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RETIREMENT OF DR G. D. ROBINSON

Dr G. D. Robinson retired from the Meteorological Office on 16 August 1968 after more than 31 years' service.

Dr Robinson graduated at Leeds University with first class honours in physics at the age of 20 and joined the Meteorological Office in 1936 after three years research work at Leeds which earned him his Ph.D. Dr Robinson first served at Kew Observatory to which he was later to return as Superintendent. One of the important projects at Kew at the time was the measurement of potential gradients in thunderstorms by means of sounding balloons. It had been initiated by Sir George Simpson and Dr Robinson took an active part in the work.

During the war years Dr Robinson was engaged in providing forecasts and other meteorological advice for the Royal Air Force including the barrage balloon units, and he completed his forecasting career at the Central Forecast Office, then at Dunstable, during the years 1943 to 1946.

Back at Kew Observatory he became Superintendent in 1947 and was granted Special Merit promotion to Senior Principal Scientific Officer in 1953. During his ten years at Kew Dr Robinson was largely responsible for developing the Meteorological Office studies of the heat balance of the atmospheric boundary layer along sound physical lines. He demonstrated the significance of radiative transfer within the boundary layer and developed practical methods of estimating the radiative flux from aerological data, drawing attention in particular to the role of atmospheric aerosol.

In 1957 the reorganization of the Office provided for a Deputy Director to control the branches of the Office engaged in physical research. Dr Robinson was promoted to fill this post which he held until his retirement. Dr Robinson's penetrating and practical insight into the role of physical measurements in the atmosphere has provided vital guidance to many aspects of Meteorological Office work. The Instrument Development Branch was for many years under his direction and the work on satellites and sounding rockets grew under his guidance.

Dr Robinson's meteorological insight has been greatly valued on many national and international committees and he served the Royal Meteorological Society as Editor of the *Quarterly Journal* from 1954 to 1958 and as President from 1965 to 1967. His Presidential Addresses to the Society display his wide range of meteorological interests and his capacity to examine critically the currently accepted viewpoints on scientific problems.

Dr Robinson leaves the Office to take up a new appointment in America. His colleagues wish him all success in his new activities and look forward to continued collaboration with him through the many international links of the meteorological community.

J. S. SAWYER

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FORECASTING MONTHLY RAINFALL FOR ENGLAND AND WALES

By R. A. S. RATCLIFFE

Summary. It has been found that monthly mean 500 mb charts can be used as a fairly reliable indicator for forecasting the rainfall of the following month for all months of the year, although results for April and May are worse than for other months.

Two methods have been developed, each showing about the same success; one method requires an upper trough near the British Isles and considers the position and spacing between this trough and the upstream Canadian trough, while the other method depends solely on the position and orientation of the jet stream in the Atlantic.

Introduction. Forecasting the mean rainfall for a month ahead is one of the tasks which the long-range forecaster has to tackle as part of the long-range forecasting routine. The standard of success achieved is low and has given cause for concern; Freeman,[1] for example, states that when forecasting rainfall in terciles the correct category is selected on only 36 per cent of occasions compared with a chance expectation of 33 per cent. Freeman's figures related to forecasts prior to September 1966 and assessment of the 12 months from September 1966 to August 1967 inclusive shows a slight improvement — 39 per cent of the rainfall forecasts were exactly right. This improvement may be due to recent work by Murray,[2] who has indicated the probability, at various times of the year, of sequences of dry or wet months in England and Wales continuing for another month. His work has been used in recent long-range forecasts with some success, nevertheless forecasts of rainfall are still far from satisfactory and it was with the hope of further improvement that the current work was undertaken.

It must be realized at the outset that rainfall is such a highly variable parameter, both in time and space, that fully accurate monthly forecasts are never likely to be achieved. For example, it is not unusual for a large percentage of the monthly rainfall to fall on one or two days of the month, as happened in June 1967 at many places in England and Wales. Again, it sometimes happens that monthly rainfall at adjacent stations may vary over a wide range, for example Dyce and Leuchars in April 1967 had respectively 135 per cent and 29 per cent of their average monthly rainfall and these stations have comparable exposures only about 70 miles apart on the east Scottish coast.

Data used. Despite what has just been said, the overall rainfall figure for England and Wales, produced by the hydrometeorological branch of the Meteorological Office for each month from all available data, is a meaningful figure and this is the figure which has been used throughout this investigation. The rainfall for each month in each year from February 1946 to January 1968 (22 years) has been compared with the 500 mb pattern of the previous month over the northern hemisphere from approximately 100°W to 40°E and between latitudes 30°N and 70°N. The 500 mb data for 1946–48 were obtained from Japanese sources[3] while data for the remaining years were extracted from various British, American or German published data.

An analysis for the period 1949–64, of the average wavelength across the long-wave ridge in the Atlantic at 500 mb at 50° N for each pentad number throughout the year, showed that there is considerable seasonal variation (see Figure 1). For example, the mean wavelength from late April to August is about 65° of longitude while that from December to February is nearly 90°. Accordingly it was decided to group the months into three periods when the wavelength was reasonably constant, May to August (65° of longitude), September to November (about 75°) and December to February (85°–90°).

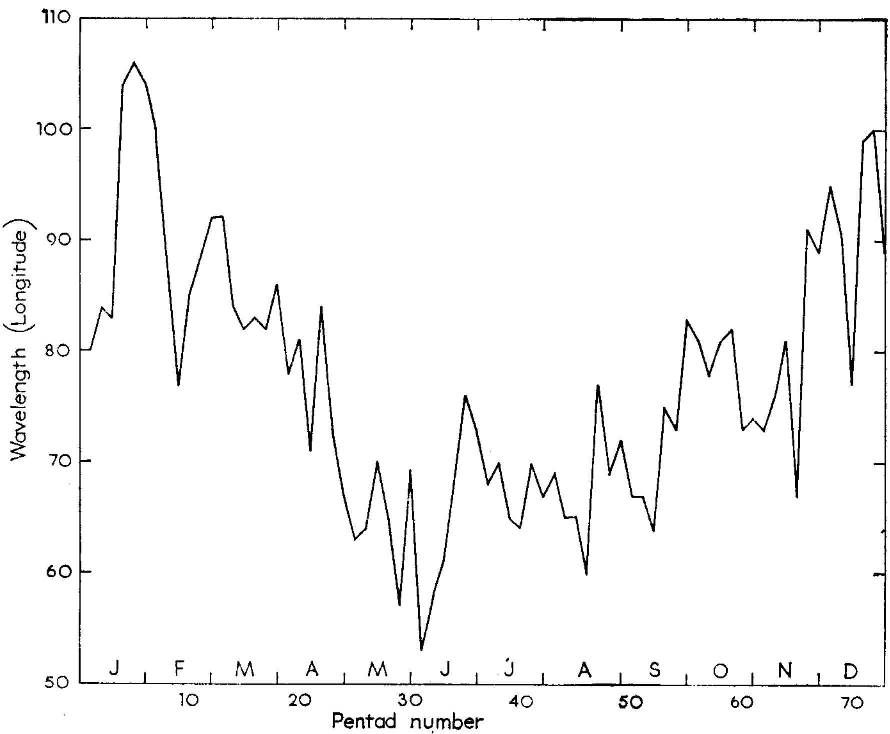

FIGURE 1—AVERAGE WAVELENGTH ACROSS THE ATLANTIC RIDGE AT 500 MB AT 50°N FOR THE PERIOD 1949–64

After some further experimentation April was included with May–August and March with December–February but, not surprisingly, the rules which are deduced give less satisfactory forecasts of the rainfall in April and May because of the transitional nature of the mean wavelength during March and April.

Figure 2 shows how the position of the 500 mb troughs and ridges across the North Atlantic at 50°N varies throughout the year. This diagram is produced from 10-day means at grid points over the period 1949 – 66 inclusive. It is noted that the approximate mean position of the Canadian trough for

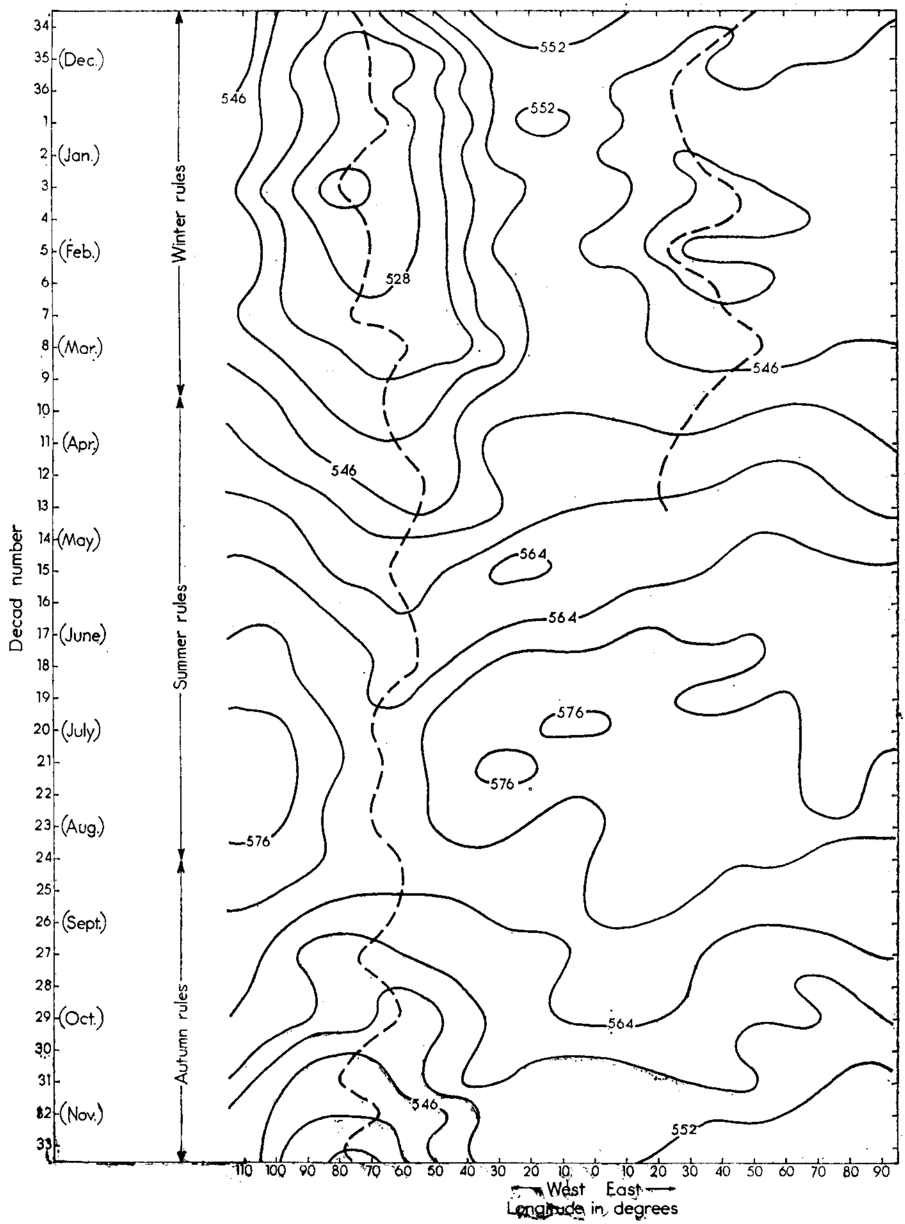

FIGURE 2—MEAN 500 MB HEIGHTS AT 50°N, BY DECADS, FOR THE PERIOD 1949–66
The broken lines indicate mean trough positions.
Contours are at intervals of 6 geopotential decametres.

the three periods selected is *(a)* 65°W from April to August, *(b)* 70°W from September to November and *(c)* 70°W–75°W from December to March approximately.

