

M.O. 524r

AIR MINISTRY

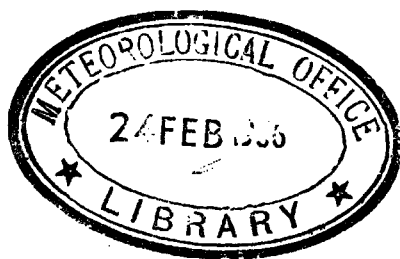
METEOROLOGICAL OFFICE

PROFESSIONAL NOTES NO. 118

*(Eighteenth Number of Volume VII)*

RAINFALL OF DEPRESSIONS WHICH  
PASS EASTWARD OVER OR NEAR  
THE BRITISH ISLES

By J. S. SAWYER, M.A.



LONDON  
HER MAJESTY'S STATIONERY OFFICE  
1956

NINEPENCE NET

# RAINFALL OF DEPRESSIONS WHICH PASS EASTWARD OVER OR NEAR THE BRITISH ISLES

By J. S. SAWYER, M.A.

**Summary.** Depressions are classified according to the latitude in which they move eastward over or near the British Isles. Maps of the average rainfall and frequency of rain from depressions in each class have been constructed and are discussed. The rainfall amounts of individual depressions are examined in relation to the characteristics of the depressions concerned but no relations have been found which are close enough to be of much value in forecasting.

**Introduction.** The physical and dynamical processes which give rise to rainfall are very complicated, and the direct physical approach to the problem of forecasting rain, in which the vertical speeds of the air and rates of condensation are calculated, has not proved practical. In the Meteorological Office, forecasts of rainfall for periods of 24 hr. or more are based, first on an estimate of the synoptic situation during the forecast period, and secondly on the forecaster's experience of rainfall from similar situations in the past. The present study was undertaken in an attempt to systematize some of the knowledge available regarding the rainfall in the British Isles resulting from depressions which move eastward over or near to the area.

Rainfall data associated with depressions which moved eastward between the Faeroes and northern France over a 10-yr. period have been extracted and examined. In the following paragraphs there is presented the average rainfall distribution accompanying the passage of depressions on particular tracks, together with some discussion of the departures from the average pattern and their association with such characteristics of the depression as its depth, speed of motion, and accompanying 1000–500-mb. thickness pattern. Although statistically significant the relationships are not close enough to be of much practical value in forecasting, and, although the figures for the average rainfall and departures from it may be a useful guide to the forecaster in deciding the most probable rainfall amount in a particular synoptic situation, they also serve to emphasize the uncertainties of rainfall forecasting.

**Method.** From an examination of the *Daily weather reports* and *Monthly weather reports*, all occasions were noted in the 10-yr. period 1941–50 when depressions moved eastward between the Faeroes and northern France. In order to provide a homogeneous set of examples it was required that there should be a closed isobar associated with the depression on at least one of the charts published in the *Daily weather report*, and the depressions were classified according to their track on the basis given below.

(i) Track A. The depression centre passed between the Faeroes and the north coast of Scotland. In order to eliminate cold depressions and completely occluded systems, it was further required that the warm sector must have extended across the British Isles as far northward as the Scottish border.

(ii) Track B. The depression centre crossed Scotland with an eastward component of motion.

(iii) Track C. The depression centre moved eastward across England remaining south of the Scottish border and north of a line joining the Bristol Channel to the Thames estuary.

(iv) Track D. The depression centre moved eastward near the English Channel. In the area between  $5^{\circ}$  W. and  $1^{\circ}$  E., the track had to be entirely north of the  $48^{\circ}$  N. parallel and south of a line joining Cardigan Bay to the Wash.

The numbers of depressions satisfying these conditions in the 10-yr. period were: 61 along Track A, 49 along Track B, 45 along Track C and 42 along Track D.

For each depression a rainfall chart for the British Isles was drawn on the basis of the observations printed in the *Daily weather report*. The period covered by the chart was chosen to include all the frontal rain from the depression; showers in the adjacent air masses were necessarily included, and difficulty in separating the rain from that of preceding or following systems arose in some cases. However, no serious uncertainty existed regarding the general shape and intensity of the rainfall distribution. Most of the rainfall charts covered a period of 36 hr. or less, but in some cases it was necessary to include a longer period which extended to 60 hr. or more in a few cases.

For each depression, except those on track A for which data were inadequate to justify the construction, a 1000–500-mb. thickness chart was prepared and examined. The charts were drawn for a time chosen so that they represented the thermal structure of the depression when it was near the British Isles. Observations were taken from the German *Täglicher Wetterbericht* to complete the British charts for the war period.

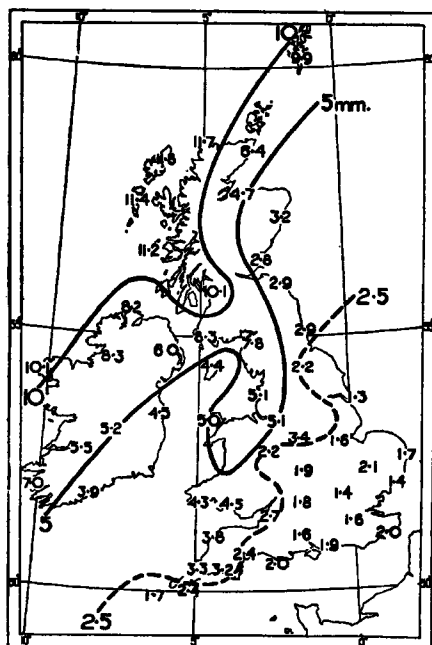
**Average rainfall distribution.** Fig. 1 shows the average rainfall for the periods during which the depressions passed eastward near the British Isles for each depression track. The charts are based on the average rainfall values shown on them, and, in calculating these, values have been interpolated from individual rainfall charts for occasions for which observations are not available in the *Daily weather report*. Since the observations, upon which Fig. 1 is based, were nearly all made on relatively low ground the charts do not adequately represent the rainfall of the hilly areas. However, some values for higher-level stations in Scotland, Wales and Devon are given below the charts. The values for Princetown (Devon), Cray Reservoir (Brexonshire) and Cwm Dyli near Snowdon were taken from autographic records; those for Eskdalemuir (Dumfriesshire) and Dalwhinnie (Invernesshire) from the *Daily weather reports*.

