M.O. 559 AIR MINISTRY

METEOROLOGICAL OFFICE

THE METEOROLOGICAL MAGAZINE

VOL. 81, No. 961, JULY 1952

USEFULNESS OF FORECASTS

By A. F. CROSSLEY, M.A.

Useful effort.—The following scheme of assessing the usefulness of a certain type of forecast has been put forward by Mr. H. Dawes of the Scientific Adviser's Department of the Air Ministry.

The type of forecast concerned is of the "black or white" type, and may relate, for example, to the suitability as regards weather of any day for carrying out a specific operation; any one day is therefore forecast as suitable or unsuitable. Dawes defines the forecast accuracy c as the proportion of all occasions which are correctly forecast ($0 \leqslant c \leqslant 1$). The "useful effort" is defined as the proportion of occasions forecast as suitable which in fact turn out to be so. If operations are conducted in accordance with the forecasts, the useful effort represents the proportion of operations which turn out successful as regards weather.

If the proportion of suitable days in a given period is denoted by b, then the proportion bc of suitable days will be correctly forecast and the proportion $(1 - b)(1 - c)$ of unsuitable days will be incorrectly forecast as suitable. Therefore the proportion of occasions forecast (rightly or wrongly) as suitable will be $bc + (1 - b)(1 - c)$, and the useful effort is given as

$$E = \frac{bc}{2bc - b - c + 1} \cdot \qquad \ldots\ldots\ldots(1)$$

This formula indicates that the useful effort depends not only on the forecast accuracy, but also on the frequency of occurrence of the element being forecast. Since one requires $E > b$ to make forecasting worth while, this necessitates $c > \frac{1}{2}$, i.e. the forecast accuracy must exceed 50 per cent.

This argument, however, assumes that the forecast accuracy is the same for suitable as for unsuitable days, and this is not in general the case. Consider an event about which little is known except that it occurs on 1 per cent. of occasions, $b = 0{\cdot}01$. It might then with some justification be regularly forecast as not occurring, and its forecast accuracy would be zero. On the other hand, forecasts of non-occurrence of the event would have an accuracy of 98/99, while the overall forecast accuracy is 98/100. Then let c denote the forecast accuracy of suitable days, and c' that of unsuitable days. The proportions of correct and incorrect forecasts in the two categories may then be set out as in Table I.

TABLE I—FORECAST CONTINGENCY TABLE

	Forecast	Not forecast	Total
Suitable	bc	$b(1-c)$	b
Unsuitable	$(1-b)c'$	$(1-b)(1-c')$	$1-b$
Total	$bc+(1-b)c'$	$b(1-c)+(1-b)(1-c')$	1

From this, the useful effort (in regard to suitable days) is given by

$$E = \frac{bc}{bc + (1-b)(1-c')} \cdot \qquad \text{.........(2)}$$

The condition for worth-while forecasting, $E > b$, then leads to

$$c + c' > 1, \qquad \text{.........(3)}$$

so that the sum of the two forecast accuracies must exceed unity. It is not therefore essential for the forecast accuracy c to exceed 50 per cent. in order to make forecasting of some particular event worth while; the accuracy can fall short of 50 per cent. provided this is counterbalanced by an accuracy above 50 per cent. for forecasts of non-appearance of the event.

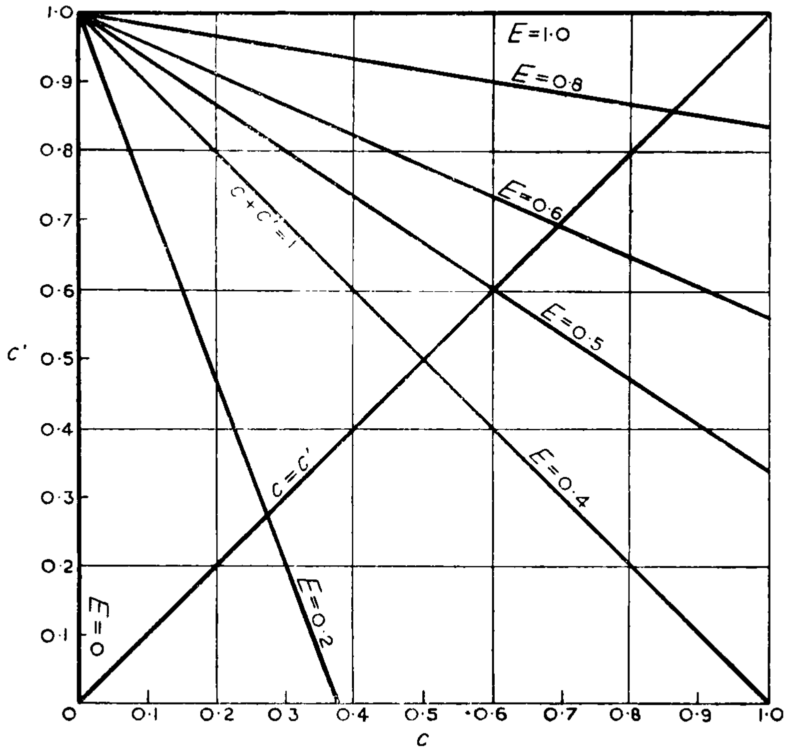


FIG. 1—USEFUL EFFORT (E) IN RELATION TO FORECAST ACCURACIES (c, c') FOR FREQUENCY OF OCCURRENCE $b = 0{\cdot}4$

Fig. 1 illustrates the relationship between useful effort and the forecast accuracies when $b = 0{\cdot}4$. In this and similar diagrams (not reproduced) for other values of b, the diagonal line $c + c' = 1$ is identical with the isopleth $E = b$. Hence for a useful effort greater than b, the point (c, c') must lie above and to the right of this diagonal. The other diagonal is the line $c = c'$, which refers to the simple case considered by Dawes. It is seen that to achieve a useful effort of 0·5 it is necessary to have one or other of c and c' more than 0·6. However, c may be for example as low as 0·3 provided c' is at least 0·8. A similar point was made by Dawes in remarking that a useful effort of 0·48 with $b = 0{\cdot}2$ requires a forecast accuracy of nearly 0·8 (i.e. with $c = c'$).

Varying the useful effort.—The useful effort is a function of the frequency b of the event forecast and of the accuracies c and c' with which both the event and its non-occurrence can be forecast. If b can be varied without invalidating the purpose for which the forecast is required, the value of the useful effort will in general be altered. It is a matter for consideration whether the useful effort can be improved. For example, suppose the event for which forecasts are required is that of "cloud base not below 13,000 ft.". This is included in "cloud base not below 15,000 ft.", and it is conceivable that the useful effort in regard to the latter event is greater than the useful effort in regard to the former. On the other hand, the operations for which the forecasts are required might well be still practicable provided the cloud base is not below 10,000 ft., and again it may be found that the useful effort is in consequence increased. In such cases—where economy of effort is the main consideration and time of less importance—the limiting situation requires to be selected not only from the point of view of feasibility of a particular operation, but also with regard to the resulting useful effort. What at first might appear to be a loss, due to restriction or extension of conditions, may be more than compensated by an increase of useful effort.

Consider again the forecasting of an event of which the frequency distribution consists of a curve with a single hump centred near (but not in general coincident with) the average value, while on either side it tails off towards zero for low and high values. Wind speed, for example, has this type of frequency distribution. Let us suppose that forecasts are required of speed greater (or less) than some value V. If V is near the average value, speeds in this neighbourhood will occur with high frequency and it will often be difficult to predict whether the speed will or will not exceed V; on the other hand, occasions of both very strong winds and very light winds will be more readily forecast successfully, since both, being infrequent, depend on exceptional conditions which will be readily recognized in advance. Thus while b decreases, the accuracy of forecasting increases. However, if variations in c' are ignored, the useful effort increases with bc and may be expected to attain its maximum values in the neighbourhood of the two points of inflexion of the frequency curve, i.e. at moderately low and moderately high values of the wind speed.

By varying expression (2) for the useful effort, it may be seen that for small variations in b, c and c' the useful effort is increased provided

$$\frac{\delta c}{c} + \frac{\delta c'}{1 - c'} + \frac{\delta b}{b\,(1 - b)} > 0. \qquad \cdots\cdots\cdots(4)$$

If the forecast accuracies remain unchanged while b is increased, then the useful effort is increased; this increase will be still greater if either or both of c and c' are increased; but some increase in useful effort may still occur even if one or both of c and c' are reduced. On the other hand if b is reduced, there may be increases in c or c' sufficient to ensure an increase of useful effort.