The European trough is not well defined for most of the year but does appear at about 30°E–40°E throughout the winter and part of spring.

Nevertheless, on more than half of the 264 individual months covered by this investigation there was a well-defined European trough between 25°W and 25°E on the monthly mean 500 mb chart. That this trough does not show on the 16-year mean is an indication of its year-to-year variability in all months, and is also a reflection of the fact that there is quite often a ridge between these longitudes.

Forecasting methods,

Method (i), based on trough spacing. Although 500 mb charts covering much of the northern hemisphere are available as far back as 1946, this period of data has, until now, been too short for adequate significance testing of any results obtained. In this paper the difficulty has been overcome partly by grouping months together and partly because of recent work by Craddock[4] who has extended significance tests by direct experimentation to small numbers of data so that, for example, the chi-square test can now be safely applied to a 3 × 3 table with an expectation of only three pieces of data per box.

By using these methods, and ideas developed from the mean seasonal positions and spacings of 500 mb troughs and ridges in the Atlantic sector, as discussed in the previous section, results have been obtained for the period February 1946 to January 1968 in regard to forecasting the tercile of England and Wales monthly rainfall from the previous month's 500 mb mean pattern and are shown in Table I (April–August). This table is a 3 × 3 contingency

TABLE I—RELATION BETWEEN MONTHLY MEAN 500 MB TROUGH POSITIONS AND ENGLAND AND WALES RAINFALL IN THE FOLLOWING MONTH (APRIL–AUGUST 1946–1967)

Actual England and Wales rainfall in following months (in terciles)	A Trough 65°* or more west and trough between 20°W and 5°*E (forecast wet)	A European trough existed but neither **A** nor **B** satisfied forecast (average)	B Trough 45° – 65°*W and trough between 5°*E and 25°E (forecast dry)
Wet	25	5	4
Average	9	8	7
Dry	2	6	11

* If trough is exactly on one of these longitudes, consider only the other trough. If both troughs are exactly marginal, forecast average.

$\chi^2 = 22{\cdot}64$. Significant at 0·1 per cent level.

table between the positions of the 500 mb Canadian and European monthly mean troughs in the period April–August (1946–67), and the tercile of rainfall over England and Wales for the following month. The tercile boundaries of rainfall used are those given by Murray.[2] Broadly, this table suggests that westward displacements of the Canadian and European troughs are more likely to be followed by wet months in England and Wales, while eastward displacements of these troughs are more likely to be followed by dry months. If one trough is displaced eastward while the other is displaced to the west, average rainfall is the most probable in the following month.

Similarly Tables II and III show the statistical results obtained during the autumn and winter seasons respectively. The more westward positions of the Canadian trough and the greater spacing between the European and

TABLE II—RELATION BETWEEN MONTHLY MEAN 500 MB TROUGH POSITIONS AND ENGLAND AND WALES RAINFALL IN THE FOLLOWING MONTH (SEPTEMBER–NOVEMBER 1946–1967)

Actual England and Wales rainfall in following months (in terciles)	**A** Trough 70°* or more west and trough between 5°* – 25°W (forecast wet)	A European trough existed but neither **A** nor **B** satisfied (forecast average)	**B** Trough 50° – 70°*W and trough between 5°*W – 25°E (forecast dry)
Wet	7	2	0
Average	3	9	2
Dry	4	3	3

* If trough is exactly on one of these longitudes, consider only the other trough. If both troughs are exactly marginal, forecast average.

$\chi^2 = 9{\cdot}85$. Significant at 5 per cent level.

TABLE III—RELATION BETWEEN MONTHLY MEAN 500 MB TROUGH POSITIONS AND ENGLAND AND WALES RAINFALL IN THE FOLLOWING MONTH (DECEMBER–MARCH 1946–1967)

Actual England and Wales rainfall in following months (in terciles)	**A** Trough 75°* or more west and trough between 20°W – 5°*E (forecast wet)	A European trough existed but neither **A** nor **B** satisfied (forecast average)	**B** Trough 50° – 75°*W and trough between 5°*E – 25°E (forecast dry)
Wet	4	4	4
Average	2	8	4
Dry	0	3	10

* If trough is exactly on one of these longitudes, consider only the other trough. If both troughs are exactly marginal, forecast average.

$\chi^2 = 10{\cdot}88$. Significant at less than 2 per cent level.

Canadian trough in winter reflect the normal seasonal differences indicated in Figures 1 and 2.

In this work the measurement of the longitude of all troughs is objective; the longitude of the trough is defined as that longitude where the contour height at 50°N on the monthly mean 500 mb chart is a minimum. This should be carefully considered when applying the results of Tables I, II and III to the forecasting of monthly rainfall.

The chi-square test applied to Table I indicates significance at the 0·1 per cent level, Table II shows significance at the 5 per cent level, while Table III shows significance at just less than the 2 per cent level.

Method (ii), based on the monthly mean jet stream. So far, only those months in which the mean 500 mb map showed a trough at 50°N in the neighbourhood of the British Isles have been considered. Such a trough occurred on rather more than half of the occasions, while in the remaining months there was no trough between 25°W and 25°E. In order to derive a satisfactory rule for all occasions some extra parameter was necessary to cover the cases when the European trough was absent.

It was considered that the position and orientation of the Atlantic jet stream might enable a satisfactory criterion to be derived. Previous work on fine spells[5] and wet spells[6] had indicated the 500 mb jet-stream patterns which are commonly associated with dry or wet weather in south-east England for periods of three days or longer. Should such patterns show a tendency to recur then an association between the jet stream and the following month's rainfall in England and Wales might become apparent. In general it was found that a strong south-westerly flow in the Atlantic with the core of the jet reaching at least 55°N at 20°W strongly favoured a dry month to follow, while a strong westerly flow with the core mostly south of 50°N often indicated a wet month to follow.

It is clearly desirable to make any rules of this nature as objective as possible and it is hoped that this has been achieved in the rules now to be described.

It was noted that the area in the Atlantic between 40°–50°N, 40°–70°W was a key area. In the individual monthly charts considered over the 22-year period, practically all had mean wind directions between 230° and 290° in this area. Careful measurements of the direction of the 500 mb contours on the normal (1951–66) charts were then made; these directions were found to vary between 260 and 270 degrees in March to October and between 250 and 260 degrees in November to February inclusive.

If the strongest flow on the 500 mb monthly mean chart in the area between 40°–60°N, 20°–70°W, is now considered, four rules regarding England and Wales rainfall for the following month can be defined as follows :

Rule 1. If the strongest flow is in the area between 40°–50°N, 40°–70°W, a wet, average or dry month follows according to whether the wind direction in that area is veered from 270°, between 260° and 270° or backed from 260° respectively (March to October). In November–February the corresponding wind directions are 260° (wet), 250°–260° (average), 250° (dry). This rule is even more successful if the strong flow exists westwards to 80°W from about the same direction. *Rule 1* occurred on 44 occasions.

Rule 2. If the strongest flow is between south and west and located between 40°–60°N, 20°–40°W a dry or average month follows according to whether the core of this jet stream is centred north or south respectively of 55°N at 20°W (33 occasions).

Rule 3. If the strongest flow is centred north of 60°N, south of 40°N or in the area 50°–60°N, 40°–70°W, average rainfall is expected in the following month. This rule arises on very rare occasions (16 occasions); usually the main flow satisfies either *Rule 1* or *2*.

Rule 4 arises when almost equally strong jet streams occur in both areas defined in *Rules 1* and *2*. It states : if almost equally strong jet streams have their cores situated in areas defined for both *Rules 1* and *2*, take the forecast from *Rule 1* and modify it one category towards dry if the jet satisfying *Rule 2* has its core north of 55°N at 20°W (original dry forecast remains dry). If the second jet core is not as far north as 55°N at 20°W change a dry forecast from *Rule 1* to average but leave other *Rule 1* forecasts unchanged. *Rule 4* occurred on 29 occasions.

The application of *Rule 4* is illustrated in Figure 3 for each season, with the original forecast shown on the left and the final one shown on the right.

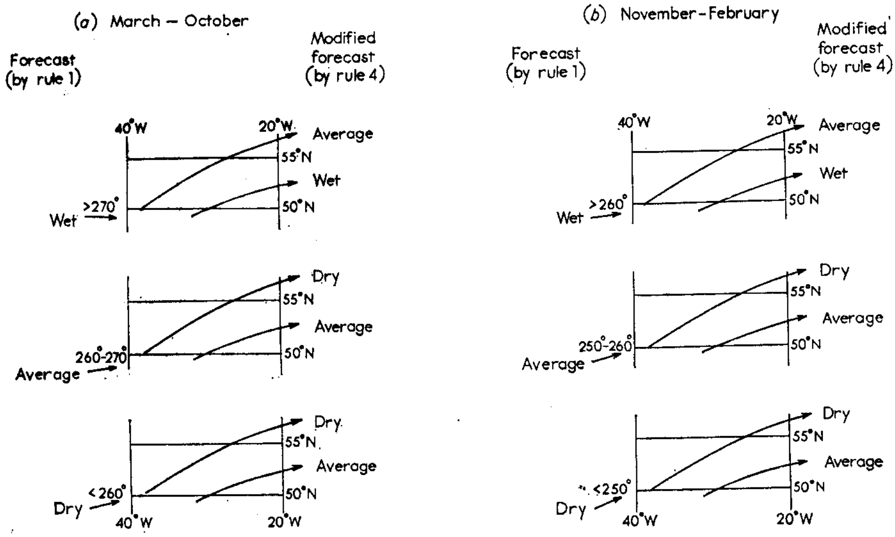

FIGURE 3—EXAMPLES OF RULE 4 MODIFYING RULES 1 AND 2
The original forecast is shown on the left and the modified forecast is on the right of each diagram.
———→ Position of strongest flow.

These rules were carefully applied using a protractor and wind scale as necessary and results are shown in the form of contingency tables in Tables IV and V. Chi-square tests show that the results are significant at about the 0·1 per cent level for Table IV and at the 1 per cent level for Table V. The significance levels of Tables I–V may be rather fictitiously high owing to the fact that the rules were developed after scrutinizing the data and also

TABLE IV—FORECAST BASED ON ATLANTIC JET-STREAM POSITION (MARCH–OCTOBER)

Actual England and Wales rainfall in following months (in terciles)	Forecast Wet	Forecast Average	Forecast Dry
Wet	9	16	1
Average	2	20	2
Dry	3	11	11

$\chi^2 = 21{\cdot}45$. Significant at about 0·1 per cent level.

TABLE V—FORECAST BASED ON ATLANTIC JET-STREAM POSITION (NOVEMBER–FEBRUARY)

Actual England and Wales rainfall in following months (in terciles)	Forecast Wet	Forecast Average	Forecast Dry
Wet	7	6	1
Average	4	13	4
Dry	0	8	7

$\chi^2 = 14{\cdot}0$. Significant at 1 per cent level.

because consecutive months are not strictly independent of one another, but these considerations are not likely to make much difference to the level of significance.