All the charts suggest a maximum of about 15 mm. near the mean track of the depression falling off both north and south. South of the track of the depression, western areas receive more rain than corresponding eastern areas, but this is not so noticeable north of the track. South of the track of the depression, the high-level stations receive much more rain than adjacent stations on low ground—amounting to three times as much in some cases. North of the depression track the orographic effect is small; this may be partly an effect of the lighter surface wind, but R. S. Scorer has pointed out in the course of discussion that the reversal of wind with height is also theoretically unfavourable for the development of systematic vertical currents over the hills.

Features of particular interest in regard to the rainfall of depressions on each type of track are described below.

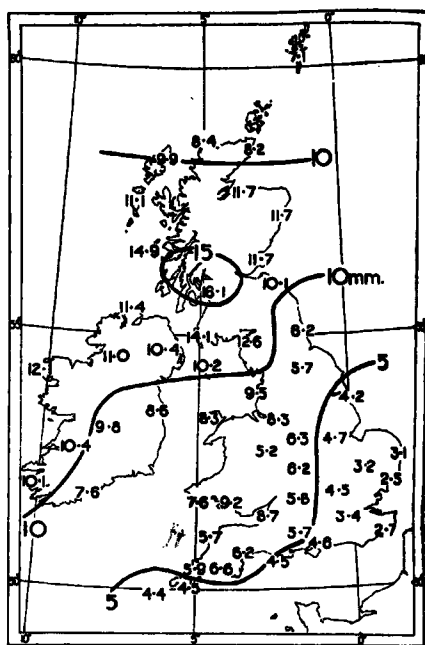
**Track A. Depressions passing between Scotland and the Faeroes.** Average rainfall decreases markedly from more than 10 mm. in the north-west to less than 2 mm. in the south-east. The west coast receives definitely more rain than the east.

**Track B. Depressions crossing Scotland.** Rainfall in the west is greater than in the east over England and Wales, but the effect cannot be distinguished over Scotland.



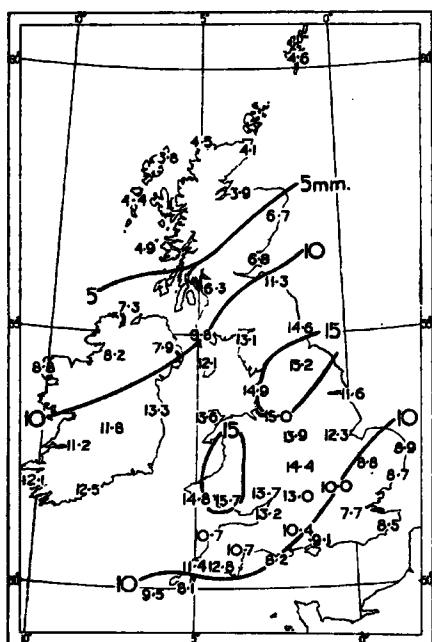
	mm.		mm.
Dalwhinnie ..	9	Cray Reservoir	10
Eskdalemuir	16	Princetown	10
Cwm Dyli ..	33		

(a) Track A. No. of depressions = 61



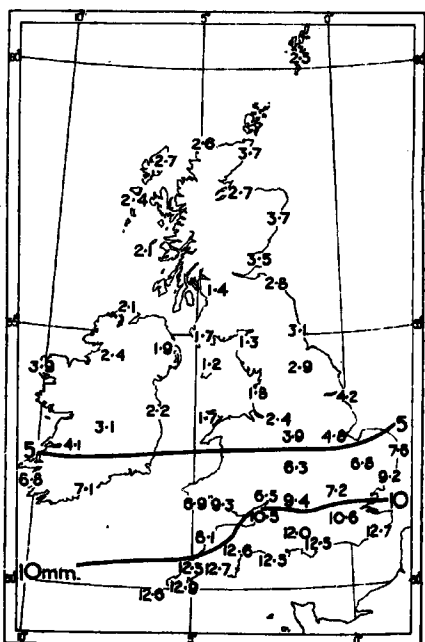
	mm.		mm.
Dalwhinnie	14	Cray Reservoir	17
Eskdalemuir	20	Princetown	18
Cwm Dyli	37		

(b) Track B. No. of depressions = 49



	mm.		mm.
Dalwhinnie	5	Cray Reservoir	23
Eskdalemuir	12	Princetown	33
Cwm Dyli	47		

(c) Track C. No. of depressions = 45



	mm.		mm.
Dalwhinnie	2	Cray Reservoir	9
Eskdalemuir	2	Princetown	18
Cwm Dyli	5		

(d) Track D. No. of depressions = 42

FIG. 1—AVERAGE RAINFALL FROM DEPRESSIONS MOVING ALONG TRACKS A, B, C AND D. PERIOD 1941-50

*Track C. Depressions crossing England.* The maximum rainfall occurs farther south in the west than in the east—probably an orographic effect. North of the track of the depressions the rainfall amounts decrease rapidly to about 4 mm. which falls mainly from showers in the polar air not directly associated with the depression.

