analysed, forecasters will often find it helpful to estimate, from the preceding series of charts, the features and their positions which could be expected on the current charts. Some features will usually have behaved in a manner very close to the short-term estimate and these features may be regarded as confirming the view up to date. On the other hand, some features will almost certainly have behaved rather differently (for example, by moving at a different speed or in a different direction, failing to intensify when they were expected to intensify, and so on). In some synoptic situations it is clear from the general situation, and from the pressure and wind fields in particular, that development is favoured in one area of the chart more than another. Observations and changes from chart to chart in these areas must be carefully studied so that the earliest possible warning of impending change is obtained. It is often of almost equal importance to observe when incipient changes fail to materialize or develop, even though the area is a favourable one. All these features will repay very careful study and an attempt must be made to explain the different behaviour and then to understand the reasons for it. The forecaster will thus concentrate attention on those areas where development is somewhat different from the pattern previously expected. At this stage, the forecaster will find it helpful to shorten both the time and distance scale of his search for understanding. Time must be found for the detailed examination of individual observations and their time changes within the area(s) where the unexpected may be happening. For example, changes in upper-cloud type or variations may yield a valuable clue as to the processes which are occurring.

With experience and good judgement, forecasters will find that it is usually possible to apportion the time available for consideration of the analysis in a reasonably satisfactory manner in order to perform these various tasks. The proportions are not, of course, fixed. In those situations with a well-established and dominant long-wave pattern, the forecaster can often proceed, after a quite short time, to a greater consideration of the short-wave pattern and developments in limited areas. On another occasion where the long- and short-wave patterns are interacting in a complex manner, which sometimes occurs during a change of synoptic type, the greater part of the time for consideration may be most profitably spent on the larger-scale developments. The ability to identify the important areas on any particular chart is obtained by a combination of theoretical knowledge, practical experience and wise judgement. This is a very great asset in the preparation of forecast charts which achieve a continuing high standard of accuracy.

In addition to taking a view which is balanced and at the same time unbalanced (in that it is often concentrated on the smaller but meteorologically more important areas of the chart) the forecaster should be as objective as possible. This is undoubtedly difficult to achieve. During the analytical stages the forecaster can scarcely fail to form a view on what he thinks is going to happen. It is only human to examine the data in the hope that these views will be confirmed. In many cases they undoubtedly will be, but there are others when much of the observational data do not confirm the view. A small minority of observations may be 'forced' into the pre-determined view on a few occasions without incurring the penalty of serious errors (that is, the discordant observations are to some extent unrepresentative of the synoptic situation). However, when a substantial number of observations are at variance with the previously expected development(s), substantial errors may be made if the forecaster persists in his previous deductions. It is most important to be aware of this. Over an area which has a close network of observations one or two isolated misfits - although naturally causing the forecaster some misgivings - should not normally be interpreted as a justification to change a concept (on the time and distance scale of prognostic charts) which is otherwise supported by the vast majority of the observations. Where the observing network is sparse a decision of major importance may have to be taken on a single observation. The ability to take the correct decision in these situations is an essential attribute of the forecaster who achieves a sustained high accuracy in the preparation of forecast charts. In this respect, as with the apportioning of the available time for considering the synoptic situation, the successful forecaster possesses a complex combination of a good theoretical understanding of atmospheric processes, a wide synoptic climatological knowledge, long experience and sound judgement.

It is pertinent to remark in this section that, when developments are running contrary to expectations, they may do so for several hours. On some occasions such developments are the harbingers of a change in synoptic type. Until it is clear in what way the atmosphere is developing, it is often very difficult to take a consistent view from chart to chart. There is a short of indeterminancy about the observations, which are capable of two (if not more) interpretations. During such periods the preparation of forecast charts is difficult and the consistency between successive sets may be poor. Perhaps the best possible advice is to take as broad and unified a view as possible of the synoptic situation and developments over the areas of the analysed and forecast charts. It is easy to become obsessed with a relatively small deviation from the expected developments. Here again, the ability to take a balanced view and to make a wise judgement is a very valuable attribute.

When considering analyses it is important to take into account the likely effect of any differences between the computer analysis, upon which the prognosis is based, and the latest manual analysis, which may take later data into account or which may have treated differently the observations from data-sparse regions. In particular, computer analyses and prognoses are carried out at 12-hour intervals; the intermediate manual analyses may show the beginnings of a change not adequately represented in the computer products.

14.3 MECHANICS OF THE PREPARATION OF FORECAST CHARTS

As a first step it is usual to mark lightly in pencil the probable positions of any large-scale synoptic surface features, which are relatively slow moving, and estimate their central pressures by using the computer-produced prognosis as a basis, but checking this against continuity and general dynamic ideas on development. On occasions when confidence in these quasi-stationary large systems is high, it may be advantageous to sketch in lightly a few tentative isobars. The next stage is to consider the more mobile systems. These may move around a major system and be thermally steered, and a fair estimate of their track can be made by considering their present position and structure, and also the present and future position and thermal characteristics of the steering system. On some occasions the mobile system may move and develop in such a way as to interact with and modify the larger system. If new systems seem likely to form, either on fronts or in air masses, tentative estimates must be made of their future positions and central pressures and these should be entered lightly on the chart.

The objective surface forecasts generally provide a good idea of the overall large-scale developments, but there are occasions when the numerical model tends to underestimate the development and movement of the shorter-wavelength, more mobile features, and the forecaster must allow for any known tendencies of this kind. In particular, he can study the performance of the earlier computer forecasts in the region of interest, to try to see how the numerical model has dealt with the situation. If, for example, the feature under consideration has developed more quickly than forecast, the same type of error may persist into the future, although this assumption must not be made blindly. With these estimates, then, of the behaviour of the more mobile systems and the earlier ideas on the quasi-stationary major features it is usually possible at this stage to visualize the broad outlines of the pressure field. Some consideration must now be given to the probable location of any fronts in the area, taking account of possible frontogenesis or frontolysis. Again the computer products provide a good deal of assistance: the precipitation charts on the fine-mesh model and the thermal vorticity prognoses provide valuable guidance in estimating frontal positions and development. If the estimated frontal positions and the surface-pressure patterns are not in good agreement, some adjustment must be made to one or both to make them mutually consistent. Any adjustment is usually based on subjective considerations. Where fronts and synoptic systems are closely linked together, the location of a centre of low pressure may provide a fix at one part of the front, and it may be possible to obtain another fix where the front is expected to move but little during the forecast period. From a consideration of the flow patterns, the existing gradient across the front and a tentative estimate from the skeletal 'prebaratic' so far prepared, a preliminary estimate can be made of movement at right angles to the orientation of the front. Care must be taken that frontal positions and shapes are not too slavishly modelled on textbook patterns. There are variations which it is legitimate and useful to portray; it is sometimes difficult, for example, to decide to what extent a warm front may be held up by ageostrophic motion - leading to more rapid occlusion. On some occasions an unexpected southward plunge of cold air in the rear of a depression may occur and carry a cold front to lower latitudes in that area. This will produce a marked concavity in the outline of the cold front on the forecast chart. In estimating frontal movements, account must be taken of actual speeds and future gradients and a suitable mean obtained.

When estimating movement, forecasters are strongly recommended to measure displacements or gradients on current and past charts, using either suitable transparent scales or dividers. Future movements should then be estimated numerically and the distances measured out on the forecast charts. Scales which give six-hour movements are available but, if speeds are estimated in knots, the distance travelled in six hours can be very readily stepped out using dividers: for example, at a speed of 28 knots a movement corresponding to 2.8 degrees of latitude will occur in six hours. The use of quantitative estimates is recommended because this will help the forecaster in keeping a clear picture of the modifications to movement which have been introduced. Experience shows that if more rough-and-ready methods are used it is easy to introduce variations different from those that were intended, that is, accelerations or decelerations may be unreasonably large.

The forecaster is now in a position to complete the frontal patterns and draw some tentative isobars. Care should be taken in drawing forecast isobars over the sea. Where pressure fields over extensive sea areas have been well established in a series of charts, pressure changes should be carefully estimated so that unreasonable changes are not unwittingly introduced. This type of error is easily made and the point needs care. It is almost inevitable that the first sketch will not inspire much confidence or look like a synoptic chart. Gradients may not match expected frontal movements; a major synoptic feature may have been extended to swamp large areas of the map. After the consideration of the first sketch of the forecast chart is the time for a vigorous but judicious use of the rubber, adjusting positions, pressures, fronts and isobars here and there to produce a plausible picture. Inexperienced forecasters should not be too despondent at the amount of erasing which may have to be done. It is often helpful, on a sort of trial and error basis, to put in lightly one or two possible variations, examine the whole critically and then finally settle for what appears the most probable. This trial basis often enables the forecaster, having seen the overall picture, to eliminate some possibilities which were previously worrying him.

It is also important to examine gradients critically. In the first attempt it is usually found that gradients have been made unduly tighter or slacker and, after a consideration of likely pressure changes, some adjustment is usually called for - this does not mean that variations must be so smoothed out that gradients are uniform over large areas, but very tight or slack gradients need good justification.

