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WEATHER, CLIMATE AND PLANT DISEASE*

By W. H. HOGG

Summary. The development of two plant diseases is described in relation to the weather. Potato blight, *Phytophthora infestans*, can be carried over from the previous season. It spreads rapidly in warm, humid weather and the warning system operated by the Plant Pathology Laboratory and the Meteorological Office is described. On average, the relative durations of potato blight weather at Plymouth, Bristol and Abingdon are 9:3:1.

The relationships between weather and black rust of wheat, *Puccinia graminis* f. sp. *tritici*, are more complicated, as the disease cannot occur unless spores are brought into this country by the wind. The use of trajectories suggests that in years when the disease appears early the spores originate in southern Europe or North Africa; in years when it appears late the spores may arrive from France. There is no warning system for the disease and the role of the meteorologist in any future scheme is discussed.

Introduction. The object of this paper is to discuss the meteorological factors concerning the occurrence and spread of two plant diseases which occur in south-west England, potato blight and black rust of wheat. From a meteorological standpoint the chief way in which these differ is in the availability of the pathogen. For potato blight it is normally present and the development of the disease awaits only the occurrence of favourable weather; for black rust of wheat it has to be imported from outside the British Isles and the possibility of spore transport is a major factor in relation to the disease. The forecasting of these diseases on meteorological grounds is also discussed. For potato blight, a workable scheme has been in operation for many years, but at present there is no warning system for black rust.

Potato blight, *Phytophthora infestans.* The dependence of outbreaks of potato blight epidemics on the weather has long been recognized and Beaumont[1] investigated this in some detail at Seale-Hayne Agricultural College. Blight appears in the crop as a result of infected tubers which may have survived in or on the ground from the previous season, or which may have been unwittingly planted. The fungus invades aerial shoots from these tubers to form foci from which the disease spreads to neighbouring plants. There are, therefore, normally ample supplies of the pathogen and the timing of the spread and the intensity of the epidemic is largely determined by the weather.

As with many plant diseases the two most important weather variables are temperature and humidity. The rate of growth of the fungus depends on

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temperature, and infection requires a film of moisture on the leaf; the longer this film persists, the greater the opportunity for infection. There are obvious difficulties in making routine inspections of potato crops to determine whether the leaves are wet and this possibility is estimated from atmospheric humidity. For the Netherlands, van Everdingen[2] established that four conditions had to be met before outbreaks of blight occurred; these involved measurement or observation of dew, temperature, cloud amount and rainfall. Beaumont tested these in the south-west of England, simplified them and finally defined a critical period as one of 48 hours when :

(i) Temperature does not fall below 10°C, and

(ii) relative humidity does not fall below 75 per cent.

His examination of the south Devon weather records for July and August over 10 years showed that critical periods occurred in 7 years and that in each of these years the first critical period was followed by blight within 22 days; in 4 of the seasons, blight followed within 15 days; and in the 3 years without critical periods there were only slight attacks of blight.

Since 1950 Beaumont periods have been used as the basis of a warning system for England and Wales, with the modification that the criteria need be met on only 46 out of 48 hourly observations. The warnings use hourly observation of air temperature and humidity from some 40 synoptic stations of the Meteorological Office, and the Plant Pathology Laboratory of the Ministry of Agriculture, Fisheries and Food maintains an operations chart, an example of which is given in Figure 1. Clearly, the success of such a service depends on close co-operation between meteorologists and plant pathologists.

The operations charts for a period of years can be used to give a general picture of the likelihood of weather favourable to the general spread of potato blight. Table I shows this for four meteorological stations in south-west England and for Abingdon in Berkshire. The values represent the number of hours of Beaumont periods during June, July and August; in other words, the total number of hours with temperature $\geqslant$10°C and relative humidity $\geqslant$75 per cent provided that these occur during or immediately following periods of 48 hours, at least 46 of which satisfy these criteria; a Beaumont period is terminated when the criteria are not reached for 3 consecutive hourly observations.

TABLE I—HOURS OF BEAUMONT PERIODS, JUNE–AUGUST 1959–68

	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	Mean
St Mawgan (near Newquay)	535	1073	633	865	1212	1270	1226	576	1293	1010	969
Plymouth	575	792	450	776	1298	1215	1379	830	1207	792	931
Exeter	381	341	6	336	599	261	350	142	242	332	299
Bristol	329	388	49	53	369	204	456	228	331	307	271
Abingdon (Berks.)	63	67	0	0	153	61	153	251	88	165	100

The chance of potato blight weather varies considerably over the West Country. As would be expected, places exposed to the moist winds off the Atlantic have far more of this weather than other parts. Exeter has lower humidities than places further west, because of its inland position in the lee of Dartmoor. It is not surprising that the values in the table are very little higher than those for Bristol. Naturally, inland places further east are still

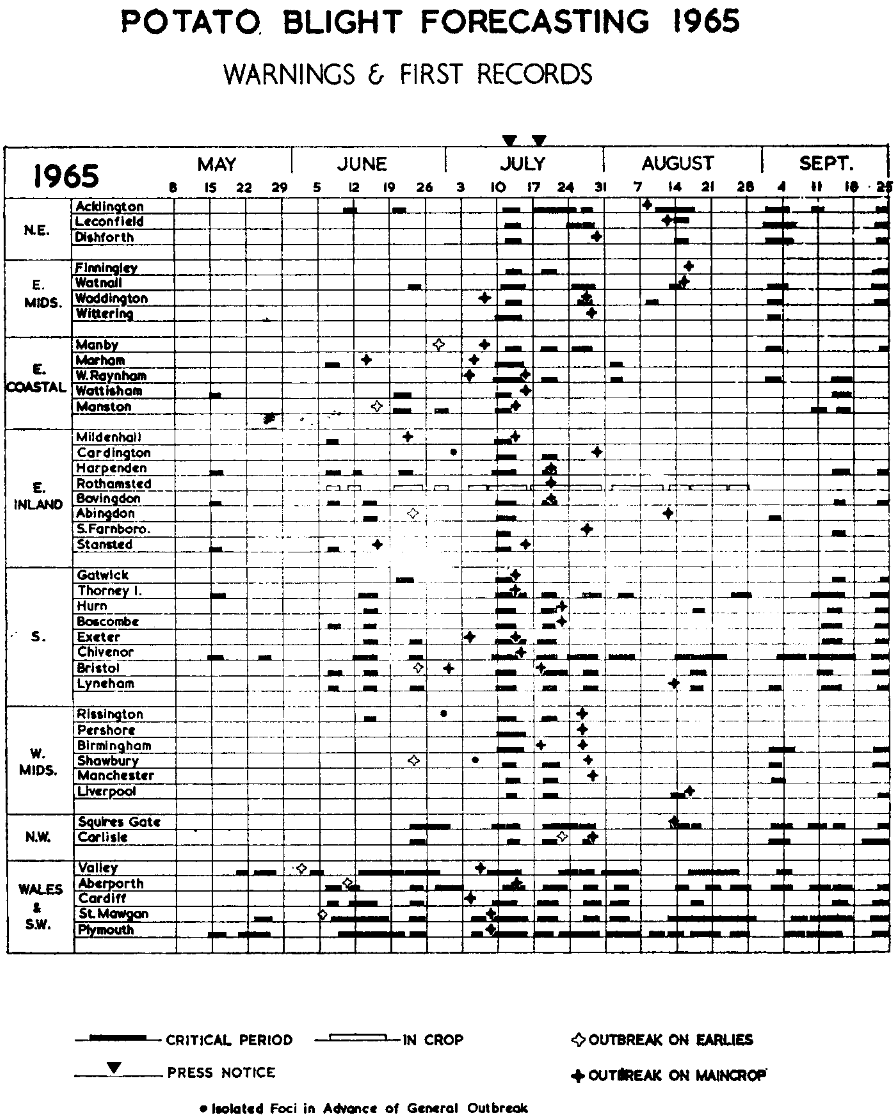

FIGURE 1—EXAMPLE OF AN OPERATIONS CHART

less likely to experience this weather and the average for Abingdon is only 100 hours. In practical terms, potato blight in the more humid parts of the West Country occurs with such regularity that a warning system is of limited use. Many farmers prefer to spray on a routine basis, confident that only occasionally will their efforts be wasted.

The potato blight warning system has on the whole proved a useful tool but it is worth considering whether it could be improved in any way. The objection is often raised that the records of temperature and humidity upon which the scheme rests are standard meteorological observations. They are taken in a thermometer screen over a grass surface at a height of about 4 feet

(1·2 m), often on an airfield, and are therefore not relevant to what may happen in a potato crop. While no doubt there are differences of micro-climate between different potato fields, the standard observations are used only as an indicator of what is likely to happen within the crop and there is no suggestion that temperature and humidity are the same as in the screen. A further point is that meteorologists should attempt to forecast the arrival of the damp warm weather of the Beaumont periods and give more time for spraying. In Ireland, Bourke[3] has identified three synoptic situations favourable for blight development :

(i) Open warm sectors of maritime tropical air, particularly when a sequence of waves is involved, bringing warm moist air with some rainfall.

(ii) Stagnant or slow-moving depressions giving long periods of wet overcast weather.

(iii) Active fronts which are more or less stationary and give long periods of wet overcast weather.

It is broadly true that similar reasoning could be applied in the west of Great Britain, but its use in the east is doubtful. The weather situations which hinder blight development can be somewhat more easily identified and Bourke gives the following as the most important :

(i) An anticyclone or a ridge of high pressure with dry sunny weather.

(ii) A direct breakthrough of cold air from northerly latitudes following a depression. Although the weather may be showery the intervening bright periods are not favourable to the spread of infection.

In the Netherlands, also, efforts are being made to predict the infection date as, from a purely practical standpoint, spraying should be done before this, since most fungicides lack any curative action (de Weille[4]). On the basis of laboratory work and field work the criteria over a period of 18 hours have been closely defined in weather terms and synoptic models have been adopted as the basis for predictive warnings.

This approach in countries to the east and west of Great Britain is interesting and may point the way to future development here. However, one must not forget that forecasting the weather will introduce a further element of uncertainty, and that reliability is the main aim.

Black rust of wheat, *Puccinia graminis* f. sp. *tritici*. In many ways our second example contrasts very much with the first. Unlike potato blight it is not a frequent disease in the British Isles and it is not economically important here, although it can be of great importance in the major wheat growing areas of the world, where it is largely controlled by breeding varieties of wheat which are not susceptible to the disease. In spite of this, serious epidemics can occur and we in Great Britain cannot rely on an indefinite immunity. Although it is difficult to control the disease other than by breeding, some progress is now being made with chemical controls. If any warning system were possible it might, within a few years, be possible to act on it. Perhaps the most fundamental way in which these diseases differ lies in the fact that black rust of wheat, unlike potato blight, is not normally capable of completing its life cycle within the British Isles and therefore it cannot occur unless a supply of inoculum is brought into the country. The only exception is that barberry may act as an alternate host allowing the disease to over-winter, and this has led to small outbreaks in Ireland (Prendergast[5]). Normally wind is the agent which transports the pathogen but many other meteorological factors are concerned with the whole process of development of the crops and disease and transport of the inoculum.

The complete life cycle of the disease does not concern us here and our interest is confined to the uredospores which may infect the crop. We shall consider the ways in which weather and climate act to determine what happens in the source area where the disease affects the local wheat crop, the ways in which the uredospores are liberated and transported from the crop to the higher layers of the atmosphere, how they are transported horizontally in the air, sometimes for long distances, how they are deposited on the wheat crop of the target area and what weather is favourable at that time to infection and, possibly, the establishment of an epidemic. Most of our attention will be directed to the question of horizontal transport of spores but a short generalized description of all the stages is given, based on Figure 2.

