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SOME EMPIRICAL RESEARCH IN SHORT-RANGE FORECASTING

By V. R. COLES

It is the hope that present and future developments in the field of dynamical research will ultimately lead to the production of forecast surface charts, upper air charts and charts depicting vertical motions in the atmosphere for periods up to 24 hours ahead, of such a standard that the practising forecaster will be able to dispense with many of his present modes of procedure. Errors in forecast surface charts, incorrect assessments of future (and present) frontal activity will then become, if not things of the past, at least much less frequent than they are now. At the present time, however, as Bushby and Whitlam¹ have indicated the standard of the forecast charts produced by METEOR is certainly not higher than that attained by the human forecaster and it appears that, although progress in the field of numerical prediction is to be expected, it will almost certainly be slow. There is still scope, therefore, at least for several years, for synoptic investigations of the many problems which still trouble the forecaster in his day-to-day duties and it is the purpose of this article to describe some aspects of current research in the Synoptic Research Branch of the Meteorological Office in the hope that the ideas put forward may prove of assistance to forecasters generally.

Three main investigations are at present under way in the section devoted to research in the short-range field. The first concerns the development and movement of depressions on the Atlantic with special reference to those depressions which deepen by 20 millibars or more in 24 hours. The second problem is that of forecasting the amount of rainfall likely from individual fronts and the third, which is associated to a certain extent with the second, is that of predicting the development of warm- and cold-front waves.

There have been many published contributions in the past on all of these topics and it might appear, at first sight, that there is little to be gained in tackling them again. However, as many practising forecasters are aware, the flow patterns at the level of strongest winds (200–300 millibars) seem often to be an important and perhaps controlling factor when unforeseen developments occur at the surface. As examples, rain often breaks out unexpectedly, or

existing rainfall becomes more intense, ahead of sharp troughs in the 300-millibar pattern and warm fronts often give a good deal of rain when the 500-millibar ridge ahead of the warm front lies well to the rear of the corresponding ridge at 300 millibars. It appeared therefore, that a study of the flow patterns above 500 millibars might provide a starting point in tackling these problems once again and that particular attention should be paid to those situations in which there is a marked difference in the direction of the 300–500-millibar thermal wind from that between 500 and 1000 millibars. In these circumstances the 500–1000-millibar thickness pattern cannot be expected to reveal the whole of the developmental picture. This aspect of the problem of development will be elaborated later.

So far as the investigation into the development and movement of depressions on the Atlantic is concerned it was decided to tackle the problem, first of all, in an almost purely statistical manner using curvilinear and graphical multiple regression techniques developed by Freeman ². Data for more than 700 depressions were extracted from the synoptic charts and numerous measurements of all possible predictors were made, including wind speeds and directions at all standard levels, vorticity advection at all levels and thermal vorticity advection for all thickness layers. The analysis has not yet been completed and it is perhaps too early to quote firm results, but it seems certain that the two most important predictors in the problem of forecasting the central pressure of a depression in 24 hours time are (i) the present central pressure of the depression and (ii) the 300-millibar wind speed over the centre of the depression. These two predictors will almost certainly yield a multiple correlation coefficient higher than 0.80 between the predicted and actual pressure in the centre of a depression in 24 hours time. Other predictors, such as the time of year, the latitude and longitude of the depression, may improve marginally on this correlation coefficient but the improvement may not be significantly large enough to warrant their inclusion in the final sets of diagrams or tables. No matter what is the outcome of this investigation, however, it has certainly pointed to the importance of the 300-millibar flow and, indeed, a cursory study of the data highlights the fact that a depression is unlikely to deepen by 20 millibars or more in 24 hours unless the direction of the 300-millibar wind over it lies between 200 and 270 degrees and the 300-millibar wind speed exceeds 70 knots. It is planned to make a synoptic study of many of the depressions which deepened by 20 millibars in 24 hours, although past experience with the problem of forecasting the visibility three and six hours ahead at London Airport² suggests that it may be very difficult to better the predictions of the general multiple regression scheme in respect of any particular class of depressions. Up to date no similar statistical analysis has been made of the movement of depressions but one suspects that the direction of the strongest 300-millibar wind in the vicinity of the centre of the depression (say within a circle of radius of 300 miles) may be the controlling factor.

So far as the problem of rainfall amounts at individual fronts is concerned, Wallington has described (in an unpublished paper) an especially interesting case of two warm fronts which were very similar in structure at all levels up to 500 millibars but which gave very different amounts of rain as they crossed the British Isles. However, Wallington did not carry his analysis of the associated fields of flow to levels above 500 millibars, and the 300–500-millibar thickness patterns showed considerable differences in the two cases. There are, of course,

several ways in which the flow patterns near the level of maximum wind speed can be included in Sutcliffe's development theory³. Thickness charts for the layer 300–1000 millibars could be constructed or use could be made of the isopleths of thickness of the 300–500-millibar layer which are drawn as routine to enable the chart depicting the contours of the 300-millibar surface to be built up from that at 500 millibars. However, the difficulty of assessing relative divergence, and therefore the vertical velocities, from either of these charts (or from the 500–1000-millibar thickness patterns) lies in the fact that, in the neighbourhood of a front, the two main terms in Sutcliffe's development formula usually contribute to the relative divergence in opposite senses. For example, using the 1000- and 300-millibar surfaces the relative divergence is expressed in the usual notation by:

$$l(\text{div } \mathbf{V}_{300} - \text{div } \mathbf{V}_{1000}) = -V' \frac{\partial}{\partial s} (2\zeta_{1000} + \zeta' + l) \quad \dots (1)$$

and whilst $-2V'\partial\zeta_{1000}/\partial s$ is normally positive over the region of a warm front, $-V'\partial\zeta'/\partial s$ is often negative. The forecaster has, therefore, to decide which term is the more important, and this is often impossible by inspection alone. However, if Sutcliffe's theory is applied to the 100–300-millibar layer the expression of the relative divergence between 100 and 300 millibars is:

$$l(\text{div } \mathbf{V}_{100} - \text{div } \mathbf{V}_{300}) = -V'' \frac{\partial}{\partial s} (2\zeta_{100} - \zeta'' + l) \quad \dots (2)$$

where V'' and ζ'' are respectively the velocity and vorticity of the 100–300-millibar thermal wind. Now Probert-Jones⁴ has shown that the 100-millibar flow is approximately non-divergent and since most contour charts of the 100-millibar surface exhibit large areas where the relative vorticity is either zero or nearly constant (see Figure 1), equation (2) above can be approximated by:

$$l \text{ div } \mathbf{V}_{300} = -V'' \frac{\partial \zeta''}{\partial s} \quad \dots (3)$$

if the change of Coriolis parameter with latitude is ignored.

Equation (3) states that the divergence at 300 millibars is represented simply by one term, namely the advection of thermal vorticity by the 100–300-millibar thermal wind, and it follows therefore that the patterns of divergence at 300 millibars are almost completely depicted by the various thermal patterns described by Sutcliffe and Forsdyke⁵ so that, for example, the left exit of a 100–300-millibar thermal jet stream is one of divergence at 300 millibars. It should be borne in mind, however, that Sumner⁶ has shown how the stability term

$$\frac{R}{f^2} \int_{p_1}^{p_0} \left\{ \nabla^2 \left(\frac{dp}{p} \right) \right\} d(\log p)$$

which was neglected by Sutcliffe³ may affect the amount of upper divergence. In the layer 100–300 millibars the quantity Γ_p is likely to be larger than in the lower troposphere, but dp/dt at these high levels is almost certainly smaller. Furthermore, if a level of zero vertical velocity at 200 millibars or thereabouts is postulated then there will be partial compensation in the 100–300-millibar layer due to the effects of opposing vertical motions above and below this level. However, the effects of the Sumner stability term with respect to the 100–300-millibar layer will need to be examined in some detail.