Where a light-table (a transparent surface illuminated from below) is available and single-sided charts are used it is often helpful to superpose the forecast chart on one or two recent analysed charts (if the forecast is on the same map scale as the working chart). This throws into high relief the relative movements of pressure systems and fronts and shows, very clearly, variations in the direction and strength of pressure gradients. This device often brings clearly to the forecaster's mind those things for which the changes so far introduced appear about right or noticeably overestimated or underestimated. Modifications can often be made on the light-table. Many experienced forecasters prefer to draw their forecast charts directly over a number of analysed charts on a light-table. This is largely a matter of preference. Although the inexperienced forecaster may find the multiplicity of lines and time scales rather confusing, the method has distinct advantages, but there may perhaps be a tendency at times to rely too much on extrapolation of recent trends.

Following this further consideration of the forecast chart, final amendments to pressure distributions and frontal positions can be made.

Little reference has been made to the upper-air pattern since it is the mechanics only which are being described in this section. More will be said about the use of upper patterns in later sections.

14.4. SOME GENERAL CONCEPTS

It is quite clear that a description of the mechanics for producing forecast charts is not sufficient to enable a forecaster to prepare useful forecast charts. It is necessary that sound and reliable estimates of movements and developments shall be made. This, of course, is the crux of the forecasting problem and, although some formal rules would be most useful, it has not so far been possible to demonstrate or commit to paper some invariant rules (such as are known in other branches of physics and mathematics) which the forecaster can use without modification, discretion or judgement. There are some underlying principles but, in every case, there is interaction between the synoptic systems, and the forecaster must exercise judgement to a greater or lesser degree in the manual preparation of the forecast charts. No series of data, analogues, examples of synoptic types and empirical rules could possibly be exhaustive and, at the same time, useful for the outstation forecaster. The rest of this chapter has been designed to give an account of various facts, theories or empirical ideas which should be in the armoury of practical forecasters. Experience allied with this knowledge should enable reasonably satisfactory forecast charts to be prepared on most occasions when they are required.

14.4.1 The use of computer prognoses

Probably the most important background aid for the forecaster is provided by the computer surface and upper-air prognostic patterns. Computer models have the advantage that they provide a completely objective assessment of future trends. For a number of reasons, which are discussed in detail in Chapter 3 - Background to computer models, the objective prognoses may suffer from a number of defects. It is important that the forecaster should be aware of any possible shortcomings of the model, although no detailed account will be given here since the models are undergoing continual improvement as time goes on. What should be said, however, is that no development suggested by the model should be rejected by the forecaster without a very good reason. On the other hand, any development, particularly of new systems, which seems reasonable according to subjective reasoning should not be omitted merely because the computer model does not show it. The use of computer prognoses demands a blend of experience and sound judgement just as much as any other aspect of the forecast procedure.

14.4.2 Extrapolation

Extrapolation is a tool which is required less extensively now than it was before computer prognoses became available, and its use is reserved mainly for local forecasting purposes for periods up to a few hours ahead. The past movement, accelerations and changes in shape and intensity of synoptic systems can usually be determined from a sequence of analysed charts with good accuracy over a land area with a dense reporting network, and it is usually in this sort of area that the technique finds its most frequent application. Extrapolation is less satisfactory in areas where the data coverage is poor, although it may need to be used to some extent in manual analysis in those areas. The crude methods of extrapolation are very simple and consist purely of an extension forward in time of the observed tracks, movements (making allowances for observed accelerations or decelerations) and development. The experienced forecaster then makes ad hoc qualitative adjustments to these extrapolations. In doing this, use is made of synoptic models (including analogues), climatological knowledge and an understanding of the dynamics of atmospheric motion and of pressure systems. Extrapolation should never be used blindly.

It is quite clear that simple extrapolation will not lead by itself to the prediction of changes which are not already in progress at the time the forecast is prepared. On some occasions a consideration of the long-wave pattern is helpful. A computation may indicate whether a long-wave feature is likely to be progressive, retrogressive or stationary and this may assist in forecasting the more gradual changes in speed and direction of movement of synoptic systems. At times, changes in speed and/or direction of movement are abrupt and virtually discontinuous on the synoptic time scale. There may, of course, also be sudden changes in the rate of development of systems. When any or all of these abrupt changes occur they are likely to lead to large errors in forecast charts. As examples, a depression may abruptly follow a different track and accelerate; there may be a sudden (but sustained) fall of pressure leading to a very extensive and deep depression, or a surge of pressure may set in and be maintained, which leads to a very substantial change in the situation during a 24-hour period. When consideration of synoptic models and dynamics are applied to surface and upper charts some estimate of the likelihood of such abrupt changes can sometimes be made. The successful anticipation of such changes is one aspect where the skill of the good forecaster is well demonstrated. The foreknowledge of the occasions and areas where extrapolation will fail is of great value and it is in the exercise of this type of judgement that the forecaster demonstrates real skill.

These may seem rough and ready methods but the necessary skills are readily acquired and applied in practice. There are more sophisticated formulae available. As long ago as 1933 Petterssen[2] published some formulae for the computation of movements. The formulae will not be quoted here, but they may be readily referred to in the textbook by Petterssen,[3] and the details of some practical applications have been given by Byers.[4]

14.4.3 Dynamical aids

The dynamical ideas behind forecasting have been discussed in some detail in Chapter 2, and the importance of a thorough understanding of the material contained therein cannot be overemphasized. The upper-air forecasts produced by the computer, together with a knowledge of the relationship between upper-air and surface features, are invaluable in the preparation of a surface prognosis. In addition, possible errors in the objective surface prognosis may be indicated by the presence of unlikely or unexpected developments in the thickness pattern. This does not mean that concepts such as thermal steering, developmental thickness patterns (e.g. Sutcliffe 'A' and 'C' areas), vorticity and vorticity advection, etc. have lost their value. They remain as valuable means of checking the computer products.

14.4.4 The use of synoptic models and analogues

A synoptic model whose life-cycle is widely known and described in most textbooks of meteorology is the wave depression with a warm sector which develops into a deep system, occludes and finally fills. There are several other basic models and there are large numbers of variations on each model - not to mention the somewhat different behaviour of subsequent members of the same family of systems. Many forecasters make use of their knowledge - based partly on theory, but also on the results of experience - of the behaviour of certain combinations of systems. Although the perfect analogue can never be found it is always useful if the memory can be cast back to similar situations in the past, but the way in which the current situation differs from those in the past is as important as the similarities. It should be remembered that in an application of synoptic models (or analogues) some account must be taken of seasonal variations. This sort of reasoning stresses the importance to the forecaster of a working knowledge of synoptic climatology.

14.4.5 Synoptic climatology

Without being too concerned about the precise definition of synoptic climatology it may, for the purpose of this handbook, be regarded as describing the totality of the weather, resulting from or at least physically related to some aspect of the atmospheric circulation as conveniently portrayed on a synoptic map. In this way is established a relation between weather and circulation and as an extension it follows that statistics of synoptic systems, their tracks, central pressures, air-mass characteristics, etc. are all closely linked in any such studies. Synoptic climatology as a term is relatively young, having been coined by Jacobs[5] in 1942, but there is little doubt that, as a general concept, forecasters have for long used a general knowledge of synoptic behaviour in the forecasting of atmospheric systems and their movement. The acquisition of such knowledge has been a long process, resulting partly as a by-product from daily experiences of forecasting the weather. There is almost a complete absence of published literature dealing explicitly with the synoptic climatology of north-west Europe. Some facts and figures regarding pressure systems near the British Isles have been included in Chapters 4-7. They should prove useful in a general sort of way but their application to one system on any one occasion must be made with care and circumspection.

14.4.6 Summary

At this juncture it is useful to summarize the approach to the preparation of forecast charts. The computer surface prognoses may be used as the main guidance tool or even as a 'first estimate'. This should be checked by consideration of the upper-air forecasts, which are usually of a higher standard than the surface prognosis, bearing in mind the relationship between the upper-air and surface features. Checks should also be made, using the more traditional manual methods outlined in earlier sections of this chapter; these concepts may be used in the variety of combinations which seem to the forecaster most likely to lead to a correct forecast for the particular situation under consideration.

In the following four sections some information on a variety of atmospheric features is presented in a way and form which should enable the forecaster to elaborate on the broad view to some extent. (A considerable amount of the content of sections 14.5 to 14.8 (pages 14-43) has been taken from Chapter 1 of the 'Handbook of Technical Forecasting'.[1] That chapter was mainly the work of C.K.M. Douglas). The dynamical ideas have been discussed in Chapter 2 of this present handbook and supplementary information is given in Chapters 4-7.

In describing some of the varieties of modes of behaviour of synoptic systems it is not possible to start ab initio and proceed in a strictly logical sequence to develop an argument and describe the main types of development and movement. This arises partly from the complexities of the atmosphere, partly from lack of theoretical understanding and partly from lack of adequate observations of the state of the atmosphere at any one time. There is a great deal of empiricism in forecasting so that it seems permissible to fashion the sections 14.5 to 14.8 in a manner and sequence which is likely to be most helpful to the practical forecaster. Individual subsections are developed in as logical a sequence as possible.

14.5 DEPRESSIONS AND TROUGHS NEAR THE BRITISH ISLES

14.5.1 Warm-sector depressions

The warm-sector depression is usually an intermediate stage which follows the formation of a small wave on a cold front but precedes any subsequent development into an occluded depression. It is not therefore particularly logical to start with the warm-sector depression; nevertheless, it is practical to do so partly because of its familiarity to most forecasters.