*Track D. Depressions moving east near the English Channel.* There is no significant difference between rainfall in the east and west of the British Isles. Average rainfall falls off steadily northward from about 12 mm. on the south coast to 2 mm. in Lancashire and Yorkshire. Over this area the average rainfall is affected little if the contribution of showers is excluded on occasions when the continuous rain area of the depression did not extend to the station concerned. Over Scotland, Northern Ireland and the extreme north of England, where the average rainfall varies irregularly between 2 and 4 mm., the main contribution to the rainfall is from showers and other minor rain areas not directly connected with the depressions which were studied.

*Average rainfall at various distances from the tracks.* In order to provide a clearer picture of the rainfall in relation to the track of the depression an estimate was made of the average rainfall over areas centred 50, 150 and 250 miles to the north and south of the track of the centre where such areas fell within the British Isles. The resulting profiles of rainfall across the depression track for tracks B, C and D are shown in Fig. 2 where the western and eastern areas of Great Britain are given separately. There is a close similarity between the rainfall profiles for the different tracks. The sharpness of the peak of about 15 mm. near the mean track of the depression is noteworthy; rainfall amounts fall off to only half this amount at a distance of 200 miles. Values for western areas are higher than for eastern areas, but the difference is small to the north of the track of the centre.

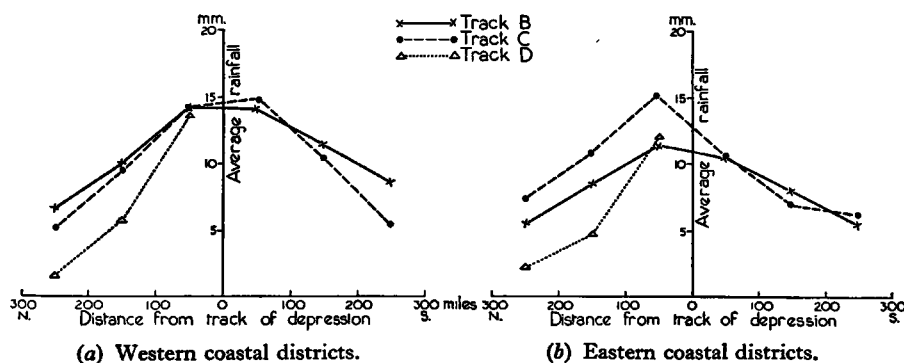


FIG. 2—AVERAGE PROFILE OF RAINFALL ACROSS THE TRACK OF A DEPRESSION MOVING ALONG TRACKS B, C AND D. Period 1941-50.

*Variability of rainfall.* Individual cases of rainfall vary widely from the mean given in Fig. 1. This is illustrated for depressions crossing England (track C), in Fig. 3 which shows the standard deviation of the rainfall of individual depressions from the mean and histograms for selected stations. The standard deviation tends to increase with the amount of rain, but over central England, close to the paths of most of the depressions, the standard deviation is a smaller fraction of the average rainfall than elsewhere.

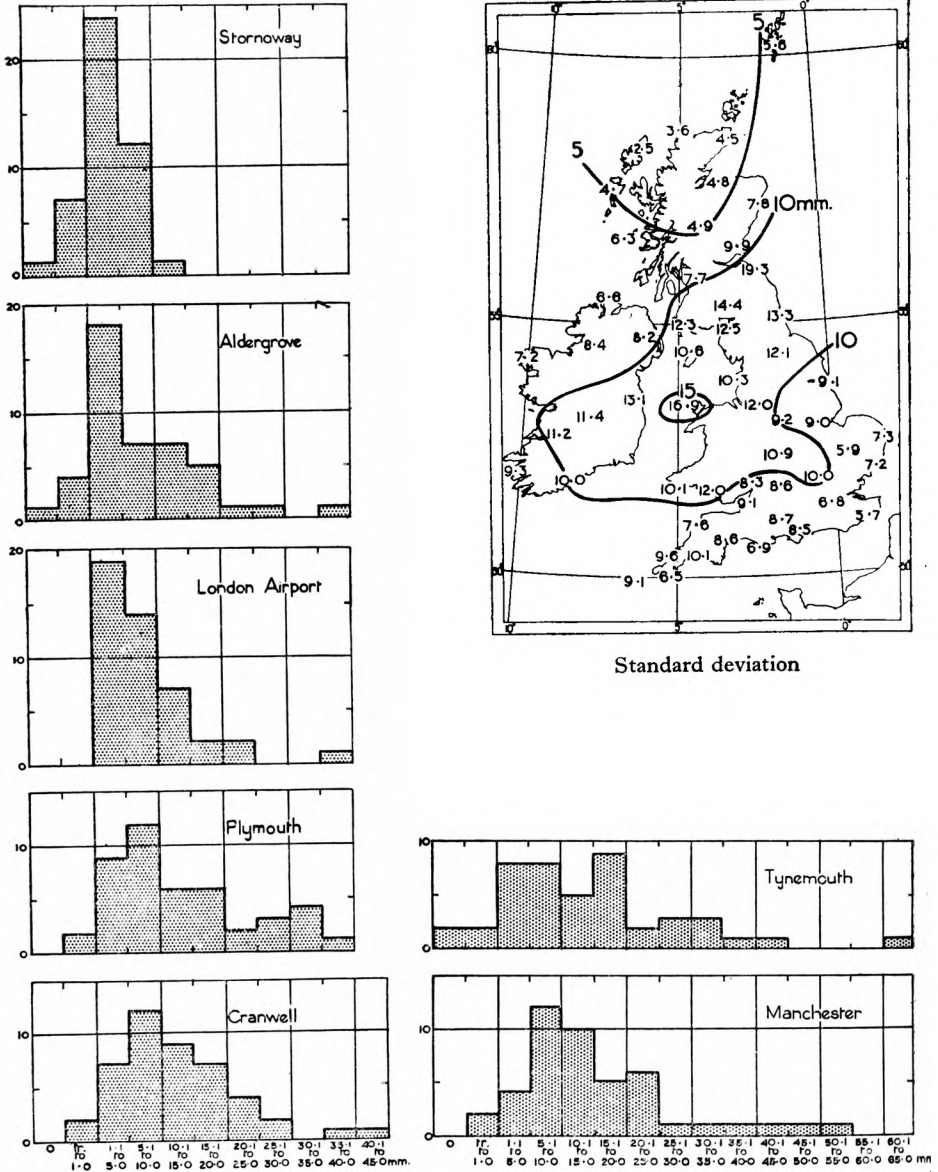
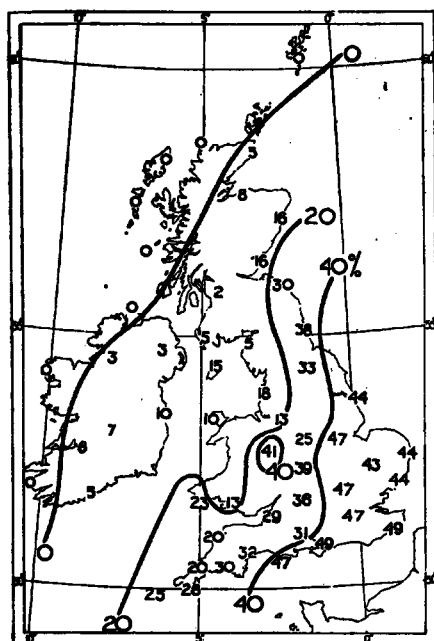