Discussion. If the occasions when there is a trough near the British Isles (*Method (i)*, see Tables I, II and III) are considered, there are 84 correct forecasts out of 149 (56 per cent), while the number of forecasts which are 2 categories wrong is 14 out of 149 (9 per cent). A skill score *(S)* can be defined by

$$S = \frac{N_f - N_c}{N - N_c}$$

where N = the total number of forecasts, N_f = number of correct forecasts and N_c = number of forecasts expected to be correct by chance; these results give a skill score of 0·34. This is still low but shows considerable improvement over the 39 per cent of correct forecasts currently achieved in long-range forecasts of district rainfall (skill score 0·1).

If the results of forecasts based on the jet stream (*Method (ii)*, see Tables IV and V) are taken together there are 67 correct forecasts out of 125 (53 per cent) while the number of forecasts which are 2 categories wrong is 5 out of 125 (4 per cent). These results give a skill score of 0·31.

It is noteworthy in Tables IV and V that the greatest success is achieved in forecasting the wet or dry months rather than those with average rainfall. Of 51 forecasts of wet or dry months over the 12 months, 34 are exactly correct (skill score 0·5), 12 are one category out and only 5 are completely wrong.

The success achieved varies from month to month and is likely to be less (at least for trough cases) when the spacing between the upper troughs is changing rapidly. As has been explained, this is during March and April, so that forecasts for April and May are less reliable than those for other times. Shortage of data precludes accurate significance-testing of each method for each month but, if both forecast methods are taken together, Table VI shows *(a)* the best results achieved (August–September) and *(b)* the worst (April–May).

TABLE VI—CONTINGENCY TABLES SHOWING RESULTS OF USING BOTH FORECAST METHODS TOGETHER OVER THE PERIOD 1946–1968, *(a)* BEST RESULTS *(b)* WORST RESULTS

(a)

Actual	Forecast (for September)		
	Wet	Average	Dry
Wet	9	1	0
Average	2	3	1
Dry	0	1	5

Significant at better than 0·1 per cent level

(b)

Actual	Forecast (for May)		
	Wet	Average	Dry
Wet	1	2	4
Average	1	7	2
Dry	0	3	2

Not significant

Here it must be pointed out that it is easier to achieve a correct forecast for England and Wales as a whole than it is to forecast correctly the monthly rainfall for a district about one sixth of that area, as is done in the long-range forecast. Nevertheless it is probable that the rules derived above do represent a definite improvement although it is unfortunate that it is not yet possible to test them against independent data.

The fact that the 500 mb patterns which are here used to forecast wet and dry months are themselves usually characteristic of wet and dry months respectively might lead one to suspect that the rules derived were no more than persistence. The success achieved suggests that this is not so.

To illustrate this matter further a run of successive months is considered (Figures 4–9*), starting in September 1949. Perhaps surprisingly with this pattern, September 1949 was a dry month but the forecast with a trough west of 70°W and another west of the British Isles was for a wet October. This was correct (October rainfall 6·2 in).

The October 500 mb pattern is shown in Figure 5. On the jet-stream rule this pattern would indicate a wet November which again was correct. The November 500 mb chart is shown in Figure 6; this pattern with troughs east of Britain and west of 70°W suggests average rain for December (as would in fact be suggested by the orientation of the jet stream). December 1949 had 3·5in of rain over England and Wales as a whole, a figure near the middle of the middle tercile.

Figure 7 shows the monthly mean 500 mb pattern for December 1949. This leads to a forecast of average or dry for January 1950 according to whether the jet stream is envisaged as having its core south or north of 55°N at 20°W. In the event January 1950 was dry.

Continuing the sequence, the forecast for February 1950, based on the dominant westerly jet near Newfoundland on the 500 mb chart for January 1950 (Figure 8), would indicate a wet February and this was amply verified with 5·6 in compared with an average of 2·6 in. The February 1950 chart (Figure 9) with a predominantly south of west flow across the Atlantic but with the core of the jet south of 55°N at 20°W indicates average rainfall for March; in fact the month was dry but the amount of rain recorded was borderline between the dry and average terciles.

Over this 6-month period there are thus four correct forecasts and two marginally correct ones but, as can readily be seen by a glance at Figures 4–9, the patterns do not indicate significant month-to-month persistence.

Conclusions. It has been demonstrated that significant success can be achieved in forecasting the tercile of England and Wales rainfall using only the monthly mean 500 mb chart for the previous month. Skill scores of between 0·3 and 0·35 are obtained over 264 monthly forecasts.

Two methods are developed, one requires a 500 mb trough near the British Isles and takes into account the position and spacing between this trough and the upstream Canadian trough, bearing in mind the average trough spacing for the time of year. Broadly, a trough west of Britain with a western position of the Canadian trough implies a wet month to follow in England and Wales but an eastern position of these troughs implies a dry month to follow.

The other method depends entirely on the position and orientation of the strongest flow in the Atlantic on the 500 mb monthly mean chart. Broadly, if this flow is south-westerly and its core reaches 55°N at 20°W then a dry month is expected to follow; whereas if the main flow is westerly and south of 50°N a wet month will probably follow.

* Figures 4 – 9 are based on maps in *GrosswettLag. Mitteleur. Offenbach (Main)*, **2**, **3**, 1949, 1950.

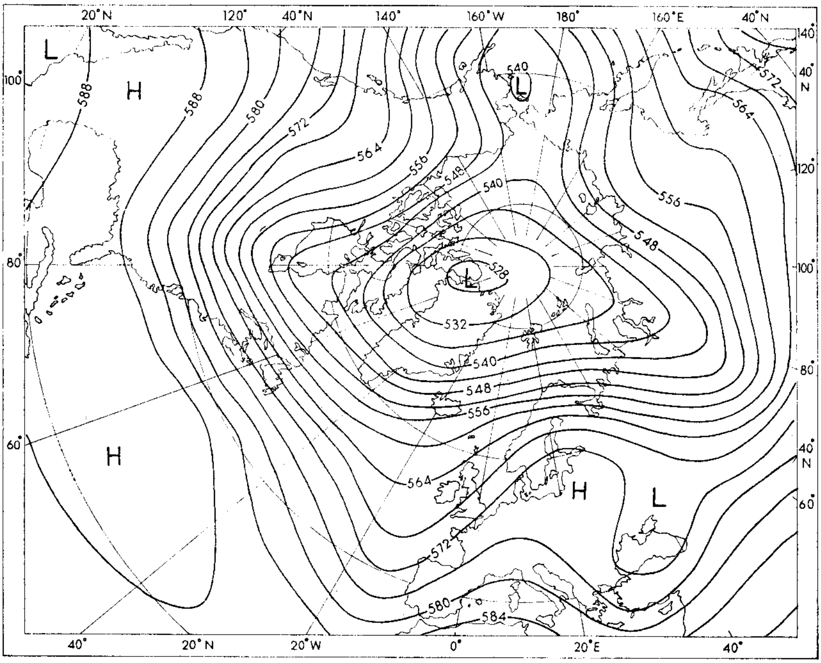

FIGURE 4—MEAN 500 MB CONTOUR CHART FOR SEPTEMBER, 1949
Contours are at intervals of 4 geopotential decametres.

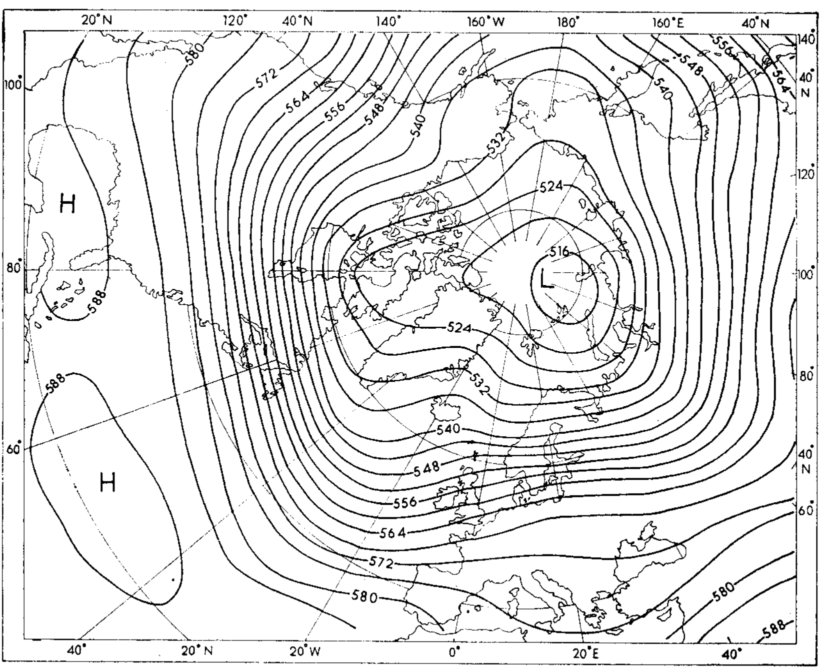

FIGURE 5—MEAN 500 MB CONTOUR CHART FOR OCTOBER, 1949
Contours are at intervals of 4 geopotential decametres.

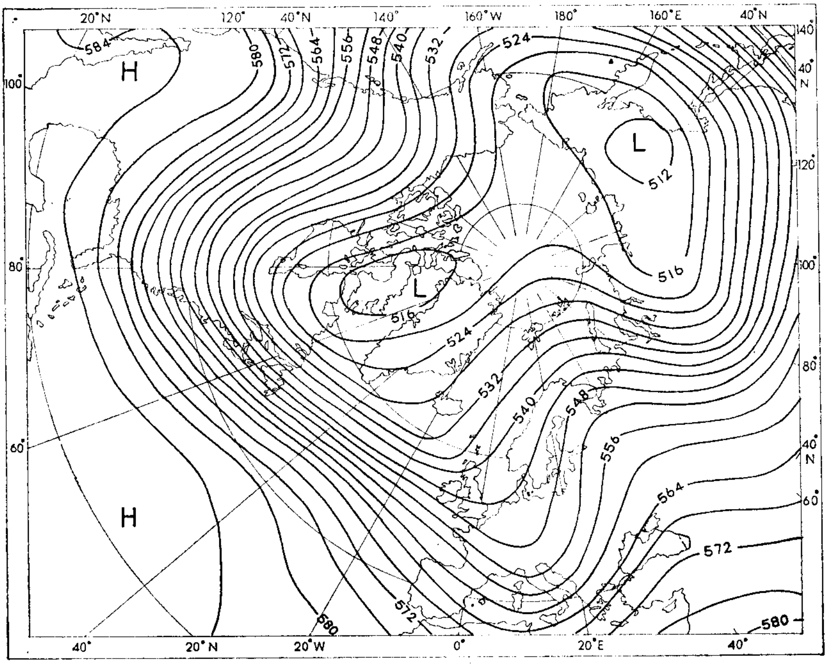

FIGURE 6—MEAN 500 MB CONTOUR CHART FOR NOVEMBER, 1949
Contours are at intervals of 4 geopotential decametres.