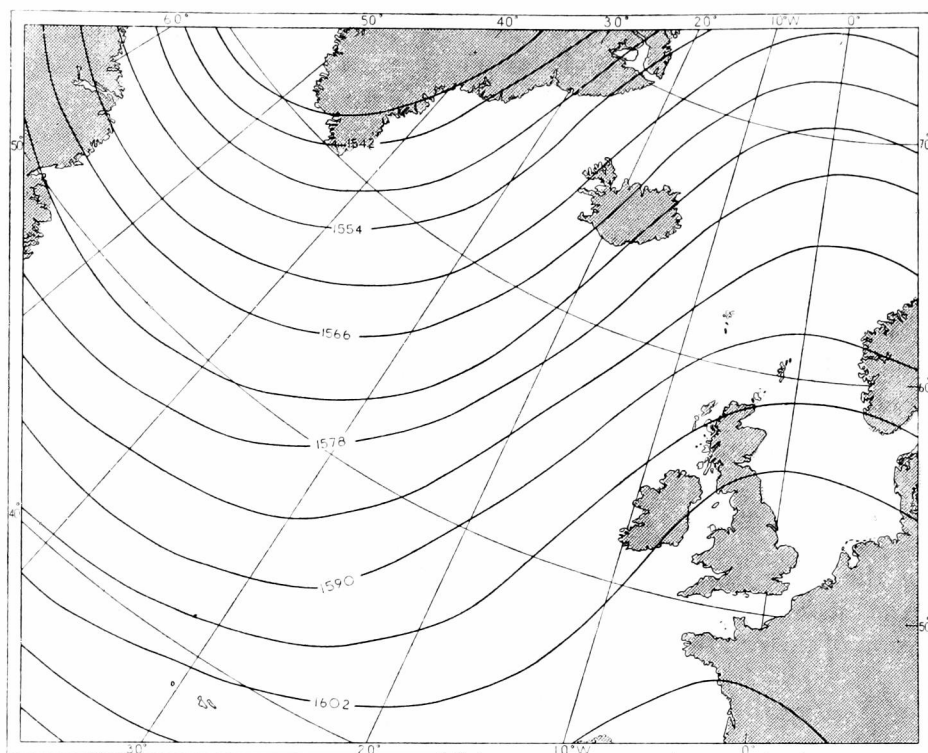
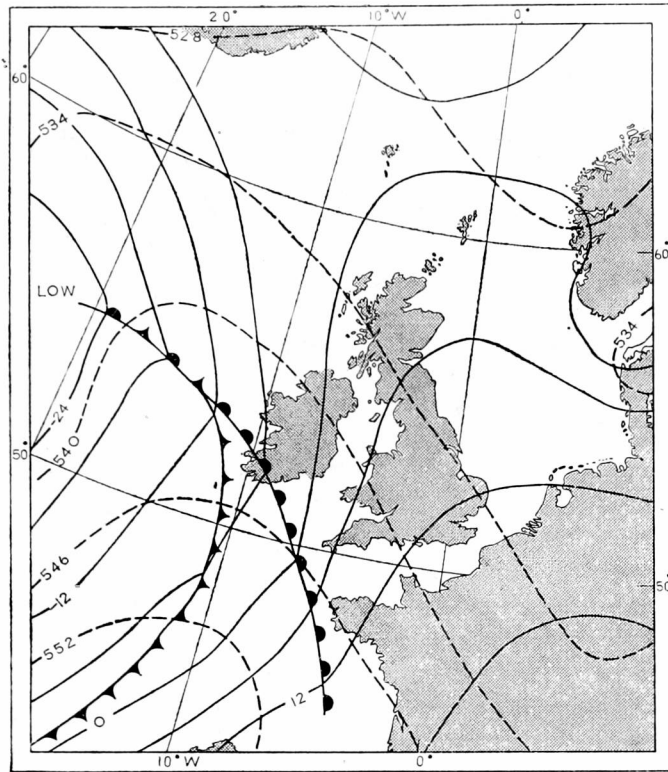


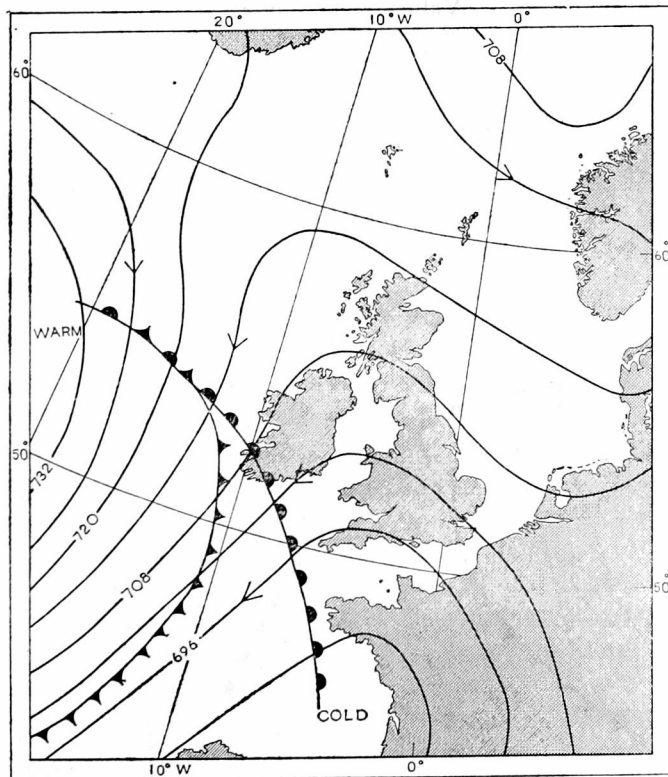
FIGURE 1—100 MB CONTOUR CHART FOR 0001 GMT, 23 FEBRUARY 1961, ILLUSTRATING CONSTANCY OF 100 MB RELATIVE VORTICITY OVER LARGE AREAS
Values in decametres

It should be possible, therefore, to obtain from the 100–300-millibar thickness pattern alone, an estimate of the divergence present at 300 millibars above individual fronts and a preliminary examination of a selection of fronts indicates that there is some hope of distinguishing between wet, moderately wet and dry fronts on the basis of the 100–300-millibar thickness patterns associated with the fronts.

Figures 2(b) and 3(b) show respectively the 100–300-millibar thermal patterns associated with a wet and with a dry warm front. It will be noted that the surface warm front in Figure 2(b) lies in a position, relative to the 100–300-millibar thickness pattern, favourable for considerable upper divergence—the forward side of a cold trough. The warm front shown in Figure 3(b), on the other hand, is situated under a region of light 100–300-millibar thermal winds indicating little, if any, upper divergence. A thorough examination is now being carried out, using METEOR, in order to establish the correlation between the estimated divergence at 300 millibars, as measured from the 100–300-millibar thickness charts, and rainfall at fronts. Such a relationship, if it exists, will mean that these thickness patterns can be used as a short-term forecasting tool (say up to 12 hours ahead). Whether they have a prognostic value over a longer period depends on our ability to forecast how the patterns change with time. The positions of the isopleths on the 100–300-millibar thickness charts are, of course, changed by advection and by adiabatic and non-adiabatic effects. Assuming a constant direction of the thermal wind between 300 and 100 millibars the thickness lines can be advected with either the wind at 300 or at 100 millibars,



**FIGURE 2(a)—1000 MB CONTOUR CHART AND 500–1000 MB THICKNESS CHART
FOR 0300 GMT, 7 FEBRUARY 1957, ASSOCIATED WITH A WET WARM FRONT**
Values in decametres



**FIGURE 2(b)— 100–300 MB THICKNESS CHART FOR 0300 GMT, 7 FEBRUARY 1957,
ASSOCIATED WITH A WET WARM FRONT**
Values in decametres

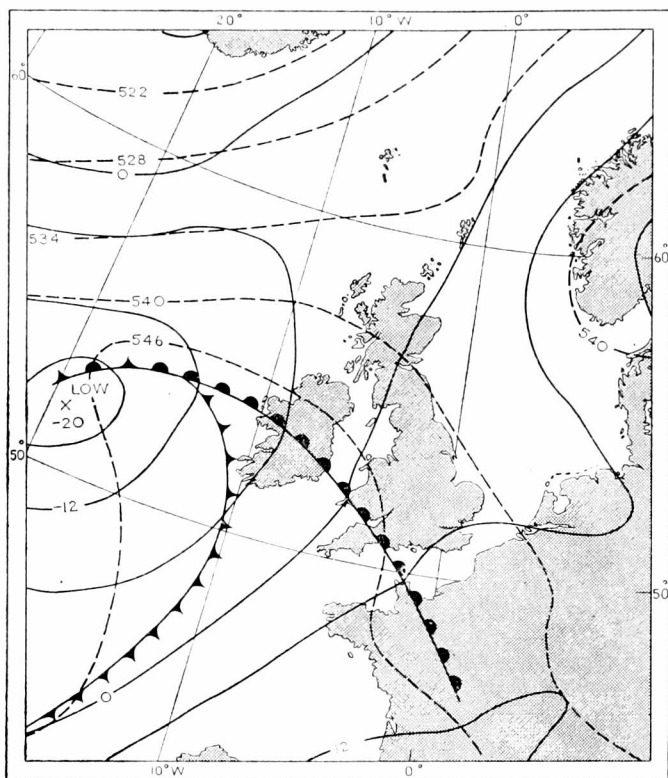


FIGURE 3(a)—1000 MB CONTOUR CHART AND 500 - 1000 MB THICKNESS CHART FOR 0300 GMT, 8 MARCH 1957, ASSOCIATED WITH A WARM FRONT WHICH GAVE LITTLE RAIN OVER MOST OF ENGLAND AND WALES
Values in decametres

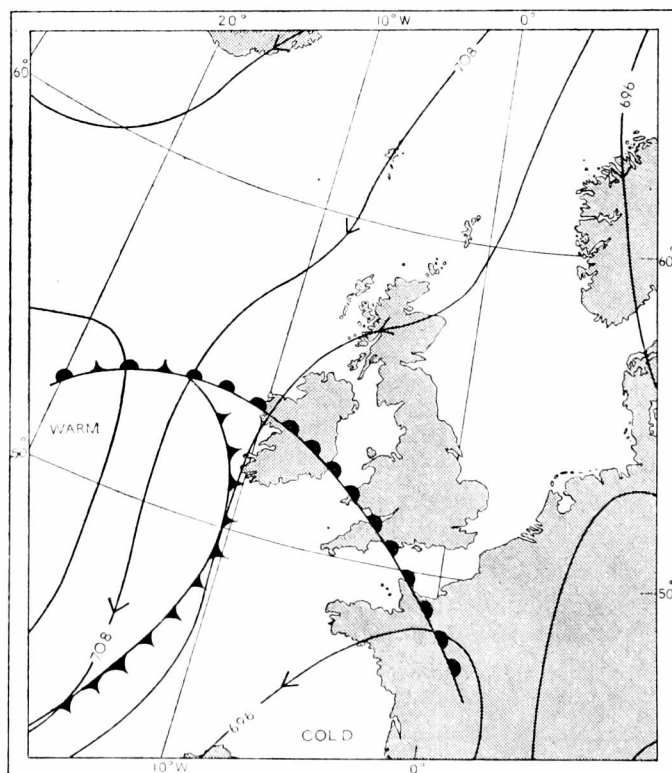


FIGURE 3(b)—100 - 300 MB THICKNESS CHART FOR 0300 GMT, 8 MARCH 1957, ASSOCIATED WITH A WARM FRONT WHICH GAVE LITTLE RAIN OVER MOST OF ENGLAND AND WALES

but since the 100-millibar flow is normally much weaker and more conservative than the flow at 300 millibars it is natural to choose this level. Non-adiabatic effects are probably very small between 300 and 100 millibars but there may be considerable modification of the 100–300-millibar thickness field by vertical motion since much of the layer is in the stratosphere. It will be necessary to determine whether changes of thickness due to vertical motion can be forecast satisfactorily before it will be possible to attempt to forecast changes of intensity of frontal rainfall over periods 12 to 24 hours ahead.