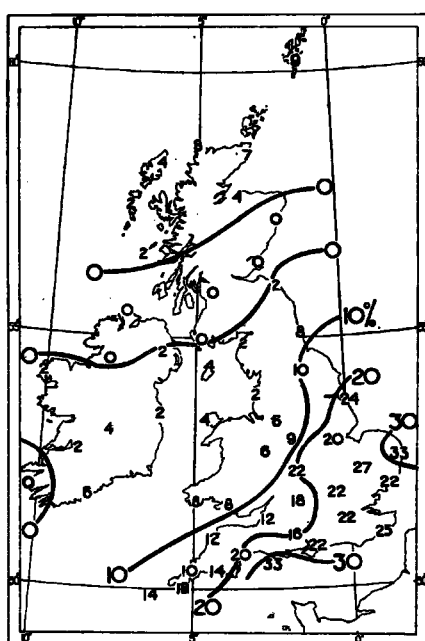
FIG. 3—STANDARD DEVIATION OF RAINFALL AND FREQUENCY DIAGRAMS OF RAINFALL TOTALS FROM INDIVIDUAL DEPRESSIONS MOVING ALONG TRACK C  
Period 1941-50. No. of depressions = 45

*Frequency of depressions giving little rainfall.* Fig. 4 shows the percentage of the depressions which gave less than 0.1 mm. of rain at stations in the British Isles. The percentages are calculated separately for each type of track. In each case there is a belt near the selected mean track of the depressions which received measurable rain from each depression. Southward from the track of the centre the frequency of cases without measurable rain increases, and reaches 25 per cent. at about 350 miles from the mean track. In the polar air north of the depression



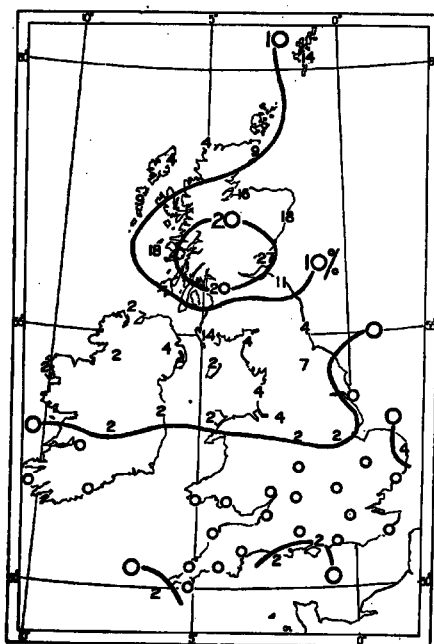
Dalwhinnie	% 3	Cray Reservoir	% 7
Eskdalemuir	0	Princetown	13
Cwm Dylli	3		

(a) Track A. No. of depressions = 61



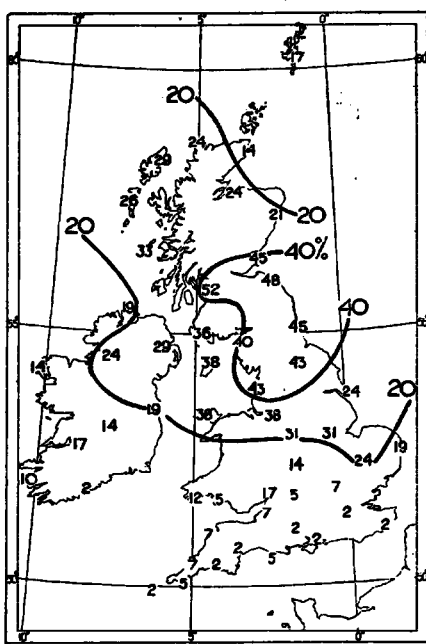
Dalwhinnie	% 0	Cray Reservoir	% 4
Eskdalemuir	0	Princetown	8
Cwm Dylli	2		