14.5.1.1 Movement. At the outset it should be stated that when a sequence of actual observations and analysed charts enables an assessment of the actual speed and direction of movement to be made with reasonable accuracy, that assessment should form the primary basis for short-period forecasting, making allowances for probable changes in speed and direction. When actual values cannot be determined owing to an open network or because the wave is newly formed an estimate of probable movement must be made. This is often particularly difficult to do for flat newly formed waves.

Sawyer[6] found that the 24-hour movement of a newly formed wave depression was within $\pm 20^{\circ}$ of the direction both of the warm-sector isobars and of the 1000-500-millibar thickness lines over its centre when it was first identified. An older empirical rule was that the movement was in the direction of the isobars in the warm sector. Hoyle[7] made a further investigation of the speed and direction of motion of simple warm-sector depressions associated with almost straight and undistorted thickness lines; the results indicated that over the North Atlantic:

(i) they move in good agreement with steering by the 1000-500-millibar thermal wind, with a speed slightly over four-fifths of the speed of the thermal wind (meaned as in (ii below) with a probable error of less than 5 knots in speed and less than 10° in direction;

(ii) better results are obtained by measuring the mean thermal wind over an area than by reading a spot value at the centre of the depression. In his investigation Hoyle calculated the west/east and south/north mean components from the difference in thickness between points 300 n. mile north and south and 300 n. mile west and east of the centre.

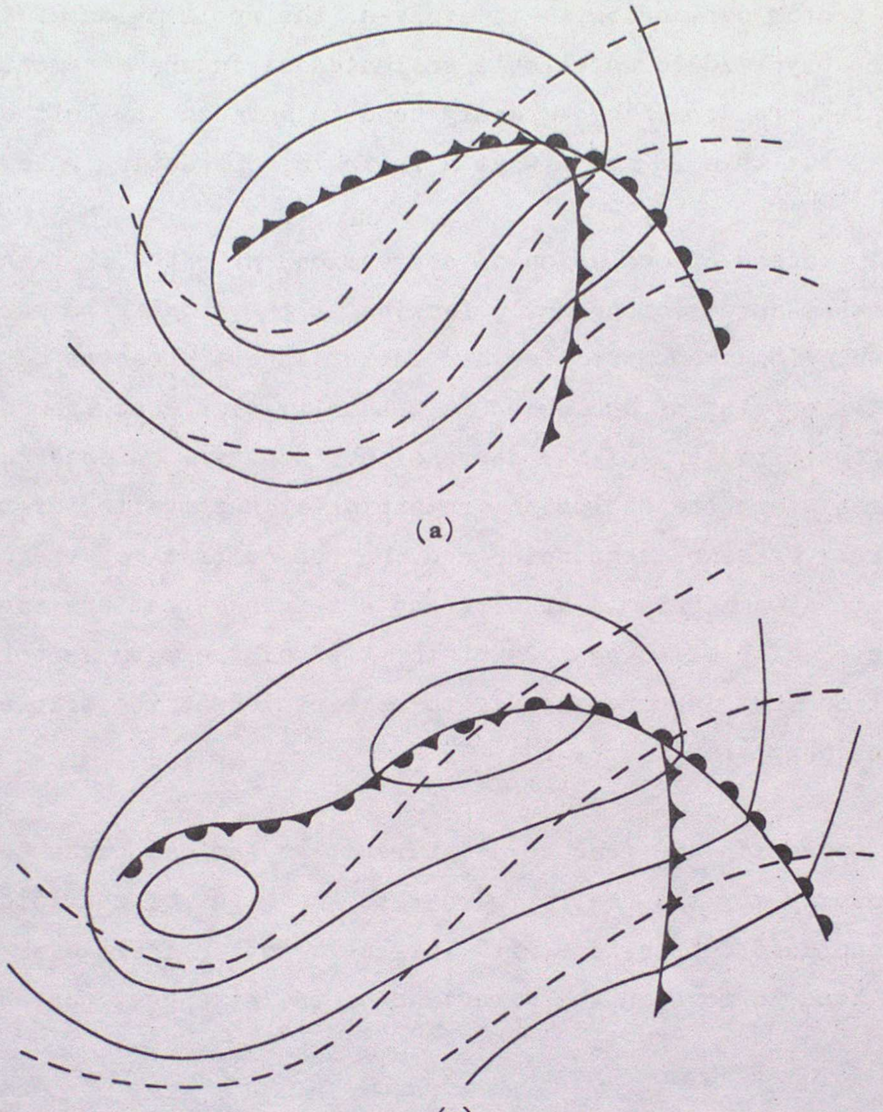
When the 1000-500-mb thickness pattern becomes appreciably distorted over the warm-sector depression as it evolves, the application of the above rules will probably lead to unreliable estimates of future movement. Depressions which are deepening markedly tend to move to the left of their previous track, but this is not always a reliable forecasting rule.

During the process of occlusion of depressions near the British Isles the centre of the depression normally remains at the end of the occlusion. Much of the occlusion then moves forward faster than the centre of the depression and the point of occlusion is gradually displaced from near the centre towards the periphery of the depression. However, on some occasions the centre moves along the occlusion, remaining at the meeting of the warm and cold fronts. Pressure tendencies and the recent track of the centre give an indication when this is likely, and a thickness pattern favourable for the formation of break-away lows at the tip of the warm sector is a useful indication that low pressure is to be expected at the triple point (see 2.3.2.2 of Chapter 2).

When the depression has reached a mature stage and has begun to fill there is a tendency for the centre to move to the right of the thickness lines. Deep occluded depressions with little thermal pattern over their central areas tend to move in the direction of the strongest current around them.

On some occasions a complex development occurs. This might be classed as movement or cyclogenesis and is illustrated schematically in Figure 1.

The figures illustrate a forward development which is more pronounced in Figure 1(b) and leads to a separate centre. If there are two such centres the foremost one often soon becomes the main centre owing to the filling up of the old one. Processes similar to (a) or (b) show up as a complex movement of an apparently discontinuous nature which can seldom be forecast accurately in detail for periods of 24 hours ahead. Once the process is seen to be occurring allowance can be made but, beforehand, precise forecasts of this type of development are difficult. Over areas where information is sparse, the double centre may be unnoticed at first and often only becomes apparent from a sudden forward movement of the centre of lowest pressure.



(a)

(b)

FIGURE 1. Forward development of a depression

(a) as an elongation,

(b) as a separate centre, which is often soon the only centre owing to rapid filling of the old one.

——— Surface isobars.

– – – – 1000-500-mb thickness isopleths

It is well known amongst practising forecasters that two lows, in relatively close proximity, tend to rotate around each other and the complex is sometimes referred to as a dumb-bell depression. The two depressions do not, however, retain a fixed distance apart and there is also usually a general, if slow, translation of the complex superimposed on the rotational motion. The precise path to be followed by the lows is rather difficult to forecast. In general, the smaller one rotates around the larger which is usually the slower-moving but, on occasions, the relative importance of the two lows may change during the period of the forecast. When this occurs, the paths followed by the lows become very complicated. Nevertheless, when two lows are firmly interlocked, the rough and ready application of the dumb-bell effect often leads to satisfactory forecasts of the tracks of the centres.

14.5.1.2 Development and decay of warm-sector depressions. There is no infallible rule for forecasting development or decay. An old rule is that wave depressions deepen in accordance with the barometric tendency in the warm sector. Observed tendencies are undoubtedly a most powerful tool but the thickness pattern is also very useful. Some waves move with but little change of intensity for some time but may suddenly deepen when they move through thickness patterns favourable for development.

Sawyer's[6] work, which was described in section 2.3 of Chapter 2, gives some values to frontal length and thermal wind which should assist in forecasting whether cold-front waves are likely to develop.

Douglas[8] found that, on the whole, it pays to be bold in deepening well-authenticated depressions with warm sectors, especially in higher latitudes.

The extension forward along the occlusion of a depression has already been illustrated in Figure 1. On some occasions a wave develops and moves through the southern flanks of a fairly deep depression. When this occurs there is often a 'sympathetic' troughing along a line from the tip of the wave towards the central region of the other depression. In many of these cases there is a temptation to indicate an occlusion extending from the trough from the older depression to the tip of the wave. Although historically this is incorrect, it is sometimes useful in both analysis and prognosis because, in the trough, rain and cloud systems develop which are similar to those of occlusions. It is emphasized, however, that this does not always happen and judgement is needed in deciding when to apply the concept. The phenomenon has been observed in satellite photographs and has been termed 'instant occlusion'.

The filling of depressions seldom leads to serious difficulty in the preparation of forecast charts. After a depression has attained its lowest surface pressure there is often a period during which the central pressure remains more or less constant before the process of filling commences. There then usually follows a sustained filling, although not necessarily at a constant rate, for many hours, and sometimes for days in the case of very deep and extensive depressions. Where a cold pool is located right over a deep depression the decay of the depression is usually gradual and, although the depression may fill, the cold pool sometimes retains its identity as an upper feature. In some cases in the later stages of filling, the depression may start to move and carry its cold core with it. The direction and speed of motion is then controlled by the large-scale upper current in which the system is embedded.

It should perhaps be remarked that some warm-sector depressions fail to develop and may even fill although they have an open warm sector. Such a process may be expected when the depression moves into an anticyclogenetic field - that is, a mutually destroying combination.