The intensification of rain on warm or cold fronts is often due to wave formation on the fronts. Some years ago Sawyer⁷ investigated such wave developments with reference to the 500–1000-millibar thickness pattern and his findings are well known. However, on many occasions waves form on warm and cold fronts and are not accompanied by the patterns Sawyer illustrated. This again lends support to the idea that surface developments cannot always be forecast satisfactorily without consideration being given to events above the 500-millibar level. Figure 4 illustrates a synoptic situation where a wave formed on a warm front and moved east-south-eastwards across the southern half of the British Isles. The appropriate 100–300-millibar thickness chart (Figure 4(d)) indicates that the pattern was suitable for upper divergence near the area of formation of the wave. The 500–1000-millibar thickness pattern, on the other hand, does not appear to be favourable for wave development. However, a large number of warm- and cold-front waves will have to be examined in order to determine how often the 100–300-millibar thickness pattern is a useful indicator of wave formation and to establish the time lapse between the appearance of the appropriate thickness patterns and the formation of the waves.

It appears, therefore, that it may become necessary to introduce into the routine the preparation of yet another upper air chart. However, if developments in the lower layers of the troposphere are controlled, even on a minority of occasions, by events at high levels then there is obviously no hope of predicting correctly such developments without some consideration being given to levels above 500 millibars. Since

$$-(\zeta_{300} + l) \operatorname{div} \mathbf{V}_{300} = \frac{\delta \zeta_{300}}{\delta t} + \mathbf{V}_{300} \cdot \frac{\delta}{\delta s} (\zeta_{300} + l) \quad \dots (4)$$

and since the speed of movement of the ridge–trough patterns at 300 millibars is usually much less than the speed of the general 300-millibar flow, it is certain that in many cases the dominant factor in determining the divergence at 300 millibars is the advection of vorticity at 300 millibars. Thus it may be possible to estimate the divergence at this level using the 300-millibar pattern alone without the need for constructing the 100–300-millibar thickness chart. However, tests of the relationship between rainfall patterns and vorticity advection at 300 millibars were made several years ago by Riehl, Norquest and Sugg⁸ and Teweles⁹ with somewhat inconclusive results and it seems that the local change of vorticity at 300 millibars, which they neglected, may be important. The effects of this term are taken into account by considering the advection of 100–300-millibar thermal vorticity by the 100–300-millibar thermal wind and it appears, therefore, that in order to obtain a more realistic estimate of the divergence at 300 millibars, it will be necessary to use a field of relative topography rather than the contour patterns of the 300-millibar surface. Indeed the 100–200-millibar thickness chart is already being drawn at London Airport¹⁰ and its use as an aid in constructing forecast charts for the 200-millibar level is now being tested.