(b) Track B. No. of depressions = 49



Dalwhinnie	% 27	Cray Reservoir	% 0
Eskdalemuir	7	Princetown	0
Cwm Dylli	2		

(c) Track C. No. of depressions = 45



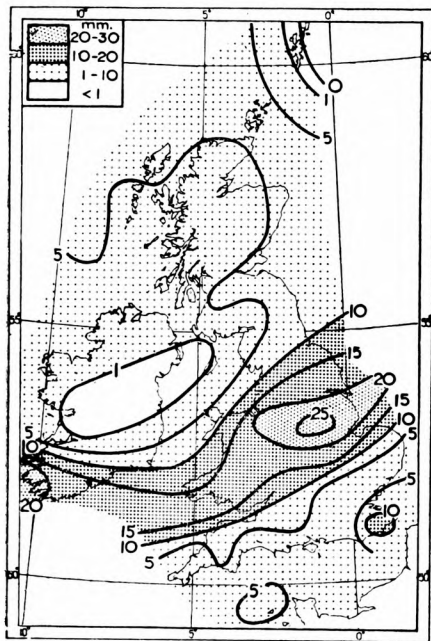
Dalwhinnie	% 19	Cray Reservoir	% 14
Eskdalemuir	36	Princetown	2
Cwm Dylli	29		

(d) Track D. No. of depressions = 42

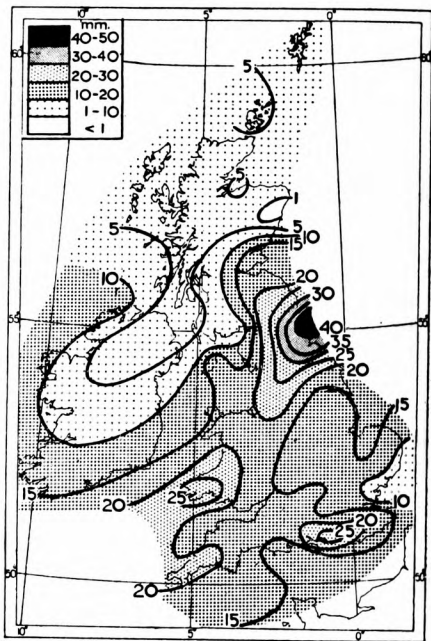
FIG. 4—PERCENTAGE OF DEPRESSIONS MOVING ALONG TRACKS A, B, C AND D WHICH GAVE LESS THAN 0.1 MM. OF RAIN. Period 1941-50

there is usually some precipitation, but this may be in the form of showers and not directly connected with the depression passing farther south. About 40 per cent. of the depressions which moved up the English Channel did so during dry periods in northern England and southern Scotland, and about 20 per cent. of those crossing England were accompanied by dry weather in central Scotland. Over England and Wales the proportion of "dry" cases is much greater in the east than in the west if the depression passes north of Scotland, but not otherwise. The difference in the proportion of cases without measurable rain between high-level stations and adjacent stations on low ground is not very great.

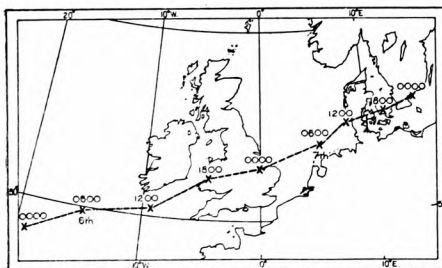
**Characteristics of individual rainfall distributions.** The individual rainfall charts showed a wide variety of patterns. About half the depressions gave a definite band of heavier rain along their track and in some cases this was exceedingly



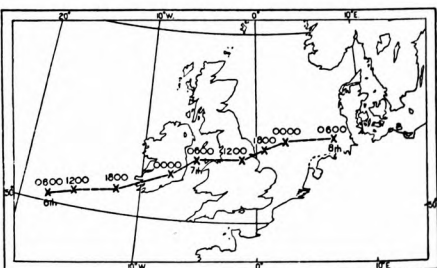
Rainfall\* for period 0900, April 6–0900, April 7, 1949



Rainfall\* for period 2100, January 5–0900, January 8, 1948



Track of depression



Track of depression

FIG. 5—RAINFALL AND TRACK OF THE DEPRESSION OF APRIL 6-7, 1949

FIG. 6—RAINFALL AND TRACK OF THE DEPRESSION OF JANUARY 7, 1948

\*Based on telegraphic reports.



well marked. The proportion of depressions crossing Scotland which gave such a band of heavier precipitation is rather smaller (14 out of 49) than of those passing farther south. This is probably due to the more irregular topography of Scotland.

Fig. 5 shows the well defined band of heavier rainfall associated with the depression of April 6-7, 1949. Fig. 6 shows a more irregular rainfall distribution for the depression of January 7, 1948. Some of the irregularities occurring in the rainfall maps were due to orographic effects and some to the occurrence of local thunderstorms or instability, but others must have been connected with irregularities in the structure of the depressions.

No reports from mountainous areas were employed in constructing Figs. 5 and 6 so that orographic maxima over high ground are not adequately shown. Orographic maxima in north-east England and south Wales, as illustrated in Fig. 6, occurred with a number of the depressions which crossed England. Rainfall from the occlusion, which often becomes slow-moving over the area as the depression passes farther south, contributes to the east-coast maximum. One case, included in the present series, is that of the depression of August 11, 1948 which gave rise to the Tweed Valley floods; that depression became slow-moving off the east coast and rainfall was unusually prolonged.

A study was made of the surface-pressure and thickness charts to find the factors which determine whether or not a definite rainfall band should occur along the track of a depression. No clear-cut relations were found. For the depressions moving across England and to the south there was a recognizable tendency for depressions moving faster than 30 kt. to give a definite track of heavier precipitation (15 out of 19 on track C, 12 out of 13 on track D), and for relatively more depressions moving slower than 25 kt. to give an irregular rainfall pattern (only 3 out of 16 such cases on track C gave a definite rainfall band and 10 out of 18 on track D). There was also a tendency for depressions associated with straight, or nearly straight, 1000-500-mb. thickness lines to give a definite rainfall band. Neither of these relations appears to apply to the depressions which crossed Scotland (track B) and they are not close enough to be of value in forecasting.