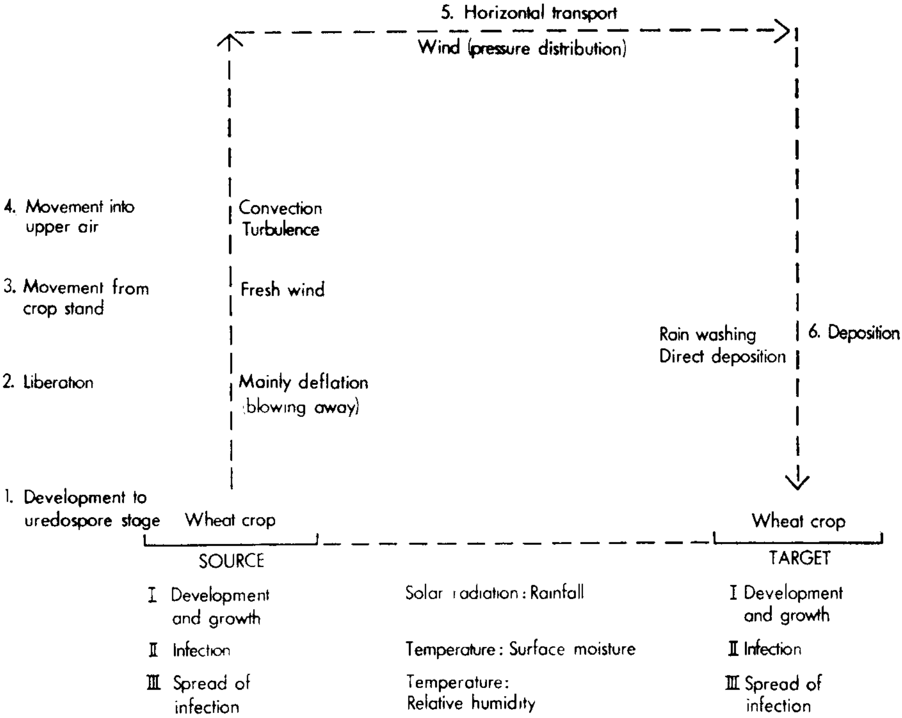

FIGURE 2—WEATHER FACTORS AND THE EPIDEMIOLOGY OF BLACK RUST OF WHEAT

It is convenient to think of a source area for the disease and a target area to which the pathogen is transported, the British Isles. Even if only the uredospore stage of the rust is considered there is a very complicated interaction between events in the source and target areas. In general terms, infection in this country depends on the phenology of the crop in both areas, the phenology of the rust in the source area and the possibility of spore transport followed by deposition and suitable weather in the target area.

The state of the crop in the source area is important in relation to the period of time for which it is exposed to infection; for example, a late crop will be at risk for a longer than normal period. This will depend fundamentally upon the weather factors of solar radiation and rainfall, though husbandry is also important. Uredospores over-winter in the source areas and infection there depends upon temperature and surface moisture. The spread of the infection is most rapid when humidity is high (temperature also needs to be high, but this is likely) and if the infection develops there will be an abundant supply of uredospores.

As a result of sporulation, the uredospores remain in place on the plant and form a dense mass of powder with little cohesion in the dry state and before dissemination they must be liberated (Zadoks[6]). Liberation is mainly achieved by deflation or shaking of the plant, though raindrop collision has already been cited as another possibility (Hirst and Stedman[7]). The next stage is movement from the crop stand and this is accomplished by the turbulent motion resulting from a fresh surface wind. At this stage horizontal motion will also increase in importance but the spores are unlikely to have a long path until they are carried higher into the atmosphere, a process assisted by larger-scale turbulence resulting from wind or convection. The horizontal transport is the result of wind at spore level and is dependent on the pressure distribution, i.e. the shape and the spacing of the isobars.

Before infection can result in the target area the spores must land on the plant, a process known as deposition. The spores are subject to gravity but sedimentation by this process alone is important only in still air, a somewhat rare occurrence. Other processes involved include turbulent deposition, direct interception or impaction, which is due to the fact that the spores cannot follow the streamlines of the air round the plants so that some of them are in collision with it. Probably the most important mechanism is rain-washing, by which the spores are brought down in the drops and the air is effectively cleansed. For infection to occur, the crop in the target area must be at a suitable stage of growth and the spread of infection will depend on local weather. The sequence of events will thus be similar to that in the source area, which may be many hundred miles and several degrees of latitude distant.

To return to the question of horizontal transport over long distances, any warning system must depend on a knowledge of source areas, so that a watch may be kept on winds from these areas. In continental areas the spread of disease over great distances can be well estimated from spore catches, the visible effects on the crop and the winds which blow between source and target areas. Such studies led to an understanding of the spread in North America, from Mexico and Texas northwards into the Prairie Provinces of Canada in spring and summer, followed by a reverse direction of movement in autumn (Stakman and Harrar[8]). For the British Isles this method is not possible because of the sea barriers between source and target areas and less direct methods msut be used.

Horizontal movement of the air is determined by the rotation of the earth and the distribution of atmospheric pressure, which can be represented on maps by isobars. In the lowest layers of the atmosphere, surface friction affects the speed and direction of wind but above about 600 m these effects may be ignored and a reasonable approximation to airflow may be derived from the direction and spacing of isobars. In general terms the wind is parallel to the isobars and speeds increase as the isobars are more closely spaced. Estimates of what is known as the geostrophic wind may be obtained without tedious calculation by using specially constructed scales but these estimates are based on certain assumptions which may not always be realized; they are, however, sufficiently close to the true wind to be acceptable as a substitute.

Pressure charts can provide an instantaneous picture of wind over the area and the lines of airflow derived from such charts are known as streamlines. The pressure patterns are, however, subject to change and displacement and they cannot therefore be used to indicate possible sources of spores except over short periods of time during which only minor changes occur in pressure distribution. It is therefore necessary to regard the pressure charts as valid only for short periods (normally the interval between successive charts). By estimating the movement of air towards the target area on a succession of charts, it is possible to indicate likely source areas and the trajectories between the source and target areas. Because any estimates of wind relate to geostrophic rather than true wind, the trajectories are only approximate and best designated as geostrophic trajectories. One interesting result which stems from the approximation inherent in the use of geostrophic trajectories is that in certain circumstances the trajectory from a possible source area for spores could reach the target area somewhat ahead of the moving air, and therefore before the spores are deposited.

For this work, spore counts were available from the Hirst spore trap at Cardiff (Hirst[9]), also from gravity slides both at Cardiff and at the Bishop Rock Lighthouse, in the Isles of Scilly. For the days on which spores were caught geostrophic trajectories were constructed reaching a target area at Plymouth. They were estimated from surface weather charts, which gave trajectories at about 600 m and also from upper air charts for the pressure levels 700 and 500 mb which gave trajectories respectively for about 3000 m and 5600 m, but only the lowest ones will be discussed here. Full results are given elsewhere (Hogg[10]); here, these may be summarized by saying that there was a close connection between spore deposition in this country and geostrophic trajectories from southerly or south-easterly directions. In years such as 1955 when the disease was observed early, the spores are more likely to have come direct from Spain or Portugal; in years when it appeared late the inoculum may have originated in France. The trajectories for 1955 are shown in Figure 3. There were spore catches on 26 May (Spanish trajectory) and on 31 May and 1 June (French trajectory) but these did not apparently lead to any infection and the main catches were on 6 June and 17/18 June, by which time the infection was probably established so that later catches were not important. The trajectory for the 6th was from southern Spain and the state of the crops at this time of the year support the idea that the uredospores were picked up from Spain.

In many ways the 1956 trajectories were interesting, particularly in that catches in June and early July occurred when trajectories at all levels were from the Atlantic. The number of spores caught was small and may not

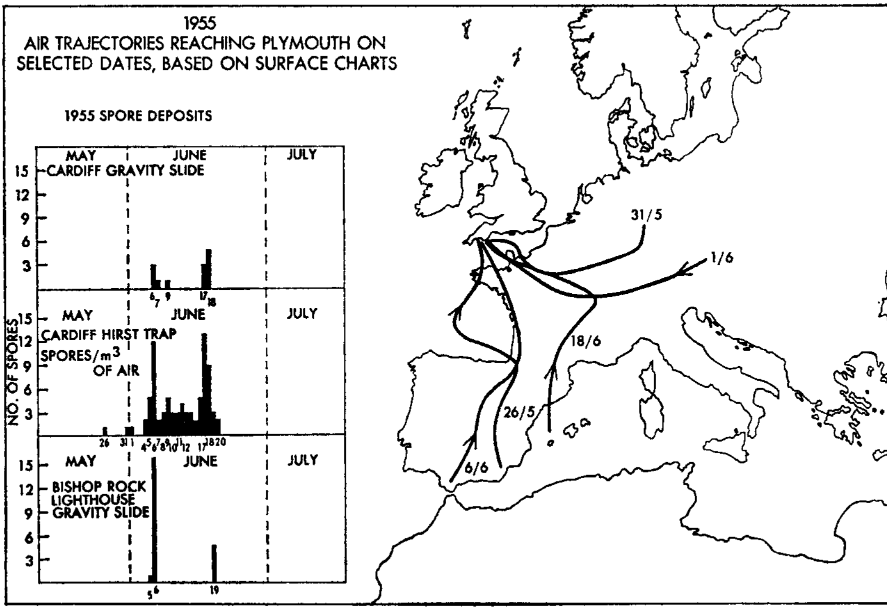

FIGURE 3—TRAJECTORIES AND SPORE COUNTS FOR MAY AND JUNE 1955

have led to infection but it raises the possibility of transatlantic transfer of spores. Some support is given to this possibility by the fact that a reasonable trajectory has been found for a moth which landed in Wales in 1954 (Hirst and Hurst[11]) but there is as yet no evidence that the disease has reached us from north America.

Finally, the validity of the results obtained from geostrophic trajectories may be demonstrated from some catches of *Puccinia graminis* uredospores made in London. An estimate of the total daily catch is given on Figure 4 (the figures are not absolute as they are derived from the addition of concentrations at various times of day, but it is clear that there are marked differences during the period). Relevant trajectories are also given on Figure 4 and it is apparent that the large catches occur with trajectories from the continent and small ones with Atlantic trajectories. Only one is doubtful, trajectory 5, for midnight on 9/10 July, which may have come from north Germany but which cannot be tracked beyond this because of the very weak pressure gradient associated with an area of high pressure. It is not certain whether north Germany should be regarded as the source, for the air may have travelled southwards along the North Sea as shown by the arrow and then turned south-westwards into the British Isles.

There is no warning system for black rust of wheat and, until recently, there was little point in devising one because no control measures existed. There are still no controls for use on a field scale but recent work on chemicals seems to be more hopeful. It may well be true that the present economic effect of the disease in this country does not justify the expenditure of much effort, but meteorologists and plant pathologists are very much concerned with what goes on in other countries and, if any warning system is possible, there can be little doubt that we should be involved at least in relation to the mainland of Europe.

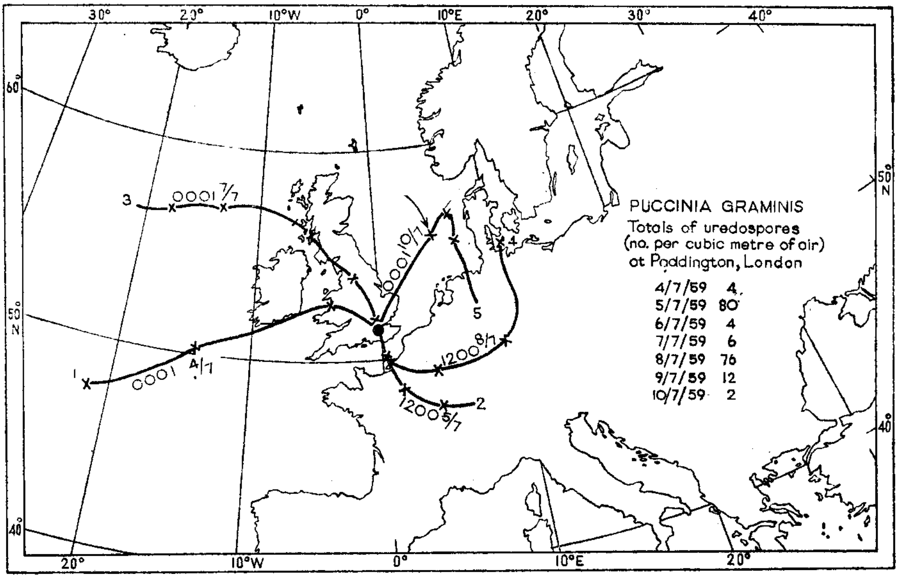

FIGURE 4—TRAJECTORIES AND SPORE COUNTS FOR JULY 1959

The trajectories are numbered from 1 to 5, and the time and date of the arrival of the air sample over London are noted for each. Crosses show estimated positions of the air samples at intervals of 12 hours.