Examples.—Some of the above ideas may be illustrated by actual results for certain forecasts. Consider first, a series of trial 4-day forecasts of weather over Great Britain made by the Forecast Research Division at Dunstable over the period February 1949 to March 1950. The series included definite forecasts of a change of weather type; such a forecast, to be correct, has to predict a change occurring on the right day of the four. Not more than one change of type occurred, or was forecast, in any one of the 4-day periods concerned.

The following table shows the results of an analysis of these forecasts, each 4-day forecast period constituting one occasion.

TABLE II—FORECASTS OF CHANGE OF TYPE, FEBRUARY 1949–MARCH 1950

Number of cases	Forecast	Not forecast	Total
Change of type	19	17	36
No change...	59	13	72
Total	78	30	108

From these figures we have the following:—

(i) Frequency of occurrence of "change", $b = 36/108 = 0\cdot33$*

(ii) Accuracy of forecasts of change, $c = 19/36 = 0\cdot53$

(iii) Accuracy of forecasts of no change, $c' = 59/72 = 0\cdot82$

(iv) Useful effort, or proportion of forecasts of change which are correct, $E = 19/(19 + 13) = 0\cdot59$.

All these figures indicate that forecasts of a change of type constitute a definite improvement on a wait-and-see policy, according to which, on average, a change of type would be expected one occasion in three. At the same time, as might have been expected, there is a much higher forecast accuracy in regard to forecasts of "no change" than there is for forecasts of "change" (82 per cent. against 53 per cent.). Depending on the "operations" concerned, which may of course include the use of the forecasts by the public, forecasts of "no change" may be of as much, or more, importance as forecasts of "change". It is equally appropriate therefore to consider the useful effort in regard to forecasts of "no change", which is $59/(59 + 17) = 0\cdot78$. Thus 78 per cent. of the forecasts of "no change" are correct. This compares with the earlier statement that 82 per cent. of the occasions of "no change" are correctly forecast. From the point of view of reliability of the forecasts, the lower figure (the useful effort) is, in this case, the more pertinent.

Another example is provided by the results of an investigation by Sawyer[1] into the application of certain criteria for the formation of secondary depressions at points of occlusion. When his results for both warm-occlusion and cold-occlusion secondaries are combined, Table III is obtained.

TABLE III—FORMATION OF SECONDARY DEPRESSIONS, OCTOBER 1947 TO SEPTEMBER 1948

Number of cases	Criteria correct	Criteria incorrect	Total
Secondary formed... ...	63	14	77
Not formed	137	23	160
Total	200	37	237

Using the same notation as before, we have

$b = 0\cdot32$, $c = 0\cdot82$, $c' = 0\cdot86$.

$E = 0\cdot73$ in regard to secondary forming,

$E = 0\cdot91$ in regard to no secondary forming.

These figures show that the criteria have a high degree of validity, especially in regard to non-development of a secondary, in which case 91 per cent. of the expectations are correct.

*This number refers only to changes occurring within the 4-day forecast periods; these did not cover the whole of the period mentioned.

Economic importance.—The economic value of forecasts has been discussed by Bilham[2] and more recently by Bijvoet and Bleeker[3]. The latter authors emphasize the economic importance by considering, as an example, the cost of taking precautions against frost damage, and the losses incurred on account of damage if no precautions are taken. Suppose that without preventive measures the average loss on a frost night is L, and that the daily cost of preventive measures is P. Two cases arise according as P is greater or less than bL, i.e. according as the cost of prevention is greater or less than the cost of damage in the absence of preventive measures. If preventive measures are applied only when frost is forecast, it is seen by reference to Table I that the average daily cost C, is given by

$$C = \{bc + (1 - b)(1 - c')\} P + b(1 - c) L.$$

Hence if $P > bL$, the average daily saving obtained by use of the forecasts is

$$B_1 = bL - C = bcL - \{bc + (1 - b)(1 - c')\}P.$$

Similarly if $P < bL$, the average daily saving is

$$B_2 = P - C = (b + c' - bc - bc') P - b(1 - c)L.$$

From these relationships, Bijvoet and Bleeker give two diagrams showing the relationship between P/L and B_1/L or B_2/L for $b = 1/10$.

Conclusion.—Such instances as that just discussed, together with the earlier considerations, show that there is little direct relationship between the value and the accuracy of a given type of forecast. The accuracy is a matter depending on the personal ability of the forecaster, the quality of his technique and the meteorological circumstances, while the value of the forecast to the user depends also on the particular circumstances in which it is applied. If the user is unwilling to risk losing an opportunity on account of a bad forecast, then forecasts (for that purpose) are of no use to him, however accurate they may be, short of perfection. Nevertheless it is desirable to have an estimate of the reliability of any given type of forecast, and expression (2) given above for the useful effort, which is also the chance that a forecast has of being correct, appears to meet this need satisfactorily.

Acknowledgement.—I am indebted to Mr. C. S. Durst for discussions which led to the writing of this note.

REFERENCES

1. SAWYER, J. S.; Formation of secondary depressions in relation to the thickness pattern. *Met. Mag., London,* **79,** 1950. p.1.
2. BILHAM, E. G.; A problem in economics. *Nature, London,* **109,** 1922, p. 341.
3. BIJVOET, H. C. and BLEEKER, W.; The value of weather forecasts. *Weather, London,* **6,** 1951, p. 36.

HURRICANE OF AUGUST 17–18, 1951, IN JAMAICA

By W. J. FOWLER

The area of formation of West Indian hurricanes during the months of August and September lies mainly to the eastward of the Lesser Antilles between latitudes 5° and 15°N. Observations show that during the early stages of hurricane development, unsettled and squally weather sets in over a considerable area of ocean. In the later stages the squalls appear to amalgamate and a depression centre forms. Once there is a centre of low pressure the hurricane usually develops rapidly and within 24 hours there may be winds of hurricane force (75 m.p.h.) near the centre. The diameter of the storm area increases to about 75 miles in the case of the small intense ones and to 500 miles for larger ones. Intense convection occurs producing cloud to over 30,000 ft. and torrential rain.

The forecasting of development and movement of these storms and the issuing of the necessary warnings is carried out under international arrangements made by the Caribbean Commission in collaboration with Regional Commission IV of the World Meteorological Organization. The Caribbean Commission is a specialized organization of the United Nations, financed by the British, United States, French and Dutch Governments. Under these arrangements the United States Weather Bureau office at San Juan, Puerto Rico, is the official central hurricane warning centre for the eastern Caribbean Sea. The British, French, Dutch and other United States meteorological offices maintain close contact with each other and with San Juan. Each office can issue a local hurricane warning but no general hurricane warning is, however, issued except in agreement with San Juan. The San Juan office controls the United States squadron of hurricane-reconnaissance aircraft, and any meteorological office can ask San Juan to arrange a reconnaissance flight if a storm centre is located from ship or aircraft reports or if there is a suspicious departure from the normal seasonal weather. The reconnaissance aircraft which then search for the eye of the storm seldom abandon the attempt to find the centre even in the dangerous flying weather of the central area with winds of up to 150 m.p.h.

Hurricanes are labelled alphabetically during the season of their activity. The first is "A" for Able, the second "B" for Baker and so on. The hurricane which struck the southern half of the Island of Jamaica on the night of August 17–18, 1951, was the third in the 1951 series and was named "C" for Charlie; Able and Baker occurred in June 1951 and never reached maturity.

"Charlie" was first located about 50 miles east of Martinique about midday on Wednesday, August 15, and by early morning on the following day it was obvious that, if it continued to move in the same direction, it would pass near and to the south of Jamaica on Friday, August 17. The timing at this stage was rather difficult because of frequent changes in its rate of movement but by 9 a.m. E.S.T. on August 17 it was forecast that the hurricane would commence about 9 p.m. E.S.T. on that day. During this pre-hurricane period the general public and shipping were kept informed as to developments by Press and Radio, which issued instructions as to what precautions to take in order to minimize the effects of the storm. The track of the hurricane is given in Fig. 1.