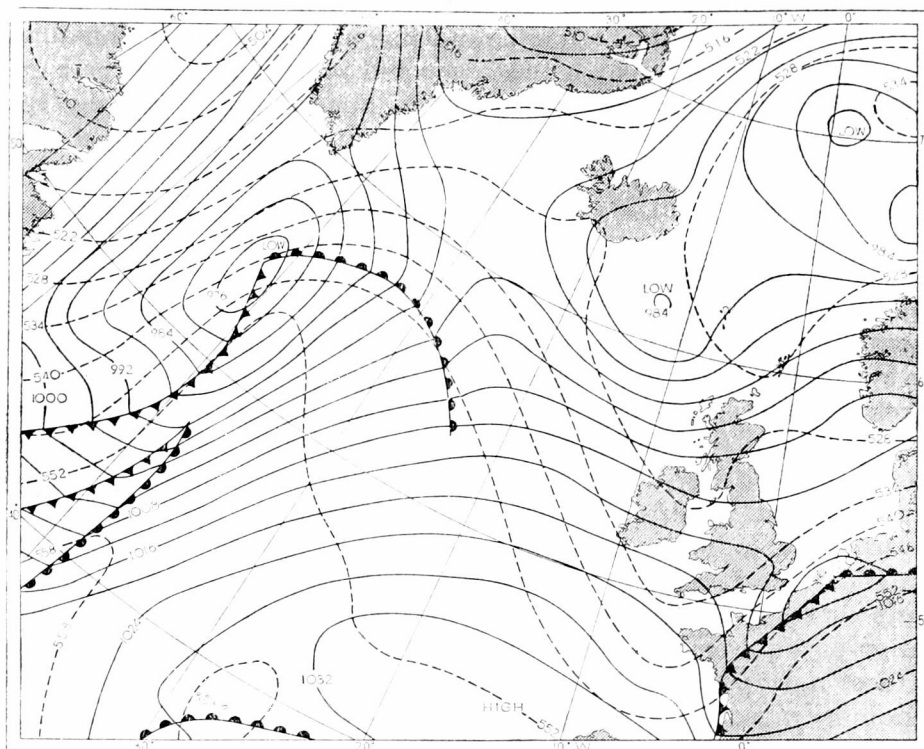


FIGURE 4(a)—SURFACE CHART AND 500-1000 MB THICKNESS CHART FOR
0001 GMT 28 FEBRUARY 1961

Broken lines are thicknesses in decametres

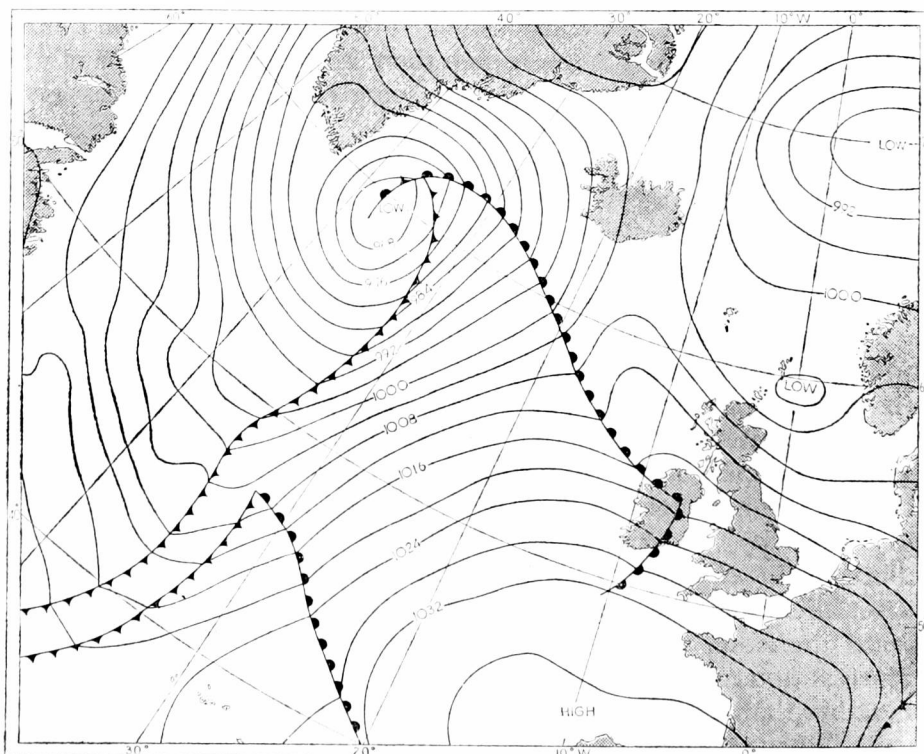


FIGURE 4(b)—SURFACE CHART FOR 1200 GMT, 28 FEBRUARY 1961

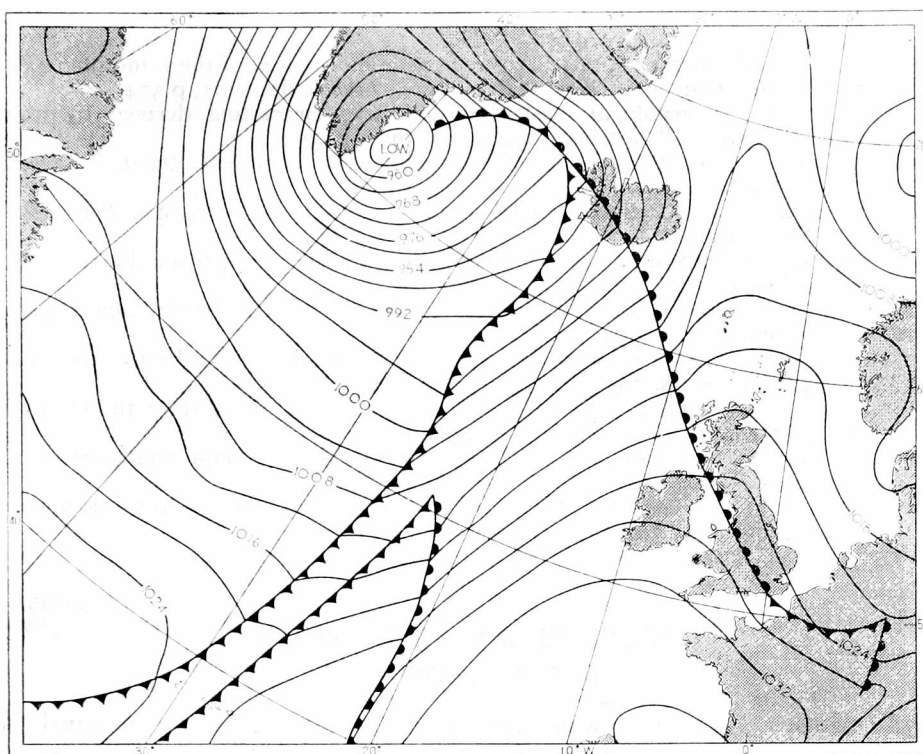


FIGURE 4(c)—SURFACE CHART FOR 0001 GMT, 1 MARCH 1961

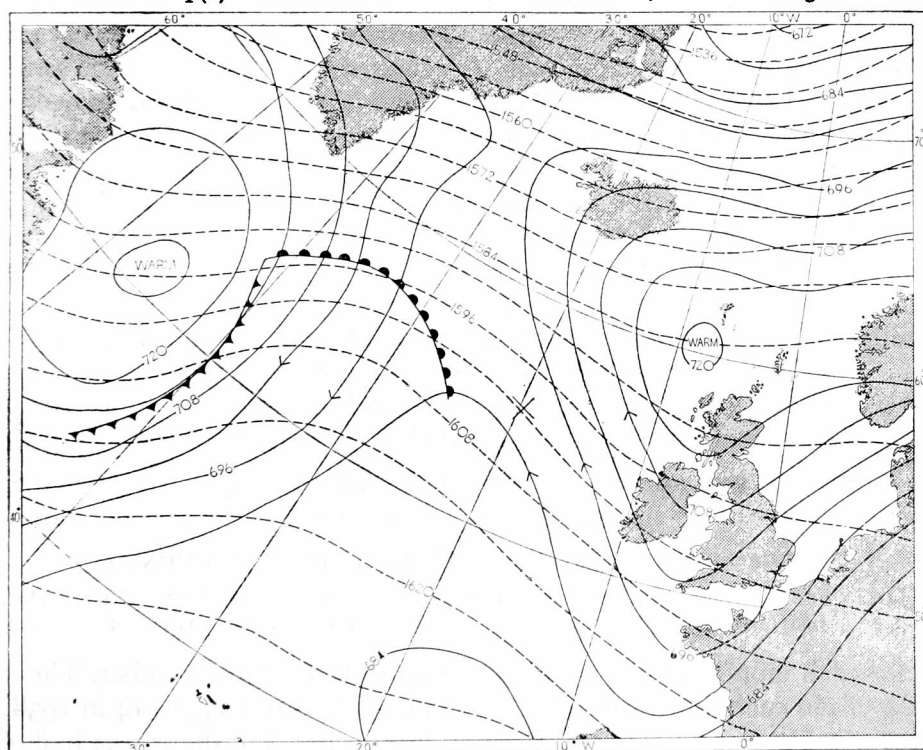


FIGURE 4(d)—100-300 MB THICKNESS CHART (FULL LINES) AND 100 MB CONTOUR CHART (BROKEN LINES) FOR 0001 GMT, 28 FEBRUARY 1961, ILLUSTRATING AT X DIFFLUENT PATTERN PROBABLY ASSOCIATED WITH WAVE FORMATION ON WARM

FRONT
Values in decametres

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WET SPELLS AT LONDON

By C. A. S. LOWNDES

Introduction.—This work was undertaken to provide a background to the problem of forecasting wet spells at London. For the purpose of this investigation a wet spell was defined as a period of five days with (i) at least 15 millimetres of precipitation and no day with less than one millimetre or (ii) at least 20 millimetres with one such day or (iii) at least 25 millimetres with two such days. A period of five days was chosen because it seemed to be the longest spell which could be related to a single weather type, e.g. the average length of the German "Grosswetterlagen" is four to five days. The histograms of daily rainfall at Kew published in the Monthly Summary of the *Daily Weather Report* were used to extract the dates of the wet spell periods. If a wet spell continued for more than five days, the first five days which fulfilled the criteria were taken and the search for the next wet spell was not begun until a day with less than one millimetre of precipitation had occurred. The spells were extracted for the 25-year period 1935 to 1959, for all months of the year. The spells occurring in each month were listed separately. Where a spell extended from one month to another, it was included in the month which contained the greater part of it.

Frequency of wet spells.—There were 225 spells during the whole period, giving an average of 0.7 spells per month. Table I shows the average number of

TABLE I—AVERAGE NUMBER OF SPELLS FOR EACH MONTH

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1.1	0.6	0.6	0.4	0.8	0.6	0.6	0.9	0.5	1.0	1.3	0.7

spells for each month, ranging from 0.4 in April to 1.3 in November. The number of spells in each individual year ranged from four in 1955 to 14 in 1958; the average number was nine, of which about five occurred in the winter half of the year and about four in the summer half.

The frequency of spells according to the amount of precipitation associated with them is shown in Figure 1. The modal value of the distribution occurs at 25 to 29 millimetres of precipitation, representing 25 per cent of the spells.

Some 92 per cent of the spells had a total precipitation of between 15 and 44 millimetres, whilst the wettest spell totalled 86 millimetres. The arithmetic mean value was 30 millimetres. The 225 spells accounted for 45 per cent of the total precipitation at Kew over the 25 years.

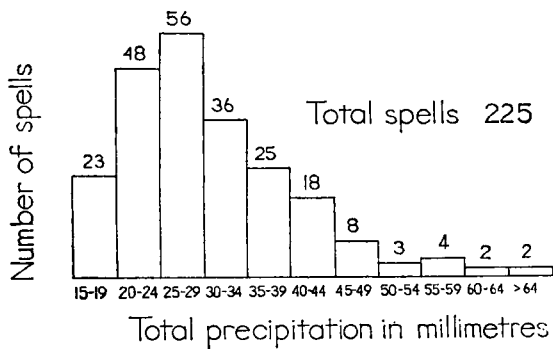


FIGURE 1—FREQUENCY OF SPELLS WITH RESPECT TO TOTAL PRECIPITATION

Synoptic types associated with wet spells at London.—A short description of the synoptic type in the region of the British Isles was written for each of the 92 spells which occurred during the 10 years 1950 to 1959. This involved a description of the position or movement of the depressions, waves, troughs or fronts with which the wet spell was associated. The types were then classified according to the region from which these features moved towards the British Isles or in which they were situated if stationary. The regions are shown in Figure 2. For example, depressions, waves, troughs or fronts moving from the west were classed as Type VI; depressions as VID, waves as VIW, troughs as VIT and fronts as VIF. Depressions or troughs which were stationary over the