It is evident that no warning system could be based on meteorological factors alone and that both wheat phenology and rust phenology would have to be considered. In addition, the possibility of airborne transport of spores will need to be studied, and observation of spore clouds may provide a good means of forecasting outbreaks and epidemics of black rust in much of Europe. Traps such as the Hirst spore trap could be used, possibly supplemented by a wider distribution of simpler apparatus to help define the spread of spores. In view of the probable origin of some spores in North Africa, spore trapping along the northern shores of the Mediterranean is desirable. The role of the meteorologist here would be to provide a background against which these biological observations may be set. A series of spore trappings becomes much more meaningful when studied in relation to trajectories based on surface and upper air charts which could form a basis for the extrapolation of spore data to areas without sampling. Also, a routine programme of trajectory plotting could give indications of the possibility of spore transport before the time-consuming examination of the slides had been finished. Even a recognition of the synoptic situations which give a high probability of transport from source areas to wheat growing areas could be very valuable at certain stages of rust and wheat phenology.

Provided that the spores are present in the air and are deposited on to plants in the right state for infection, the possibility of spore germination depends on weather and the main criteria are fairly high temperatures with free water on the plant surface. Generalizing from Zadoks[6] the optimum temperature can be taken as ranging from 20 to 29°C for different stages of the infection process and bright weather is probably the most suitable with little cloud and dew-formation during radiation nights. As a slow evaporation of dew after sunrise is an advantage, high humidity is favourable.

However, these are optimal conditions and epidemics occur and spread in a suboptimal environment and one problem remaining is the definition of the limits which if surpassed will give a high probability of the disease, provided that the uredospores have been transported from a source area in sufficient quantity.

Acknowledgements. My thanks are due to the Director, Plant Pathology Laboratory, for permission to use Figure 1.

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A NOTE ON THE USE OF THE UPPER WIND HODOGRAPH

By A. E. PARKER

Summary. The average wind field for eight warm fronts which gave rain was used to calculate total divergence and vertical motion at various heights and distances from the surface warm front. It is shown both theoretically and practically that the wind components towards the cold air and normal to a rainy warm front increase with height above the frontal surface. Data for the average wind field were used to construct typical upper wind hodographs at various distances from the surface warm front. Finally an interesting example of an inactive warm front is examined.

Introduction. In a previous paper* the present writer discussed the different types of wind hodographs from upper wind soundings made in the vicinity of active and inactive fronts. A forecasting rule was derived that a

* PARKER, A. E.; Relation between upper wind structure and rainfall at fronts. *Met. Mag., London*, **78**, 1949, pp. 247–258.

warm front will be active (i.e. produce rain) if the wind component normal to the front and towards the cold air increases markedly with height above the frontal surface. In the present paper a theoretical derivation of this rule is given. The mean wind fields for eight warm fronts giving rain are also examined in order to calculate the vertical motion in the neighbourhood of an average active warm front.

A theoretical estimate of the cross-frontal flow at an average active warm front. If pressure p is used as the height co-ordinate, the vertical motion ($\mathrm{d}p/\mathrm{d}t$) in the atmosphere may be obtained by integrating the equation of continuity, in the form

$$\frac{\partial}{\partial p}\left(\frac{\mathrm{d}p}{\mathrm{d}t}\right) = -\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right)$$

over the height range p_1 to p_2 to give

$$\left[\frac{\mathrm{d}p}{\mathrm{d}t}\right]_{p_1}^{p_2} = -\int_{p_1}^{p_2}\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right)\mathrm{d}p, \qquad \ldots(1)$$

where u and v are isobaric wind components in the directions x and y, normal to and parallel to the front, respectively, these axes being embedded in a constant-pressure surface and depicted in Figure 1. Component u is positive towards the cold air and component v is positive towards low pressure. The

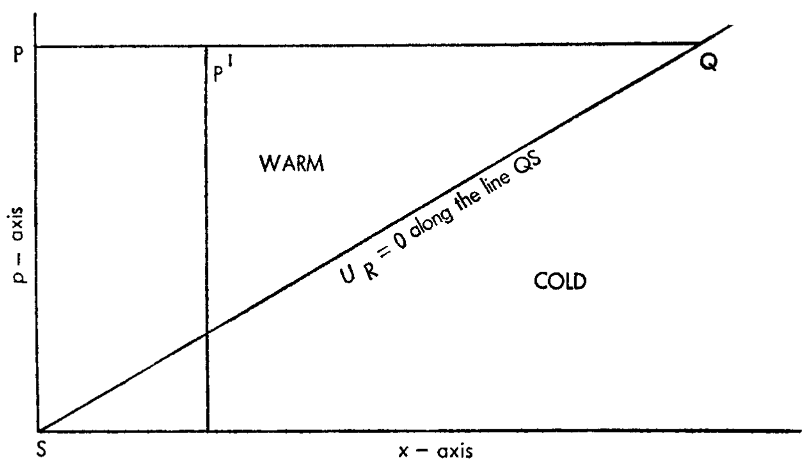

FIGURE 1—VERTICAL CROSS-SECTION THROUGH A WARM FRONT

The y-axis is directed into the paper. At P the velocity relative to the warm front and in the x-direction is u_2.

right-hand side of equation (1) is not an easy quantity to deal with and a practising forecaster needs something which will indicate positive or negative vertical motion almost at a glance. If for the moment the term $\partial v/\partial y$ in equation (1) is ignored, the vertical motion is given by

$$\left[\frac{\mathrm{d}p}{\mathrm{d}t}\right]_{10} - \left[\frac{\mathrm{d}p}{\mathrm{d}t}\right]_{2} = -\int_{2}^{10}\frac{\partial u}{\partial x}\,\mathrm{d}p, \qquad \ldots(2)$$

in which suffix 10 denotes 1000 mb, and suffix 2 a level of lower pressure.

Since $(\mathrm{d}p/\mathrm{d}t)_{10}$ may be taken as zero,

$$\left[\frac{\mathrm{d}p}{\mathrm{d}t}\right]_2 = \int_2^{10} \frac{\partial u}{\partial x}\,\mathrm{d}p.$$

Now refer to Figure 1 which depicts a vertical cross-section of winds relative to a warm front, i.e. the speed of the front has been subtracted from all the u components. If $(\mathrm{d}p/\mathrm{d}t)_2$ is not to be zero then $\partial u/\partial x$ cannot be zero, and the larger $\partial u/\partial x$ is (for an active front it will be negative) the larger $\mathrm{d}p/\mathrm{d}t$ becomes. Let the u component relative to the front be u_R.

Since u_R is zero at S and Q the velocity u_2 at P can be written

$$\int_S^P \frac{\partial u}{\partial p}\,\mathrm{d}p \text{ or as } -\int_Q^P \frac{\partial u}{\partial x}\,\mathrm{d}x,$$

and it follows that $-\partial u/\partial p$ cannot be zero and for an active front u_R must increase with decrease of pressure, i.e. u_R must increase with height, a result which is really obvious from Figure 1.

Estimation of the value of u_R at some height to produce a given vertical motion at that height. It will be of interest to make an estimate of the cross-frontal flow to be expected at an average active warm front in order to see if it would be apparent on a wind hodograph. As wind speeds were measured in knots, horizontal distances have been quoted in nautical miles so that horizontal divergence appears in knots/n. mile. (Conversion to SI units may be made by using the relationships 1 knot $\approx$ 0·5 m/s; 1 n. mile $\approx$ 1850 m; 1 mb = 10^2 N/m^2.)

If $\mathrm{d}p/\mathrm{d}t$ is 35 mb/h at the point P′ in Figure 1 at a height of 465 mb and 50 n. miles from the surface front, then from equation (2)

$$-35 = (\partial u/\partial x)_m 535$$

where $(\partial u/\partial x)_m$ is the mean value of $\partial u/\partial x$ over the pressure layer 1000 to 465 mb, i.e. 535 mb. Therefore

$$(\partial u/\partial x)_m = -35/535 = -0{\cdot}065 \text{ knots/n. mile.}$$

If the distance P′Q is 300 n. miles and if $\partial u/\partial x$ over this distance has a mean value similar to $(\partial u/\partial x)_m$ then u_R at 465 mb will be 0·065 × 300 = 20 knots. In practice $\partial v/\partial y$ is not zero but positive and so u_R must be larger than 20 knots to give the assumed upward motion of 35 mb/h. The foregoing estimate of cross-frontal flow is of course rather crude but it does suggest that the cross-frontal flow at an active warm front will be appreciable and easily apparent on an upper wind hodograph.

Average values of u_R from eight warm fronts. Some data have recently been made available which may here be taken as representative of an average active warm front. Figure 2 (personal communication from M. K. Miles), is a vertical cross-section giving mean values of u_R from eight well-marked warm fronts with rain. These fronts were chosen as clearly defined fronts which were located conveniently in relation to available radiosonde ascents. The mean cross-section was prepared in the hope that it would bring out some of the features of the wind fields common to the individual warm fronts. The velocity u_R was obtained by subtracting the speed of the front from all the values of u, to give the flow relative to the front. The zero isotach of u_R may be taken to define the front for the purpose of this paper and has a slope of about 1 in 110. The strong convergence along and above the front is apparent, i.e. there are large negative values of $\partial u/\partial x$. The calculations made in the previous section apply to a vertical section 50 n. miles from the surface front (i.e. at P′ in Figure 1) where the value of u_R from Figure 2 is 27 knots, i.e. larger than 20 knots, as suggested in the previous section. The value of dp/dt at 465 mb and 50 n. miles from the surface front in Figure 2 was estimated as 35 mb/h. The strong cross-frontal flow is apparent at a glance from Figure 2.

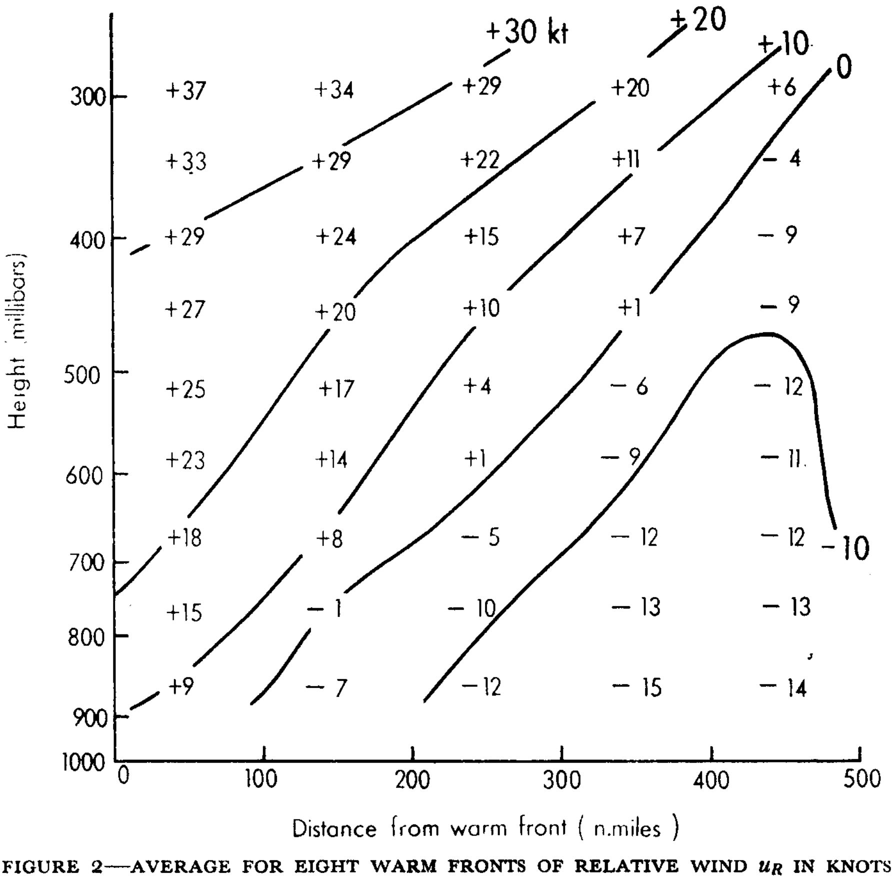

FIGURE 2—AVERAGE FOR EIGHT WARM FRONTS OF RELATIVE WIND u_R IN KNOTS

The vertical motion at an average active warm front. From Miles's data in Figure 2 and the data for $\partial v/\partial y$ in Table I (also a personal communication from Miles), the total divergence was calculated at various pressure levels and distances from the surface front and the results are given in Figure 3. Interpolations and extrapolations were used to obtain values of $\partial v/\partial y$ not given in Table I. At 100 n. miles from the surface front there is convergence from 1000 to 455 mb with increasing divergence at pressures less than 465 mb. The convergence in the lower levels of the troposphere decreases with distance from the front and at 400 n. miles there is divergence from 1000 to about 525 mb and convergence at lower pressures.