Before the arrival of the hurricane, Jamaica experienced about five hours of heavy rain which put telephones out of action, probably on account of landslides carrying away poles and breaking the lines, and it was not possible until August 24, when reports began to arrive by post, to track the actual course of the centre across the island. The eastern parishes were the first to be affected, torrential rain and winds of 80–90 m.p.h. being experienced by about 8.30 p.m. E.S.T. These conditions moved slowly westward over the southern half of Jamaica and finally cleared the extreme west by 5 a.m. E.S.T. on Saturday, August 18.

The hurricane struck Kingston, a city of about 125,000 inhabitants, at 9.45 p.m. E.S.T. on August 17 when the wind suddenly increased to an average speed of over 85 m.p.h. with gusts in excess of 110 m.p.h. This approximation is necessary as the two recording wind instruments in the district ceased to register above these limits. There have been rumours that other anemometers

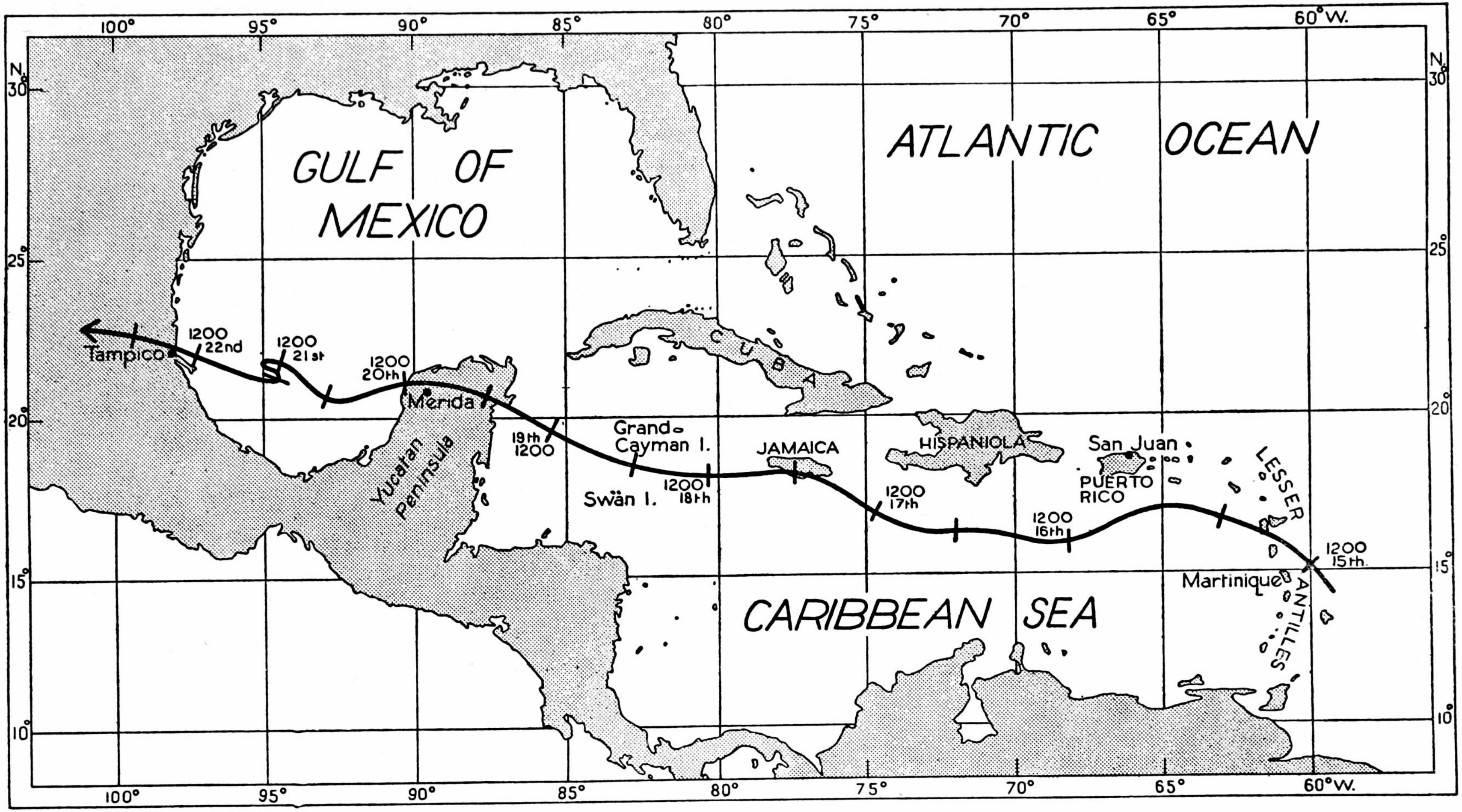


FIG I—TRACK OF THE HURRICANE ACROSS THE CARIBBEAN SEA, AUGUST 15–22, 1951 recorded gusts of 140–160 m.p.h. before being wrecked but these instruments are of the revolving-cup pattern, which over-read considerably at high speeds. It is considered that a reasonable approximation may be given as an average wind speed of 85–90 m.p.h. with gusts to 120–125 m.p.h. These hurricane-force winds continued for about six hours, during which time trees were blown down, roofs blown off and much general damage was done by flying debris, such as branches of trees, pieces of timber and sheets of corrugated iron, the latter being used extensively for garage roofs and outbuildings in the towns and as general roofing material throughout the island.

The south-east quarter of the island suffered the most—Morant Bay, Yallahs, Port Royal and parts of Kingston being the worst affected. The number of deaths in Kingston was 56 and the total for the whole island 152. There was considerable damage to shipping in Kingston Harbour and five large vessels were driven ashore.

During the passage of the hurricane, torrential rain was experienced and over a wide area in the southern parishes amounts in excess of 10 in. were recorded while extreme values of up to 17 in. fell in the Kingston area and locally along the mountain ridge. The rain-gauge at Palisadoes, the airport for Kingston, overflowed because the gauge became clogged with sand and small gravel and the actual rain collected was 430 mm. (16·93 in.); how much rain was lost is not known so we give the figure as 17+in. Fig. 2 shows the rainfall chart for Duckenfield in the extreme south-east corner of the island about 40 miles east of Palisadoes.

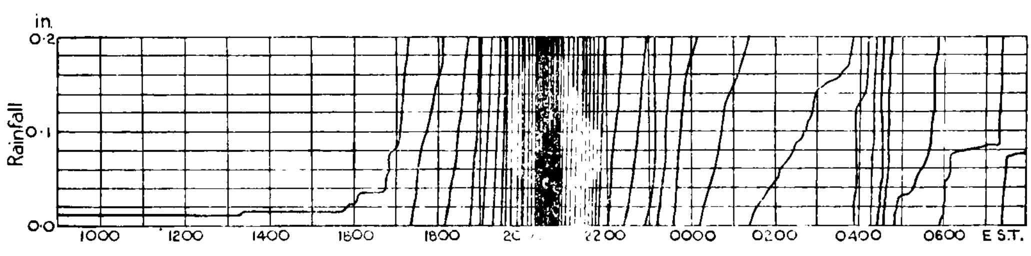


FIG. 2—RAINFALL CHART FOR DUCKENFIELD, AUGUST 17–18, 1951

For about three hours before the passage of the centre the barometer fell very rapidly, as will be seen fron the Palisadoes barogram in Fig. 3. The minimum value recorded at Palisadoes was 973 mb. (28·74 in.). It is estimated that the centre passed about eight miles south of Palisadoes Airport—that is, about ten miles south of Kingston—and that the pressure at the centre, allowing for a five-mile area of uniform pressure in the "eye", was about 964 mb. (28·47 in.). I am indebted to the Rev. Canon H. W. Cope of Savanna la Mar and to Mr. E. P. Buckley of Kingston, both keen amateur meteorologists, for providing me with half-hourly barometer readings throughout the night of the hurricane and thus assisting in tracking its course across the island. From the accompanying map, Fig. 4, it can be seen that the centre passed over the coast to the south-west of Kingston.