14.5.2 Waves on warm fronts

Waves on warm fronts are much less common than waves on cold fronts. In addition, although warm-front waves may have a short-lived phase of rapid deepening, they seldom (if ever) develop into large systems so that, from the point of view of isopleths on surface or upper charts, the errors incurred when these are not forecast are relatively small. However, in the short term, the weather associated with the wave may be substantially different from that deduced from a forecast chart which does not indicate such a wave. These warm-front waves tend to be accompanied by rather narrow fast-moving belts of fairly intense and considerable precipitation, extensive low cloud and strong surface winds - more particularly on the cold side of the warm front.

Sawyer's[9] study of warm-front waves which was described in Chapters 2 and 6 will yield a clue as to when the 1000-500-millibar thickness pattern is favourable for the formation of a warm-front wave, so that the forecaster may be on the alert. It should be remembered that the existence of a suitable thickness configuration is not sufficient evidence always to justify a forecast of a warm-front wave. When a wave occurs on a warm front it is usually a single one, but if the generating pattern is persistent there may very occasionally be a second. The wave usually moves fast and has a relatively short life as it generally soon runs into an anticyclogenetic area where it decays. Anticyclonic building often occurs in the warm air in the rear of the wave. Warm-front waves which affect the British Isles usually form in the north of the central or eastern Atlantic and occasionally as far away as the area between Iceland and Greenland.

At the surface, warm-front waves usually have a very narrow isobaric pattern, elongated in the direction of the front. They rarely contain more than one or two closed isobars and often resemble pronounced V-shaped troughs down the front. The effect of these waves on the upper flow is usually very transient and little can be done to indicate their effect on upper forecast charts. At high levels the winds are usually strong and quasi-parallel to the surface warm front when waves are likely. For most practical purposes the relatively slight and transient variations which occur in the upper flow during the passage of a warm-front wave are of little concern to aerial navigation.

14.5.3 Cyclogenesis associated with occlusions

The warm-front waves forming on the right of a thermal confluence associated with an occluding depression have already been described in 14.5.2. In addition, the forward extension of depressions by secondary development on the occlusion has been illustrated schematically in Figure 1.

Sawyer[9] illustrated the characteristic isobaric and thickness patterns accompanying the formation of a secondary depression at the triple point on warm and cold occlusions. An account of this work was included in section 2.3.2.2 of Chapter 2.

14.5.4 Cyclogenesis associated with the meridional extension of thermal troughs

The forward part of a thermal trough, i.e. ahead of the trough line, is an area usually favourable for cyclogenesis, and this effect is often enhanced when the thermal trough itself is developing and extending towards lower latitudes. In a study of thermal troughs occurring during the years 1953-56, Miles[10] found that meridional extension by 5 degrees of latitude or more in 24 hours was nearly always accompanied by a substantial fall of surface pressure to the south-east of the trough. This was generally reflected in the south-east movement of a surface depression, in the formation of a new low centre, or in marked troughing in the cold air when the associated cold front was well to the east of the thermal trough. Miles also studied the conditions leading to meridional extension, and his findings are illustrated in Figure 2.

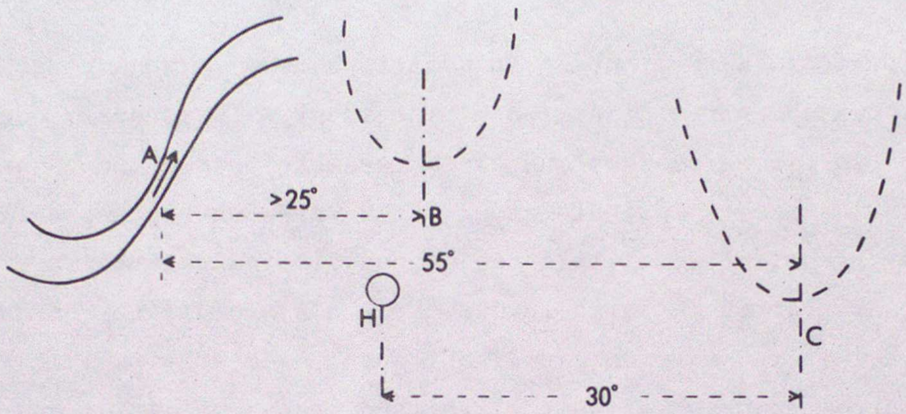


FIGURE 2. Conditions for meridional extension of a thermal trough

It was found that on about 70 per cent of occasions meridional extension by at least 5 degrees of latitude began within 12-24 hours when a strong southerly flow developed upstream, provided that:

(a) the direction of the 500-mb flow at the inflexion point A was between 150° and 225°.

(b) the speed of the 500-mb flow at A was not less than 40 knots, and

(c) the nearest 1000-500-mb thermal trough axis B was at least 25 degrees of longitude downwind from A.

When extension occurred, the thermal trough usually stabilized, within 48-72 hours of the initiation of the strong southerly flow, at C, where AC is about 55 degrees of longitude (with a root-mean-square error of 11°). Alternatively, when there was a strong surface high, H, north of 40°N, the trough axis was such that HC was about 30 degrees of longitude with an r.m.s. error of 15 degrees.

Miles illustrated the accompanying changes of surface pressure by means of the grid shown in Figure 3.

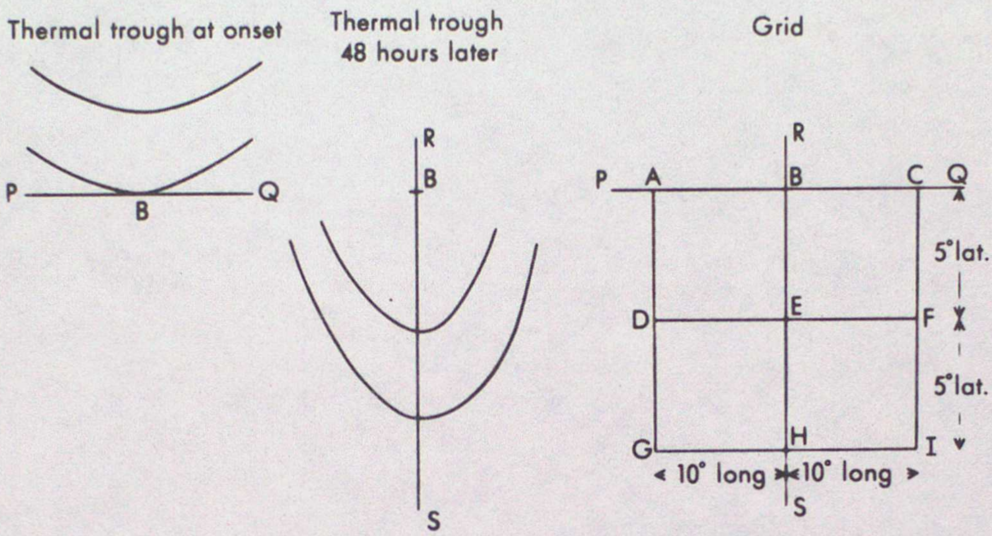


FIGURE 3. Schematic illustration of the grid over which surface-pressure changes were computed

The grid was located by placing the axis RBEHS on the longitude of the thermal trough 48 hours after the onset of meridional extension, and the line PABCQ was located at the latitude tangential at the time of onset to the southerly part of the thickness line undergoing maximum displacement. The values obtained by Miles for the mean surface-pressure changes in the first and second 24-hour periods following the start of meridional extension are shown in Figure 4.

In using these indications in forecasting, of course, the axes of the grid would be estimated positions. For further details the reader is referred to Miles's paper.[10]

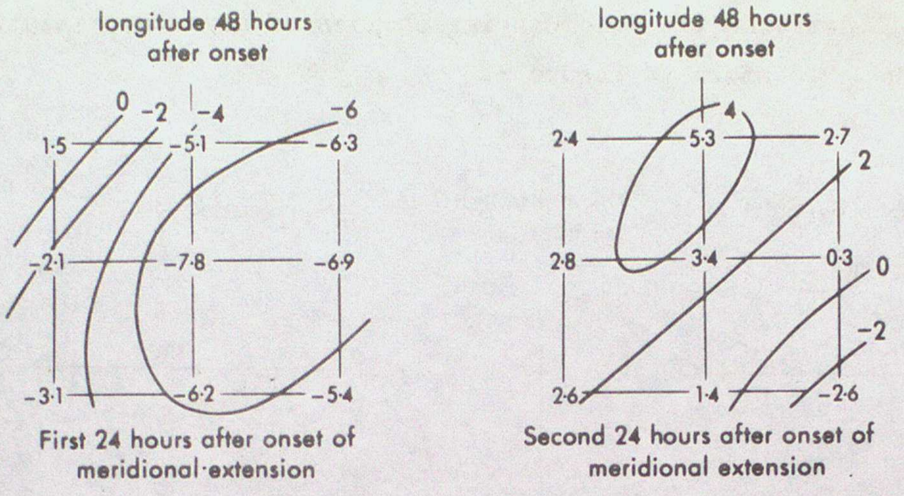


FIGURE 4. Mean surface-pressure changes and estimated mean isallobars for periods of 24 and 48 hours over the grid defined in Figure 3

14.5.5 Non-frontal depressions

Depressions which develop from waves on fronts usually lose most of their frontal characteristics during the later processes of filling and decay. In these closing stages of their life they approximate to deep vortices often extending through much, and sometimes all, of the troposphere. Some remarks on these later stages were included in parts of 14.5.1 (page 14); (see also section 6.3.1, page 12, of Chapter 6 - Depressions and related features).