TABLE I—VALUES OF $\partial v/\partial y$ FOR AN AVERAGE ACTIVE WARM FRONT

Pressure	$\partial v/\partial y$
mb	*knots/100 n. mile*
850	7
700	9·5
500	6
400	7
300	8·5

Note : According to Miles the above values are practically constant over several hundred nautical miles at right-angles to the front.

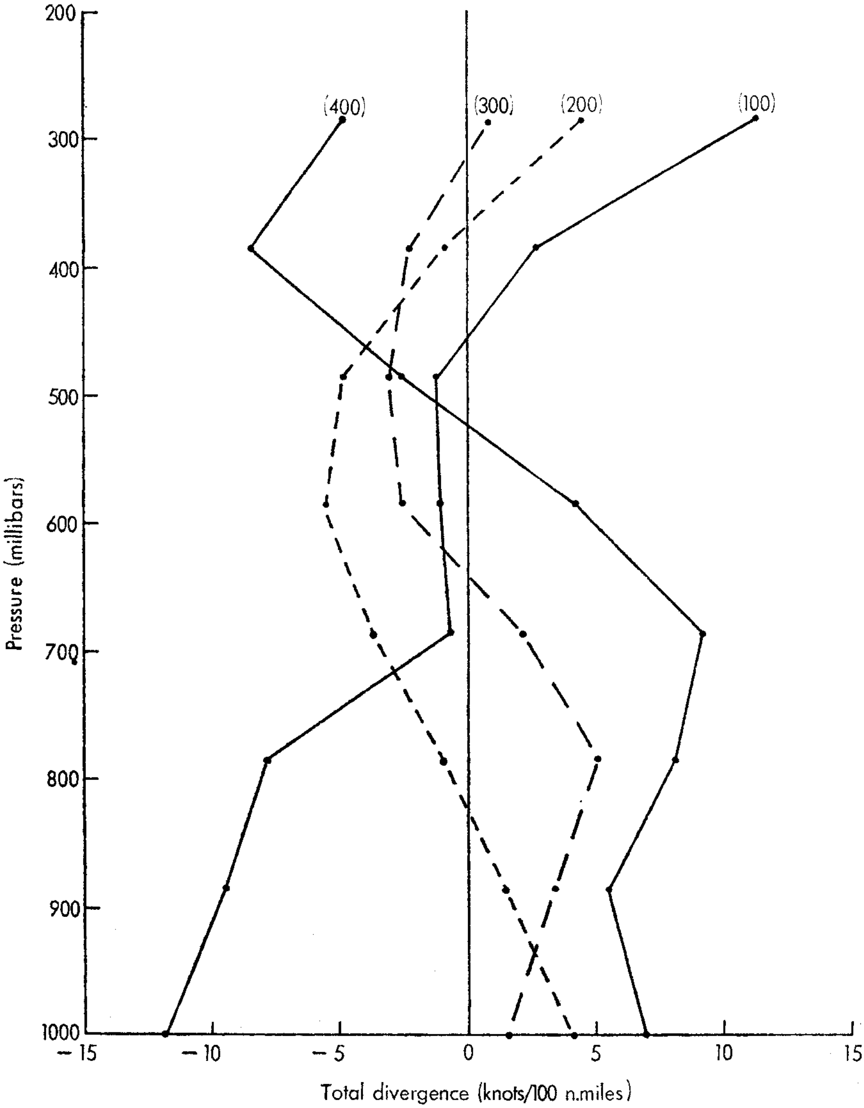

FIGURE 3—THE VARIATION OF DIVERGENCE WITH PRESSURE AT VARIOUS DISTANCES FROM THE SURFACE WARM FRONT FOR AN AVERAGE ACTIVE WARM FRONT

The numbers in brackets indicate the distance from the surface warm front in nautical miles.

The divergence values given in Figure 3 were integrated with respect to pressure using the simple trapezoidal rule to give (dp/dt – pressure) profiles which are given in Figure 4. At 100 n. miles from the front dp/dt is negative for all pressures less than 1000 mb. There is subsidence from 1000 to 655 mb at 200 n. miles from the front with upward motion for pressures less than 655 mb. The strong subsidence at 500 mb and 400 n. miles from the front is noteworthy and is due to high-level convergence.

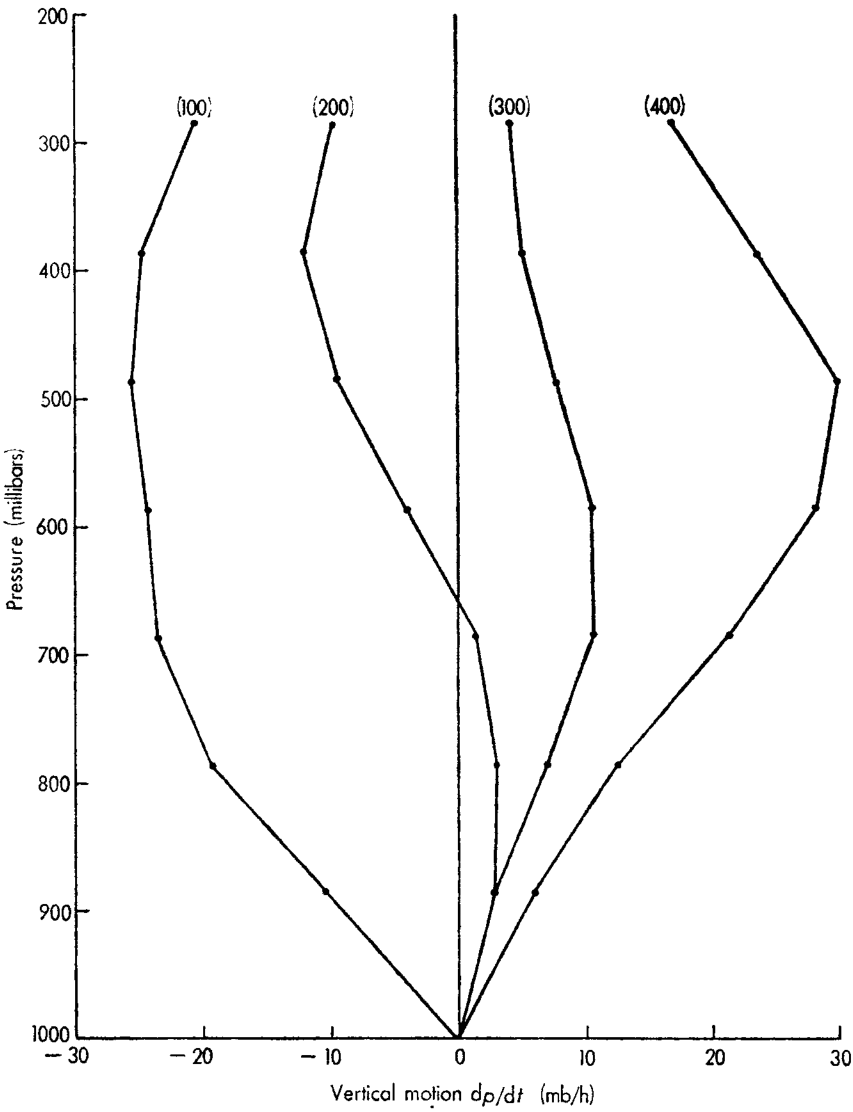

FIGURE 4—THE VARIATION OF VERTICAL MOTION WITH PRESSURE AT VARIOUS DISTANCES FROM THE SURFACE FRONT FOR AN AVERAGE ACTIVE WARM FRONT

Finally the results given in Figure 4 were used to produce the cross-section of vertical motion shown in Figure 5. This cross-section is of great interest

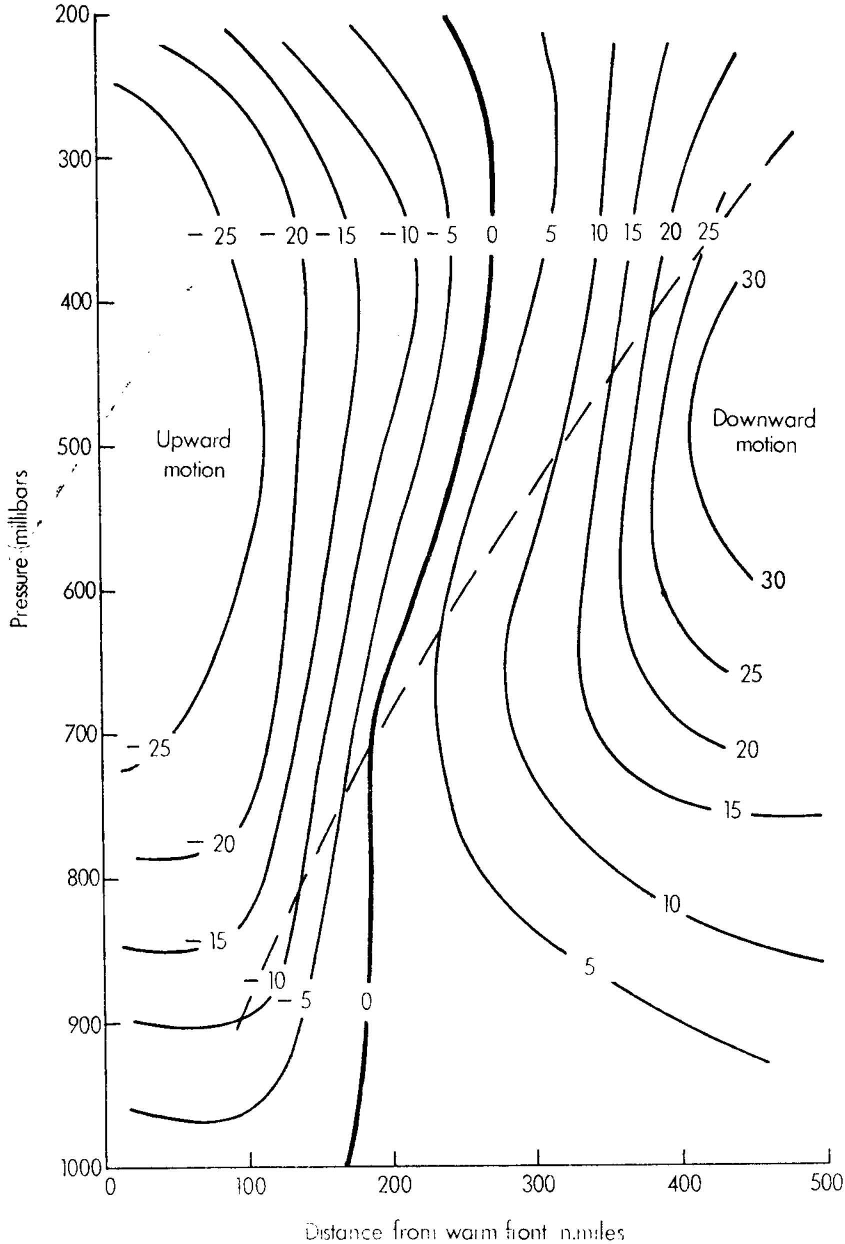

FIGURE 5—AVERAGE FOR EIGHT WARM FRONTS OF THE CALCULATED VERTICAL MOTION

Isopleths give vertical motion in millibars per hour. The pecked line gives the position of the zero isopleth of u_R as given in Figure 2 and may be taken to represent the slope of the front.

as it illustrates a number of characteristics of warm fronts which have been observed in practice. Firstly note the position of the zero isopleth of d*p*/d*t*. It does not lie along the front. At first sight one might be tempted to expect no frontal cloud to the right of this isopleth but this would not be so as cloud formed to the left of this line could be advected to the right of it and then be dissipated by subsidence. It follows that the slope of the frontal cloud is greater than the slope of the front, a fact which has been observed from an analysis of aircraft observations. Secondly the front itself is subsiding to the right of the isopleth delineating zero vertical motion and so must be ill-defined in this region. To the left of this isopleth the air has upward motion and this also applies to the air below the front which is possibly somewhat surprising. The convergence and vertical motion serve to keep the front quite sharp to the left of the zero isopleth of d*p*/d*t*.