**Variation in rainfall amounts in relation to specific characteristics of the depression.** A systematic study was made of the departure of the rainfall of individual depressions following the track between Scotland and the Faeroes (track A) from the average for the track, in relation to a considerable number of characteristics selected to represent factors in the synoptic situation, which were expected to have an influence on the rainfall. Some significant correlations between the rainfall and the selected synoptic characteristics were found, and regression equations for estimating the rainfall from the selected synoptic characteristics were derived. However tests of these prediction equations on data from an independent series of depressions gave little or no success in estimating the rain over most areas of the British Isles, and, in view of the errors likely to occur in forecasting the characteristics themselves, it was concluded that none of the relations were sufficiently close to be of direct value in forecasting.

This study was carried out in more detail for depressions following track A than for depressions on tracks B, C and D; characteristics which gave no significant relation for depressions on track A were not studied in respect of depressions on the remaining tracks. The rainfall values, which were used for comparison with the synoptic characteristics, were based on the average of the values at four or more stations chosen to represent a substantial part of the British Isles. The correlation between the average rainfall at two such groups of stations in the same area was more than 0.8 (for example for depressions on track B the correlation coefficient between the rainfall at two groups of six stations in Scotland is  $+0.86$ ) so the average rainfall from such groups of stations was regarded as reasonably representative

of the area. Correlation between the rainfalls at non-overlapping groups of stations fall off to  $+0.43$  between twelve stations in Scotland and six stations in the southern half of England for depressions on track B.

The following sections outline the results of the studies of the relation between the rainfall and selected synoptic characteristics.

*Rainfall and the surface pressure field.* An obvious synoptic characteristic for study is the central pressure of the depression. This has a negative correlation with the rainfall over England for depressions on tracks C and D (correlation coefficients  $-0.46$  and  $-0.35$  respectively); the central pressure of depressions on track B (crossing Scotland) also has a negative correlation of about  $-0.35$  with the rainfall in both England and Scotland. The central pressure of depressions on track A, the centres of which pass north of the British Isles, has no significant correlation with rainfall in the British Isles, but a useful indication of the rainfall is given by the minimum sea-level pressure in the trough in the latitudes of the British Isles. Measured by the mean of the minimum sea-level pressures in latitudes  $50^\circ$  and  $55^\circ$  N., this gives a correlation of  $-0.59$  with the rainfall in the south of the British Isles and  $-0.31$  with rainfall in the north. Similarly with depressions crossing Scotland (track B), the pressure in the trough in latitude  $50^\circ$  N. has a correlation  $-0.60$  with the rainfall in England.

These results may be summarized as indicating that the rainfall near the track of a depression has a small negative correlation (about  $-0.3$  or  $-0.4$ ) with its central pressure. A similar negative correlation between rainfall and vorticity of the geostrophic flow was obtained for track C, for which it was evaluated. South of the track a better indication of the rainfall is given by the minimum pressure in the trough line, which has a negative correlation about  $-0.60$  with the rainfall in some areas.

*Rainfall and pressure tendency.* For depressions on track A the relation between the rainfall and the pressure changes was also studied. Two characteristics were used:—

(i) The fall of pressure from preceding ridge to trough line of the depression in latitudes  $50^\circ$  and  $55^\circ$  N., for which correlations range from  $+0.41$  with rainfall in the north to  $+0.67$  with rainfall in the south of the British Isles.

(ii) The largest downward 3-hr. pressure tendency at selected stations, which gives positive correlations up to  $+0.7$  with rainfall for pressure tendencies in south and east England.

These investigations were not extended to depressions following the remaining tracks because of the difficulty of predicting pressure tendencies.

*Rainfall and speed of the depression.* The speeds of the depressions have a small negative correlation with their rainfall. Values of the correlation coefficients which were obtained vary with the track of the depression and the area in which the rainfall was measured. Largest (negative) values were around  $-0.4$  and were obtained with rainfall in England for depressions on tracks A and B.

*Rainfall and the track of the depression.* There is also a slight tendency for depressions moving with a component of motion towards the south to give less rain than those with a component towards the north. Correlation coefficients between rainfall in England and the orientation of the track were found to be  $-0.25$  for track B,  $-0.43$  for track C and  $-0.33$  for track D.

*Rainfall and the 1000–500-mb. thickness pattern.* The 1000–500-mb. thickness pattern gave no clear indication of the amount of rain which accompanied a depression. Some relation with the orientation of the thickness lines exists corresponding to the relation between the rainfall and the track of the depression, and there is also a tendency for the existence of a thermal trough west of the centre to

be associated with more rain. The correlation between the rainfall and the thermal gradient in the direction of motion of the depression is, however, small (about  $+0.35$  for track B).