There are some depressions which do not originate on fronts. For example, sometimes an old decaying depression moves across the east coast of North America to the North Atlantic where it may be rejuvenated. When this occurs there is usually a cyclogenetic area indicated on the upper-air patterns but there may be no pre-existing well-marked frontal system. As the process of deepening goes on, it is usually possible to insert a pattern of fronts into such depressions but that pattern is often complex and is difficult to forecast with much accuracy before the shape and orientation can be reasonably determined from a sequence of analysed charts.

The region ahead of an upper trough is a well-favoured region for deepening and, when an old depression and an upper trough are in suitable juxtaposition, that area of the charts should be watched with special care for signs of deepening and development which sometimes occur suddenly and at a rapid rate.

The conditions leading to the formation of other types of non-frontal low have been discussed in Chapters 2 and 6, and some indication of their properties has been given.

14.6 ANTICYCLONES AND RIDGES

The absence of any theory for anticyclogenesis which is comparable with frontal theory for cyclogenesis is one reason why the problem of forecasting anticyclogenesis is generally more difficult than that of cyclogenesis. The anticyclogenetic process differs fundamentally from that of cyclogenesis, generally occurring at a slower rate, but extending over much larger areas and being sustained for longer periods.

In Chapters 2 and 7 it was shown how dynamical concepts and the use of 1000-500-millibar thickness patterns lead to the recognition of areas where anticyclogenesis is favoured. From these results the forecaster can derive a practical working insight into the probable movement and intensification of both the classical warm anticyclone and the mobile cold anticyclone embedded in the baroclinic zone and migrating with the travelling low-pressure systems in a pseudo-recurrent sequence. For existing anticyclones much reliance can often be placed on persistence, and extrapolation is usually a particularly powerful tool. Tendencies are also extremely valuable but they do not indicate a rise of pressure in advance of its commencement. Further, after a spell of falling pressures some anticyclones are rejuvenated so that simple extrapolation of such tendencies will lead to erroneous forecast charts. There is little doubt that accurate forecasting of initial formation and final decay of major anticyclones is difficult to achieve.

The existence of a thickness pattern favourable for anticyclogenesis in association with travelling pressure systems may lead to a variety of developments. Such developments range from the formation of a migratory cold anticyclone at one extreme, through the development of a feeble, small and transient ridge, to a temporary filling (or cessation of deepening) of a depression as it moves through the thermal pattern.

In an attempting to systematize an approach to the forecasting of anticyclones and ridges it is convenient to start with the problem of the existing anticyclone.

14.6.1 Existing anticyclones

When, on the latest analysed charts, well-established and extensive high-pressure areas already exist in locations where they may affect the pattern over the forecast area during the period, the forecasting problems are mainly of movement and changes in shape and intensity. Close attention should be paid to barometric tendencies and characteristics on a sequence of recent synoptic charts. The pressure variations are often particularly valuable in estimating the trends for the shorter term. It should be remembered, however, that tendencies in well-established highs are often relatively small and that the semidiurnal pressure waves (maxima occur at about 1000 and 2200 and minima at about 0400 and 1600 local time) may materially enhance or detract from the change in pressure attributable to anticyclonic building or decay. Allowance for the semidiurnal waves of pressure should therefore be made when interpreting observed barometric tendencies and characteristics.

Sawyer[11] has classified anticyclones into the following three distinct types according to the 1000-500-millibar thickness pattern; the results often provide a useful guide to the movement of, and pressure changes within, an existing anticyclone (see also Chapter 7 - Anticyclones and related features):

Type 1: Cold anticyclone - mobile type

The features of the thermal field are:

(a) Strong thermal wind over the centre (usually 40-50 knots over the layer 1000-500 mb).

(b) 'Flat-wave' pattern of thickness lines with the anticyclonic centre between a 'thermal ridge' and the next 'thermal trough' in the direction of the thermal wind; (for this purpose a 'flat-wave' pattern may be regarded as one in which the maximum inclination to the general stream is less than 45^{o}).

The simultaneous behaviour of the centre is:

(i) Fast motion towards the 'thermal trough'. The average speed is about 25 knots but varies over a wide range; motion is in a direction roughly perpendicular to the trough line but there appears to be a tendency to move towards the region where the thermal wind is strongest.

(ii) Central pressure may rise or fall slowly; possibly rising pressure is slightly more frequent.

Type 2: Cold anticyclone - slow-moving type

The features of the thermal field are:

(a) Strong thermal wind over the centre (usually 40-50 knots when taken over the layer 1000-500 mb).

(b) A 'wave' pattern of wide amplitude in the thickness lines with the anticyclonic centre between a 'thermal ridge' and the next 'thermal trough' in the direction of the thermal wind. The difference between this type and the preceding type is in the distortion of the wave pattern which should twist the thickness lines to an angle of more than 45° from the general stream, i.e. from the general direction of the thickness lines over a wide area over which the distortion in the region of the anticyclone can be ignored.

The simultaneous behaviour of the pressure centre is:

(i) Slow motion (10-25 knots) towards the 'thermal trough'. The direction is usually inclined to the right of the perpendicular to the trough line, but involves displacement across the thickness lines into the cold air.

(ii) Central pressure changing little or rising slowly.

Type 3: Warm anticyclone

The features of the thermal field are:

(a) Very weak thermal gradients near the anticyclonic centre.

(b) Anticyclonic centre lies on or near the axis of the warm tongue.

The characteristic behaviour is:

(i) Very slow motion (usually less than 10 knots).

(ii) Direction of motion usually in a direction between the axis of the warm tongue towards the higher temperature and the direction from the anticyclone centre to the apex of the cold trough.

(iii) Little change in central pressure.

A fourth type, of which there were few examples, was similar to the warm anticyclone, but the following thermal trough was approaching the high centre rapidly. Motion was generally in a similar direction to the warm anticyclone, but quicker (15-20 knots), and the central pressure decreased, sometimes rapidly.

Where the thickness patterns over an existing anticyclone do not fit readily into Sawyer's[11] classification, the dynamics of the problem can be taken into account in a qualitative manner by examining the thickness patterns over the area. It will be recalled from Chapter 2 that the left flank of a confluence and the right flank of a diffluence in the thickness pattern are anticyclogenetic. It is important, however, to draw attention to a distinction between them. Any moving system overtaking a confluence is accelerated and any tendency for the self-generating process is checked whereas, when overtaking a diffluence, a system is retarded and the self-generating process is enhanced. There is often a pronounced thermal ridge in association with a diffluence and the right flank is markedly anticyclogenetic.

Some cold, initially mobile anticyclones slow down and gradually evolve into warm slow-moving anticyclones with associated changes in the thickness pattern. This evolutionary process is well known and widely recognized and applied in practice by experienced forecasters. In the application of Sawyer's[11] work to practical forecasting the stage of the life history of the anticyclone must be considered. This consideration coupled with the changes in thickness pattern may yield a clue as to the occasion on which a cold anticyclone may transform into a warm one.

Once a warm slow-moving high is well established its persistence with only slow changes of pressure and little movement can usually be relied upon until persistent falling pressures occur. Ultimately, of course, it must decay. The process of decay will usually take at least 48 hours before it is complete but there are often false alarms. For example, steady falls of pressure may be sustained for several hours, sometimes 24 hours or more, and the anticyclone seems to be decaying but there may then follow a period of further building - and during this rebuilding period there is often considerably more movement than previously. In some cases the period of diminishing pressure may be associated with the advance of a cold front towards the anticyclone, and in the rear of this cold front there may be a building ridge or anticyclone. The cold front continues to advance and often ultimately to move through the old high which continues to decay. The high to the rear of the cold front continues to build and also to advance and, at times, appears to amalgamate with and absorb the older high. The combined high-pressure area usually comes to rest or becomes slow-moving in a position close to that previously held by the preceding high. The broad synoptic pattern is, as it were, re-established and the old high is rejuvenated - although historically it is in some respects a new centre formed by amalgamation of the old system with the new advancing and building system.

In addition to this rejuvenation and pseudo-persistence of warm highs due to the advance of cold air down their eastern flank from the north, warm anticyclones may be reinforced by the northward movement of warm air along their western flank. The circulation of a high which is established through much of the tropopause tends, in itself, to lead to the southward advection of cold air on its eastern flank and the northward advection of warm air on its western flank. When there is a deep, often slow-moving depression well away to the west, with a belt of winds with a substantial southerly component through much of the troposphere, then a very pronounced thermal ridge may be built up over the western parts of the high, leading to a strengthening of the old high, which then tends to extend northwards and, at times, may move bodily north or north-east. It is important that a substantial isobaric or thermal gradient continues to exist for a sufficient time to effect the northward transport of large masses of warm air and that there should be adequate horizontal separation of the centres of these major high- and low-pressure areas - probably at least 1500 km or so.