Upper wind hodographs at various distances from the surface front for an average active warm front. The data given in Figure 2 and values of *v* (obtained from a personal communication from M. K. Miles but not reproduced here) were used to construct upper wind hodographs for positions at various distances from the surface front and on the cold side of it. The results are given in Figure 6 in which wind components have been plotted, since Miles gave the data in this way. The strong cross-frontal flow at 50 n. miles from the surface front should be noted and in particular at 300 mb the air was moving 37 knots faster than the front. However it does not always follow that there is upward motion if the wind component normal

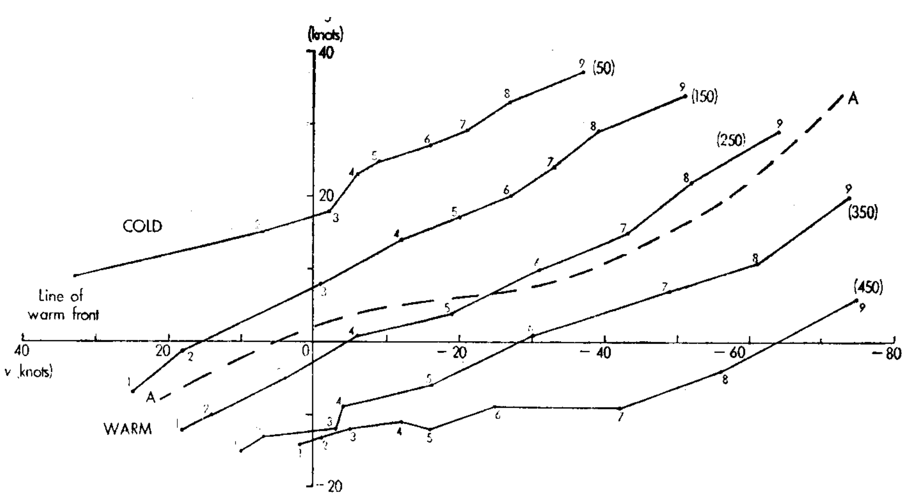

FIGURE 6—UPPER WIND COMPONENTS RELATIVE TO THE FRONT AT VARIOUS DISTANCES FROM THE SURFACE FRONT

The numbers in brackets at the end of each line indicate the distance in nautical miles from the surface warm front. The pecked line AA represents the *u*, *v* values corresponding to the heights and positions, with respect to the front, of the zero isopleth of d*p*/d*t* in Figure 5. The values were obtained from Figure 2 and corresponding data for *v*; d*p*/d*t* is negative on the cold side of the pecked line.

Heights in millibars for the plots numbered 1–9 :

Plot	1	2	3	4	5	6	7	8	9
Height *(mb)*	900	795	700	615	540	465	410	355	300

to the front is greater than the speed of the front. For example at 350 n. miles from the front and at a height of 300 mb the u_R component from Figure 6 is 20 knots (i.e. 20 knots faster than the front) but Figure 5 shows that the air was subsiding at this level. Nevertheless one would be justified in concluding from this rather large cross-frontal flow of 20 knots that there would be upward motion nearer the front and thus that it would be active. This follows since the u_R components increase progressively as the front is approached.

At this point it may be instructive to restate the prognostic criterion for the activity of a moving warm front. A moving warm front will be active if the u components increase appreciably with height through the frontal surface, an average value for the rate of increase required being shown by Figure 6 in which the pecked line corresponds to no vertical motion. A warm front will be inactive if the u components above the frontal surface do not increase with height faster than a certain value which is determined of course by the values of $\partial v/\partial y$.

An example of an inactive warm front. Rather a lot of attention has been devoted to active warm fronts in the previous sections so it should be interesting and instructive to examine the wind structure of an inactive warm front. Table II gives the upper air sounding for Camborne at 12 GMT on 26 March 1968. The winds for the 12 GMT sounding have been plotted on a diagram in Figure 7 which gives the components normal to and parallel to the warm front. At the time of the sounding the warm front was approaching Camborne from about west-north-west and it was estimated that the base of the warm air over Camborne was at about 799 mb but its exact height is not important for the present analysis. The fact that it was a warm front with a large temperature discontinuity is confirmed by the direction of the wind shear above 799 mb and by the magnitude of the wind shear of about 74 knots from 799 to 300 mb.

From 799 to 640 mb the u component of wind decreases with height, which represents downward motion. Consequently subsided (dry) air would be expected at 700 mb and this is confirmed since the depression of the dew-point was 22 degC at 700 mb and was probably even greater at 640 mb. The u component of wind increased from 640 to 500 mb so the relative humidity

TABLE II—UPPER AIR DATA FOR CAMBORNE AT 12 GMT, 26 MARCH 1968

Pressure *mb*	Wind *degrees/knots*	Dry bulb *°C*	Dew-point depression *degC*
(Surface)	230/12	10·6	4·2
1000		7·6	6
850	245/23	−1·2	8
799	250/27		
717	260/17		
700	275/10	−6·2	22
640	360/08		
574	330/13		
510	320/15		
500	320/15	−19·4	10
449	350/18		
400	340/30	−32·1	9
300	005/58		
239	015/76		

at 500 mb would be expected to be higher than that at 640 mb, a point confirmed by the dew-point depression of 10 degC at 500 mb. The *u* components in the layer 400–300 mb were greater than the speed of the front but no upward motion would have been expected owing to the strong subsidence lower down. The absence of frontal cloud on this front was confirmed by an aircraft from the Meteorological Research Flight which investigated it.

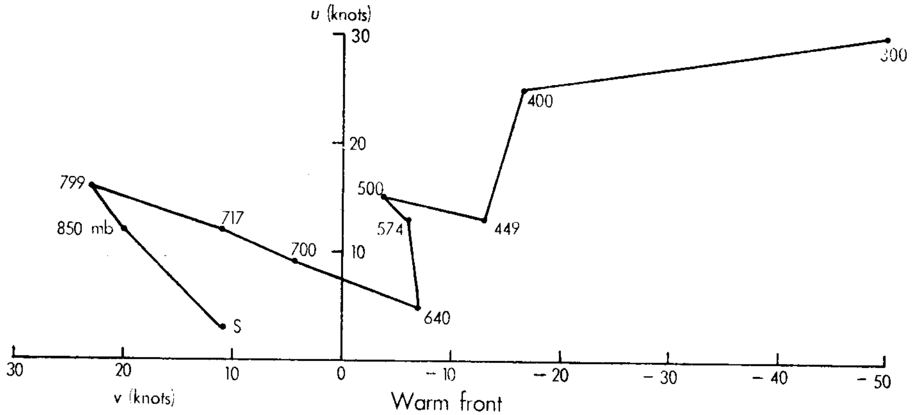

FIGURE 7—WIND COMPONENTS, NORMAL TO AND PARALLEL TO THE FRONT, DERIVED FROM THE CAMBORNE SOUNDING AT 12 GMT, 26 MARCH 1968

S indicates the surface wind and the other heights are in millibars.

Some remarks on wind structure at cold fronts. Some instructive examples of the wind structure on cold fronts were given in the 1949 paper. Three types of cold front occur in practice and are as follows :

(i) The most frequent active cold front in which the wind shear vectors remain approximately parallel to the front but with no large cross-frontal component.

(ii) The katafront in which the *u* components, in the warm air above the frontal surface, increase rapidly with height and are greater than the speed of the front.

(iii) The anafront in which the *u* components in the warm air above the frontal surface decrease with height and are considerably less than the speed of the front.

The weather which occurs with types (ii) and (iii) is what would be expected from the characteristics of the *u* components but there is comparatively little cross-frontal flow with type (i). Since the term $\partial u/\partial x$ seems small the vertical motion must stem from fairly large negative values of $\partial v/\partial y$. An analysis of examples of this type of front on the lines of the analysis carried out by Miles would be very valuable and enable the values of $\partial u/\partial x$ and $\partial v/\partial y$ to be obtained.

Final remarks. The main conclusions to be drawn from the results presented in this paper are summarized below.

(i) At an active warm front the vertical motion is due entirely to convergence towards the front which is manifested by an increase with height of the *u* wind component above the frontal surface — a most useful prognostic tool. However owing to the positive value of $\partial v/\partial y$ the *u* component must exceed a certain value before upward motion occurs.

(ii) In the upper portions of an average active front there is subsidence while upward motion occurs in the lower parts. From this it follows that the lower parts of the front remain sharp but the upper parts become diffuse and acquire the properties of a subsidence inversion.

(iii) The zero isopleth of $\mathrm{d}p/\mathrm{d}t$ does not lie along the frontal surface. This means that the frontal cloud has a steeper slope than the front itself and implies that a single observer would tend to overestimate his distance from a surface warm front if he based his estimate on the height of the leading edge of cirrus cloud.

The writer has found the variation of *u* component with height a most useful prognostic tool and it is most valuable when considering the onset or otherwise of activity at stationary fronts; but caution should be used in the neighbourhood of occlusions.

Finally the writer feels that in spite of sophisticated atmospheric models and the use of large computers there should still be a place in the forecaster's repertoire for the use of the upper wind hodograph which is so quick and easy to apply.

Acknowledgement. The writer would like to thank Mr M. K. Miles for making his data for eight warm fronts available for this study.

551.515.4

A SUDDEN SQUALL AT SHARJAH, TRUCIAL STATES

By H. DOUGLAS

Summary. On 17 January 1970 at Sharjah there was a noteworthy squall at about 21 GMT in which the wind gusted to 47 knots and the temperature fell by about 8 degC. Instrumental records of surface conditions and a time cross-section of upper air ascents in the area are presented and discussed. The instability which gave rise to the squall is attributed to the overrunning of air with a high wet-bulb potential temperature by a high-level trough. The peak wind observed was found to be in good agreement with the value which would have been forecast by application of the technique due to Fawbush and Miller.

A good example of the wind squall and fall of temperature often associated with well-developed cumulonimbus clouds was recorded at Sharjah, Trucial States, at about 21 GMT on 17 January 1970 and is illustrated in Figures 1 and 2.

The anemograph record (Figure 1) shows that the squall, in which the wind gusted to 47 knots (24 m/s), occurred in a period of otherwise light winds. The sudden onset of the north-westerly surface wind is seen to have occurred some three hours later.