As is usual when a hurricane passes over land the winds decreased in violence as it travelled westwards across the southern part of the island. The wind dropped to an average of about 60–70 m.p.h. and the rain became less intense. Even so the wind was strong enough in the western areas of Jamaica to break

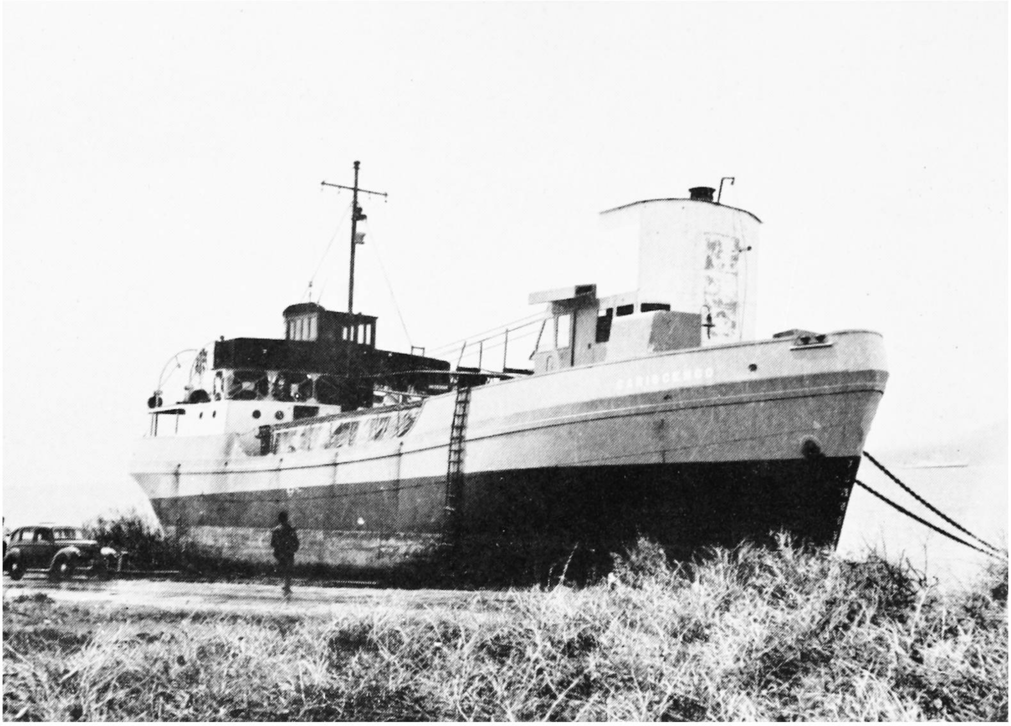
[To face p. 200

Reproduced by courtesy of the Daily Gleaner, Jamaica

ST. GEORGE'S COLLEGE, KINGSTON

Reproduced by courtesy of the Daily Gleaner, Jamaica

TYPICAL VIEW OF THE DAMAGE CAUSED TO HOUSES DURING THE HURRICANE OF AUGUST 17–18, 1951



Reproduced by courtesy of the Daily Gleaner, Jamaica

LARGE CARGO STEAMER DRIVEN ASHORE WITHIN THREE YARDS OF THE KINGSTON-PALISADOES ROAD

Reproduced by courtesy of the Daily Gleaner, Jamaica

REMAINS OF THE MAIN AIRPORT BUILDING AFTER THE HURRICANE OF AUGUST 17–18, 1951 banana plants and sugar canes and unroof houses. The northern parishes of the island escaped the worst fury of the storm. The wind there, with a highest reported value of 40–50 m.p.h., was enough to cause a fair amount of damage to crops but not to cause much structural damage. The rainfall in the north was very patchy; some places reported 5–7 in. while others escaped with a mere 2 in. which is, it may be mentioned, of the same order as the average monthly rainfall in south-east England.

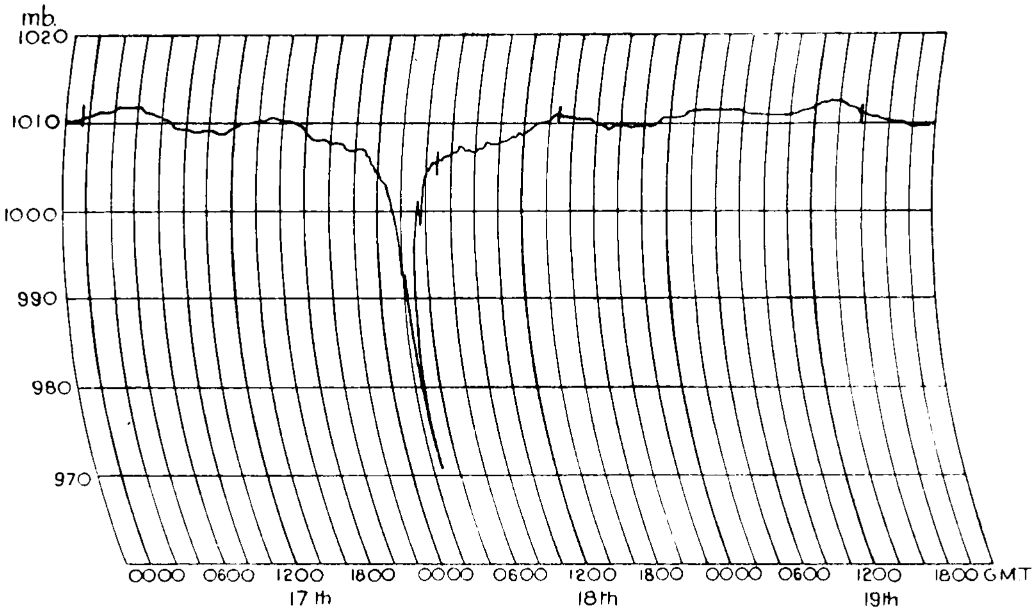


FIG. 3—BAROGRAPH FOR PALISADOES, AUGUST 17–19, 1951

As it approached Jamaica, the centre was moving towards west-north-west but it left the island at a point almost due west of the point of entry. Possibly the east-to-west range of mountains across the island had some influence on the change of track. After leaving, it resumed its normal track towards west-north-west passing between Swan Island and Grand Cayman Island about 24 hours after it had struck Kingston. In the meantime, it had regained full hurricane force and the wind was reaching 120–130 m.p.h. in gusts. By midnight of the 19th, the centre had travelled to north Yucatan and passed close to the important town of Merida during the morning of August 20. From here, it passed out into the Gulf of Mexico, where it remained almost stationary for a period of 12–15 hours. The intensity of the storm had again shown great variation, having decreased during its passage over the Yucatan Peninsula, and regained what it had lost during its slow journey over the Gulf of Mexico. By early morning on August 22 the centre was once again continuing its west-north-west movement towards Tampico, Mexico. The "eye" of the hurricane passed over this town between 1 p.m. and 1.30 p.m. on August 22 and the inhabitants there experienced the calm period, associated with the centre, between hurricane force winds of 100 m.p.h. from opposite points of the compass.

Records of hurricanes affecting Jamaica date back to 1689 and since then Jamaica has experienced 39 hurricanes, 17 of which could be classified as "violent". The following table gives the number experienced month by month during the last 262 years:—