14.6.2 Formation of new anticyclones

So far the treatment has been concerned with the modification to pre-existing anticyclones. There are, from time to time, new centres formed and some remarks on them will now be made. Sutcliffe[12] examined the formation of new anticyclones - a new anticyclone, for this purpose, was defined as the emergence of a centre of relatively high pressure on the surface chart not continuous with any pre-existing centre (but omitting weak short-lived cells in a ridge situation). Some 42 cases were found for the period 1950-51 over the area of western Europe, the eastern and central Atlantic. From a classification of the anticyclones with respect to the 1000-500-millibar thickness pattern over them, Sutcliffe came to the conclusion that there are probably only two modes of breakdown of the zonal westerlies which lead to new anticyclonic centres. One of these modes may be termed the simple sinusoidal oscillation. This is, in effect, the pattern associated with an unstable wave depression developing between the thermal trough and ridge, and high pressure building between the thermal ridge and the succeeding thermal trough. The other mode was termed the anticyclonic disruption.

Out of 42 cases Sutcliffe found 25 cases of new anticyclonic centres forming in association with simple sinusoidal oscillations. The synoptic patterns fell into two distinct classes. In the one case the belt of baroclinic westerlies was bounded on the south by the subtropical anticyclone; with this type of situation there were only 4 occurrences of formation of new anticyclones. In the other case the synoptic patterns showed generally lower pressure to southward of the belt of baroclinic westerlies; there were 21 cases of new anticyclonic development of this class. The very few cases of new anticyclones when the Azores anticyclone lay south of the westerlies was surprising. Although the other class is apparently much more favourable, neither is reliable as a forecasting rule since the appropriate thickness and isobaric patterns occurred many times more frequently than the new anticyclonic centres. When the patterns did exist, they usually led to substantial ridge development but without a distinct closed centre of high pressure.

Of the remaining 17 cases of development of new anticyclonic centres, some 8 were too complex to fall into a reasonably simple classification but the remaining 9 exhibited the common feature which Sutcliffe termed anticyclonic disruption and which has been described in section 2.3.2.2 of Chapter 2. It may occur when an oscillation of the baroclinic westerlies builds up to large amplitudes: the current and the wave pattern disrupt, the stream divides and two distinct wave-like distortions move at different speeds, rapidly becoming out of phase. Geometrically the disruption may be imagined as taking place by relatively faster progression of one of the wave-forms. One of the wave-forms moves at higher latitudes and the other at lower latitudes. The more rapid movement of the northerly waveform is the more common and definite process which leads to disruption and anticyclonic building between the high- and low-latitude system. However, at times the southerly system moves more quickly eastwards and undercuts a higher-latitude ridge between the northerly and southerly systems.

Although nine separate anticyclonic centres formed in the two-year period in association with the process of anticyclonic disruption, it should be noted that the process more commonly leads only to a ridge development or a displacement across the neck of a pre-existing high from the west; (there were 33 such occurrences in one year alone).

From a practical point of view the investigation was of limited value for the forecasting of new anticyclonic centres, but an account has been included in this handbook since the processes often lead to ridge development. Thus forecasters may be reasonably confident in forecasting building pressure but there is little clue as to when to forecast a separate centre.

Another type of pattern which sometimes leads to the formation of a new anticyclone is a deep depression well to westward which throws up an extensive warm tongue to high latitudes: the cyclogenesis occurs to westward of a diffluence, the deep depression is, or becomes, slow-moving and pressure builds in the anticyclogenetic region of the diffluence. This situation leads sometimes to a blocking high, that is a warm high situated in rather higher latitudes than normal.

Haworth and Houseman[13] have drawn attention to a particular 1000-500-millibar thickness pattern which is favourable for anticyclogenesis. The thermal pattern is really a combination of a diffluent ridge and a confluent trough as shown schematically in Figure 5.

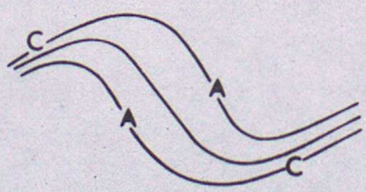


FIGURE 5. Combined diffluent ridge and confluent trough in the thickness pattern

A and C are regions of maximum anticyclonic and cyclonic development respectively.

In this case the warm side of the diffluence and the cold side of the confluence are favourable for anticyclogenesis. Haworth and Houseman remark that the pattern must persist, and argue that depressions approaching the diffluence tend to slow down whilst those forming in the confluence accelerate so that the separation between the depressions increases, thereby leaving room for a disruption of the mobile westerlies. If the advection pattern implies that the diffluent ridge/confluent trough configuration will be maintained (or enhanced) for a reasonable period (for example, 24 hours or so) then anticyclonic building is likely to occur. A number of synoptic examples of actual anticyclogenesis are cited but no statistics are given which enable an estimate to be made as to how often the pattern is in fact followed by anticyclogenesis. Nevertheless this brief account has been included as forecasters may find it useful. The following remarks regarding practical use are taken verbatim from the authors'[13] account:

'Practical application to forecasting: To use the diffluent ridge/confluent trough for forecasting the formation of a new anticyclone, the following factors must be kept in mind:

(i) Advection such as to keep the pattern in existence over a sufficiently long period.

(ii) Sharp diffluence on the ridge and confluence on the trough with sharp ridge and trough lines.

(iii) Orientation of the thickness lines in the A-A region [on Figure 5] should be near to the west-east direction and the thickness lines in the C areas should be near to the south-north direction.

(iv) The whole pattern should have a high mean latitude, say above 50°N.

If any one of the above conditions is not fulfilled, the intensity of the resulting anticyclogenesis will be reduced. A new anticyclone will not usually develop unless conditions (i), (ii) and (iv) are fulfilled, but other symptoms of anticyclogenesis, e.g. filling depressions, weakening fronts, will be manifest.'

Miles[14] has made a useful synoptic study of the factors associated with the formation and persistence of all surface anticyclones spending more than one day in the Scandinavian region during the winter half of each of the twelve years 1946-57 inclusive. His main findings may be summarized:

(a) Somewhat less than a fifth of the anticyclones appearing in the region persisted beyond three days.

(b) Nearly all of the strong anticyclones developed some 600 nautical miles to the east of a large-amplitude thermal ridge. Continued growth of this ridge for at least 24 hours after the anticyclone appeared in Scandinavia was usually required for persistence of the anticyclone.

(c) Several other factors which appear to be relevant to the persistence of these anticyclones have been elucidated. The strength and position of the major thermal troughs upwind to 110°W longitude, the strength of any warm anticyclones to the south and south-west of Scandinavia and the maintained growth of the large-amplitude thermal ridge appear likely to have the greatest prediction value.

Some of the detailed conclusions of Miles's study seem likely to be useful on the forecast bench and the following extract is reproduced. (D = first day the surface anticyclone was over Scandinavia; D-1 and D+1 are the preceding day and the succeeding day respectively).

'The formation of winter anticyclones over Scandinavia is found to occur usually in association with a large thermal ridge which first forms over or just to the west of Iceland and then extends north to north-eastwards across the Norwegian Sea. Occasionally, cells of high pressure appear over Scandinavia associated with deep cold air with a more or less zonal circulation pattern over the Atlantic, but they do not grow above about 1020 millibars and rarely last more than a day or two. In October and March, anticyclones occur in association with blocking situations over east Europe and west Russia, that is, the original blocking anticyclone is centred to east or south-east of the Scandinavian region.'

'Besides the large thermal ridge in the neighbourhood of Iceland on day D-1 the following factors leading to its further growth are usually present:

(i) Deep surface low about 60°N and between 30° and 45°W (that is some 20° longitude west of the thermal ridge).

(ii) Well-marked southerly current at 500 millibars north of 50°N and between longitudes 20° and 35°W.

(iii) The east Atlantic high-pressure cell displaced north-eastwards towards the English Channel.

'For the persistence of the resulting anticyclone the following conditions are usually required to be satisfied on D day.

(iv) A single thermal trough in the Atlantic-American sector with a negative thickness anomaly greater than 20 decametres and located east of 70°W. (A second trough west of 70°W is allowed if its negative anomaly is less than 20 decametres).

(v) The absence of a closed-contour high exceeding 570 decametres at 500 millibars in the region between 40° and 55°N, and 25°W and 10°E.

(vi) The closed anticyclone over Scandinavia west of 20°E on first appearance.

(vii) The main warm advection not further west than about 20°W longitude.

'A rule based on (iv) and (v) for D day would have correctly predicted the persistence of ten out of twelve persistent highs in the period November to February and wrongly predicted two of eighteen non-persistent highs to be persistent. At D+1 a further criterion that the total thickness at Bear Island should have increased by 6 decametres or more between D and D+1 would have confirmed the earlier prediction of persistence in nine out of the ten and corrected the previous indication of persistence in one of the two non-persistent cases.'

'Non-persistence arose most often (about two-thirds of all cases) as a result of movement east or south-eastwards out of the Scandinavian region. The eastward movement could be attributed to continued mobility (and occlusion) of the thermal ridge, and the south-eastward movement to thermal steering on the forward side of the thermal ridge, when this was being maintained by a warm blocking high near the British Isles. Decline of the anticyclone accounted for about a third, and this could sometimes be attributed to the intensification of a trough in the zone 0°-20°E as a result of fresh ridge growth well west of Iceland.

'The strength of the Scandinavian anticyclone on the day of its first appearance offers no guide to persistence. The mean central pressure for the non-persistent cases was 1030 millibars compared with 1028 millibars for the persistent ones.'