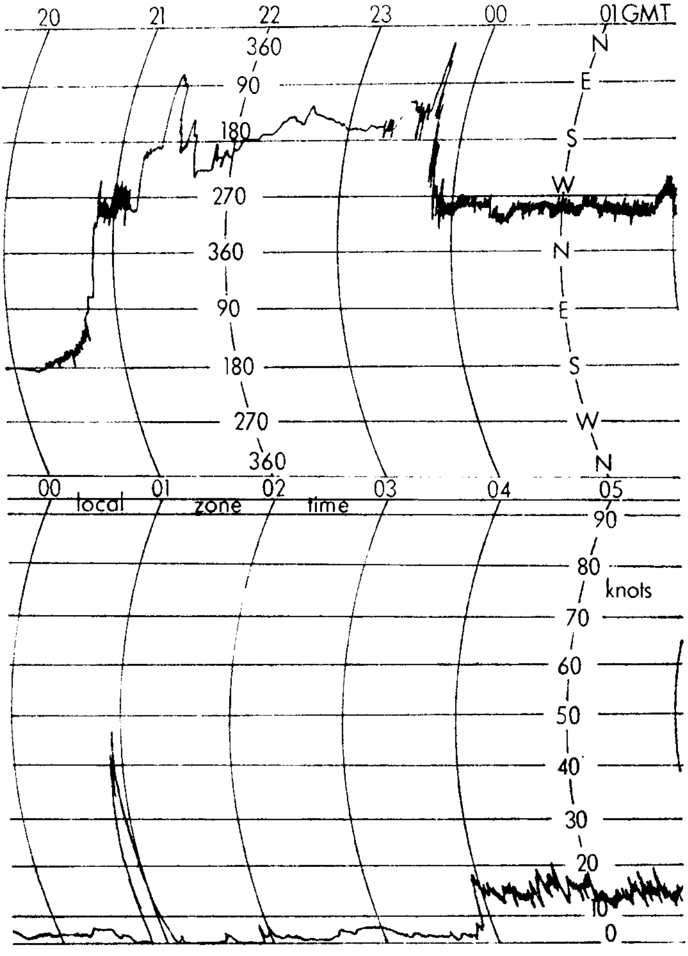

FIGURE 1—DIAGRAMMATIC REPRESENTATION OF THE ANEMOGRAPH RECORD AT SHARJAH 17–18 JANUARY 1970

Times are shown in GMT and in local zone time (GMT + 4 hours).

The thermograph record (Figure 2) shows a rather unsteady fall of temperature during the afternoon and evening prior to the onset of the squall, when a rapid fall of some eight degrees took place. After the squall the temperature rose a little, and with the arrival of the north-westerly wind recovered to about 18°C, rising further after dawn. The temporary drop in temperature on the 18th between 06 and 08 GMT (10 and 12 local time zone) was associated with a further veer of the surface wind.

The synoptic situation at 12 GMT on the 17th is shown in Figure 3. The depression over south-east Arabia moved from the eastern Mediterranean

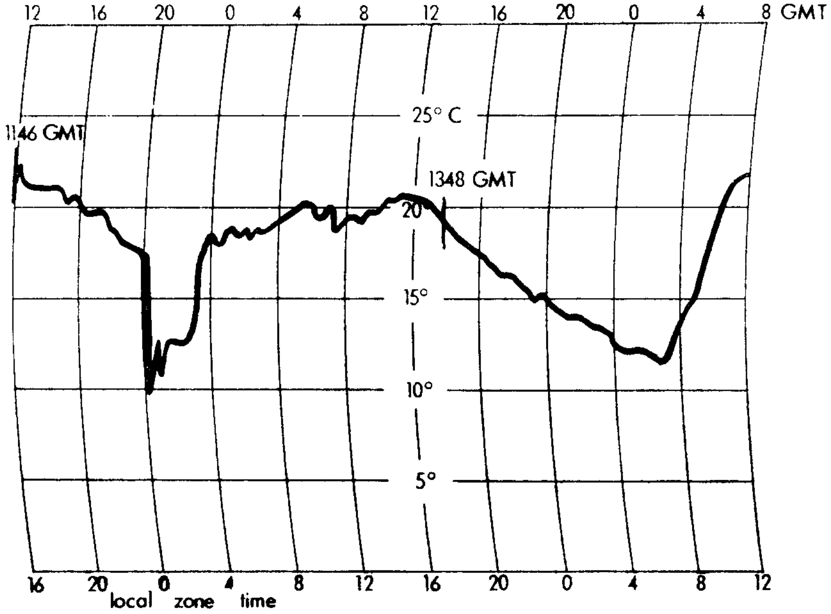

FIGURE 2—THERMOGRAPH RECORD AT SHARJAH 17–19 JANUARY 1970

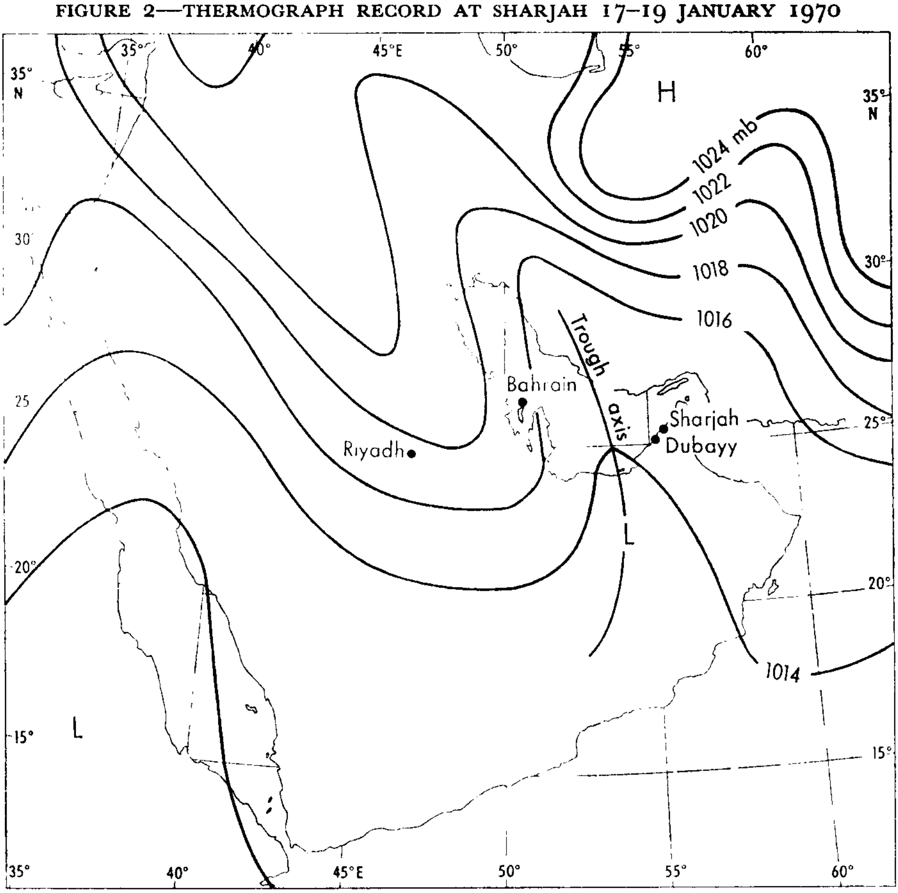

FIGURE 3—SYNOPTIC SITUATION AT 12 GMT 17 JANUARY 1970

on the 14th, across southern Syria, then turned south-east into Arabia and passed between Riyadh and Bahrain. It subsequently continued east across southern Oman into the north Arabian Sea. Its movement was associated with that of a trough in the strong flow at high levels.

This synoptic situation is similar to that associated with the more severe storm of 23 November 1957 described by Murray and Coulthard;[1] in particular, the surface low-pressure area on both of these occasions passed to the south of Sharjah.

A detailed mesoscale analysis of the situation is not possible owing to the scarcity of observations in the area. (The Meteorological Office at Sharjah does not maintain a full observing watch and indeed was closed at the time of the storm — another, rather unfortunate, similarity between this occasion and the one described by Murray and Coulthard.)

A time cross-section of the radiosonde ascents made at Bahrain (Figure 4), however, reveals that the orientation of the trough axis was not uniform with height. The veer of wind at high levels occurred at the same time as that at low levels, but the veer at middle levels occurred later. No precipitation was reported at Bahrain during the passage of the trough but outbreaks of rain and thunderstorms developed as it moved eastwards. One of these thunderstorms gave the squall at Sharjah and the 15 mm of rain recorded overnight was attributed to this storm. By contrast, although lightning was seen at Dubayy Airport, 8 miles (13 km) to the south, no rain fell there nor were any strong gusts experienced.

An examination of the wet-bulb potential temperatures (WBPT) shows that the lowest WBPTs in the upper troposphere were associated with the axis of the upper trough, and that the highest WBPTs in the lowest layers were found ahead of the surface trough.

The surface low passing to the south of Sharjah would serve to delay the onset of the surface north-westerlies and thus maintain air with a high WBPT at low levels. The overrunning of this air by the unimpeded high-level trough axis with its low WBPTs is thought to have produced the unstable situation in which the storm occurred.

Fawbush and Miller[2] have described a technique for forecasting the peak winds in non-frontal thunderstorms. They associated the strength of the peak winds with the difference between the surface air temperature ahead of the storm and the temperature of the 'downdraught' when it reaches the surface. They found that an estimate of the 'downdraught' temperature at the surface was given by the WBPT at the level at which the wet-bulb temperature was 0°C.

The Bahrain ascent for the 17th at 00 GMT (Figure 5) has been taken as being fairly representative of conditions at Sharjah at the time of the storm, although the air at Sharjah probably had a higher WBPT at low levels and a lower WBPT at high levels than this ascent indicates. The wet-bulb temperature is 0°C at 780 mb, giving a WPBT of 11°C. This compares well with the 'downdraught' lowest temperature of 10°C recorded on the thermograph and confirmed by the minimum-thermometer reading of 9·7°C.

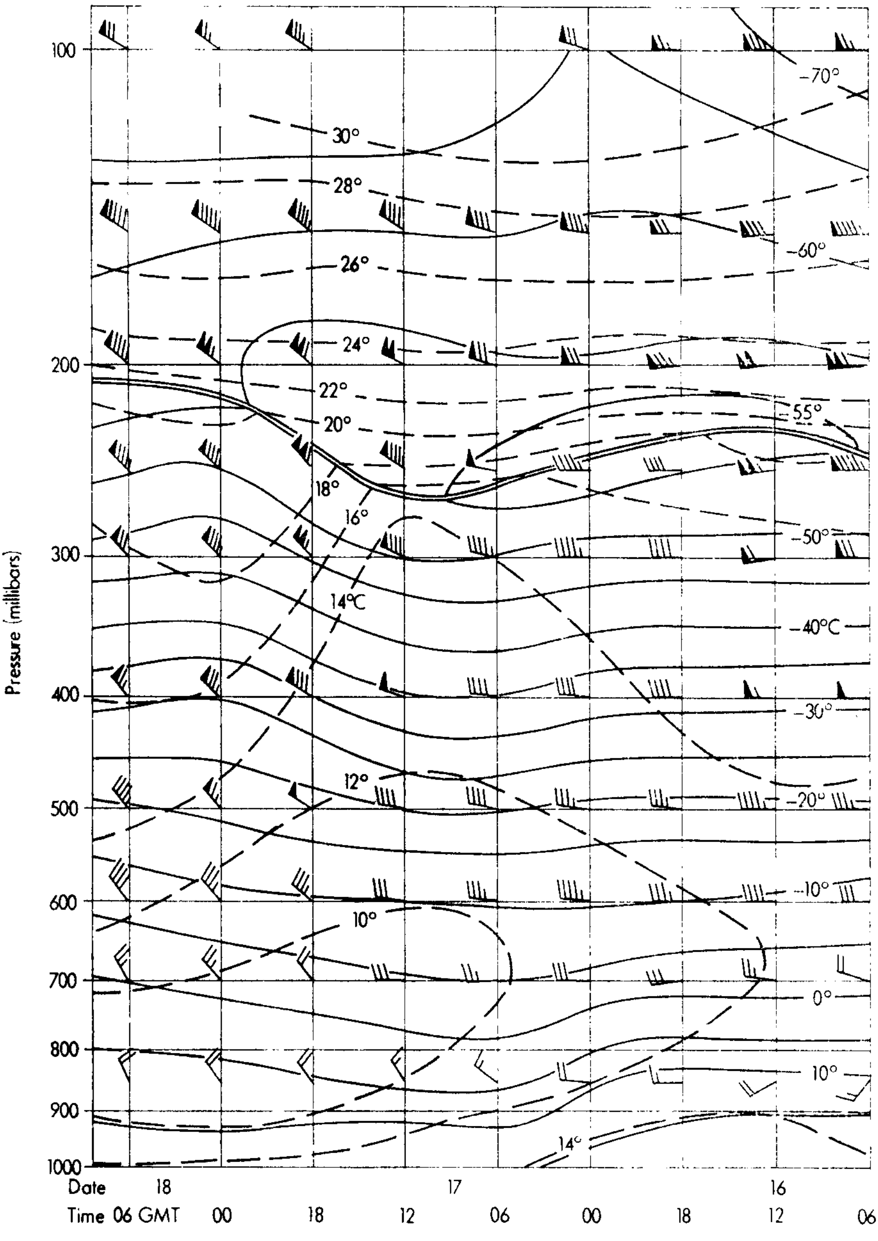

FIGURE 4—TIME CROSS-SECTION THROUGH THE UPPER AIR SOUNDINGS AT BAHRAIN 06 GMT 16TH TO 06 GMT 18TH JANUARY 1970

═══════ tropopause ——————— isotherms

- - - - isopleths of wet-bulb potential temperature below 350 mb, potential temperature above 350 mb