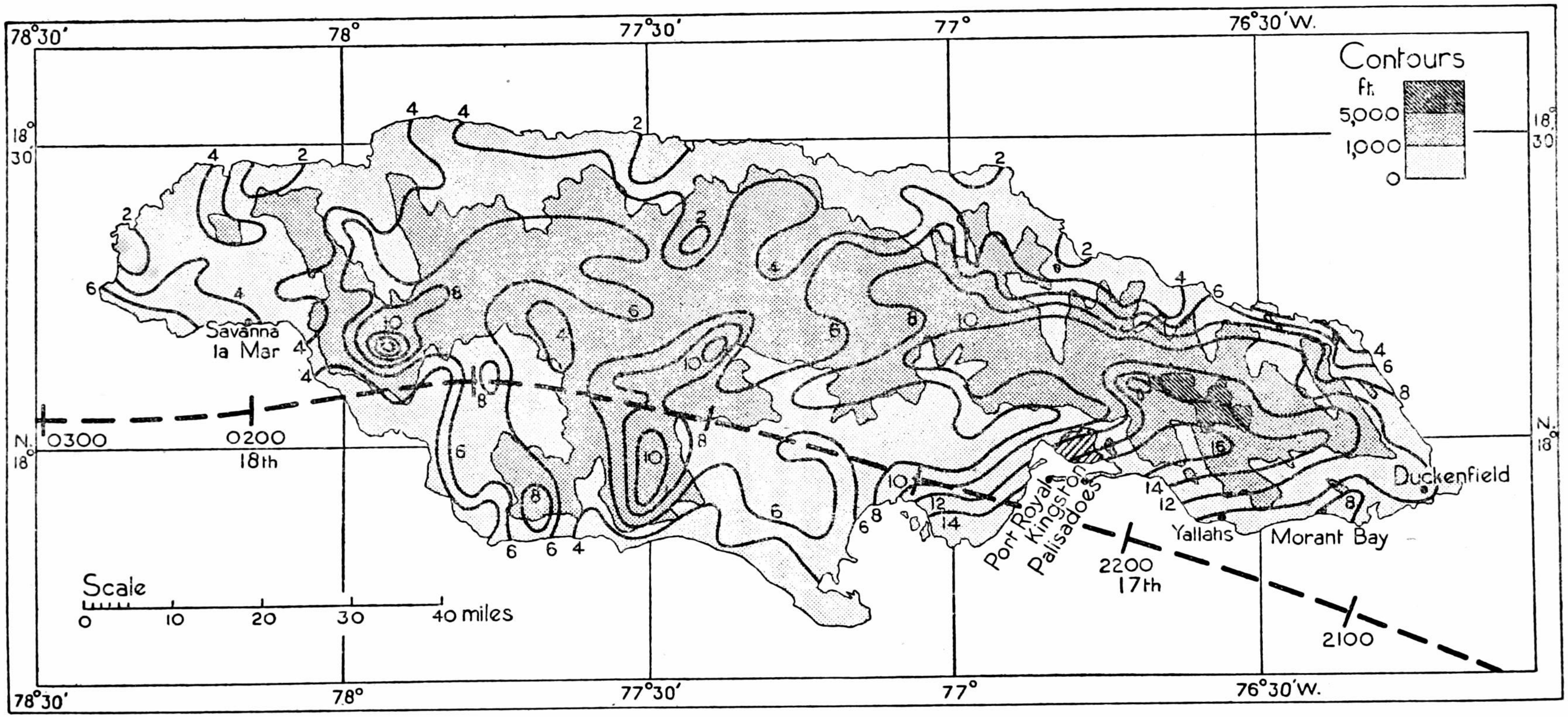


FIG. 4—RAINFALL FOR THE 24 HOURS ENDING AT 0700 E.S.T., AUGUST 18, 1951
Values of the isohyets are given in inches. The probable track of the hurricane is shown by a broken line.

	Total storms	Violent hurricanes		Total storms	Violent hurricanes
June	2	0	September ...	4	1
July	1	0	October ...	11	6
August	18	7	November ...	3	2
			Total ...	39	16

From this table it is evident that August is the month of greatest risk of hurricanes. The average frequency of violent ones is one in sixteen years but this figure must not be taken to imply any sort of periodicity as in some years there have been more than one—there were three in 1916 and two in 1813 and 1915—and on the other hand, there have been in the past 250 years, periods of over 20 years without one.

Although the October 1933 hurricane was disastrous to the western parishes, we have to go back to August 1903—48 years earlier—to find such widespread damage as that experienced during the passage of hurricane "Charlie" during the night of August 17–18, 1951.

DAILY MAXIMUM TEMPERATURE OF THE SURFACE OF THE GROUND

By R. W. GLOYNE, B.Sc.

Introduction.—Although the temperature of the surface of freely exposed ground is often required, information on this important meteorological factor is widely scattered. Two empirical formulæ were recently published dealing with the relationship between the daily maxima on the ground and in the screen which might usefully be brought to the notice of a wider public; and, in this present note, some observations on surface temperatures are discussed against the background of the two formulæ.

In the following paragraphs we shall use the terms "surface" temperature and "skin" temperature to refer to the results obtained by methods which measure respectively a mean temperature of a shallow surface layer and a true surface temperature. Vaartaja[1] has suggested that the daily maximum skin temperature might be some 9°C. higher than the corresponding surface temperature, and, as will be seen later, an additive correction of this magnitude is sufficient to reconcile surface temperatures measured by the two methods.

Empirical relationships between the maximum air temperature in the screen and maximum surface and skin temperatures.—(*a*) Penman[2], at the Rothamsted Experimental Station, Hertfordshire, obtained continuous records, covering most of the period June 1940–August 1941, of the temperature given by a mercury-in-steel thermograph, the 1-in. diameter bulb of which was half buried in fallow soil, the upper semi-circular surface being freely exposed to air and sun. This was calibrated with respect to a mercury-in-glass instrument so mounted as to give the mean temperature of the top ½-in. layer of soil. If values of this daily surface maximum are denoted by T and the corresponding screen maxima by t, Penman deduced:—

$$T \doteqdot t \text{ when } T < 52°\text{F.}$$
$$T \doteqdot 2t - 52 \text{ when } T > 52°\text{F.} \qquad \ldots\ldots\ldots(1)$$

with an accuracy of about ± 10°F. or so judging from Fig. 4 in his paper.

(*b*) Debrach[3], working near Rabat (Morocco) in 1942–43, measured the temperature of a bare soil "surface" with the aid of a fine mercury-in-glass thermometer buried 3 mm. below the surface, and found that the readings at 1300 local time of this thermometer and of that in the screen (in degrees Centigrade) were connected by the relationship

$$T = 2t - 10 \qquad \ldots\ldots\ldots(2)$$

with a tolerance of $\pm$ 5°C. This and the second of Penman's relationships are virtually identical.

(*c*) Mackenzie Taylor[4], in the Egyptian desert during 1924, used a method very similar to that employed by Penman. The relationship between his values of the monthly means of daily maximum surface temperature T and of maximum screen temperatures t (in degrees Centigrade) may be expressed as follows:—

$$T = 1 \cdot 98t - 11 \cdot 29$$

with a correlation coefficient of over 0·95.

(*d*) Vaartaja[1], in Finland, measured with the aid of fine thermocouples skin temperature (T') in a number of different types of country. If we select those few quoted results which were obtained in reasonably flat open countryside we have (in degrees Centigrade):—

t......	19·3	25·3	25·7
T'......	35·0	44·0	49·0

Adopting his suggestion (mentioned earlier) that

$$T' = T + 9 \qquad \ldots\ldots\ldots(3)$$

we have T......26·0 35·0 40·0

which compares with values 28·6°C., 40·6°C. and 41·4°C. computed by Debrach's equation (2).

(*e*) Rider and Robinson[5], in the Appendix to their paper on heat and vapour exchange over a short turf surface, quote a number of simultaneous measurements of a skin temperature and screen temperature at various heights. Since the maximum temperature is not reached at the same time at the surface as at 1·4 m., days for which appropriate observations are available are limited to four (June 20, 21 and 23 and July 1, 1949).

Using $T = 2t - 50$ we have, in the four cases, T = 90°, 97°, 88° and 102°F. which are respectively 12°, 9°, 15° and 8°F. below the observed values of T' thus leading to a relationship between T' and T approximately as given by equation (3).

(*f*) Yakuwa[6], measured temperature in plots of different soil types. From his results for a particular day we find:—

Soil type	loam	clay	"bog"	volcanic sand	sand
T(°C.)	46·7	35·9	39·0	48·6	53·5

and t = 27·5°C.

It is not clear from the paper which of the five soil types is representative but the result for "loam" is consistent with equation (2).

(*g*) Observations of T' and t in degrees Fahrenheit quoted by Pasquill[7] for three days in March agree approximately with

$$T' = 2t - 50.$$

Penman, however, found that when T < 52°F. the relationship was $T \simeq t$, and as the skin temperatures quoted by Pasquill were 62°F. or less we may allow the possibility that neither equation (1) nor equation (3) apply in this particular case.

(*h*) Johnson and Davies[8] reported the monthly means of daily maximum and minimum temperatures obtained at 1-cm. depth in various types of surface, amongst these chalk with and without a cover of short turf. Making a rough assessment of the extent to which the 1-cm. thick layer of soil (and the additional thickness of turf in one instance) decreases the diurnal range of temperature experienced at the surface, it would appear that a functional relationship of the form

$$T = at - b, \; a \doteqdot 2$$

represents the trend of the observations fairly well.