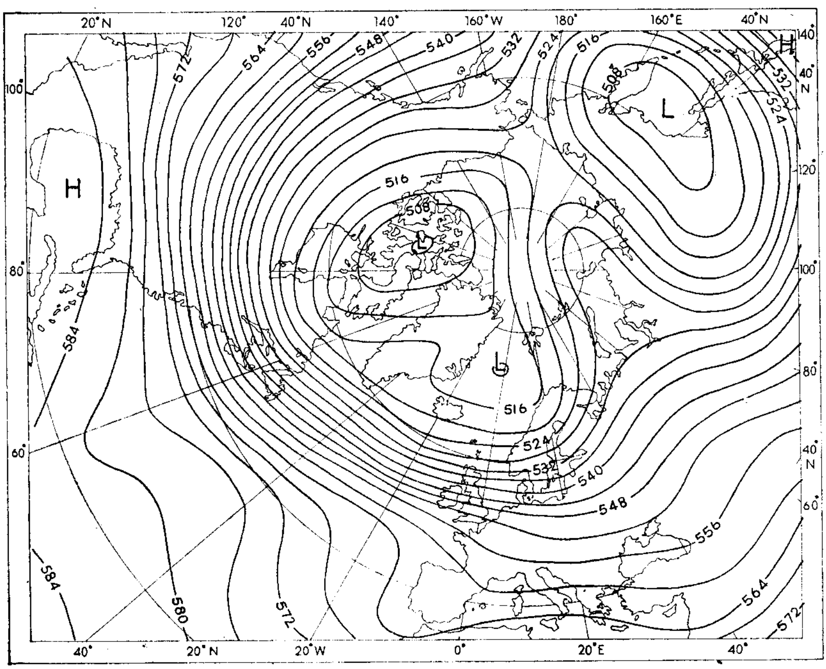

FIGURE 7—MEAN 500 MB CONTOUR CHART FOR DECEMBER, 1949
Contours are at intervals of 4 geopotential decametres.

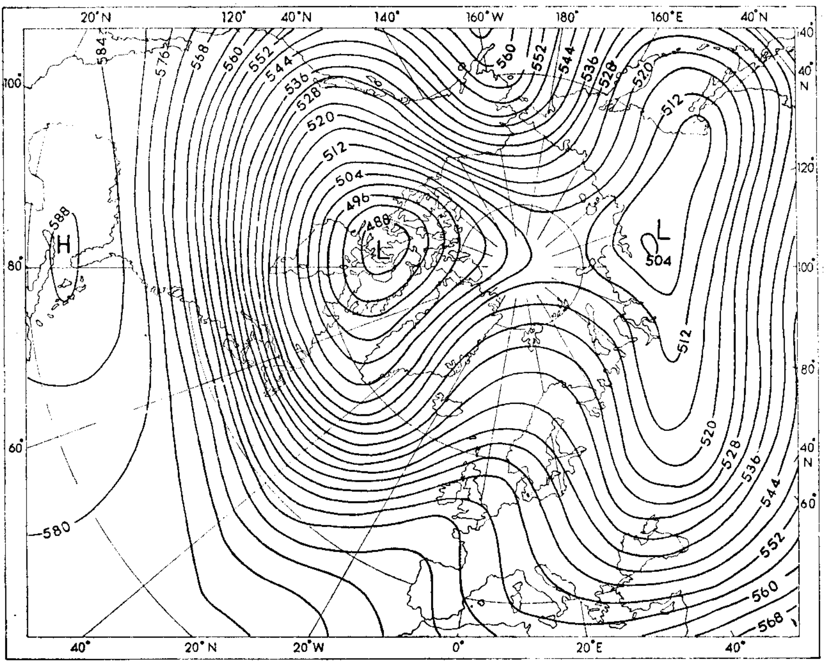

FIGURE 8—MEAN 500 MB CONTOUR CHART FOR JANUARY, 1950
Contours are at intervals of 4 geopotential decametres.

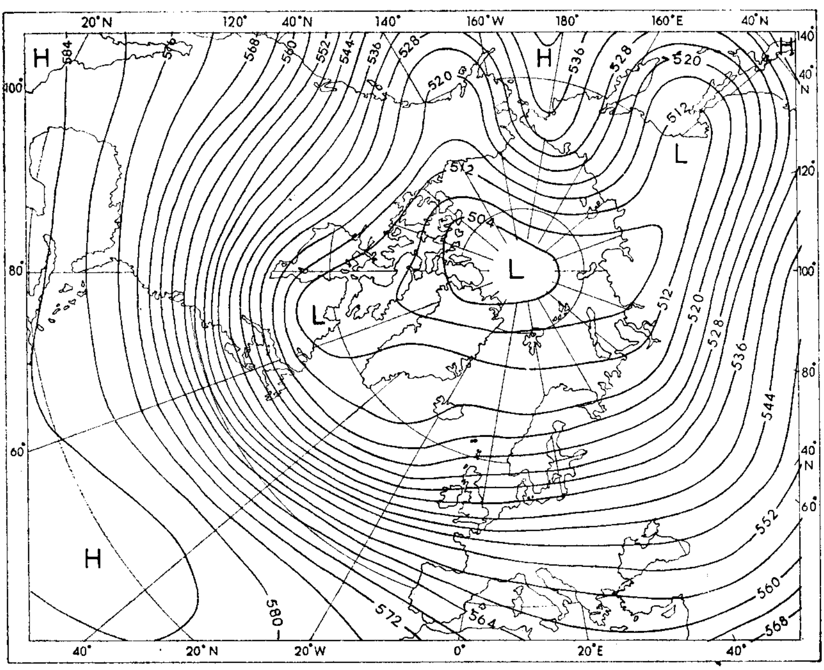

FIGURE 9—MEAN 500 MB CONTOUR CHART FOR FEBRUARY, 1950
Contours are at intervals of 4 geopotential decametres.

Acknowledgement. The help of Mr P. Collison in carrying out an independent assessment of the results and also in developing the rules based on the jet stream is gratefully acknowledged.

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THE DEVELOPMENT OF LOW-LEVEL MIDDAY AIR TEMPERATURE INVERSIONS

By E. N. LAWRENCE

Summary. Occasions are described when atmospheric temperature inversions seem to develop during the daytime, in a stable layer, in the region of 3500 – 6000 ft (about 1 – 2 km) above MSL at Crawley, Sussex. Spells of the phenomenon are infrequent or even rare.

Introduction. In an investigation of meteorological conditions associated with days of relatively high concentration of air pollution (sulphur dioxide) in summer, at Kew Observatory, it was observed that on a number of these occasions there was (at Crawley radiosonde station): (i) a surface air temperature inversion at midnight and (ii) a low-level midday air temperature inversion in a layer well above the top of the previous midnight surface inversion layer and where no inversion existed at midnight. The phenomenon is not the same as the formation of a nocturnal surface inversion subsequently eroded either at the bottom by thermal instability due to solar radiation during the morning or fog-top cooling at night. The present note describes examples of this phenomenon with an indication of its frequency and possible causes.

Data. Most of the data refer to Crawley, Sussex (51°05′N 00°13′W, 471 ft (144 m) above MSL), for the five-year period April 1960 to March 1965 inclusive. These data include upper air temperatures and dew-points for various pressure levels (from which heights were computed), and surface, 900 m and 850 mb winds.

Profile temperature and pressure data for Larkhill, Wilts (51°12′N 01°48′W, 431 ft (131 m) above MSL), are used for the months of May, June, July and August during 1947 (0600 GMT) and 1948–51 (0300 and 0900 GMT).

Data for days of special interest are supplemented by (i) upper air temperature soundings at Cardington (52°06′N 00°25′W, 93 ft (28 m) above MSL) made from tethered balloons for most of the relevant six-hourly observations at 0000, 0600, 1200 and 1800 GMT, generally up to 3937 ft (1200 m), (ii) radiosonde temperature soundings at 0000 and 1200 GMT at Hemsby (52°41′N

01°41′E, 42 ft (13 m) above MSL), (iii) surface meteorological reports for south-east England, especially for London/Gatwick Airport (51°09′N 00°11′W, 192 ft (59 m) above MSL) and (iv) Meteorological Office surface synoptic charts.

Analysis and results. Figure 1 shows examples of low-level midday air temperature inversions which apparently developed at Crawley during the day and which were distinct from the nocturnal surface inversions. The examples illustrate the three longest spells of the phenomenon during the months of May, June, July and August in the period May 1960–August 1964 inclusive. Two of these spells (1960 and 1963) had mainly easterly winds and the other (1964) mainly westerlies (Table 1). The two spells with easterlies approximately coincided with two spells of persistent high sulphur-dioxide air pollution at Kew Observatory.

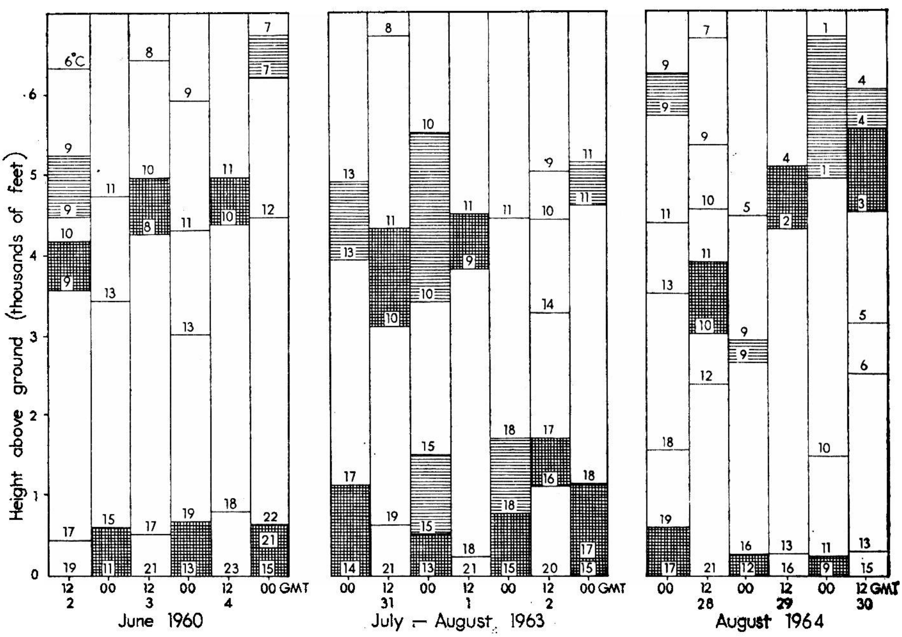

FIGURE 1—EXAMPLES OF THE DEVELOPMENT OF LOW-LEVEL MIDDAY AIR TEMPERATURE INVERSIONS AT CRAWLEY, SUSSEX

The temperatures at levels of discontinuity are given in degrees Celsius. Temperature lapse rates are shown : unshaded — positive lapse rate, light shading — isothermal, dark shading — inversion.

During the spells, weather was neither anticyclonic nor particularly disturbed (see Figure 2). Generally, there were partly cloudy conditions and an absence of any substantial rainfall. In the two easterly spells, weather was hazy at Gatwick, with improving surface visibility during the afternoon. In the westerly spell, visibility was mainly moderate at least, and good during the afternoon.