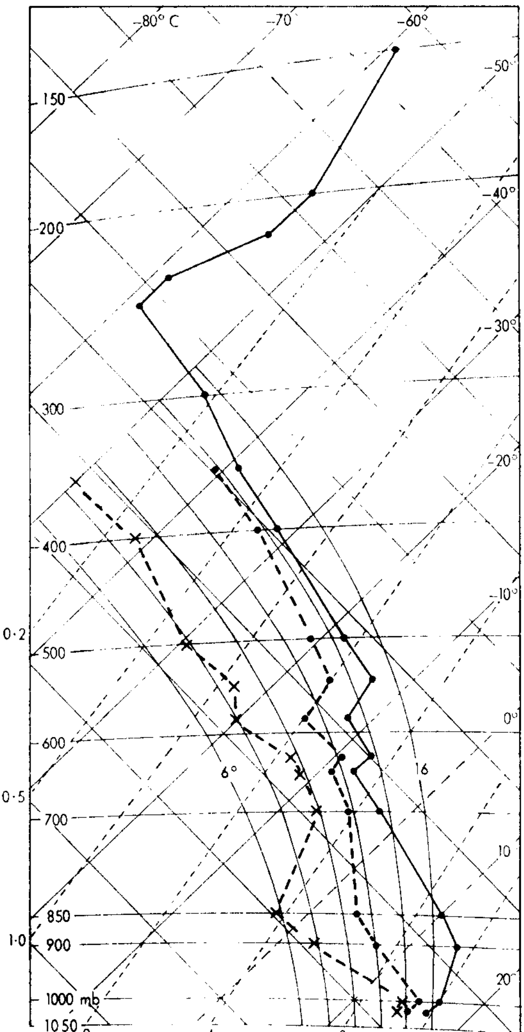

FIGURE 5—UPPER AIR SOUNDING AT BAHRAIN 00 GMT 17 JANUARY 1970

·———· dry-bulb temperature ·- - - -· wet-bulb temperature

x - - - x dew-point temperature

Applying the recorded temperature difference of 8 degC to the graph given by Fawbush and Miller[2] (Figure 6), a forecast peak wind speed of 50 knots is obtained, in excellent agreement with observation.

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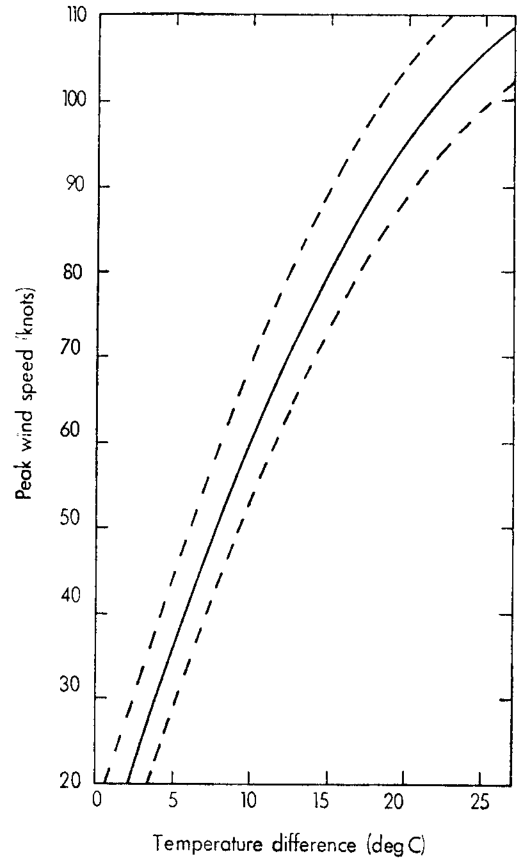

FIGURE 6—PEAK GUSTS AND TEMPERATURE DIFFERENCES IN THUNDERSTORMS IN THE UNITED STATES OF AMERICA

Abscissa is temperature just prior to the thunderstorm minus temperature immediately after the downrush.

——— regression curve — — — standard error of estimate

(After Fawbush and Miller[2])

551.509.325

FORECASTING THE TIME OF FOG CLEARANCE*

By V. L. PATTERSON and J. CRABTREE

Summary. A published method of forecasting the time of clearance of fog by solar radiation was tested at Mildenhall. The method was combined with a means of allowing for wind speed and wind direction. The combined method was found to give better overall results than a method taking into account only solar radiation as a clearance mechanism.

Introduction. Kennington[1] described a method of forecasting the time of clearance of radiation fog. The method requires an estimate to be made of the amount of solar energy required to establish a saturated adiabatic lapse rate from the surface to the fog top, an allowance being made for the

* This paper is a shortened and slightly amended version of a report,[5] of the same title, by SSgt V. L. Patterson, USAF. It is published with the permission of the Air Weather Service, United States Air Force, who also provided the data for the tests carried out in 1968.

energy needed to evaporate the fog droplets. Barthram[2] produced a set of diagrams which provide a quick and convenient way of calculating the forecast clearance time. Heffer[3] carried out a test of the method at a number of stations, using the Cardington BALTHUM ascents to provide information on the depth of the fog. Atkins[4] showed how a reasonable estimate of the depth of fog could be made, using surface data only.

The problem at Mildenhall was to forecast the time of clearance of fog by a method requiring only data available by 06 GMT. This ruled out the data from the 06 GMT BALTHUM ascent, and it was decided to test the Kennington–Barthram–Atkins method.

Test of the Kennington–Barthram–Atkins method. The data under test comprised 76 occasions when there were less than four oktas of cloud above 1000 ft (300 m), neglecting cirrus, from a selection of winter months (October to March) in 1959 and during 1962–65. For operational reasons, the upper limit of visibility in fog was taken to be 0·5 nautical mile (927 m), instead of the usual 1000 m, but this probably has little effect on the results because the clearance process, once started, is normally quite rapid. The method requires a knowledge of the temperature at dawn, T_1, and an estimate of the temperature, T_2, at which the fog may be expected to clear. In the present tests, T_1 was taken as the temperature at 06 GMT if dawn occurred later than that time. The clearance temperature was assumed to be given by the formula used by Atkins[4]

$$T_2 = T_d + 2 \text{ degC},$$

where T_d is the dew-point temperature when the fog is formed. If $T_1 > T_d + 2$, T_2 was taken to be $T_1 + 1$ degC.

On 12 of the 76 occasions, when the forecast clearance temperature was 0°C or below, the clearance times were erratic; on only two such occasions was the forecast time of clearance correct to within one hour. When the forecast clearance temperature was above freezing-point, the forecast clearance time was correct to within an hour on 30 occasions out of 64 (i.e. 47 per cent), the percentage of correct forecasts being greater when the sky was obscured (21 occasions out of 38, 55 per cent) than when the sky was not obscured (9 occasions out of 26, 35 per cent). On 10 occasions the fog cleared before sunrise.

The forecast clearance temperature was compared with the actual clearance temperature; the difference was 1·5 degC or less on 80 per cent of occasions, the maximum difference being 5 degC. An attempt was made to improve the forecasting of the clearance temperature by means of an analysis of the distribution of fog and temperature on the 03 GMT and 06 GMT charts. The area upwind was studied, and the clearance temperature was taken to be higher than any within the foggy area but lower than any temperature outside this area. On the whole, this approach was no more successful than that in which the clearance temperature was estimated by adding 2 degC to the value of T_d. However, on the eight occasions when $T_1 > T_d + 2$ degC, the forecast obtained from the surface chart analysis was closer to the actual clearance temperature than was $T_1 + 1$ degC.

The actual fog clearance temperatures were used to test Barthram's diagrams and also Atkins's rules for estimating the thickness of the fog. The results were correct (within 30 minutes) on 55 per cent of occasions; Atkins's rules appear to be reasonably satisfactory.

The Kennington–Barthram–Atkins technique showed a marked improvement over the use of climatological data; the most likely time of clearance would have given a good estimate of the clearance time (within one hour) on only 27 per cent of occasions.

The pressure diagram. The method described above provides reasonably accurate forecasts of the time of fog clearance when insolation is the main clearance mechanism. Other factors, however, often have some effect on the clearance time. Previous studies at Mildenhall by Edwards[6] had shown that the surface wind speed and direction were important factors in determining whether or not fog would clear by 12 GMT. These studies had led to the introduction of a pressure-grid diagram (Figure 1), in which the abscissa was the mean-sea-level pressure difference at 06 GMT between Wittering and Wattisham, and the ordinate was that between Cardington and West Raynham. The distances between Wittering and Wattisham and between Cardington and West Raynham are approximately equal and the

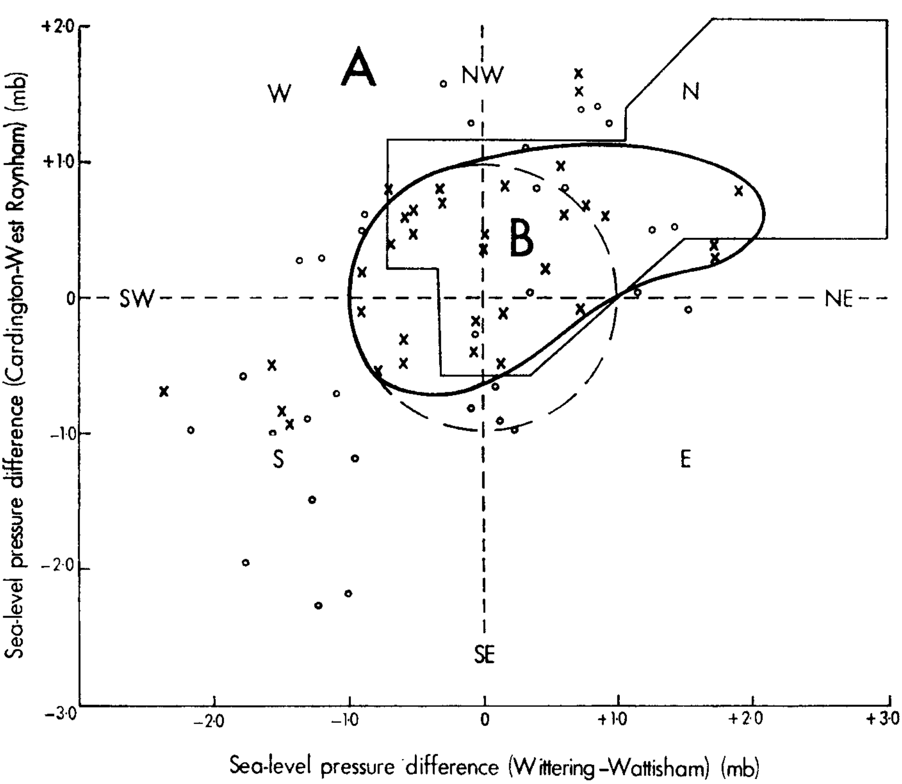

FIGURE 1—PRESSURE-GRID DIAGRAM

lines joining these pairs of stations are approximately at right angles. If the point fell within the area enclosed by the light lines, the fog was forecast not to clear by 12 GMT; if outside, the fog was expected to clear by that time. In practice it was found that a fog at any time of the day tended to clear in one hour to a visibility of 0·5 nautical mile or more, if the pressure differences were such that the point representing the fog fell outside the area enclosed by the light lines, i.e. if geostrophic winds exceeded the strength represented by the light lines.