(*i*) In a technical memorandum[9] issued by the Meteorological Office in 1942 a few extreme surface temperatures obtained in hot countries are noted. These, which are probably surface and not skin temperatures, are found to obey the relationship (in degrees Fahrenheit)

$$T = 2t - 50$$

to an acceptable degree of accuracy.

Discussion.—There appears to be some evidence that the maximum temperatures at the surface and in the screen can be linked by a linear relationship which applies over an unexpectedly wide range of conditions. The relationship seems to be valid in dry tropical or subtropical climates throughout the year, and in temperate regions in the summer half year at least. Although both Penman and Debrach make it clear that values for any particular day may deviate appreciably (say $\pm$ 5°C.) from the average relationships expressed in equations (1) and (2), it is nevertheless striking to note that the same empirical relationship between screen and surface maxima obtains in the British Isles, where evaporation at the surface is an important sink for solar energy, as in the desert, where it can only play a minor role.

Implicit throughout is the assumption that the temperature of the air is determined by the soil temperature in the same neighbourhood. Therefore the surface temperature of small plots differing markedly in character from that of the surrounding countryside, will not necessarily be related to the air temperature by equation (1). In this, as in other similar studies, due weight must be allotted to the customary rule that the rate of development of vertical temperature, moisture and velocity profiles in the air, appropriate to the surface over which the air is flowing, is of the order of 1 ft. for every 100 ft. of unobstructed fetch from the windward boundary of the surface.

There is no need to stress the potential importance of the relationships discussed earlier if they can be established as a general rule. It is also possible that the deviations in any particular case will be related to the soil type and its condition (especially moisture content) at the time, and to short-period variations in the vertical fluxes of heat and vapour.

Summary.—An examination of some recent observations of the maximum temperature on or near the surface of the ground and of the corresponding screen air maximum temperature support the empirical relationship deduced independently by Penman in England and Debrach in Morocco.

If T = daily maximum temperature (in degrees Fahrenheit) of a layer a few millimetres thick at the surface,

t = daily maximum temperature in the screen (in degrees Fahrenheit)
T' = skin temperature of the surface (in degrees Fahrenheit),
then $T = 2t - 50$
and $T' = T + 15$

This result seems to apply generally over bare soil in dry subtropical regions throughout the year, and over bare soil and short turf in the summer half of the year in temperate regions, providing that the soil is not waterlogged and that the surface whose temperature is being observed is reasonably homogeneous for some hundreds of feet upwind.

REFERENCES

1. VAARTAJA, O.; High surface soil temperatures. *Oikos, Copenhagen*, **1**, 1949, p. 6.
2. PENMAN, H. L.; Daily and seasonal changes in the surface temperature of fallow soil at Rothamsted. *Quart. J. R. met. Soc., London*, **69**, 1943, p. 1.
3. DEBRACH, J.; Effects thermiques du rayonnement solaire: temperature superficielle du sol. *C. R. Soc. Sci. Nat. Moroc., Rabat*, No. 4, 1950, p. 64.
4. TAYLOR, E. MACKENZIE; Soil temperatures in Egypt. Report on Agricultural Meteorological Conference 1928, London, 1929, p. 63.
5. RIDER, N. E. and ROBINSON, G. D.; A study of the transfer of heat and water vapour above a surface of short grass. *Quart. J. R. met. Soc., London*, **77**, 1951, p. 375.
6. YAKUWA, R.; Über die Bodentemperaturen in den Verschiedenen Bodenarten in Hokkaido. *Geophys. Mag., Tokyo*, **14**, 1946, p.1.
7. PASQUILL, F.; Eddy diffusion of water vapour and heat near the ground. *Proc. roy. Soc., London*, A, **198**, 1949, p. 116.
8. JOHNSON, N. K., and DAVIES, E. L.; Some measurements of temperatures near the surface in various kinds of soils. *Quart. J. R. met. Soc., London*, **53**, 1927, p. 45.
9. London Meteorological Office. Extremes of air temperature and humidity and of surfaces exposed to direct sunshine. Unpublished, copy in Meteorological Office Library, 1942.

RADIO-WAVE PROPAGATION AT 89 Mc./sec. IN RELATION TO SYNOPTIC CONDITIONS

By C. W. SPENCER, B.Sc.

(Communication from the National Physical Laboratory)

Summary.—The correlation between wave-propagation characteristics at a frequency of 89 Mc./sec. over a 257-Km. path and the occurrence of isothermal or temperature inversion layers in the troposphere, the type of isobaric curvature, and the general weather situation is examined. It is shown that these layers may have a marked effect on the field strength at the receiving point; the curvature of the isobars has a smaller significance. Field strengths greatly exceeding the value to be expected under conditions of standard refraction may occur in any weather situation, but are more probable in some types than others.

Introduction.—Radio waves in the 1–10-m. wave-length band, i.e. in the frequency range 300–30 Mc./sec., are being used increasingly for broadcast, television and communication services. It is essential, therefore, that the propagation characteristics of radio waves in this wave-length band should be clearly understood so that the most efficient allocation of the available wave-lengths to the various services may be made. The propagation of the waves at the long wave-length end of the band is affected by the ionosphere, but when the wave-length is less than 5 or 6 m. refraction in the troposphere is the more important factor. This refraction, which varies with the weather conditions, may cause the field strength at a distance of 200–300 Km. from a transmitter to be similar to that normally expected at a distance of only 50–100 Km. under standard refraction conditions. These conditions may be defined as those under which the radius of curvature of a radio ray path, initially nearly horizontal, is four times that of the earth's surface. This corresponds to a linear gradient of refractive index with height of $-3 \cdot 9 \times 10^{-8}$ per metre, which is closely approached up to at least 1 Km. in a well mixed atmosphere.

Satisfactory reception of transmissions in the metre wave-length band under standard refraction conditions is not possible at points much beyond the horizon as seen from the transmitter. Meteorological situations may exist, however, which lead to either super-refraction or sub-refraction; of these the former occurs more often and has an important bearing on the planning of very high-frequency radio services.

The super-refraction may be intense enough to produce a duct in which "guided-wave" propagation[1] takes place; this type of propagation often occurs at the centimetre wave-lengths used in radar systems but is rare at metre wave-lengths. The difference is due to the magnitude of the track width of the first guided propagation mode in the two cases. This width is of the order of 25 m. and 200 m. for wave-lengths of 10 cm. and 3 m. respectively, but duct thicknesses of more than 100 m. are known to occur rarely in the region of the British Isles, the area dealt with here.

The effect of increased refraction near the ground on propagation at metre wave-lengths can usually be taken into account by slightly increasing the curvature of the ray paths; then the estimation of field strengths involves only diffraction round an earth with an effective radius suitably larger than the actual value. The effective earth-radius factor corresponding to standard refraction is $1 \cdot 33$; it may be as much as 3 for super-refraction conditions.

Elevated isothermal or temperature-inversion regions, however, often have a great influence on propagation at metre wave-lengths. Although still essentially super-refracting regions, they may be considered as partially reflecting layers for transmitting and receiving points well below them[2].

Mention should also be made of the scattering of radio waves caused by the variations of refractive index in turbulent eddies in the atmosphere. The extent of this phenomenon is not yet fully understood but there is reason to believe it may be the most important factor causing abnormally high field strengths at extreme ranges (several hundred kilometres), particularly at the high-frequency end of the metre wave-length band.

It has been known for some twenty years that the weather affects the propagation of metre wave-length radio waves; it is only recently, however, that sufficient systematic observations have been made in the British Isles for a general correlation between the propagation conditions and the features of the meteorological situation to be attempted. In this paper the correlation between the occurrence of isothermal and temperature-inversion regions and of field strengths exceeding those to be expected with standard refraction prevailing is investigated. The relative importance of ground-based and elevated regions is examined, together with the general influence on propagation of the isobaric curvature and the over-all weather type in the neighbourhood of the transmission path.

The period covered is only from July to December 1950, inclusive, but already some general trends are apparent; it is intended later to extend the analysis to cover a much longer period, and to examine the meteorological conditions and the propagation characteristics in finer detail.