Heights and temperatures, up to 7000 ft (2133 m), of inversions, isothermal layers and some standard levels, for all three spells, are given in Figure 1. An example of the temperature profiles for one of the days is illustrated in the

FIGURE 2—SURFACE SYNOPTIC CHARTS DURING THREE SPELLS OF THE DEVELOPMENT OF LOW-LEVEL MIDDAY AIR TEMPERATURE INVERSIONS AT CRAWLEY, SUSSEX

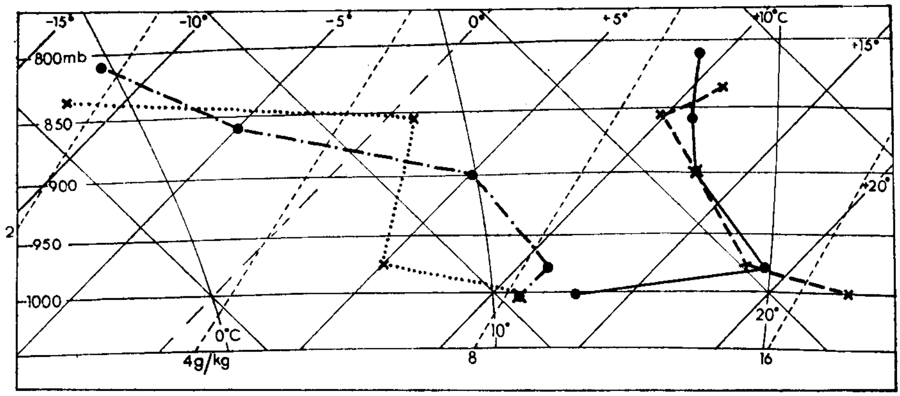

FIGURE 3—AN EXAMPLE OF THE TEPHIGRAM PROFILES (OF TEMPERATURE) ON A DAY OF DIURNAL DEVELOPMENT OF A LOW-LEVEL MIDDAY AIR TEMPERATURE INVERSION AT CRAWLEY, SUSSEX, 4 JUNE, 1960

●————● Dry bulb temperature at midnight. ●—·—·—● Dew-point at midnight.
x— — — —x Dry bulb temperature at midday x · · · · · x Dew-point at midday.

tephigram of Figure 3. It can be seen that during these spells there was a surface inversion at midnight, while at midday there was an inversion in the region of 3500–6000 ft (about 1–2 km) above MSL and usually well above the midnight surface inversion layer.

It might be considered that the midday inversion was merely a residue from a nocturnal surface inversion which had increased considerably in depth after midnight. Figure 3 and data for Cardington (not shown) suggest that this was not so for at least some of the occasions described. The low-level midday inversion of 2 August 1963 (Figure 1) may well have been the residue of a nocturnal inversion but, in general, the Cardington data suggest that in similar synoptic situations (i) the midnight surface inversions at the more inland station of Cardington were similar to or deeper than the corresponding ones at Crawley, (ii) at Cardington, the inversion tops in existence at 0600 GMT (when the top of a nocturnal inversion is probably near its maximum height) were usually similar to or somewhat higher than the preceding midnight inversion tops and (iii) at Cardington, both the midnight and 0600 GMT low-level inversions were below the upper limit of the sounding (normally 3937 ft (1200 m)) and the levels of the midday inversions at Crawley.

Furthermore, a study of data from Larkhill for the years 1947 (0600 GMT) and 1948 to 1951 (0300 and 0900 GMT) shows that surface (nocturnal) inversions at these times extended only very rarely to a height of 2000–3000 ft (about 1 km) above the ground and then only on isolated days.

It should be noted that at midnight at Crawley, air above and below the level of the subsequent midday inversion was generally rather stable and sometimes isothermal: also, air above this level was not particularly unstable either at midnight or midday (see Figure 1 and Table I).

Discussion. The data of Table I suggest that the midday inversion layer approximately coincides with a marked hydrolapse or with a moisture dis-

TABLE I—WIND SPEED AND DIRECTION AT SURFACE, 900 M AND 850 MB; AND HEIGHT ABOVE GROUND, PRESSURE, TEMPERATURE AND DEW POINT AT 850 MB AND AT SIGNIFICANT LEVELS BELOW 700 MB* AT CRAWLEY, SUSSEX, DURING SPELLS OF DEVELOPMENT OF LOW-LEVEL MIDDAY AIR TEMPERATURE INVERSIONS

				WIND						850 MB			SURFACE		
Year	Month	Day	Time of ascent	Surface		900 m		850 mb		Height	Temp.	Dew-point	Pressure	Temp.	Dew-point
			GMT	*deg*	*kt*	*deg*	*kt*	*deg*	*kt*	*ft*	*°C*	*°C*	*mb*	*°C*	*°C*
1960	June	2	12	090	03	060	06	050	09	4700	09	—09	1009	19	08
		3	00	080	03	070	12	070	15	4680	11	—05	1008	11	09
			12	060	10	100	12	110	11	4650	09	—07	1006	21	13
		4	00	060	06	110	17	140	05	4580	11	—06	1003	13	11
			12	020	10	090	12	080	10	4520	10	—04	1000	23	11
		5	00	060	03	140	14	170	10	4450	12	—05	997	15	11
1963	July	31	00	030	08	040	09	030	10	4630	13	—01	1005	14	12
			12	080	08	090	13	070	07	4500	10	—07	1001	21	11
	Aug.	1	00	110	05	110	10	200	03	4430	10	—04	999	13	11
			12	110	03	130	05	270	04	4390	11	—01	997	21	14
		2	00	090	10	120	12	160	08	4420	11	08	997	15	11
			12	060	07	100	16	130	15	4420	10	05	997	20	15
		3	00	000	00	190	06	210	08	4410	11	08	997	15	15
1964	Aug.	28	00	000	00	240	05	230	15	4590	11	08	1003	17	15
			12	250	03	230	09	250	17	4530	10	—01	1002	21	15
		29	00	260	08	290	22	270	21	4480	05	01	1002	12	09
			12	300	15	330	20	320	21	4610	02	—02	1008	16	07
		30	00	360	03	010	14	330	07	4730	01	—02	1014	09	05
			12	360	05	260	02	330	03	4770	03	—06	1014	15	09

* Data above the 700 mb level are given in the absence of data between 700 mb and the level of the midday air temperature inversion indicated in Figure 1.

TABLE I—*continued.*

HIGHER SIGNIFICANT LEVELS

Pressure *mb* (Height *ft*)	Temp. °*C*	Dew-point °*C*	Pressure *mb* (Height *ft*)	Temp. °*C*	Dew-point °*C*	Pressure *mb* (Height *ft*)	Temp. °*C*	Dew-point °*C*	Pressure *mb* (Height *ft*)	Temp. °*C*	Dew-point °*C*	Pressure *mb* (Height *ft*)	Temp. °*C*	Dew-point °*C*
994 (410)	17	07	887 (3540)	09	—08	867 (4160)	10	—05	857 (4470) 801 (6300)	09 06	—06 —06	833 (5250) 761 (7670)	09 05	—08 —07
987 (570)	15	11	890 (3420)	13	—11	717 (9260)	03	—08						
988 (500)	17	07	862 (4250)	08	—02	841 (4910)	10	—10	795 (6440)	08	—29			
979 (670)	19	11	900 (3010)	13	05	858 (4310)	11	—05	809 (5920)	09	—12			
973 (770)	18	05	855 (4330)	10	01	837 (4910)	11	—12	395* (23050)	—32	—40			
985 (340)	21	10	975 (630)	22	08	797 (6190)	07	—01	781 (6730)	07	—11	755 (7650)	06	—18
965 (1120)	17	04	872 (3930)	13	05	841 (4920)	13	—04	778 (7040)	10	—10			
999 (60)	19	08	895 (3100)	10	06	855 (4340)	11	—06	783 (6720)	08	—11			
981 (500)	15	09	947 (1480)	15	05	882 (3430)	10	04	818 (5470)	10	—08	738 (8250)	07	—11
990 (200)	18	12	870 (3750)	09	06	847 (4480)	11	—06	720 (8870)	05	—12			
971 (740)	18	12	939 (1670)	18	09	767 (7200)	05	03	757 (7550)	06	01			
957 (1150)	16	12	938 (1700)	17	08	887 (3250)	14	03	837 (5000)	09	05			
990 (200)	17	14	957 (1140)	18	13	844 (4610)	11	08	828 (5130)	11	07	746 (7950)	05	03
981 (620)	19	13	949 (1550)	18	13	885 (3490)	13	11	857 (4360)	11	09	815 (5730) 800 (6230)	09 09	—01 05
921 (2340)	12	09	898 (3030)	10	08	870 (3900)	11	01	825 (5340)	09	—04	786 (6650)	07	00
992 (230)	16	12	909 (2630)	09	02	900 (2900)	09	05	748 (7790)	—04	—08	737 (8170) 709 (9180)	—02 —04	—13 —20
1000 (220)	13	05	859 (4310)	02	00	835 (5060)	04	—07	619* (12820)	—10	—24			
1005 (240)	11	05	961 (1460)	10	04	842 (4990)	01	—02	810 (6010)	01	—14	789 (6700)	01	—14
1004 (270)	13	07	926 (2470)	06	04	904 (3110) 809 (6060)	05 04	03 —15	857 (4530) 752 (8000)	03 03	—04 —19	827 (5470) 723 (9040)	04 02	—11 —16

Note: See first part of Table for dates and times.

continuity with the drier air above. The hydrolapse rates and the dry adiabatic temperature lapse rates in the surface layer, shown in Figure 1 and Table I, and also the cloud base at midday at Gatwick (around 3000–4000 ft on the seven days with low cloud), indicate that the upper stable layer, at midnight and midday, was near to the top of the midday surface mixing layer. Such temperature profiles may well be associated with a haze (and water-content) profile which could cause a relative warming near the top of the haze layer, resulting mainly from absorption of solar radiation by suspended matter.[1] It has been shown[2] that, at levels (e.g. temperature-inversion bases) where atmospheric turbulence diminishes with height, suspensoid clouds should settle more slowly than elsewhere. This is confirmed by observations of aerosol concentrations beneath low-level inversions. Also, Zobel[3] concluded that atmospheric heating below an inversion layer, during a fine summer day in southern England, was caused mainly by direct solar radiation and entrainment of warm air from above and not by upward (turbulent heat) flux from the surface.

Meteorological Research Flight aircraft observations over south-east England are available for the 1963 spell. The reports refer to the period 0730–0800 GMT and show that there was a haze top of 1700 ft above MSL on 31 July and 900 ft above MSL on 1 August. On 1 August, at 0800 GMT over Farnborough, a further haze top at 6000 ft was reported. The report for 2 August did not mention haze but on this day, as already suggested, the very low midday inversion was, seemingly, the remains of a nocturnal inversion.

The haze layer top of 6000 ft, reported by the Meteorological Research Flight, may well be the result of diurnal convection on a previous day. Such haze layers would radiate considerably between midnight and dawn and they could account for the often distinctly lower temperatures in the midday inversion layer as compared with similar levels at the preceding midnight. The cooling of haze layers could aid the upward development of nocturnal surface inversions and on extremely good radiation nights the inversion would, presumably, extend to the levels of the midday inversions here described.

The explanation of the diurnal development of a midday inversion by the absorption of solar radiation by a dust or smoke pall is weakened somewhat by the fact that one of the three spells described occurred with westerlies — which are not specially noted for their pollution content.