14.6.3 Weakening of anticyclones

The decay of a large well-established anticyclone usually takes a considerable period - two or three days is probably about the norm but there are substantial variations. The rate of weakening is not usually steady and over a few hours there may be variations in tendency which are disconcerting to the forecaster. For example, negative tendencies - sometimes as high as 2 millibars per 3 hours - may persist almost unchecked for perhaps 24 hours and it appears that the anticyclone is in the final stages of decay when subsequently there is a rejuvenation, the high rebuilds (or a new building high becomes dominant and effectively absorbs the old high) and is re-established as a long-lived slow-moving feature. Some of the types of rejuvenation already described may assist the forecaster in deciding whether such a process may revivify a decaying high.

On a few occasions a high decays quite rapidly. Sawyer[11] indicated one type of thermal distribution when central pressure sometimes decreases rapidly. In this pattern the anticyclone was associated with a diffluent thermal ridge but a thermal trough was advancing towards the anticyclonic centre. Douglas also commented in a similar vein and remarked that the weakening of anticyclones is usually slow until an external influence, usually an upper trough, comes into the picture.

14.6.4 Ridges

Much of the text on anticyclones is applicable to the forecasting of ridges. In 14.6.2 it was seen that many of the anticyclogenetic areas often lead to the formation of ridges rather than closed anticyclones. An estimate of the extent of such ridging is very important when preparing forecast charts but accurate numerical estimates are difficult to make. The assessment of ridging ahead or in the rear of fronts has a marked effect on the estimated future position of these fronts. If the estimate is seriously in error, substantial errors in forecasts of weather and in timing are likely to occur. For example, strong ridging in the rear of a cold front usually leads to a pronounced penetration of the front, whilst strong ridging ahead of the front in a warm sector will effectively hold the front back. It is readily seen that both under- and over-estimates can lead to substantial errors in both frontal configurations and positions. It is unfortunately true that accurate quantitative estimates of ridge building are almost as difficult to make as are forecasts of new anticyclones.

It is pertinent to remark that ridges sometimes decay much more rapidly than anticyclones. This is particularly true of the more mobile smaller ridges. Such ridges often bring a few hours of clear dry weather in spells of generally unsettled weather and the successful forecasting of such ridges is therefore of some considerable practical importance. When a ridge following a depression suddenly collapses the succeeding depression usually advances quickly, bringing a renewal of wet weather. At times the thickness pattern may yield a clue but this is not always so. The intensity of the ridge does not seem directly related to its ability to persist for some quite feeble patterns can persist and be traced over many charts. Broad, extensive ridges of a quasi-barotropic character and apparently joining up extensive anticyclones are, however, often persistent features of a chart over several days.

14.7 FRONTS

14.7.1 General

When attempting to deal with fronts in the preparation of forecast charts it is important that the forecaster should examine the frontal structures in the right perspective.

A careful examination of a very detailed and densely plotted chart on a large scale will usually reveal some evidence of minor fronts or lines of demarcation of weather which are often not fronts at all. These systems may maintain their identity and exhibit a coherent pattern of configuration and movement on a sequence of detailed charts. They can accordingly be identified and tracked on charts, and extrapolation of movement is often of very great value for very short-period forecasting. However, these minor features, even when identified, can seldom be satisfactorily predicted in detail for as long as 24 hours in advance. The insertion of these minor fronts (or discontinuities) on analysed charts undoubtedly complicates the pattern. For the preparation of forecast charts for periods of about 24 hours ahead it is important, as previously stressed, that the forecaster should take a broad view. He must therefore concentrate on the major fronts associated with strong contrasts, pronounced cyclonic shear and marked thermal patterns. A multiplicity of fronts on a chart is often a positive hindrance to a forecaster when preparing 24-hour forecast charts. For this purpose it is therefore useful to mark in only the major frontal surfaces.

Apart from the confusing picture which a multiplicity of fronts on an analysed chart conveys to the forecaster, the person receiving and using a forecast chart with a similar multiple frontal structure will have considerable difficulty in interpreting the chart in terms of weather. There is much difficulty in interpreting even major fronts accurately in terms of weather, and experience shows that the minor fronts are usually of value to the forecaster only for the shorter-term forecast, when some success can be obtained by advection and extrapolation of currently reported weather at the minor front, modified slightly at times to make allowance for topography, diurnal variations, etc. Occasionally it may seem preferable to include multiple fronts, but the point can often be adequately covered in any plain-language message accompanying the charts.

14.7.2 Warm fronts

The motion of warm fronts can usually be satisfactorily forecast by taking it as two-thirds of the geostrophic wind speed measured at the front in a direction at right angles to the orientation of the surface front, although Hinkel and Saunders[15] suggest that a factor of four-fifths should be used over the oceans. The geostrophic wind is readily obtained from the surface isobars (see Chapters 2 and 6) and must be suitably time-averaged throughout the forecast period. For periods up to 24 hours it is usually satisfactory to measure the geostrophic wind speed on the latest actual and on the tentative forecast surface chart and then to make some approximate interpolations for intervening periods of suitable duration, for example, six-hourly periods. A statistical investigation of the success achieved by using the two-thirds rule has been carried out by Matthewman[16] who found that it is difficult to improve on it by statistical regression equations. There was some slight improvement if the speed was taken as two-thirds of the component (normal to the front) of the geostrophic wind at 900 millibars measured in the cold air some 75 miles (120 km) ahead of the front. Matthewman found that the speed of a warm front was very close to the component of the actual wind in the cold air below the frontal zone and above the friction layer, say at 900 millibars. If such an observation is available it can be used as an estimate of the frontal speed (for short periods). Statistically Matthewman found that this gave an algebraic mean error of less than 1 knot and a root-mean-square error of less than 6 knots. It is only over dense observing networks that such observations are likely to be generally available but forecasters should use them whenever they are. A direct wind observation is very valuable because it takes implicitly into account the effect of ageostrophic motion in the cold air. Although ageostrophic components normal to a warm front are generally larger than at a cold front (Matthewman found for some 18 well-marked warm fronts values ranging approximately from 2 knots to 35 knots with a mean of about 15 knots), nevertheless it is the errors in estimating the geostrophic wind speeds at right angles to the front which lead to the largest part of the error in forecasting the movement of warm fronts for periods as long as 24 hours (see also Miles[17]).

Where there is large ageostrophic motion of the cold air towards the front, rainfall amounts are usually large and the front slows down. When a cold front advances at the normal geostrophic speed towards such a warm front the combined effect leads rapidly to occlusion.

14.7.3 Cold fronts

Most cold fronts move with a speed almost equal to the component geostrophic wind at right angles to them, and an estimate of their future position, based on a suitable time-average between the speed deduced from the isobaric patterns on the latest actual and tentative prebaratic charts, often forms a good forecast. Even this simple rule must be used with discretion and there are certain points which should be mentioned.

Firstly, where there is very little pressure gradient on one part of a front it is sometimes difficult to make reliable estimates of movement. However, such a cold front often has a turning point beyond which it returns to act as a warm front. A forecast of the position of such a turning point will provide a convenient 'anchor' for one part of the front. If no development is in progress, the turning point runs along its own isobar with the speed of the warm air which is the geostrophic speed when the curvature effect is too small to be appreciable. This is shown schematically in Figure 6.

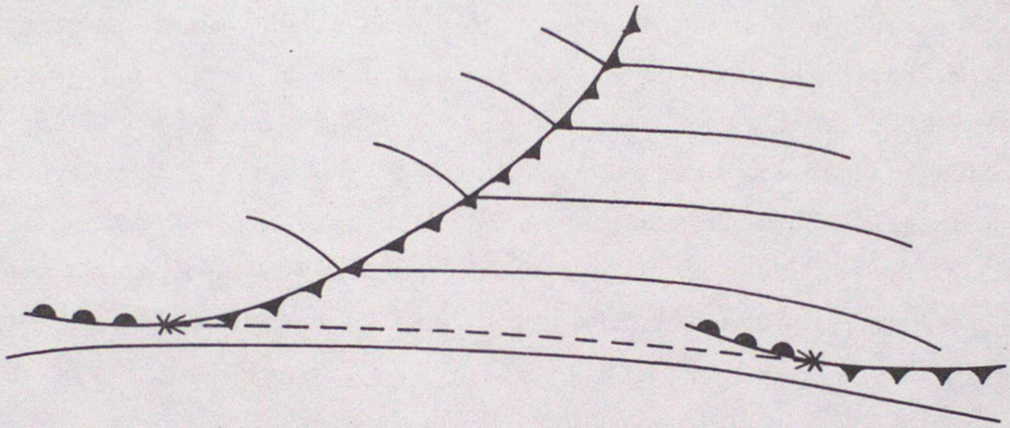


FIGURE 6. Cold front becoming quasi-stationary in the position shown on the right of the diagram

In many cases the isobars are straight or nearly straight and the method is easy to use. Where there is a considerable length over which the cold front is quasi-stationary then the movement of both ends of this part must forecast. In practice, in such situations, the forecast problem is often difficult because of the possibility of wave development. Development upwind of the turning point must be considered. For example, if a wave depression upwind is deepening and the warm sector isobars become backed, then the cold front near the turning point does not progress so far, that is to say it becomes retrograde. In the opposite sense anticyclonic building in the cold air will result in a rather greater progression of the cold front. The final estimate of the movement of the front depends in a complex way on developments and changes in the synoptic patterns.