However, the forecasting problem under consideration is rather different from that for which the diagram was devised, and the diagram had to be modified. This was done by plotting fog on the diagram in two ways. The pressure difference at the time of an initial observation of fog was plotted in the form of a small circle if the fog cleared within 2 hours, and in the form of a cross if the fog did not clear in 2 hours. The data were obtained from the same period as was used in the test of the Kennington–Barthram–Atkins method but no limitations were made on cloud cover or time of day. A line was drawn, the heavy line of Figure 1, to provide optimum separation of area A, containing mostly circles, from area B, containing mostly crosses. For points within area A, it was found that the fog usually cleared within about one hour, and the following forecasting rules were derived :

(i) If the plot lies outside the heavy line, i.e. in A, forecast clearance within one hour of the time of observation.

(ii) If the plot lies inside the heavy line, i.e. in B, solar radiation will be the major factor determining clearance time, and the Kennington–Barthram–Atkins method should be used.

A test on independent data for 1966 showed the usefulness of the above rules, but too few cases were available to enable firm conclusions to be drawn: the first rule proved useful at night, when the second method is not applicable. A further independent test was carried out during the period September 1967 to February 1968; out of 21 occasions, the time of fog clearance was forecast to within one hour on 62 per cent of occasions, compared with 47 per cent for the earlier tests using only the Kennington–Barthram–Atkins method.

Physical basis of the pressure-grid diagram. The diagram is, in essence, an approximate representation of the pressure gradient, and hence of the geostrophic wind or wind in the free atmosphere. If the wind is light, i.e. if the plot of pressure differences on Figure 1 lies close to the origin, solar radiation is the main fog-clearance mechanism. As the wind increases and the plot moves away from the origin, turbulent mixing becomes more effective until, when the point reaches a certain distance from the origin, it is sufficient to clear the fog fairly quickly. Ideally, the critical distance from the origin would be the same for all wind directions, and the line dividing the two areas would be a circle. (In Figure 1 the dashed circle represents a geostrophic wind speed of 13 kt.) However, differences in the properties of the air masses associated with different wind directions, and variations of topography, etc., are likely to have some effect, and the critical distance may vary with wind direction, as it apparently does at Mildenhall.

Conclusions. It has been shown that the pressure-grid diagram, giving an approximate measure of the wind in the free atmosphere, can provide a useful aid to the forecaster by enabling him to decide whether solar radiation will be the major factor in effecting fog clearance, or whether turbulent mixing will be strong enough to play an important part. The principles of the method should be readily applicable at other stations, but the areas A and B will, of course, be different from those at Mildenhall, and will need to be determined for each station on the basis of its own observations. If analysed charts are available for the required times of observation, an equivalent method would be to plot on the diagram a vector representing the geostrophic wind, instead of the pressure differences between pairs of stations.

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551.509.324.2

ADVECTION OF RAIN BELTS WITH THE 700-mb WIND

By W. E. SAUNDERS

This note reports the results of tests of a method of forecasting the speed of movement of rain belts which is due to McElmurry.*

From an examination of some 200 cases, McElmurry found that the wind at the 700-mb level is the most useful one to use for the advection of a rain area. The movement of a rain belt was found to be so nearly that of the 700-mb wind component normal to the leading edge of the precipitation that no adjustments were required. The investigation was restricted to rain belts approaching the Midlands from between west and south. McElmurry also proposed a method of dealing with those occasions when a blocking patterns exists which causes a rain area to decelerate or even to retrogress.

In the test now described, McElmurry's method was used at two airfield meteorological offices in eastern England, Stradishall and Cranwell. The work was carried out between January 1965 and October 1967. The number of blocking occasions was too small to warrant any conclusions being reached. The cases used in the test described here were therefore only those in which there were no signs of blocking. They were all in fact mobile situations, with the normal wind components varying widely between 9 and 43 knots. As

* MCELMURRY, T. M.; Forecasting rain with low stratus in the Midlands of England. *Bull. Am. met. Soc., Lancaster, Pa*, **42**, 1961, pp. 817–822.

soon as a rain belt spreading from between west and south had reached a position over Ireland, Wales and south-west England, such that the leading edge of the rain could be clearly defined, the normal 700-mb wind component was used to forecast the time of arrival of continuous rain at the selected stations. The results were later checked against the stations' observations.

The number of occasions tested was 85. The forecasts were made, on average, 7¾ hours before the actual time of arrival of the rain. The average error was 57 minutes. On 74 per cent of occasions the forecast was correct to within one hour, while 88 per cent were correct to within two hours. Differences in accuracy between the two stations were negligible. Errors were sufficiently evenly distributed to confirm McElmurry's statement that no adjustments are required.

At Stradishall the work was carried out by Mr R. G. Surman. At Cranwell the tests were carried out by the duty forecaster and a number of individuals co-operated. These forecasters are thanked for their efforts.

REVIEW

Weather economics, by J. A. Taylor (editor). 235 mm × 155 mm, pp. 126, *illus.*, Pergamon Press Ltd, Headington Hill Hall, Oxford, 1970. Price: 60*s*.

This is a report of eight papers and the discussion thereon at the eleventh of an annual series of symposia held at the University College of Wales, Aberystwyth. This 1968 meeting courageously attempted to study the complex relation of meteorological conditions to industry and agriculture from the economic point of view. As admitted by the Editor in the Introduction 'meteorology and economics make strange bed-fellows', but he makes a strong case for the need to assess the hazards of weather and climate in economic as well as physical terms. The title of the book may be a little misleading as the material relates mainly to 'weather-sensitive' industries such as farming and forestry.

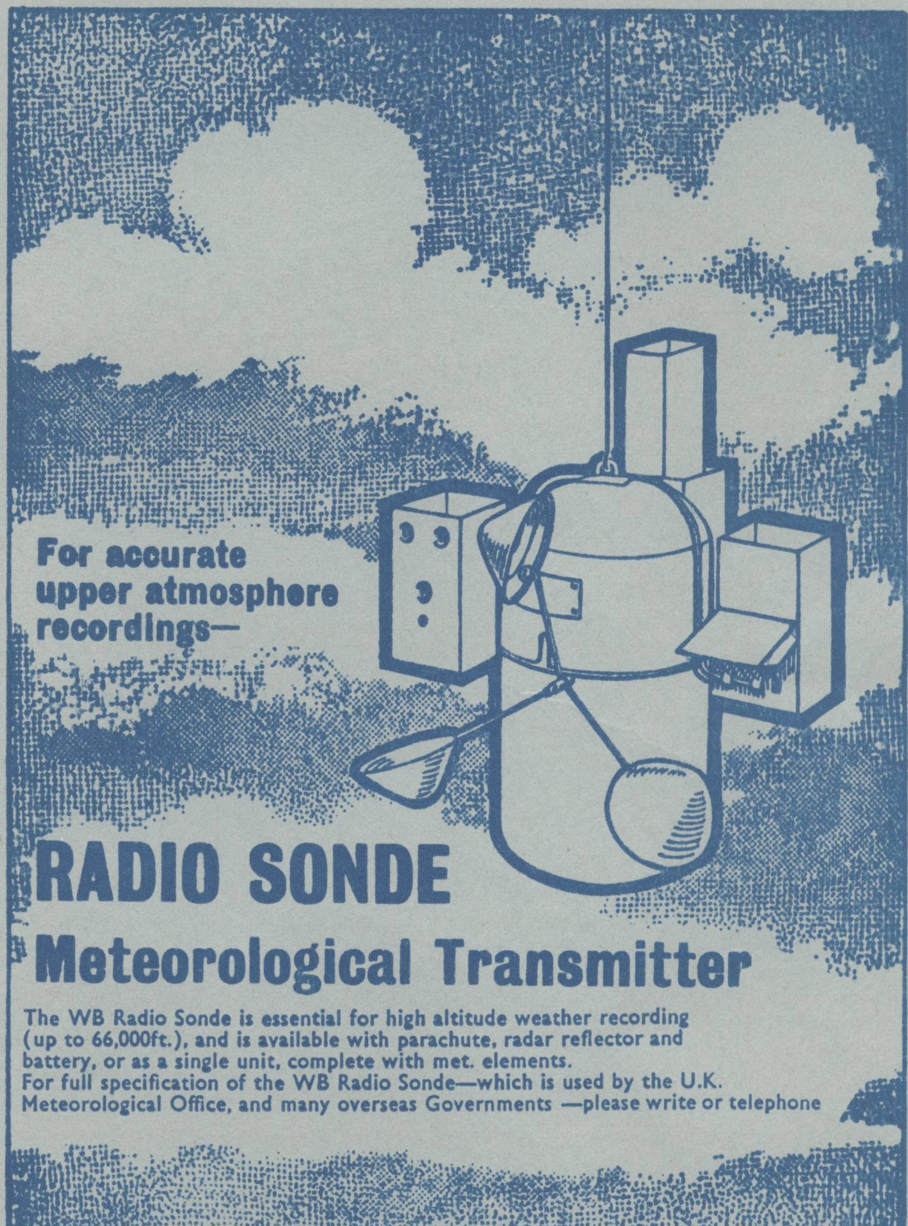
Certainly the opening chapter entitled 'The cost of British weather' embraces many examples of the adverse financial effect of meteorological factors on industrial as well as agricultural efficiency — but it would be nice to see figures showing the other side of the picture! Chapter 2 consists of a detailed survey of the economic effect of weather on farm organization and management and highlights the need for the farmer to have adequate and reliable weather advice. The following chapter deals mainly with the relationship between weather and the planning and carrying out of farming operations; in particular, it discusses the value of extended forecasts directed especially to the farmer. By means of examples involving frost, irrigation and degree-day data, Chapter 4 illustrates how climatological data may be used for planning purposes. Then follows a short chapter in which the possibility is considered of measuring the effect of weather variations on the availability of farm labour. Chapter 6 is essentially a regional study which indicates the range of environments for early potato production in Pembrokeshire and the possible extent to which various environmental factors can be expressed in financial terms. In the next chapter the effects of meteorological conditions on forestry planning and practice are examined; it deals especially with 'wind-throw' and fire losses. Finally, in Chapter 8 there is a discussion, with an operational example, of the application of cost-benefit studies in the interpretation of weather forecasts specifically for agriculture and industry; it emphasizes the importance of taking into account the effect of local geography. The book concludes with an edited report of the discussions at the symposium plus an 'economic postscript' which deals with the problem of the extent to which expenditure on insurance or providing physical protection against adverse weather is really worth while.

It is obvious from this book that the subject of weather economics calls for close collaboration between all concerned — meteorologists, geographers, biologists, economists and, of course, the 'entrepreneurs'. To assess and dovetail all the many factors involved is by no means easy; but to all those who are working on, or interested in, the subject, this book is recommended as a guide to what can be achieved and as a spur to further efforts.

R. G. VERYARD

OBITUARY

It is with regret that we have to record the death of Mr A. G. Holgate (Signals Officer) on 11 August 1970.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