At the lower part of the upper stable layer, there may be a relative cooling due to convective and turbulent mixing with cold air from the preceding nocturnal surface layer. However, during the westerly spell (see Figure 1 and Table I), the midnight layer of cold surface air was not, seemingly, deep enough to lead to the formation of an upper inversion at the following midday entirely by this process. According to Grant,[4] a possible explanation of the cooling of the lower part of a stable layer is that cold patches may develop near the tops of thermals which, because of a stable layer above, have reached the peak of their development; the air above the thermal may be forced up into the stable layer and thus become colder than its environment. Grant reports an occasion of such a patch of air, colder by 1½ degF and 800 yd long, measured from an aircraft in flight over the top of a cumulus cloud. Under particular synoptic conditions, thermals may be especially associated with the two valleys near Crawley.

A further possible cause of the midday inversion development is diurnal subsidence, possibly resulting from local topography. As the phenomenon occurs with both easterlies and westerlies, it seems unlikely that it is always caused by diurnal differential land-sea heating or by the subsidence of air advected from over the sea. On the other hand, air above the east-west orientated Crawley ridge might subside, for example as a result of the canalization of diurnally increased winds in the adjacent parallel valleys or as a balance to excess diurnal convection in these valleys. With westerlies, at least, it seems possible that there could be a direct (mechanical) build-up of pressure at Crawley, on the windward end of the Crawley ridge. The very limited data for Cardington show no indication of a midday inversion in the upper part of the available temperature soundings for corresponding days, in the region of 3000–4000 ft above MSL but the absence of midday inversions at Cardington might possibly be due to the rather flat terrain (shallow valley). Also, at Hemsby near the east coast, where shallow surface inversions developed at midnight on the corresponding dates, the phenomenon was much less evident on these occasions. However, Hemsby in general may experience a greater frequency of development of low-level midday inversions during land- and sea-breeze conditions. The effect of topography requires further investigation.

To examine the possibility of the occurrence of subsidence, lifting and/or advection, wet-bulb potential temperatures were estimated from the data of Table I, by means of a tephigram. The results of the analysis suggest that (i) in the two easterly spells, air at the level of the midday inversion is more likely to have been lifted than to have subsided and (ii) in the westerly spell, lifting, subsidence or advection could have been significant.

In the 5-year period, the diurnal development of a spell of low-level midday air temperature inversion at Crawley is less frequent in winter. Its frequency might be expected to be greater in winter if such an inversion were merely the residue of a deep winter nocturnal surface inversion eroded at the bottom by thermal stirring due to solar radiation. However, apart perhaps from the development of marked rather low-level haze discontinuities, the possible causes here described would generally be less operative in winter, on account of reduced insolation and convection.

Conclusion. Inversions may develop during the daytime, in a stable layer, in the region of 3500–6000 ft (about 1–2 km) above MSL at Crawley, Sussex, but spells of the phenomenon are infrequent or even rare.

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RELATIONSHIPS BETWEEN AUTUMN RAINFALL AND WINTER TEMPERATURES

By R. F. M. HAY, M.A.

Summary. Monthly rainfall amounts during 1869–1966 for Scotland and for England and Wales have been ranked and allotted terciles. Winter temperatures for central England over the same period have been ranked and allotted quintiles. Wet (tercile 3) autumns over England and Wales, especially if accompanied by wet autumns over Scotland, showed a strong tendency to be followed by cold (quintile 2) winters in central England. Dry (tercile 1) autumns in England and Wales tended to be followed by mild (quintile 4) and very mild (quintile 5) winters in central England irrespective of rainfall in Scotland in autumn. If autumn is limited to the months of September and October these statements are still true and use of the shorter period tends to increase the prediction value of the results and makes them available a month earlier. The synoptic types in wet early autumns and in subsequent cold winters are briefly described. It is also noted that most of these cold winters had near average rainfall over England and Wales but that few of the mild winters following dry early autumns had average rainfall.

Introduction. In an earlier investigation Smith[1] found that wet autumns at Kew are associated with cold weather at Kew in the following winters and this paper confirms and extends his conclusions. Results from other work[2] suggest that an inverse relation exists between monthly mean pressure in October at 63°N 20°W (near Iceland) and subsequent winter temperatures in central England as defined by Manley.[3]

Experience with monthly mean pressure charts suggests that it is reasonable to expect monthly mean pressure near Iceland and over Scotland in the same month to be positively correlated; hence Octobers when pressure is high near Iceland should generally have high pressure in Scotland with accompanying dry weather. A contingency table (not included here) between monthly pressure in October at 63°N 20°W (near Iceland) and rainfall in the same month over Scotland for the period 1873–1962 showed a strong association between dry Octobers in Scotland and simultaneous high pressure near Iceland, with a chi-square value above the 0·1 per cent level of significance. Likewise, Octobers with low pressure near Iceland should be wet in Scotland.

The relationship between the Iceland pressure and the rainfall in England and Wales is less readily identified, but a clue is provided in a paper by Glasspoole.[4] Broadly he found *(a)* that Oxford 'experiences the largest fluctuations of annual rainfall in the British Isles' and by examining the correlations of the annual rainfall at Oxford with that at other stations in Britain he found *(b)* that 'everywhere except in the north of Scotland the fluctuations of annual rainfall from year to year are similar, as if controlled by some common factor'. Thus a relationship involving rainfall over Scotland is likely to apply also to rainfall over England and Wales.

Data and results. Reliable monthly rainfall totals for Scotland are available back to 1869. These monthly totals were ranked and allotted to their appropriate tercile (dry—tercile 1 (R_1), average—tercile 2 (R_2) and wet—tercile 3 (R_3)) for the 98 years 1869–1966 inclusive, and the procedure was repeated for monthly rainfall totals for England and Wales. Then central England winter temperatures (as defined by Manley) were each ranked and allotted a quintile (very cold—quintile 1 (Q_1), cold—quintile 2 (Q_2), average—quintile 3 (Q_3), mild—quintile 4 (Q_4) and very mild—quintile 5 (Q_5)) using data for winter temperature anomalies for central England (related to previous 25-year running means) beginning with the winter of 1869–70 and ending with 1966–67. This information was used to prepare three types of contingency tables:

(i) Relating October rainfall in *(a)* Scotland and *(b)* England and Wales, with winter temperatures in central England.

(ii) Relating autumn* rainfall with winter temperatures (same localities).

(iii) Relating rainfall for early autumn* with winter temperatures (same localities).

As these contingency tables resembled each other to a considerable extent only the results of general interest are included here (Table I). They can be summarized thus:

(i) Occasions of R_3 (wet) in September and October in either or both localities (England and Wales, Scotland) tended to be followed by cold (Q_2) or very cold (Q_1) winters, with a preference for Q_2 winters. In this instance the distribution of winters in quintiles 1 to 5, with frequencies of 3, 10, 5, 0 and 1 respectively, is significant at the 0·5 per cent level.

(ii) Occasions of R_1 (dry) in September and October in either or both localities (England and Wales, Scotland) tended to be followed by mild (Q_4) winters.

TABLE I—FREQUENCY OF WINTER TEMPERATURES (CENTRAL ENGLAND) RELATED TO AUTUMN RAINFALL (1869–1966) IN SCOTLAND, ENGLAND AND WALES

Tercile of rainfall: England and Wales	Tercile of rainfall: Scotland	Rainfall period	Quintile of winter temperature: Q_1	Q_2	Q_3	Q_4	Q_5	Total number of occasions	Chi-square	Significance level (per cent)
R_3	R_3	October	3	6	6	2	0	17	8·0	10
R_3	R_{123}	October	9	7	9	4	3	32	4·9	Not significant
R_3	R_3	Autumn	4	9	5	1	0	19	13·4	1
R_{123}	R_3	Autumn	7	13	8	4	2	34	10·4	2
R_1	R_{123}	Autumn	5	4	6	7	10	32	3·3	Not significant
R_3	R_3	September October	3	10	5	0	1	19	16·5	0·5
R_{123}	R_3	September October	5	12	9	3	4	33	8·7	5
R_3	R_{123}	September October	6	12	7	4	4	33	6·6	Not significant
R_1	R_1	September October	2	0	5	7	6	20	8·5	5
R_{123}	R_1	September October	8	0	7	8	10	33	8·4	5
R_1	R_{123}	September October	4	5	7	10	7	33	3·2	Not significant

Explanation: The symbol R_1 is used to denote a month with rainfall in tercile 1, etc.
The symbol R_{123} is used to denote a month with rainfall in tercile 1 or 2 or 3.

Monthly pressure pattern in autumn. Next, the displacements of the Iceland low centre in Octobers in which early autumns were wet or dry, both in England and Wales and in Scotland were examined by means of two charts, *(a)* for occasions of wet early autumns and *(b)* for occasions of dry early autumns. These charts (not included here) showed the geographical distribution of the monthly low and high centres with respect to the temperature quintiles of the subsequent winters in central England. A study of the

* Autumn refers to September, October and November and early autumn refers to September and October.

charts clearly indicated that in the Octobers of wet early autumns as defined earlier, and before very cold and cold winters (quintiles 1 and 2) the deepest monthly low centres on the North Atlantic were then mostly displaced to east or south-east of the position shown on the normal chart for October and were found mostly to south or east of Iceland. By contrast, in the Octobers of dry early autumns and before mild and very mild winters (quintiles 4 and 5) the deepest low centres were displaced towards the southern tip of Greenland, i.e. to the west or west-south-west of the average position for October.

Although the winter of 1967–68 was not included in the statistics used in this paper, the monthly pressure pattern in the Atlantic-European sector for October 1967 was later found to be a good example of the typical pressure pattern which yields a wet early autumn in Britain. Charts of the mean pressure and of the pressure anomaly for October 1967 are shown in Figures 1 and 2. The September–October rainfall in 1967 was above average (R_3) in Scotland and in England and Wales, and the subsequent winter (1967–68) was cold (Q_2) in central England.

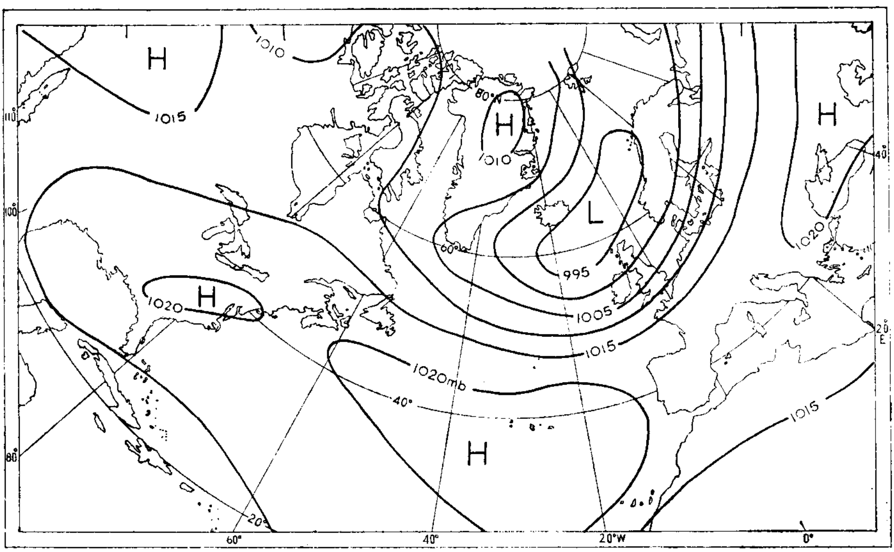

FIGURE 1—CHART OF MEAN PRESSURE FOR OCTOBER, 1967
Isobars are at intervals of 5 mb.