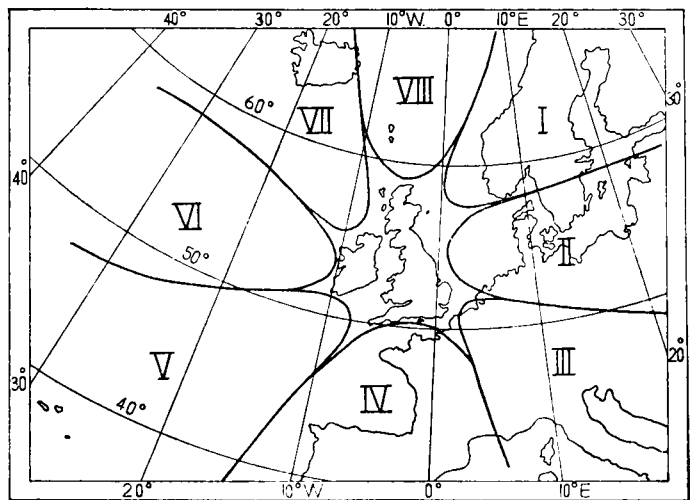
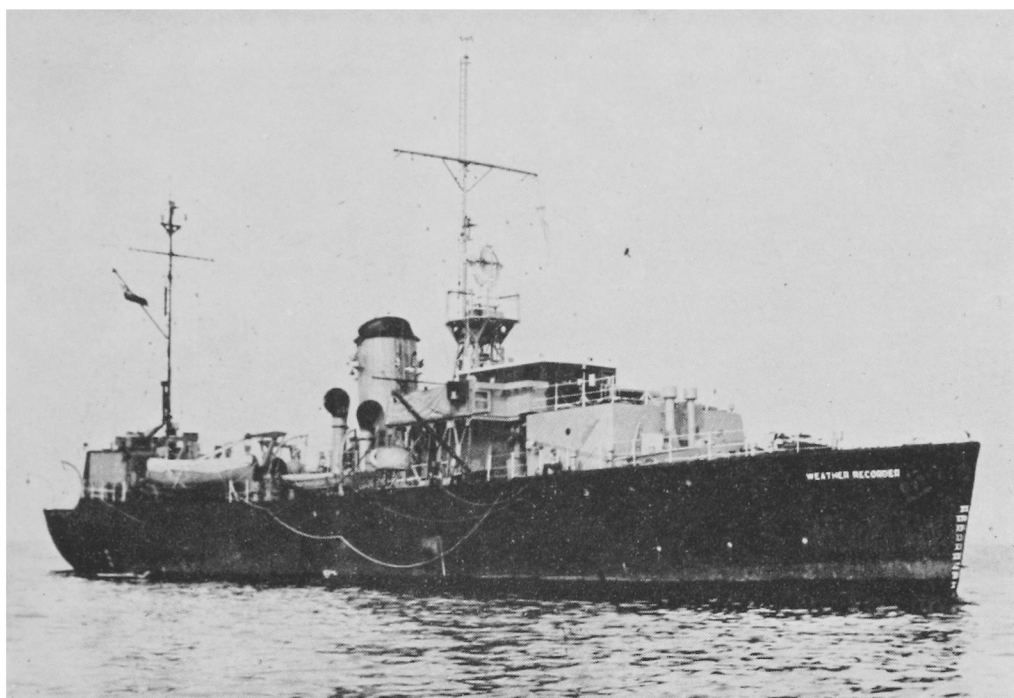


FIGURE 2—REGIONS USED IN THE CLASSIFICATION OF SYNOPTIC TYPES

British Isles were classed as Type IX. The types were sub-classified by a suffixed figure according to the track taken by the depression or wave across the region of the British Isles and by a suffixed letter according to the type of front or frontal system. In the main each spell was associated with from two to five sub-types. In some cases all the sub-types were different, but in others the same one

TABLE II—CLASSIFICATION OF SYNOPTIC TYPES (TOTAL OCCURRENCES 260)

Synoptic type	Class	Number of occurrences
Depression over southern North Sea	IID	1
Cold front from east moved westward across British Isles	IIF _c	1
Depression over Holland	IIID	1
Wave from France moved to North Sea	IIIW	1
Depression from Biscay or France moved northward across British Isles	IVD ₁	2
Depression from west of Spain or Biscay moved along Channel region	IVD ₂	2
Depression from France moved to North Sea or North Germany	IVD ₃	4
Shallow depression slow moving over France	IVD ₄	4
Wave from Spain, Biscay or France moved northward across British Isles	IVW ₁	9
Wave from Biscay moved across England to North Sea	IVW ₂	2
Wave from Spain or Biscay moved along Channel region	IVW ₃	7
Wave from France moved to North Sea	IVW ₄	1
Warm front from south moved northward across England or to Channel region	IVF _w	3
Cold front from south moved northward across England	IVF _c	2
Occlusion from south moved northward across England	IVF _o	3
Depression from south-west moved { northward across British Isles across England to North Sea along Channel region to France	VD ₁ VD ₂ VD ₃ VD ₄	10 14 18 1
Wave from south-west moved { northward across British Isles across England to North Sea along Channel region	VW ₁ VW ₂ VW ₃	2 10 18
Warm front from south-west moved north-eastward across England	VF _w	4
Cold front from south-west moved north-eastward across England	VF _c	6
Occlusion from south-west moved north-eastward across England	VF _o	5
Partly occluded frontal system from south-west moved eastward or north-eastward across British Isles	VF _s	15
Depression from west moved { across Scotland to North Sea across England to North Sea across England to Channel along Channel region	VID ₁ VID ₂ VID ₃ VID ₄	1 10 4 5
Wave from west moved { across England to North Sea along Channel region	VIW ₁ VIW ₂	10 3
Warm front from west moved eastward across England	VIF _w	9
Cold front from west moved eastward across England	VIF _c	8
Occlusion from west moved eastward across England	VIF _o	3
Partly occluded frontal system from west moved eastward across British Isles	VIF _s	32
Trough from west moved eastward across British Isles or England	VIT	6
Depression from north-west moved { east of British Isles to Continent across British Isles to Continent	VIID ₁ VIID ₂	1 2
Cold front from north-west moved south-eastward across British Isles	VIIIF _c	3
Occlusion from north-west moved south-eastward across British Isles	VIIIF _o	1
Depression from north moved east of British Isles to southern North Sea	VIIID	2
Wave from north moved southward across British Isles	VIIIW	1
Cold front from north moved southward across England	VIIIF	3
Occlusion from north moved southward across England	VIIIF _o	1
Depression stationary over British Isles	IXD	5
Trough stationary over British Isles	IXT	4



Photograph by O. M. Ashford

“WEATHER RECORDER”
(see p. 107)



Photograph by S. Soulsby.

“WEATHER MONITOR”
(see p. 107)



335°

350°

NORTH

Crown copyright

CUMULUS CLOUD GENERATED BY A RUBBER PLANTATION FIRE IN SOUTH MALAYA
(see p. 104)



Photograph by G. Nicholson

FULWELL STATION AT 8 P.M. ON 24 AUGUST 1961
(see p. 111)

To face p. 101



Photograph by J. J. H. Pennells



Photograph by J. J. H. Pennells

SNÓWFALL OF 31 DECEMBER 1961
(see p. 110)

occurred more than once. The amount of precipitation at Kew associated with each sub-type was noted. Sub-types which were associated with only one or two millimetres of precipitation were not included. The complete classification is shown in Table II, together with the number of occurrences of each type.

The most frequently occurring types during the wet spells were Types V and VI. Type V occurred in 73 per cent of the spells and Type VI in 64 per cent. Type IV occurred during the course of 33 per cent of the spells. At least one of these three types occurred during each of the 92 spells.

Amount of precipitation associated with the various synoptic types.—Of the total precipitation, 91 per cent was associated with Types IV, V and VI; 41 per cent with Type V, 32 per cent with Type VI and 18 per cent with Type IV. Of the total, 63 per cent was associated with depressions or waves, 18 per cent with single fronts and 14 per cent with partly occluded frontal systems.

TABLE III—AMOUNT OF PRECIPITATION ASSOCIATED WITH SYNOPTIC TYPES IV, V AND VI

	Type IV			Type V			Type VI			
	D	W	F	D	W	F	D	W	F	T
Percentage of total precipitation	7	7	4	21	11	9	9	5	16	2
Average precipitation (mm)	15	9	13	13	9	8	11	10	8	8

Table III shows the amount of precipitation associated with Types IV, V and VI in more detail. Of the total precipitation, 21 per cent was caused by depressions from the south-west and 16 per cent by fronts from the west. The highest average precipitation of 15 millimetres was associated with depressions from the south. Fronts from the south and depressions from the south-west produced an average of 13 millimetres. The lowest average of eight millimetres was associated with fronts from the south-west and west and with troughs from the west.

About 50 per cent of the total precipitation was associated with eight of the 47 synoptic types listed in Table II. These eight types are shown in Table IV, together with the percentage of the total precipitation and the average precipitation associated with each.

TABLE IV—SYNOPTIC TYPES ASSOCIATED WITH MOST PRECIPITATION DURING WET SPELLS

Synoptic type	Precipitation	
	Per cent	Average mm
Depression from south-west moved along Channel region (VD_3)	10	14
Depression from south-west moved northward across British Isles (VD_1)	5	13
Depression from south-west moved across England to North Sea (VD_2)	6	11
Wave from west moved across England to North Sea (VIW_1)	4	11
Wave from south-west moved across England to North Sea (VW_2)	4	11
Partly occluded frontal system from west moved across British Isles (VIF_s)	10	8
Wave from south-west moved along Channel region (VW_3)	6	8
Partly occluded frontal system from south-west moved across British Isles (VF_s)	4	7

Some 10 per cent of the total precipitation was produced by depressions from the south-west which moved along the Channel region and a further 10 per

cent by partly occluded frontal systems from the west which moved across the British Isles. The highest average precipitation of 14 millimetres was also associated with depressions from the south-west which moved along the Channel region. Depressions from the south-west which moved northward across the British Isles produced an average of 13 millimetres. The lowest averages of seven or eight millimetres were associated with partly occluded frontal systems from the west or south-west and with waves from the south-west which moved along the Channel region. Six of the synoptic types were associated with depressions, waves or partly occluded frontal systems which moved from the south-west (Type V) and two with waves or partly occluded frontal systems which moved from the west (Type VI).

From an examination of rainfall data associated with depressions which moved eastward across the British Isles over the period 1941-50, Sawyer¹ found that the average amount of precipitation at stations near the depression track was about 15 millimetres. Depressions which passed between Scotland and the Faeroes gave an average of about two millimetres at London and depressions which crossed Scotland about three millimetres. Depressions which crossed England gave about eight millimetres at London and depressions which moved east near the English Channel some 11 millimetres. The present investigation shows that depressions which moved eastward across England gave an average of 10 millimetres at London and depressions which moved along the Channel region gave 14 millimetres. These amounts are a little higher than the comparable values obtained by Sawyer, but may be biased by the inclusion only of occurrences within wet spells.