Radio-propagation data.—It had been intended that the field-strength levels at the Radio Research Station, Slough, from the pulsed 89 Mc./sec. (3·4 m.) transmitter operated by the B.B.C. at Moorside Edge, over a non-optical distance of 257 Km. (160 miles), should be continuously recorded from 12.30 p.m. to 9.30 a.m. daily (except for Saturdays, Sundays and public holidays). An over-all examination of the recordings for the period July-December 1950, however, shows that, owing mainly to the high level of general interference, particularly during the daylight hours, a continuous record of the transmissions was not obtained. Therefore, it is not possible to derive a true statistical analysis of the field-strength variations. It is considered, however, that valuable information can be obtained by examining the meteorological conditions during the times when high field strengths were recorded.

Classification of the radio propagation data.—Because the nature of the recordings indicated that all field strengths of 3 microvolts per metre and greater are recorded, such signals have been classed as "high"; the field strength at Slough, corresponding to standard refraction[3] is of the order 1·2 μv./m.

For the analysis, each daily recording has been divided into the four observation periods, morning 0400–0930, day 1230–1700, evening 1700–2200 and night 2200–0400. If, during any part of one of these periods, the field-strength level was equal to or greater than 3 μv./m., whether continuously or in isolated rapidly fading bursts, the period has been classed as one of high field strength.

Meteorological data.—The meteorological data were obtained from the *Daily Weather Report* and *Daily Aerological Record* of the Meteorological Office. For each observation period as defined above when the transmissions took place, irrespective of whether the field strength was sufficient to be recorded or not, the following meteorological factors have been examined:—

(i) curvature of the isobars which covered the transmission path;

(ii) presence or absence of isothermal or temperature-inversion regions, with respect to pressure, shown by the radio-sonde ascents from Larkhill and Downham Market;

These regions have been classified according to whether their base was on the ground, above the ground but below 950 mb., or between 950 and 900, 900 and 800, 800 and 700 mb.; no account has been taken of any of these regions at pressure levels less than 700 mb., i.e. at heights greater than approximately 3 Km. (10,000 ft.). One of these regions is considered to have been present during an observation period if it was recorded at either Larkhill or Downham Market; no distinction is drawn between the case where a region was recorded at only one of the stations and the case where it was recorded at both of them. The location of the radio-sonde stations and of the transmission path is shown in Fig. 1.

(iii) The general weather type[4,5] as determined by the distribution of the centres of high and low pressure around the British Isles at 1200.

Normally the weather situation changes slowly from one type to another; so, to simplify the analysis, the type at 1200 has been taken to apply to the 24-hour interval starting at 0400. That is, in general, each weather type at 1200 applies to four observation periods; the change of weather type, if any, is assumed to have taken place between the 2200–0400 and the 0400–0930 periods.

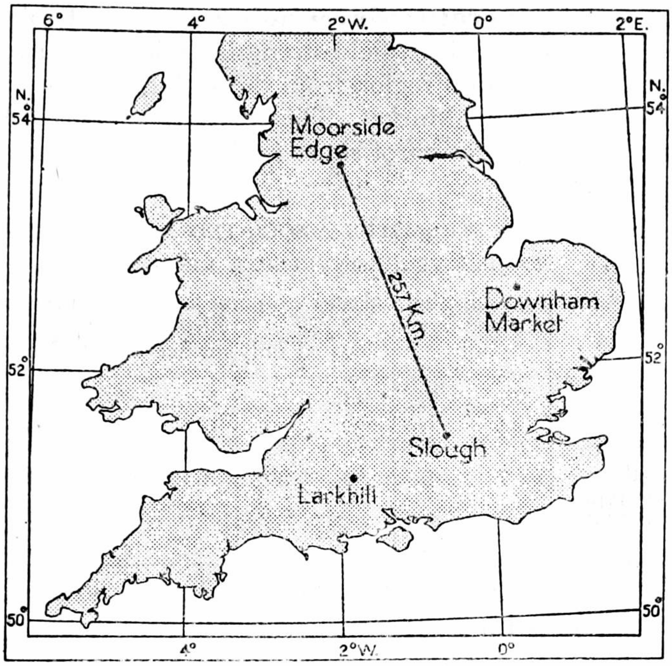


FIG. I—LOCATION OF DOWNHAM MARKET AND LARKHILL RADIO-SONDE STATIONS AND THE TRANSMISSION PATH

The weather situations have been divided amongst the eight types—anticyclonic, cyclonic, westerly, north-westerly, northerly, easterly, southerly, and col, with an additional type, indefinite, for the few synoptic situations which do not readily fall into any of the eight main types. These are often a combination of two of the main types.

Discussion of results.—*Isobaric curvature.*—It is seen from Table I that the curvature was cyclonic for about half of the observation periods and anticyclonic for about one quarter. Hence, although the chance of a high-field-strength period occurring with anticyclonic curvature seems to be twice that of it occurring with cyclonic curvature, the total number of high-field-strength periods during these seven months was about the same for each type of curvature.

TABLE I—HIGH FIELD STRENGTH ASSOCIATED WITH ISOBARIC CURVATURE

	Types of curvature								
	Anticyclonic		Cyclonic		Col		Indeterminate		Total
	No.	%	No.	%	No.	%	No.	%	No.
Number of periods ...	132	28	238	51	17	4	80	17	467
Number associated with high field strength ...	59	41	51	35	11	8	23	16	144
Percentage of given type with high field strength		45		21		65		29	...

The relatively high percentage for the occurrence of high-field-strength periods in a col situation should be noted; although it must be remembered that there were relatively few examples of this situation. It might be expected that the percentage occurrence of high-field-strength periods would lie between the cyclonic and anticyclonic values, but it is considerably higher than either. The indefinite group is made up mostly of the occasions when the isobars were practically straight.

Isothermal and temperature-inversion regions.—Table II shows that less than 1 per cent. of the high-field-strength periods occurred when there was no isothermal or inversion region from the surface to 700 mb. recorded at either Larkhill or Downham Market. This is in agreement with the accepted fact that anomalous propagation of short radio waves does not take place in a well mixed atmosphere.

TABLE II—HIGH FIELD STRENGTHS ASSOCIATED WITH ISOTHERMAL AND TEMPERATURE-INVERSION REGIONS

	Isothermal and temperature-inversion regions								
	Surface-based only		Elevated only		Elevated and surface-based		No regions		Total
	No.	%	No.	%	No.	%	No.	%	No.
Number of periods ...	44	9	232	50	123	26	68	15	467
Number associated with high field strength ...	7	5	81	56	55	38	1	0·7	144
Percentage of given type of region with high field strength ...		16		35		45		1·5	...

The fact that 56 per cent. of the high-field-strength periods can be associated with elevated regions with no simultaneous surface-based region, indicates that, at the frequency in question and over this transmission path during this time, elevated regions were of much greater importance than those based on the surface of the ground.

About 40 per cent. of the total number of elevated regions were associated with high-field-strength periods. In this connexion it is of interest to note that an analysis of the refractive-index changes through elevated layers, using Larkhill and Downham Market radio-sonde data, shows that 35–45 per cent. of these layers have a refractive-index gradient greater than that corresponding to standard refraction.

TABLE III—HIGH FIELD STRENGTH ASSOCIATED WITH BASE HEIGHTS OF ISOTHERMAL AND TEMPERATURE INVERSION REGIONS

	Base height of isothermal or temperature inversion				
	on surface	above 950 mb.	950–900 mb.	900–800 mb.	800–700 mb.
Number of periods with base of region at given height	163	50	84	219	208
Number associated with high field strength	62	27	45	93	78
Percentage at given height with high field strength...	38	54	54	42	37

The percentage number of high-field-strength periods that occurred at the same time as a temperature inversion or isothermal region with its base within a particular height interval is shown in Table III. Although the regions occur most frequently in the pressure interval 900–800 mb. (950–1,950 m., 3,100–6,400 ft.), those most likely to coincide in time with high-field-strength periods occur at a lower altitude, 950–900 mb. (490–950 m., 1,600–3,100 ft.), This may be due in part to the greater angle of incidence upon the lower layers resulting in a relatively greater reflection coefficient.[2]

General weather types.—The number of observation periods with each type of weather, and the percentage number of each type associated with high-field-strength periods are shown in Table IV.