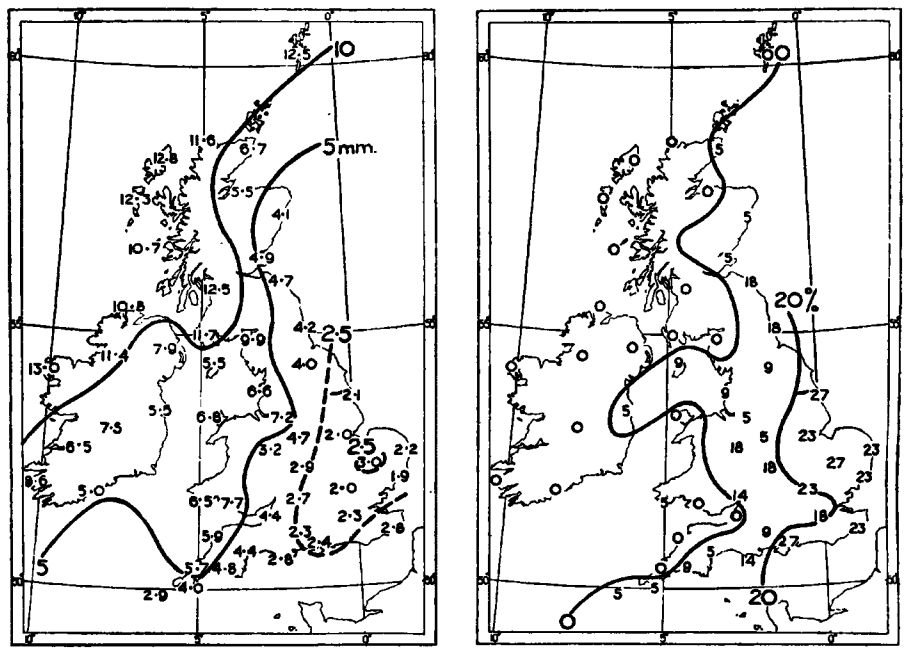
*Rainfall and the moisture content of the warm air mass.* A thorough search was made for any relation which might exist between the rainfall amount and the moisture content of the warm air mass in respect of depressions on track A but no significant relation was found. The characteristics which were used to represent the available moisture were the surface dew point, the difference of the surface dew point from the seasonal normal, and the dew point between 800 and 700 mb. In view of the negative results this investigation was not extended to depressions on the other tracks.

*Rainfall and the stability of the warm air mass.* Similarly negative results were obtained from a comparison of rainfall with the stability of the warm air mass for depressions on track A. Difficulty was experienced in finding a characteristic which was representative of the stability of warm air. Strongest correlation was between rainfall and difference in wet-bulb potential temperature between 950 and 500 mb. but this correlation did not exceed  $+0.40$ .

*Rainfall and the frontal structure.* Clearly the distribution and movement of the fronts in the circulation of the depression are of considerable importance in determining the rainfall, particularly in the areas south of the centre. No entirely satisfactory way of comparing the rainfall and frontal structure exists, but Fig. 7 illustrates some of the effects by showing the average rainfall and percentage of cases without measurable rain for depressions on track A separated into classes according as both fronts, warm or cold front alone, or neither crossed the whole of the British Isles. As would be expected rainfall amounts are considerably less when neither front crosses all the country (Fig. 7 (d)) than in the other cases. The differences between Fig. 7 (d) (neither front crossing all of the country) and Fig. 7 (a) (both fronts crossing all of the country) is greater in respect of the south-east of the British Isles but rainfall in the former diagram is somewhat lower even in west Scotland. The percentage of cases without measurable rain is also much greater among the depressions of which neither front crossed the whole of the country.

**Application to forecasting.** The investigation presented here serves to systematize some knowledge of the relation between the synoptic situation and the rainfall which accompanies it. It was undertaken with a view to providing some help to the forecaster who has constructed a forecast chart for the following day and wishes to interpret it in terms of rainfall amounts. The information about the average rainfall associated with depressions on various tracks which is presented in Figs. 1-3 may provide useful information for this purpose, but the variability among individual cases is large, and it is clear that no accurate predictions of rainfall amounts can be achieved by this approach.

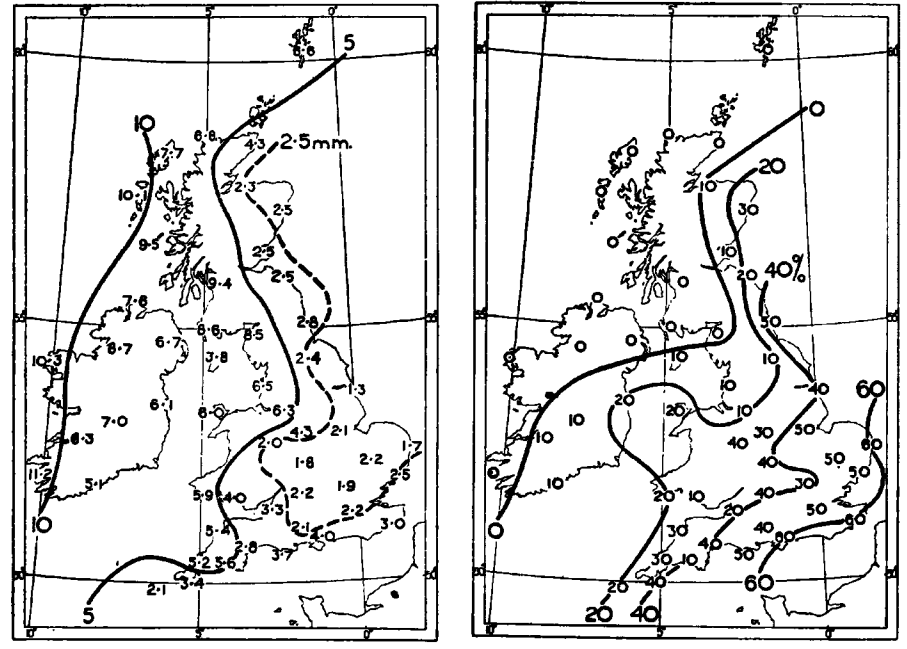
Study of the variations of rainfall between individual depressions confirms that relations exist between the rainfall and various synoptic characteristics in agreement with general forecasting experience. Thus the deeper a depression, the slower it moves, the greater its component of motion to the north and the deeper the thermal trough which follows it, the greater its rainfall is likely to be. However none of these relations is close enough to provide a useful numerical prediction of the rainfall. The regression equations for calculating rainfall from them provide total correlations between calculated and observed rainfall of only about  $+0.6$ . In view of the uncertainties of predicting the synoptic characteristics themselves, it does not appear worth while to use the statistical relations numerically in forecasting. The general relations described in the preceding sections may however be of value to the forecaster in forming his judgement of the rain to be expected.