There were 47 cases of partly occluded frontal systems of which 32 moved from the west and 15 from the south-west. Those from the west produced an average precipitation of eight millimetres and those from the south-west an average of seven millimetres.

In 23 cases the point of occlusion crossed England with an average precipitation of seven millimetres and in 18 cases crossed southern England or the Channel region with an average of nine millimetres. In four cases the point of occlusion crossed Scotland and in two crossed well to the south of the British Isles.

Thunderstorms and thundery rain.—Of the 92 wet spells which occurred during the 10 years from 1950 to 1959, 58 were associated with reports of thunderstorms in southern England. Heavy rain was reported during a further 32 spells.

TABLE V—FREQUENCY OF WET SPELLS ASSOCIATED WITH THUNDERSTORMS

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
3/6	3/9	2/7	3/3	4/5	5/6	7/8	10/10	8/8	4/9	5/13	4/8

Table V shows the number of spells associated with reports of thunderstorms in southern England for each month of the year, expressed as a fraction of the total number of spells for each month. Nearly all the spells which occurred during the months April to September were associated with reports of thunderstorms but only about one-third to a half of the spells which occurred during the winter half of the year were similarly associated.

From data for Kew, Cheshire and Plymouth for the months May to August, over the period 1941 to 1945, Douglas and Moorhead² showed the importance

of rains of thundery origin, generally moving from some southerly point. They concluded that over a large area of England extending from the south-east coast to the Mersey, more than half the summer rain was of a thundery type.

Northerly outbreaks which preceded wet spells.—The beginning of a wet spell was usually associated with a depression near the British Isles or a complex area of low pressure to the west. In many cases there was a strong northerly flow on the western flank of the depression or low-pressure area. By tracing it back from chart to chart, the date of the first appearance of the northerly ("outbreak") over the Atlantic was obtained. This was taken to be the date on which the northerly, of comparable intensity and latitudinal extent, first appeared.

Of the 92 wet spells, 61 were preceded by such an outbreak of northerly surface winds over the Atlantic. The following details of the outbreaks were noted: (i) longitude, (ii) width in degrees of longitude, (iii) the lapse of time in

TABLE VI—LONGITUDE OF NORTHERLY OUTBREAKS

	Longitude (°W)					
	0°-9°	10°-19°	20°-29°	30°-39°	40°-49°	50°-59°
	<i>number of wet spells</i>					
Six summer months	2	2	7	5	8	2
Six winter months	0	0	5	6	11	13
Year	2	2	12	11	19	15

hours between the outbreak and the beginning of the wet spell at London. The longitude of the northerly outbreaks are shown in Table VI. Over the whole year, 93 per cent occurred between 20°W and 60°W. The most striking difference between the summer and winter months was concerned with the number of cases between 50°W and 60°W. During the summer months there were only 8 per cent of cases but in the winter months there were 37 per cent. In the winter months there were no cases east of 20°W.

TABLE VII—WIDTH OF NORTHERLY OUTBREAKS

	Width (° longitude)				
	5°	10°	15°	20°	25°
	<i>number of wet spells</i>				
Six summer months	1	15	4	5	1
Six winter months	0	6	19	7	3
Year	1	21	23	12	4

Table VII shows the width of the northerly outbreaks estimated to the nearest five degrees of longitude. Over the whole year, 92 per cent were from 10° to 20° of longitude in width. During the summer months the most frequent width was 10° but in the winter months was 15°.

TABLE VIII—TIME LAPSE BETWEEN NORTHERLY OUTBREAK AND BEGINNING OF WET SPELL

Lapse in hours	6-12	13-24	25-36	37-48	49-60	61-72	73-84
Number of cases	6	18	8	12	12	2	3

Table VIII shows the time lapse which occurred between the onset of the surface northerly and the beginning of the wet spell at London. In 82 per cent of cases the time lapse was between 12 and 60 hours. There was no significant difference between the distributions for the summer and winter months. No clear-cut relationship could be found between the time lapse and the longitude

of the northerly. However, on average, the time lapse tended to become longer the farther west the northerly outbreak occurred.

Position of persistent anticyclones.—Of the 92 wet spells, 33 were associated with blocked situations in the region of the British Isles. In 17 cases a blocking anticyclone was situated to the east over Russia, in six cases to the north-east over Scandinavia and in 10 cases to the north of the British Isles.

Blocking was associated with five of the six wet spells during which the precipitation was produced entirely by fronts. In two cases the anticyclone was situated to the east and in three to the north-east. In all these cases the fronts became slow moving or quasi-stationary, orientated north-south or north-west-south-east parallel to the surface isobars to the east or north-east of the front. A further 22 spells were associated with high pressure over Greenland. In all these cases there was no blocking in the region of the British Isles.

Conclusions.—In the period 1935 to 1959, the wet spells, as defined in this paper, averaged nine per year and accounted for 45 per cent of the total precipitation at Kew.

In the period 1950 to 1959, the spells had an average total precipitation of 30 millimetres and were associated in 90 per cent of cases with depressions, waves, fronts, or troughs which in general moved from the south, south-west or west across the British Isles. Of the total precipitation, 63 per cent was associated with depressions or waves and 32 per cent with fronts. Depressions from the south and south-west and fronts from the south provided the highest average precipitation. The point of occlusion of partly occluded frontal systems crossed England or the Channel region in 87 per cent of cases.

Nearly all the wet spells during the summer months were associated with thunderstorms in southern England. In the winter months about one-third to a half were similarly associated.

In many cases, the wet spells at London were preceded by an outbreak of surface northerlies over the Atlantic and associated trough development in the surface isobars to the west of the British Isles. This type of development is to be studied more closely in an attempt to formulate rules for the forecasting of wet spells at London.

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551.509.68 : 551.576.11

CUMULUS CLOUD GENERATED BY A RUBBER PLANTATION FIRE IN SOUTH MALAYA

By P. F. McALLEN

The photograph between pp. 100-101 was taken at 1415 local time on 27 June 1961, looking due north from Royal Air Force, Changi, Singapore, and shows cumulus development resulting from an extensive fire on a rubber plantation in south Johore, Malaya. The deliberate burning of rubber estates is a common

practice in Malaya as a means of clearing the rubber trees that have outlived their useful productive life. Rubber trees are very resinous and when burning liberate considerable heat, and cumulus development over such fires has often been observed, but not to the magnitude of that shown in the photograph. One of the most impressive aspects of this cloud was its very rapid development and bubbling turbulence which presented a spectacle surpassed only in the writer's experience by the convection generated by an atomic explosion on Christmas Island.

The fire occurred during a relatively dry spell, and after an early morning shower on 27 June there were only very small amounts of fair weather cumulus with about half cover of medium and high cloud, the surface wind being light southerly. The exact time at which the fire started is not known, but dense smoke and rapid cumulus development were observed at about 1330 local time, when the top of the cloud was already approximately 20,000 feet. By the time the photograph was taken at 1415 local time the top of the cloud had reached its maximum height of about 32,000 feet, as measured by clinometer using a base-line of $8\frac{1}{2}$ miles. The remains of a well marked pileus cap which had formed at about 30,000 feet can still just be seen to the right of the highest peak in the photograph. It is of interest to note that at the height of 32,000 feet where the temperature was -36°C there was no evidence of glaciation. The only other low clouds in the sky were small amounts of cumulus with bases about 3000 feet and with tops up to 7000 feet, some of which can be seen in the left foreground.

The cumulus development resulting from the fire produced a well defined precipitation echo on the storm warning radar at Royal Air Force, Changi, which showed the cloud to be $8\frac{1}{2}$ miles from the point where the photograph was taken. Rain can in fact be seen falling from the cloud in the photograph and this rain continued until 1430 local time.

The winds at low levels were light south-westerly becoming westerly 15–20 knots from 7000 feet to 20,000 feet. At 20,000 feet the winds became light and variable, and above this height they were 080° 40 knots at 32,000 feet increasing to 57 knots at approximately 40,000 feet. This wind shear can be clearly seen in the photograph, with the cloud being very discoloured by smoke up to the level at which the wind régime changed and the increase in wind speed above 20,000 feet causing a more rapid dispersal of the smoke.

A pennant cloud was observed to stream from the cumulus between 20,000 feet and 30,000 feet giving evidence of the relatively strong easterly winds at these levels, but this pennant cloud dispersed within a few minutes, indicating that the cloud consisted of water droplets and not ice particles. Shortly after the pennant cloud was observed the cumulonimbus attained its maximum vertical development and then rapidly dispersed.