As in the case of warm fronts, some account must be taken of ageostrophic motion. When the isobars are strongly curved, as in deep depressions, the effect of cyclonic curvature is to reduce the wind speed across the front below the geostrophic value. Although in such cases the cold front often moves at sub-geostrophic speed, the occlusion process usually proceeds and the forecasting of the movement of the depression centre may present the greater forecast problem.

When there is anticyclonic building to the rear of a cold front, its motion tends to be super-geostrophic. It is not usually practicable to obtain a close numerical estimate of the ageostrophic speed from current working charts but the isallobaric wind (see section 16.2.2.2 of Chapter 16) may provide a guide: the ageostrophic component may amount to as much as 10 knots and, in very well-marked cases, sometimes more. Super-geostrophic motion of cold fronts may also occur, notably in summer at the end of hot spells. These cold fronts are often upper cold fronts and a pseudo or actual air-mass boundary may extend right down to the surface if there is a descending squall. In many such cases the main cold air comes in at about 4000-8000 feet (1-2.4 km) but if there are heavy thunderstorms the cold air in a squall may descend from great heights.

14.7.4 Occlusions

If an occlusion has a substantial depth of warmer air behind it then it acts and moves as a warm front. It should be noted, however, that some occlusions which appear to be warm at the surface act as cold fronts at upper levels. The depth of warm air necessary to make an occlusion act as a warm type is not known precisely but experience suggests that a depth of warm air extending above 800 millibars is probably necessary in many cases.

With cold occlusions the rules for movement of cold fronts apply and it is often found that the sharper the isobaric trough at a cold-type occlusion the more likely it is to be moving at its geostrophic speed. Some occlusions move at super-geostrophic speed and the remarks in 14.7.3 on that aspect of cold fronts also apply to cold occlusions. The majority of occlusions near the British Isles move like cold fronts.

Douglas[8] found that there was a tendency for summer occlusions to move faster than the air masses low down. He felt that this fact was worth keeping in mind and that the 700-millibar charts should be useful for this problem. Jones[18] also found that occlusions tended to arrive earlier than forecast. However, of those occlusions which were not early, some 40 per cent did not arrive at all.

When occlusion may possibly take place within 24 hours the problems are to decide whether there will be occlusion and, if so, how far from the centre of the depression it will extend. The extent to which a warm sector is occluded depends on the motion of cold and warm fronts. Thus a first estimate of the extent of occlusion is obtained from the predicted motion of the warm and cold fronts. After this has been done it is usually necessary to make some adjustments to produce a plausible chart, and there is a certain amount of empiricism in the final decision. The extent of occlusion depends to a considerable degree on the ageostrophic motion of the warm front and on the rate of deepening of the depression. With very deep depressions, once the occlusion process commences it is often nearly complete within 24 hours or, at least, it has extended to a point a few hundred nautical miles from the centre of the depression.

14.7.5 Frontogenesis

It is readily shown that the velocity field is frontogenetic or frontolytic according as the isotherms lie within 45° of the axis of dilatation or not (for example, see Petterssen[2]). Sawyer[19] has made an investigation of the relationship between fronts and frontogenesis and concluded that:

'The large-scale circulation around depressions and anticyclones inevitably contain regions of confluence and when these are associated with a temperature gradient perpendicular to the axis of dilatation frontogenesis results. This frontogenesis leads to a vertical circulation which causes the ascent of warm air and the descent of cold air and the formation of an inclined frontal zone.

'Synoptic evidence suggests that such frontogenesis is in progress in association with most active fronts and it seems likely that they owe their characteristic features to it.'

This is valuable in that it sets a scale on which to look for frontogenesis in the first instance. The velocity and isotherm fields should be kinematically favourable before large-scale frontogenesis is forecast.

If convergence is also occurring in that area then the chances of frontogenesis are considerably enhanced. If in addition to these two features a depression forms in the area, the typical frontal surfaces seem to be established in a few hours. However, the mere formation of a depression without a classical frontal structure is not a signal to introduce on the prebaratic new fronts in a stereotyped way. There should always be also good physical, kinematical and dynamical reasons before frontogenesis is predicted.

In a number of cases, what purports to be frontogenesis is the rejuvenation of an old front which may have been dropped from previous analyses. The problem of the retention of old inactive fronts is a difficult one to solve in practice. Those analysts who invariably retain all fronts or only one are extremists and are likely to be wide of the mark. Some middle course is usually preferable.

There are certain preferred geographical regions for frontogenesis. The best known is near the eastern seaboards of the major continental land masses in mid latitudes in winter. In such areas the temperature differences between air over adjacent land and sea are often large and strong fronts occur. Of direct interest to forecasters in the British Isles is the formation of a strong polar front off the eastern seaboard of North America.

Frontogenesis is not a frequent occurrence near the British Isles. When it does occur it is often due partly to land and sea distribution. However, owing to the irregular coastline, such fronts are often local or complex and are not readily incorporated into forecast charts. For the weather of the British Isles the most important of such fronts occur in the southerly thundery type in summer.

14.7.6 Frontolysis

Frontolysis is not usually a factor which leads to serious errors in forecast charts but it may cause large errors in the weather to be inferred from such charts. As with frontogenesis there should be good kinematical, dynamical and physical reasons leading to an expectation of frontolysis. The mere commencement of building of pressure on either side of a front is not a sufficient condition to forecast frontolysis.

For example, between a warm and cold high the upper flow may remain parallel to an intervening frontal surface which retains its identity and often becomes an active feature when the next depression approaches, an occurrence which is not usually long delayed in typical mobile situations. In this case, even though pressure is rising, the thermal contrast near the front is often maintained. When there is persistent and prolonged rising pressure around a frontal surface the associated subsidence will usually destroy the front. Further, if a front gets into an anticyclonic flow pattern and is at a large angle to the upper flow there is often little thermal contrast in depth across the front and subsidence will usually destroy such weak frontal characteristics as may exist. If such events have persisted for several hours and seem likely to continue it would be wise to forecast frontolysis and drop the front.

14.8 CONCLUDING REMARKS

In spite of the great advances in numerical models, the prediction of the surface pressure pattern and fronts 24 hours ahead is still, in the mid 1970s, a largely subjective matter. The forecaster has for his guidance the upper-air and surface forecasts from the computer but, while these have arguably led to an improvement in the forecasts finally issued, it is not yet possible to use the surface prognoses as they come from the machine. Allowances must be made for known deficiencies in the model and for the limitations of the analyses, for example because of missing data, upon which the forecasts for a given time are based. In particular, the forecaster will probably need to insert detail on a scale smaller than can be handled effectively by the model. He may also have information which has not been incorporated into the computer analysis, such as late observations, sferic and radar observations, and satellite photographs. The meteorologist will need to use his experience and judgement in the assessment of all the different types of available information in order to produce the best possible surface prognosis.

After the preparation of a surface prognosis its interpretation must be carried out in the light of likely errors. Tests carried out in the Central Forecasting Office at Bracknell of 24-hour forecasts over the period 1951-68 (unpublished) show mean errors in the positions of depressions of 300-400 km, with errors for anticyclones slightly less, about 250-350 km. The mean error for frontal positions was about 150-200 km, with a corresponding timing error for passage across a given place of about five hours. In some instances confidence in the forecast will be fairly high, in others not as high; any qualifications can usually be mentioned in the plain-language guidance which complements the surface prognosis.

Finally, the author can find no better words to provide the finishing touch to Chapters 13 and 14 than the concluding paragraphs of an article by Kirk:[20]

'Throughout this account, a situation has been envisaged in which the forecaster has access to sources of information and theory additional to the available computer products. It is this additional information and knowledge which provide the basis and the justification for his attempts to modify any numerical forecasts. In practice, only he can decide the extent to which he is justified; for certain purposes and in certain situations he may know from evaluation studies that the numerical product already satisfies the operational need and hence that modification would be unnecessary. In other instances it may be known that subjective modification, although inherently desirable, is ineffective in practice. Some requirements, particularly those concerned with detailed distributions of weather elements in space and time, may demand that the forecaster use the numerical products as guidance only, basing his final forecasts partly on the automated products and partly on additional data, empirical knowledge and theoretical considerations extraneous to them. It must be remembered that most models are based on relatively few analytical parameters and that a vast amount of data is not utilized. This extra-model information, although perhaps of little relevance to large-scale atmospheric circulation, may be vital for a local problem.

'In considering the conclusions of a study by Brown and Fawcett[21] it appears that the meteorologist produces a better forecast by using the automated products as a basis because they are derived objectively, by known mathematical procedures, from well-established physical principles. Within the limitations of the physical model there is no different method capable of providing a better basis. Numerical models, like all other physical models, must be tested and evaluated. Known limitations provide a means of improvement either by subjective modification or, better still, by improvements to the model itself. Improvements to the numerical model entail a diminishing possibility for further subjective criticism. The area of subjective modification progressively diminishes, but this does not render the forecaster any the less necessary. Forecast periods are being extended in time and there will always be demands at the margin of the capability of present models offering scope for subjective criticism and forecast modification. The development of mesoscale models is only in its infancy and subjective interpretation and forecast modification have an even more important role to play in this field. Interpretation, on which any forecast modification must be based, implies the application of theoretical knowledge and information not intrinsic to the model under consideration. With the ever-present tyranny of detail it is difficult to envisage either a time or a situation when the forecaster will not be able to make valuable contributions to at least some forecast products.'

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