Average rainfall

Percentage of cases which gave less than 0.1 mm. of rain

(a) Frontal class I—both fronts crossed all of the British Isles. No. of cases 22

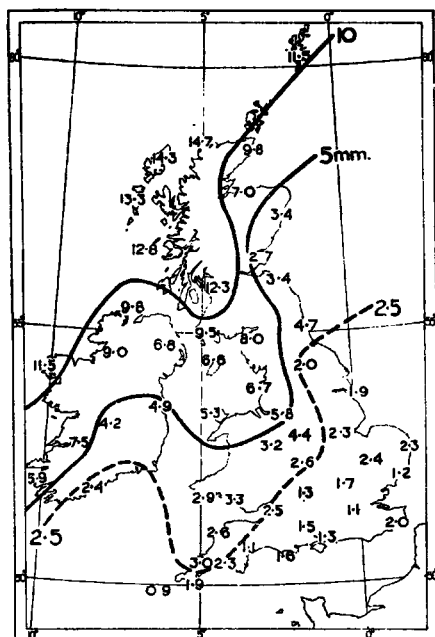


Average rainfall

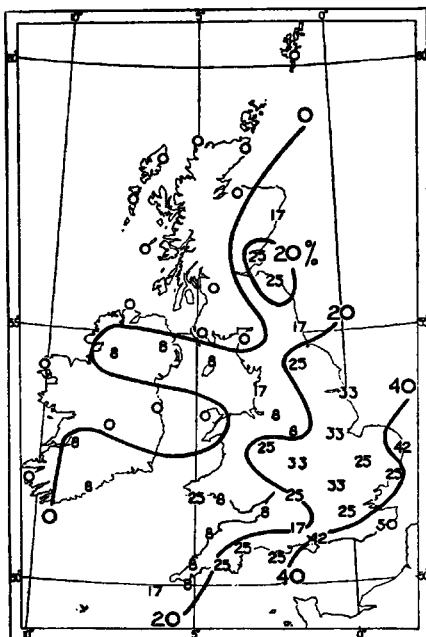
Percentage of cases which gave less than 0.1 mm. of rain

(b) Frontal class II—warm front only crossed all of the British Isles. No. of cases 10

FIG. 7—AVERAGE RAINFALL AND PERCENTAGE OF CASES WHICH GAVE LESS THAN 0.1 MM. OF RAIN FOR DEPRESSIONS ON TRACK A SEPARATED INTO FRONTAL CLASSES (continued)

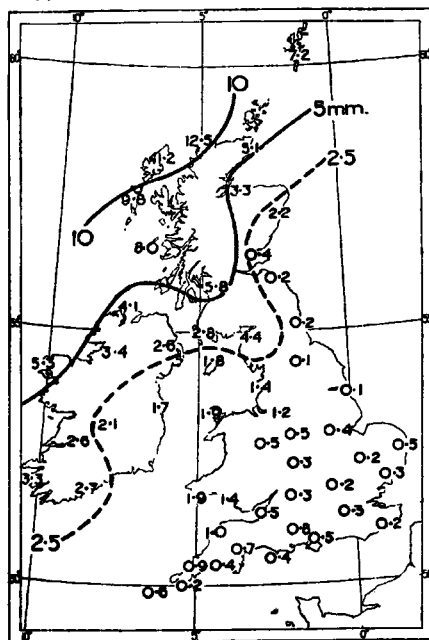


Average rainfall

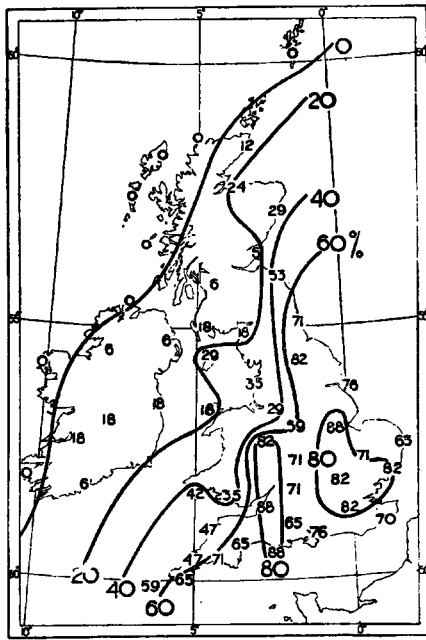


Percentage of cases which gave less than 0.1 mm. of rain

(c) Frontal class III—cold front only crossed all of the British Isles. No. of cases 12



Average rainfall



Percentage of cases which gave less than 0.1 mm. of rain

(d) Frontal class IV—neither front crossed all of the British Isles. No. of cases 17

FIG. 7—AVERAGE RAINFALL AND PERCENTAGE OF CASES WHICH GAVE LESS THAN 0.1 MM. OF RAIN FOR DEPRESSIONS ON TRACK A SEPARATED INTO FRONTAL CLASSES

*Crown Copyright Reserved*  
Published by  
HER MAJESTY'S STATIONERY OFFICE

To be purchased from  
York House, Kingsway, LONDON, W.C.2  
423 Oxford Street, LONDON, W.1  
P.O. Box 569, LONDON, S.E.1  
13a Castle Street, EDINBURGH, 2  
109 St. Mary Street, CARDIFF  
39 King Street, MANCHESTER, 2  
Tower Lane, BRISTOL, 1  
2 Edmund Street, BIRMINGHAM, 3  
80 Chichester Street, BELFAST  
or from any Bookseller

Printed in Great Britain under the authority of Her Majesty's Stationery Office.  
by The Campfield Press, St. Albans

14124. Wt. 3369. BM4176. K6. 2/56. S.P. & S. G.9-8-8.

S.O. Code No. No. 47-57-10-18