In Figure 1 the Paya Lebar radiosonde ascent on this day is compared with that of 19 June 1961, an occasion discussed by Frost¹, when cumulonimbus development extended almost to the tropopause and a false cirrus canopy which formed at about 32,000 feet streamed out over Singapore. A small difference which may have been a limiting factor to the height of the top of the cumulus development over the fire, is the slightly warmer air between 335 mb and 200 mb. It will be noted that although the normal cloud development was very different on these two days, and in fact on the second had it not

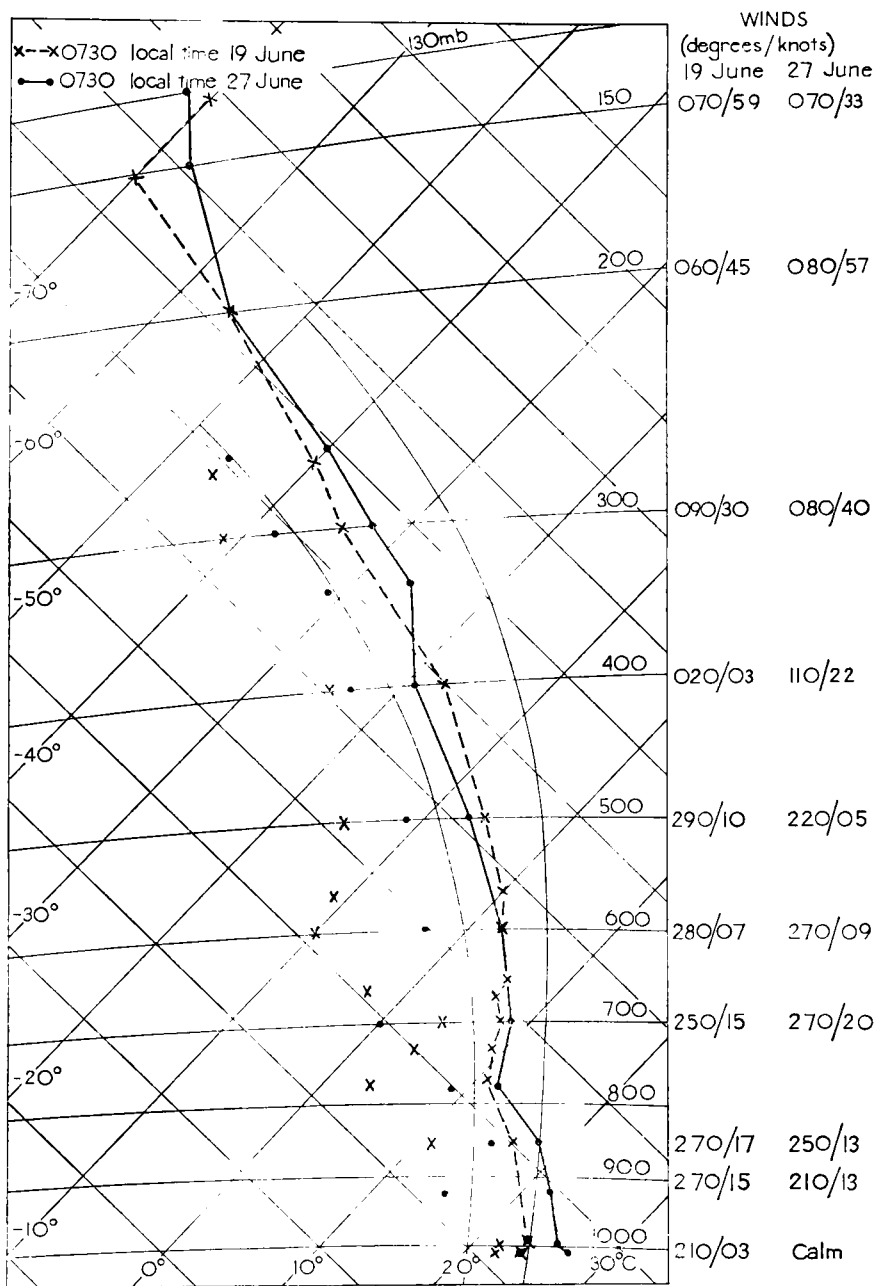


FIGURE 1—UPPER AIR ASCENTS FOR PAYA LEBAR, SINGAPORE,
0730 LOCAL TIME, 19 AND 27 JUNE 1961

been for the fire, development would have ceased at 7000 feet, the wind régimes were broadly similar and the temperature differences at all levels were so slight as to be almost within the range of instrumental error. This perhaps serves to illustrate the difficulty often experienced by a forecaster in the tropics in interpreting upper air soundings and how fine is the critical margin between the fair weather sky and cumulonimbus development giving showery weather.

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“WEATHER MONITOR” TAKES THE PLACE OF “WEATHER RECORDER”

By C. E. N. FRANKCOM, O.B.E.

At 12.30 p.m. on 30 May 1961 *Weather Recorder* arrived in Greenock, and thus completed her 106th and last voyage as an ocean weather ship in the North Atlantic. On 15 June *Weather Monitor*, the third of the “Castle” class vessels to be converted to an ocean weather ship, sailed from Greenock for Ocean Station “Juliatt”, thus taking the place of *Weather Recorder*.

Weather Monitor, formerly the “Castle” class frigate H.M.S. *Pevensey Castle*, was officially given her new name on 12 May at a little ceremony in Blyth (Northumberland) by Mrs. A. C. Best, wife of the Director of Services of the Meteorological Office. The renaming took place in the dockyard of the Blyth Dry Dock and Ship Building Co. Ltd., which had done the extensive job of converting the ship to make her suitable for her new duties. The ceremony, which was pleasantly informal, was attended by the Mayor and Mayoress of Blyth and representatives of the Meteorological Office, Ministry of Aviation and Admiralty. The ship was “dressed” with the national flags of the countries which operate ocean weather ships in the North Atlantic and, as the weather was appropriately kind for this meteorological occasion, she looked quite gay. Members of the ship’s company who had already joined the ship were assembled on the quay and each of them was introduced to Mrs. Best and her husband. A number of the Blyth Dry Dock Company’s men who had done the conversion work were also present.

Mrs. Best boarded the ship, accompanied by Captain A. A. Robinson, the temporary Master, and having cut a tape which released a canvas cover to disclose the ship’s name, said “I rename this ship *Weather Monitor*. May God bless her and all those who sail in her.”

After a tour of inspection of the ship, the visitors were entertained to luncheon by Mr. Mitcheson, the General Manager of the shipyard. In a brief informal speech, Dr. Best said how impressed he had been with the good job that the shipyard had made of this conversion, and mentioned in particular the high quality of the woodwork and general layout of the accommodation. He emphasized the useful work that weather ships have done and are doing in the somewhat inclement waters of the North Atlantic: without the meteorological information provided by these ships, supplemented by that provided voluntarily by merchant ships, the job of the meteorologists in Europe would be made very much more difficult. Also, the ships provide very useful navigational aids and communication services for transatlantic aircraft. The North Atlantic weather ship scheme provided an outstanding example of effective international co-operation for peaceful purposes, from which a large number of countries and individuals benefited. Mr. Mitcheson, in reply, said how pleased he was that his shipyard had had the opportunity of converting three of these ships (*Amberley Castle*, *Pevensey Castle* and, still in the process of conversion, *Rushen Castle*).

The general layout of *Weather Monitor* is almost exactly the same as that of *Weather Adviser* which sailed on her maiden voyage as an ocean weather ship

in September 1960. *Weather Monitor* is fitted with all the equipment necessary to perform her duty as an ocean weather ship and the general standard of her accommodation is as good as will be found in any other ship of a similar size.

Weather Recorder was formerly the "Flower" class corvette *Genista*; launched in 1941, she served as an escort trawler during the last war, mostly in the South Atlantic and Indian Ocean areas. Converted to an ocean weather ship in Devonport dockyard, she sailed on her first patrol at an ocean station in October 1947. During her fourteen years' service as an ocean weather ship in the North Atlantic she carried out her various duties very efficiently. The following extracts from the Master's voyage reports of *Weather Recorder* during her last five voyages will perhaps serve as an epitaph.

Voyage 102 to Station Juliett, October 1960

"For the first two weeks on station the weather was varied, ranging from good spells to rather uncomfortable ones. During the final week a severe storm developed; it became so bad that it was necessary, in the interests of safety, to turn ship and run before the wind which, blowing hard for many hours in one direction, built up a tremendous sea. Ship was driven . . . to the S.S.E., i.e., more than 100 miles off the Grid. When the weather finally eased sufficiently so that ship could be turned into wind and sea, there was insufficient fuel, and time remaining to get back again before being relieved. The appropriate Authorities were advised and ship remained in this approximate area until the *Weather Adviser* reached the corresponding longitude . . ."

Voyage 103 to Station Juliett, December 1960

"A Methop exercise in which two aircraft from St. Mawgan took part occurred on the 22nd. December. One aircraft carried out the exercise while the other photographed the proceedings. It was with great surprise and pleasure that we were told by the pilot of one of the aircraft that Air Vice-Marshal Bower, Air Officer Commanding, No. 19 Group, Royal Air Force, was present. At the end of the exercise, after the mail had been recovered, our distinguished visitor passed a Christmas Message to the Ship's Company. A further mail-drop, this time by an aircraft from Kinloss, took place on the 24th of December. The mail delivered on these two occasions was very much appreciated by all—the cakes and Christmas tree suffered no harm from their undignified drop into the North Atlantic."

Voyage 105 to Station Kilo, March 1961

"A surprise visit was made to the ship on Thursday, 23rd. March, by a French Air Force aircraft; he seemed to be rather surprised to find a British ship on station instead of a French one. This is borne out by the fact that he came armed with a large quantity of current French newspapers and magazines which he offered to drop if we wanted them. This offer was accepted and proved to be a windfall for the erudite few but a disappointment to the less well endowed majority."