Synoptic type in cold winters. In a previous paper it was shown[2] that cold (Q_2) winters, *(a)* had a higher frequency of northerly synoptic types than the winters of any other quintile and *(b)* had a relatively high frequency of westerly types. The feature of enhanced frequency of northerly types was also true for average (Q_3) winters. Thus, during the past 90 years a high proportion of the winters in central England which have followed wet early autumns have been Q_2 or Q_3 winters; and these winters have, on the whole, been associated with an enhanced frequency of northerly and westerly types of circulation.

Further evidence of this characteristic of cold (Q_2) winters has just become available, based on information from a recently completed catalogue of

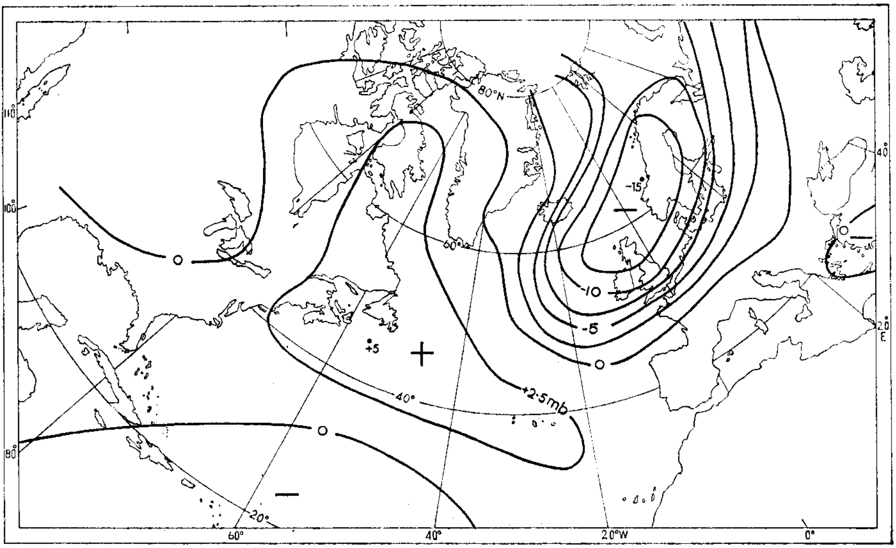

FIGURE 2—CHART OF PRESSURE ANOMALY FOR OCTOBER, 1967
Isopleths are at intervals of 2·5 mb.

monthly pressure patterns for the region of the British Isles for the period 1873–1963. Each month in this period has been classified in accordance with *(a)* isobar pattern (defined as cyclonic, mainly straight isobars or anticyclonic), and with *(b)* a general direction of the flow pattern over and upwind of the British Isles.

Frequencies of patterns of cyclonic type related to the directions of flow pattern near the British Isles were extracted for each winter month from this catalogue. After relating them to the temperature quintiles of the winters in which they occurred a contingency table was derived, as shown in Table II.

The value of chi-square computed for this table is 19.15. For a 5 × 2 table a value of chi-square of 18.5 is needed for significance at the 1 per cent level. Hence it can be concluded that the difference between the distribution of

TABLE II—FREQUENCIES OF CYCLONIC TYPES OF MONTHLY PRESSURE PATTERNS OVER THE BRITISH ISLES IN WINTER MONTHS (1874–1963)* RELATED TO DIRECTIONS OF FLOW PATTERNS OVER THE BRITISH ISLES

	Directions of flow patterns over the British Isles					
	South-west	West	North-west	South-east, South	North, North-east, East, No direction	Totals
Months in cold winters (Q_2)	4 (9.9)	12 (9.5)	5 (1.6)	1 (2.8)	3 (1.2)	25
Months in all remaining winters (Q_{1345})	45	35	3	13	3	99
Totals	49	47	8	14	6	124

* For example 1874 refers to the winter December 1873 to February 1874.

monthly pressure patterns in Q_2 winters and in remaining winters ($Q_{1,3,4,5}$) is significant at better than the 1 per cent level. The figures in this computation (not included here) also showed that the largest contribution to the value of chi-square is made by those winter months which have a north-westerly pressure pattern.

Winter rainfall. For each quintile of winter temperature the associated rainfall for England and Wales has been listed according to terciles (tables are not shown). In a high proportion of the cold winters (Q_1 and Q_2) following wet early autumns the winter rainfall in England and Wales was near the average, and 8 out of 9 of the cold (Q_2) winters had near average rainfall. The mild winters (Q_4 and Q_5) after dry early autumns were wet or dry on 6 and 5 occasions respectively, and on only 2 occasions in 13 was the winter rainfall near the average.

Conclusions. The main conclusions based on data for 1869–1966 are :

(i) Occasions of tercile 3 rainfall (wet) in September and October in Scotland, England and Wales showed a strong preference for a cold (quintile 2) or very cold (quintile 1) winter to follow in central England, with a higher probability for a cold rather than for a very cold winter.

(ii) Occasions of tercile 1 rainfall (dry) in September and October in Scotland, England and Wales showed a marked preference for a mild (quintile 4) or very mild (quintile 5) winter to follow in central England.

(iii) Occasions of tercile 3 rainfall (wet) for autumn (September, October and November) also showed a strong preference for a cold or very cold winter to follow in central England.

(iv) In wet early autumns the monthly low centres tended to be displaced to the east or south-east of the average position for October.

(v) Cold winters following wet early autumns were associated with an enhanced frequency of northerly and westerly types of circulation.

(vi) Most of the cold winters following wet early autumns had near average rainfall but few of the mild winters following dry early autumns had average rainfall.

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AN INDEX OF COMFORT FOR LONDON

By H. V. FOORD

Introduction. Previous papers by Stephenson,[1] McLeod[2] and Watt[3] examined the climates of Singapore, Gan and Bahrain respectively from the point of view of human comfort, using effective temperatures (a combination of dry-bulb and wet-bulb temperatures and wind speed) from the scale devised by the American Society of Heating and Ventilating Engineers (S.H.V.E.)[4] and also published by the Air Ministry.[5] These papers should prove of great interest to staff likely to serve in tropical areas but it was felt that a better idea of the relative comfort of the various climates would be obtained if a similar investigation was made for London.

The three tropical climates were analysed by using mean monthly values of dry-bulb temperature, wet-bulb temperature and wind speed but since the mean monthly dry-bulb temperature in London does not exceed 64°F a different approach had to be made using daily rather than monthly values. The comfort zone of effective temperature in temperate regions is between 60–66°F (15·5–19°C) in summer and 57–63°F (14–17°C) in winter.[5] Excursions above the upper limit of the comfort zone (66°F effective temperature) occur periods of a few hours rather than in prolonged spells of weeks or months for and are extremely rare outside daylight hours.

Summary of the data used. The observations made at the London Weather Centre (L.W.C. Victory House until 1959, Princes House until 1965, then Penderel House, High Holborn) were examined for the 20 years 1947–66 inclusive. During most of this period temperatures were read in degrees Fahrenheit and throughout the period the corresponding figures in degrees Fahrenheit were available. The scale of effective temperature devised by S.H.V.E. and also published by the Air Ministry is also in degrees Fahrenheit, and public enquiries about the comfort index almost invariably refer to the Fahrenheit scale. Hence the Fahrenheit scale has been used in this investigation. Days when the simultaneous combination of dry-bulb temperature, wet-bulb temperature and wind speed gave an effective temperature greater than 66°F were extracted. Any observation which gave the above result was used, i.e. one or more observations which qualified on one day gave one occasion. Observations at L.W.C. were made at 0000, 0300, 0600, 0900, 1200, 1500, 1800 and 2100 GMT throughout the period but from 1960 onwards during periods of British Summer Time extra observations were taken at 0500, 0800, 1100, 1400 and 2000 GMT. In practice the observations at 1200, 1400, 1500 or 1800 GMT were normally the only ones to qualify.

Mean values of wet-bulb temperatures are not available for L.W.C. so in Table III 30-year mean values of monthly effective temperatures for Kew have been calculated for comparison with similar values for Singapore, Gan and Bahrain. The mean effective temperature at Kew for the months November – April inclusive proved to be too low to be read off the diagram published by S.H.V.E.[4]

Discussion of Data. From Table I it can be calculated that the average number of days per year when the upper limit of comfort is exceeded is 9·5 days and only one day during the 20-year period had an effective temperature above the comfort zone of a tropical area (66–76°F (19–24·5°C) effective temperature). The number of days of discomfort (from high temperature) varies from nil in 1962 to 29 in 1949 and only 3 years had more than 20 days above the comfort zone.

The final column in Table I shows the maximum effective temperature from the available observations for each year. The average of these maxima is 72·9°F and the annual maximum ranged from 66°F in 1962 to 77°F in 1948. In fact 30 July 1948 was the day of greatest discomfort during the period under review and may well be remembered as being the second

TABLE I—ANALYSIS OF DAYS WITH EFFECTIVE TEMPERATURE ABOVE 66°F, AND MONTHLY AND ANNUAL MAXIMUM EFFECTIVE TEMPERATURES AT LONDON WEATHER CENTRE 1947–66

	May		June		July		Aug.		Sept.		Annual
Year	*D*	E_{max} °*F*	*D*	E_{max} °*F*	*D*	E_{max} °*F*	*D*	E_{max} °*F*	*D*	E_{max} °*F*	E_{max} °*F*
1947	5	70	5	73	7	75	6	73	2	67	75
48	0	—	1	68	5	77	0	—	0	—	77
49	0	—	5	73	10	73	10	72	3	71	73
50	0	—	5	76	1	68	1	67	0	—	76
51	0	—	0	—	1	67	0	—	0	—	67
1952	2	69	4	75	7	74	2	69	0	—	75
53	2	72	2	68	0	—	2	73	0	—	73
54	1	70	0	—	0	—	2	68	1	72	72
55	0	—	0	—	8	71	7	72	0	—	72
56	1	67	0	—	3	71	0	—	0	—	71
1957	0	—	6	76	5	76	1	68	0	—	76
58	0	—	0	—	7	72	1	68	1	76	76
59	1	67	2	70	8	75	8	74	2	74	75
60	1	68	5	73	0	—	0	—	0	—	73
61	0	—	3	71	1	75	2	72	1	68	75
1962	0	—	0	—	0	—	0	—	0	—	66
63	0	—	0	—	1	69	0	—	0	—	69
64	0	—	2	67	4	73	3	69	3	71	73
65	1	73	0	—	0	—	1	67	0	—	73
66	0	—	1	67	1	69	3	71	1	67	71
Mean	0·7		2·1		3·5		2·5		0·7		72·9
Highest		73		76		77		74		76	77

The effective temperature exceeded 66°F on two other occasions; 29 April 1958 and 3 October 1949; on both days it was 67°F.
D = Number of days with effective temperature above 66°F.
E_{max} = Maximum effective temperature in degrees Fahrenheit.

day of the 1948 Olympiad held at Wembley. During this period the effective temperature reached 73°F on the 29 July and was still 71°F at 0000 GMT on the 30th; it fell to 56°F by 0600 GMT then rose to 67°F at 0900 and reached 77°F at 1500 GMT on the 30th.