Voyage 106 to Station India, May 1961

"The weather encountered throughout the period on station was, like that on Station Kilo last voyage, very good indeed. It would appear that whosoever controls the weather had decided to cast a benign eye on this, the *Weather*

Recorder's last voyage as a weather ship Members of the crew also indulged in swimming using rubber dinghies.

"One sad occurrence marred the voyage and that was the receipt of the news of the death of the Chief Engineer's wife It was fortunate that, just at that time, the *Weather Watcher* was homeward bound from Station Alfa and her Chief Engineer agreed to change places with my Chief Engineer, so that he could get home much sooner than otherwise would have been the case. The exchange took place on the 23rd. of May despite the temporary deterioration in the weather which made the operation not without a certain degree of hazard to the Chief Engineers and the boat's crew.

"On the 26th. May the German Navy Training Barque *Gorch Fock* closed the ship and sent over two officers—one, a meteorologist and the other an executive officer—to see a weather ship in action; they were most interested and left two cases of German beer, while we in turn gave them a case of English lager and a case of Guinness along with a bottle of whisky for the Commander of the German ship, Captain Erhardt. A photograph of the *Gorch Fock* was also given to us."

NOTES AND NEWS

British Glaciological Society 25th Anniversary Celebrations and Symposium, Cambridge 6-7 January 1962

The twenty-fifth anniversary of the formation of the British Glaciological Society was celebrated with a banquet in St. John's College and by a two-day symposium on the "Problems of mass balance studies". Though closely related to climatic and meteorological factors it was surprising that so few meteorologists were present to learn of the work and problems in a neighbouring field of study. Delegates from a dozen nations attended including some from across the Atlantic. All in all a good proportion of the world's active glaciologists were there and it served to show the international esteem for the British Glaciological Society and its Journal.

The first session, under the Chairmanship of Dr. G. de Q. Robin (Director, Scott Polar Research Institute) sought to bring unanimity to the terminologies that have been applied to the budget terms of a glacier (Dr. Meier, United States of America) and to explore the implications of mass balance studies (Dr. J. F. Nye, Great Britain). Dr. Nye defined climatic change as, denoted by the function $a_1(t)$, the changing accumulation and/or ablation budget, that is, the net effect of all climatic changes of the region concerned. He was able to show analytically that $a_1(t)$ is some function of the total thickness of the glacier $h_1(t)$, and can be represented by the polynomial $a_1 = \lambda_0 h_1 + \lambda_1 dh_1/dt + \lambda_2 d^2h_1/dt^2 + \dots$. Changes in the value of h_1 are directly proportional to advance or retreat of a glacial snout, which is easily determined. With additional knowledge of the flow rate of a glacier, the width and slope, the coefficients λ_n may be determined. This has been done for one glacier in North America, but glaciers that are well documented for velocities and snout positions dating back to the last century are scarce. Even so this offers the climatologist and hydrologist a tool for estimating precipitation and glacial extent at some time other than the present.

Professor Hoinkes (Austria), and Dr. V. Schytt (Sweden) described actual work on glaciers in their respective countries. These are by no means academic studies; the shrinkage of European glaciers is a serious problem and must be studied fully to be understood. Dr. Schytt was well aware that his impressive large-scale experiment needed the services of a meteorologist to study synoptically the weather related to his annual budget problem.

The second session, with Dr. Fristrup (Denmark) as Chairman, covered the "Seasonal velocity changes of temperate glaciers" (G. R. Elliston, Great Britain), "The assessment of glacier mass budgets from air photographs" (Dr. E. R. LaChapelle, United States of America), "Mass balance of the Ellesmere Ice Shelf" (Dr. H. Lister, Great Britain), and some "Hydrological investigations into the mass balance of a Greenland glacier" (Dr. F. Nusser, Germany).

W. O. Field of Canada was the Chairman of the last session, which after an account of work in the Canadian Arctic (Dr. Müller) turned to the Antarctic. In an excellent discourse J. T. Hollin stated the problems of the Antarctic mass budget. With a continent of the size of the Antarctic and a time lag in change of the ice cap probably of the order of some 4000 years behind the climate, it was difficult to find any evidence of change in mass. Most accumulation data are obtained in the less windy regions, the other regions are too uncomfortable to inhabit and make accumulation measurements. It is in these regions that there is probably a net loss of snow cover, thus reducing the net annual accumulation for the whole continent. Neither was there sufficient data on the calving rate, or under-water melting of the ice shelves. He concluded that he would regard the Antarctic ice cap as being in equilibrium until there was proof to the contrary.

Further problems arose when C. R. Bentley (United States of America) produced results of seismic and gravity traverses in west Antarctica. Surface features showed little relation to the rock profile at the bottom of the ice, and the basal shear stresses were less than two bars, which Dr. Nye pointed out was the minimum necessary to produce movement of a cold ice sheet. Was this static ice, despite the apparently significant surface slope? And, if so, is the mass of the continent increasing?

Discussion was lively and to the point throughout the symposium and much valuable knowledge and "knowhow" was exchanged. Obviously the scope of this type of work will increase, limited only by finance and man-power.

D. W. S. LIMBERT

Snowfall of 31 December 1961

The two photographs facing p.101 show an unusually heavy accumulation of snow on a thin wire. They were taken by Mr. J. J. H. Pennells, Meteorological Office cartographic draughtsman at his home in Reading between 9 and 10 a.m. on 31 December 1961. He states that rain commenced between 2.30 a.m. and 3 a.m. turning to snow about 3.30 a.m. The rain caused glazed frost on which the snow subsequently accumulated to a total diameter of $1\frac{1}{2}$ to 2 inches.

Fulwell Station on 24 August 1961

The photograph between pp. 100-101 shows an unusual production of condensed water vapour in the atmosphere. It was taken by Mr. G. Nicholson at 8 p.m. on 24 August 1961 at Fulwell Station. British Railways (Southern Region) state that the efficiency of the insulators had been greatly reduced by being partially submerged. The current passing over the insulators therefore produced local heating and consequent steaming.

OFFICIAL PUBLICATION

The following publication has recently been issued:

SCIENTIFIC PAPER NO. 11—*Some calculations of terms in the energy balance for monthly periods at the ocean weather stations I and J in the North Atlantic*, by H. C. Shellard, B.Sc.

Meteorological data from the North Atlantic ocean weather stations I and J for the period 1948-56 are used to compute monthly values of terms in the energy balance. The annual and year-to-year variations in the various terms are discussed and comparison is made between the mean seasonal and annual values of evaporation, sensible heat exchanged between sea and atmosphere, total energy exchanged between sea and atmosphere and of the Bowen ratio, and the corresponding values found by W. C. Jacobs for the same areas. It is suggested that in general Jacob's values are too low. Estimates are also made of the average annual amounts of heat advected into the two areas by ocean currents, and bathythermograph observations during six months in 1956 are used to show that this advection term may vary considerably from one month to the next.

METEOROLOGICAL OFFICE NEWS

Sports activities

We learn from the Senior Meteorological Officer, Royal Air Force, Khormaksar that in the Station Sports, held on 29 January and 2 February 1962, Mr. R. M. Blackall, Meteorological Office, finished first in the 3 miles, the 1 mile, the 3000 metres steeplechase and the 880 yards. In the Middle East Command Trials on 13 February, he was first in the 3 mile and 1 mile events, and second in the 880 yards. And in the Middle East Command Cross-Country Championship on 20 February, over a 4 mile course, Mr. Blackall finished first among 50 competitors.

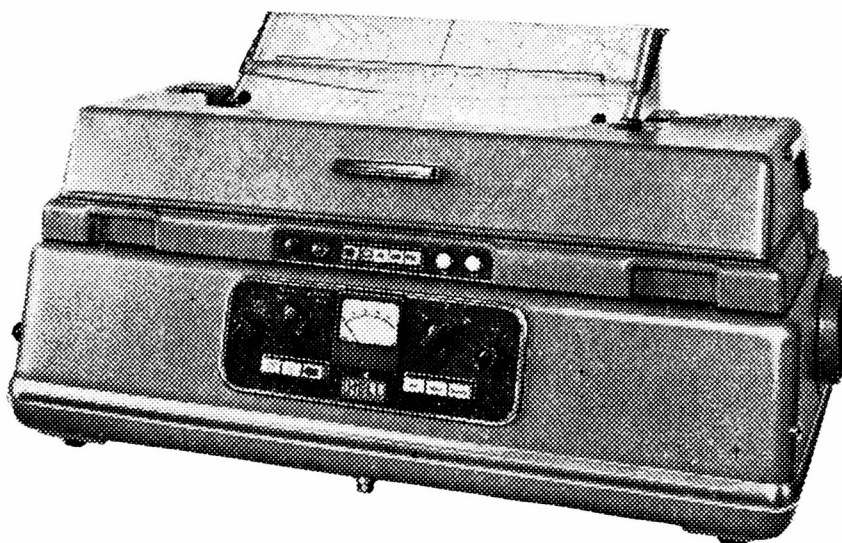
CORRIGENDUM

Distribution of total solar radiation on a horizontal surface over the British Isles and adjacent areas.

In Table 1 on page 272 of the October 1961 *Meteorological Magazine* the body responsible for Valentia Observatory should, of course, be the Irish Meteorological Service.

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