The earliest date in the year when the upper limit of comfort was exceeded was 29 April 1958. The latest date was 3 October 1949. Indeed these were the only days in April and October to exceed the upper limit during the 20 years.

The highest effective temperature in March was 64°F. As already stated, high effective temperatures were normally confined to daylight hours and throughout the period the effective temperature at 0300 and 0600 GMT never exceeded 64°F although, as mentioned above, the maximum value at 0000 GMT was 71°F on 30 July 1948.

During the three summer months of June, July and August 84 per cent of the discomfort occurs—July having a rather higher average than the other months. However, high values of effective temperature can occur from May to September inclusive and it is notable that 76°F effective temperature (the upper limit of tropical comfort) was recorded as early as 4 June 1950 and as late as 5 September 1958.

Table II gives the frequency distribution, in 4-day stages, of the annual totals of days exceeding the comfort zone. This shows that 5–8 days of discomfort are more usual than the range 9–12 days, despite the arithmetic mean being 9·5 days per annum. Of the years reviewed, 25 per cent had 13 or more days above the comfort zone and 75 per cent had 12 days or less.

TABLE II—FREQUENCY DISTRIBUTION OF ANNUAL TOTALS OF DAYS ABOVE 66°F EFFECTIVE TEMPERATURE AT LONDON WEATHER CENTRE 1947-66

	Number of days						
	0	1–4	5–8	9–12	13–16	17–20	>20
Number of years	1	5	6	3	2	0	3

Comparison with Singapore, Gan and Bahrain. Table III shows the monthly mean values of effective temperature for the various places, using Kew for London, and reveals the low mean values in the United Kingdom. The three warmer climes have long, continuous periods of discomfort whilst London experiences much shorter spells, the longest being of 7 consecutive days in July 1955. Table IV gives the frequency distribution of the length of spells of high effective temperature. It must be borne in mind that this does not mean a period of continuously high effective temperatures but merely that at least one observation on each day gave an effective temperature above the upper limit of the comfort zone. There were 95 such spells during the 20-year period, ranging from 1 – 7 days in duration; 52 per cent were one-day spells and 27 per cent were of two days duration.

TABLE III—MEAN EFFECTIVE TEMPERATURE AT SINGAPORE, GAN, BAHRAIN AND KEW

	Period	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
							degrees Fahrenheit						
Singapore	1952–61	71	73	75	76	**77**	76	75	75	75	75	74	73
Gan	1959–64	71	71	**73**	**73**	71	71	71	71	71	70	70	71
Bahrain	1962–66	48	52	57	64	72	77	81	**82**	79	73	64	52
Kew	1931–60					37	47	**50**	49	44	34		

Highest values for each place are printed in bold type.

TABLE IV—FREQUENCY DISTRIBUTION OF LENGTH OF 'SPELLS' ABOVE 66°F EFFECTIVE TEMPERATURE AT LONDON WEATHER CENTRE 1947–66

	Length of spell (days)						
	1	2	3	4	5	6	7
No. of occasions	49	26	7	3	6	3	1

A 'spell' is defined as a number of consecutive days when the effective temperature rose above 66°F for at least one observation each day.

London experiences far longer periods during the year when discomfort is due to low effective temperatures — below the lower limit of comfort for winter in temperate regions (57°F). Indeed, the months of November, December, January and February were constantly below this lower limit during the review period, and an effective temperature below 57°F occurs frequently in any month of the year at London.

However, the annual maxima in Table I show that effective temperatures similar to those experienced in the three warmer climates (i.e. 72 degF or above, effective temperature) occur in three years out of four, although for a few hours rather than months at a time.

Conclusions.

(i) A comfort index is applicable to London but may not be exceeded in some years. Cold discomfort is far more frequent than warm.

(ii) During the brief intervals when effective temperatures rise to maximum values they are comparable with the figures obtaining at Singapore, Gan and Bahrain but any mitigating factor such as air-conditioning or forced ventilation would easily return the situation to a comfortable one.

(iii) Critical effective temperatures causing dangerous rises in body temperature are extremely unlikely in London, and excessive exercise should rarely prove dangerous from this source. By coincidence, some of the 1948 Olympiad took place in the worst conditions experienced in the period under review, without any adverse effect on health that the writer can remember.

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REVIEW

Cloud studies in colour, by R. Scorer and the late H. Wexler. 33 cm × 23 cm, pp. xi + 44, *illus.*, Pergamon Press Ltd, Headington Hill Hall, Oxford, 1967. Price: 42*s.*

The book can be conveniently reviewed in three sections, the centre section being the colour illustrations. The preface to the book gives a brief historical survey of the naming of cloud forms, from Luke Howard, 1803, to the present day. This is followed by a section of text, with small monochrome photographs, setting out the naming system adopted by the authors, based on the genetic origin of clouds. A further section of text, again with small monochrome pictures, gives the details of the magnitude of air motion to be expected in the atmosphere, both in the horizontal and in the vertical.

The main feature of the book undoubtedly is the colour section, in which appear 122 pictures of clouds and allied phenomena, reproduced in full colour. There are eight photographs 6 cm × 9 cm on each right-hand page and on the opposite left-hand page appears an explanatory note for each picture. This note details the points of interest and discusses the physical processes taking place. Some of the pictures are in time sequence to illustrate the changes visible even in short periods of time. The authors have chosen the photographs carefully to illustrate the particular point they wish to bring out. The standard of colour reproduction is very good, especially so when one considers the price of the book for such a large number of full-colour pictures.

The final section of text deals in detail with various air motions in the atmosphere and the clouds so produced. Clear line-diagrams are given to illustrate this text. There is also a diagram of cloud mechanisms and a page of explanation. This diagram is not as complex as it would first appear and it will certainly help the reader to understand the many stages through which the air must pass before certain types of cloud are formed. The authors have added some questions to start the student in his discussions on the processes of cloud formation and dispersion. Finally, there is a comprehensive combined index and glossary of the terms used, with references to the photographs illustrating them.

It is noted that page numbers do not appear on pages ix to xi. On page ix (cloud names) the second monochrome cloud picture bears the name 'alto-strato-cumulus'. It is suggested that this is probably a misprint for 'alto-cumulus', because the definition of 'alto' on that page, on page 41 of the glossary and in para 3. ix of Dr Scorer's original paper in the *Quarterly Journal of the Royal Meteorological Society* (Volume 89, No. 380) does not permit the combination of 'alto' and 'strato'. The book will be very useful indeed to the student of meteorology and to the sixth-form pupil studying the subject. In addition the man in the street will find the book very interesting and readable with its clear diagrams and well reproduced photographs. It is very attractively bound, with colour pictures on the cover to catch the eye of the casual reader.

I shall not comment on the merits and demerits of the authors' nomenclature and that employed by the World Meteorological Organization (WMO). There is, as Dr Johnson wisely said, 'much to be said on both sides.' It is to be hoped that names in general use in the WMO cloud classification will not be used with a different meaning in another system.

R. K. PILSBURY

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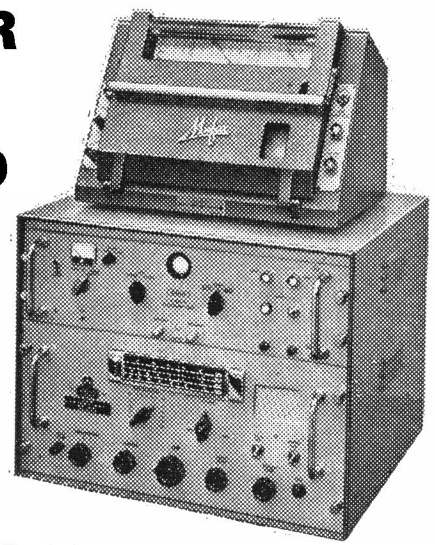

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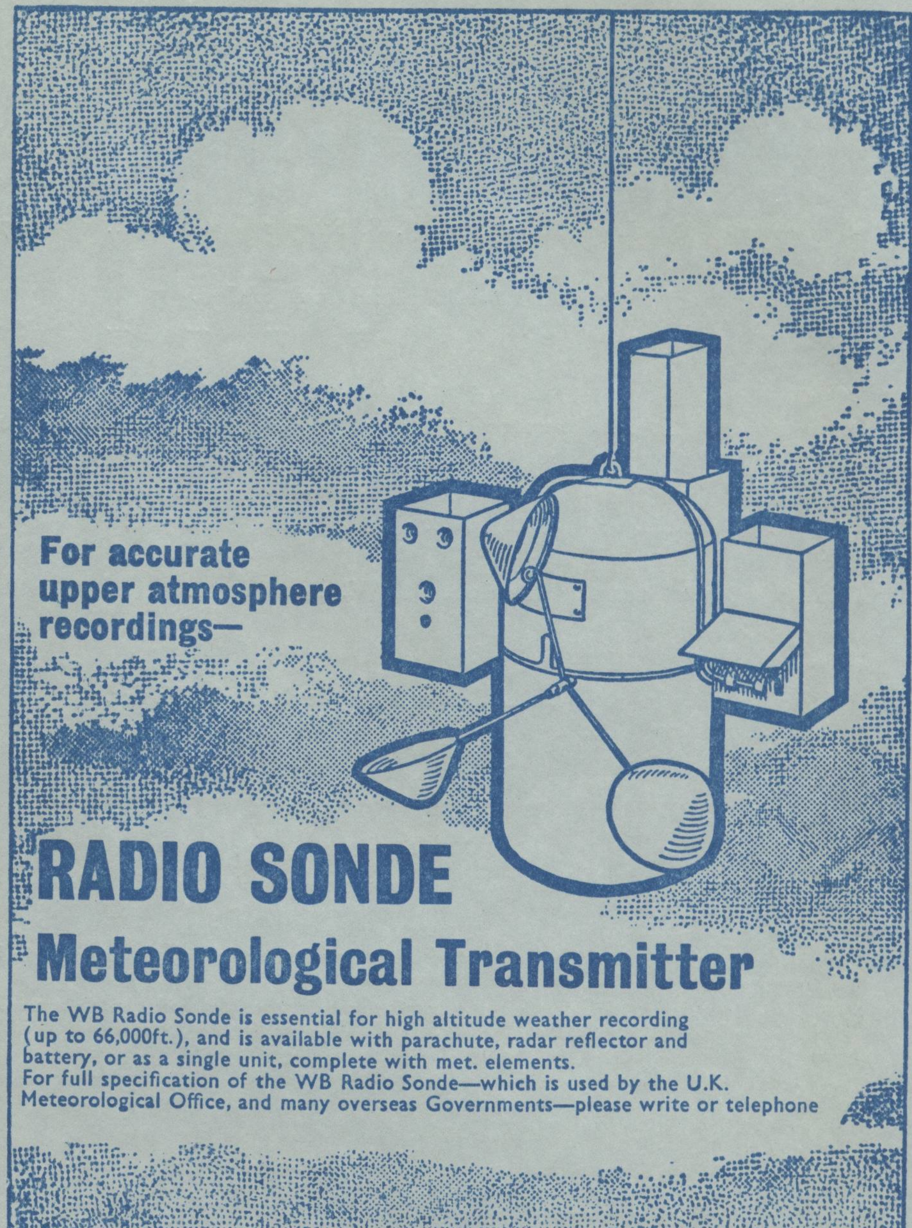
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