TABLE IV—HIGH FIELD STRENGTH ASSOCIATED WITH DIFFERENT WEATHER TYPES

	AC.	C.	W.	NW.	N.	E.	S.	Col	Indef.	Total
Number of periods with given weather type	27	64	212	40	23	21	49	15	16	467
Number associated with high field strengths	21	6	57	6	0	14	24	8	8	144
Percentage of given type with high field strengths ...	78	9	27	15	0	67	49	53	50	31

AC. = anticyclonic C. = cyclonic

The great preponderance of a westerly type of weather is in agreement with the average for the British Isles over a number of years[4,5]. Anticyclonic weather is the most likely to produce high field strength, followed by easterly, col and southerly types in that order. Cyclonic and north-westerly types are relatively unlikely to produce high-field-strength periods, while none at all were recorded in the few examples of the northerly type. The indefinite group consists mainly of weather situations which were a combination of southerly with either easterly or westerly types; it falls, in this case, into the group with the larger percentages of high-field-strength periods. Westerly types lie between the two groups but it should be noted that, because of more frequent occurrence, they do in fact produce by far the greatest number of high-field-strength periods. These results are consistent with what would be expected from a simple consideration of the characteristics of the various weather types. A further interesting fact has emerged during the analysis, namely that on several occasions high field strengths coincide with the presence of the warm sector of a depression over the transmission path.

Conclusions.—High field strengths appear to be about twice as probable with anticyclonic curvature as with cyclonic curvature. The latter is, however, about twice as frequent as the former, so that the number of occasions of high field strengths over a long time are likely to be equally divided between the two types.

Isothermal and temperature-inversion regions, and in particular elevated ones, have a marked influence on the field-strength level either directly or because of some atmospheric conditions which are more likely to arise in their presence.

The weather-type analysis shows that there is no general synoptic situation which entirely precludes the possibility of high field strengths. This is in spite of the fact that, so far, no cases have been found in the northerly type, for there are so few examples of this type included in the present investigation that it would be unwise, at this stage, to make it an exception to the general conclusion.

It thus appears that there is no simple classification of the weather situation which by itself would give a reliable indication of the possibility or impossibility of the non-standard propagation of metre wave-length radio waves. On the other hand, it may be that a further examination will eventually reveal some factors common to all which are responsible for such propagation.

Acknowledgements.—The work described above was carried out as part of the programme of the Radio Research Board. This paper is published by permission of the Director of the National Physical Laboratory and the Director of Radio Research of the Department of Scientific and Industrial Research.

The author wishes to acknowledge the advice given by Dr. J. A. Saxton on the presentation of the paper.

REFERENCES

1. BOOKER, H. G. and WALKINSHAW, W.; The mode theory of tropospheric refraction and its relation to wave-guides and diffraction. "Meteorological factors in radio-wave propagation". London, 1946, p. 80.
2. SAXTON, J. A.; The propagation of metre radio waves beyond the normal horizon. Part I: Some theoretical considerations, with particular reference to propagation over land. *Proc. Instn elect. Engrs, Pt. III, London,* **98,** 1951. p. 360.
3. SAXTON, J. A., LUSCOMBE, G. W. and BAZZARD, G. H.; The propagation of metre radio waves beyond the normal horizon. Part 2: Experimental investigations at frequencies of 90 and 45 Mc/s. *Proc. Instn elect. Engrs, Pt. III, London,* **98,** 1951, p. 370.
4. BILHAM, E. G.; The climate of the British Isles. London, 1938.
5. LAMB, H. H.; Types and spells of weather around the year in the British Isles: Annual trends, seasonal structure of the year, singularities. *Quart. J. R. met. Soc., London,* **76,** 1950, p. 393.

TEMPERATURE AND WIND DISTRIBUTION IN THE LOWER STRATOSPHERE

By M. K. MILES, M.Sc.

Introduction.—For the purpose of this study, which is based on charts drawn at the Central Forecasting Office of the Meteorological Office, the layer between 200 and 100 mb. (say 40,000–55,000 ft.) has been taken as typical of the lower stratosphere. The thickness patterns for this layer have provided the data for studying the temperature configurations.

Radio-sonde errors at these levels are commonly large enough to make the thickness pattern uncertain on any one occasion, but by considering a sequence of charts and the wind shear in the layer (200–100 mb.) the large-scale pattern can nearly always be established with reasonable certainty.

The contour pattern is more difficult to ascertain when winds are light, so that study has been mainly concentrated on temperature distribution and certain aspects of wind behaviour.

Temperature distribution.—The broad feature in summer is a fall of temperature equatorward, but in winter there is often a more complex distribution. Where arctic air has moved far south accompanied by a cold stratosphere a belt of maximum stratosphere temperature is found in middle latitudes. Again there may be a roughly meridional distribution as during the last three weeks of February 1952, when maximum stratosphere temperature was in a belt from Newfoundland to east Greenland with temperature falling south-eastwards to a general minimum in the neighbourhood of the British Isles. These large-scale effects have been noted on several occasions to be quite persistent.

Embedded in this almost hemispherical temperature pattern there are smaller patterns associated with tropospheric systems. Warm ridges in the troposphere have cold tongues above them and cold troughs, warm tongues. These thermal tongues travel with their associated tropospheric features and decay and intensify generally in phase with them. It should be noted that the stratospheric cold tongues normally have their roots to the south so that the wind shear in the lower stratosphere ahead of a thermal ridge is usually south-easterly backing to north-easterly behind the ridge. It is occasionally possible to establish that the stratospheric wind change occurs before the tropospheric ridge axis passes. Similar evidence with cold troughs indicates a small forward displacement of the stratospheric tongue relative to the associated tropospheric thermal system. These cold troughs normally lag behind the surface pressure systems by a greater amount than this, so it appears that the thermal features of the stratosphere may occupy an intermediate position.

Warm and cold pools are fairly common in the stratosphere. Broadly speaking they occur above tropospheric cold and warm pools respectively, though many thermal troughs and ridges in the troposphere are accompanied by them. Cold pools occur on the north side of warm anticyclones and at the north-east tip of some warm sectors. In the latter situation they disappear quickly with the occlusion of the warm sector, but with warm anticyclones they can be followed for several days. They move considerably more slowly than the air near their centre at 100 mb. Warm pools often persist for several days sometimes centred directly above the cold pool or cold trough of the low, and sometimes, though less often, above the surface low-pressure centre. The majority examined have no cyclonic circulation round them at 100 mb., and occasionally there is a nearly straight flow across them. Seven cases of this kind were examined in detail, and the ratio of their speed to the mean wind near the centre at 100 mb. was found to average nearly a half, with extreme values of 0·35 and 0·70. This implies that the air in the stratosphere descends as it flows into the pool and ascends on leaving it. Rough estimates of the rate of vertical motion yield values about 5 cm./sec. The direction of movement is nearly that of the wind at 100 mb. with deviations on either side up to about 20°. A fairly common characteristic of these pools is their rapid decay when fresh cyclonic development is occurring to westwards with formation of a new warm pool over the new low. This sequence of events can be observed along the belt of maximum stratospheric temperature mentioned earlier, and suggests that the high stratospheric temperature is to some extent dynamically maintained.

The thermal features of the stratosphere mostly respond immediately to tropospheric changes. When a cold air mass warms by subsidence the associated warm pool or tongue weakens and perhaps disappears, and when a warm anticyclone collapses the associated cold pool disappears. The large meridional features mentioned earlier are probably an exception to this state of affairs. They can be thought of as exercising a control to the extent that big tropospheric changes do not occur. In February 1952 a large warm anticyclone was centred throughout on the south-east side of the stratospheric temperature maximum with a more or less stationary cold pool on its eastern side. The persistence of the thermal gradient in the stratosphere with the prevailing northerly winds at 100 mb. required a steady ascent of air on its track at an estimated rate of 10 cm./sec. That a persistent high-pressure system drifted slowly towards the southern end of the track suggests that in this case at any rate the stratosphere may have controlled the broad tropospheric events.

There is an interesting association of tropopause structure with these stratospheric patterns. The tropopause is clearly defined, generally with an inversion at the base of the stratosphere, in warm and cold pools. The inversion is normally most marked with the latter, and in this situation occur some of the lowest tropopause temperatures of middle latitudes. The arctic stratosphere is at varying heights and the tropopause is not so well defined. There is normally a region of reduced lapse rate below the tropopause or a region of temperature lapse in the stratosphere depending on the application of the criteria for choosing the tropopause. Away from the well marked stratospheric temperature patterns the tropopause is of intermediate height and often poorly defined.

Wind distribution.—Perhaps the most striking feature of the winds at 100 mb. is their steadiness and constancy over quite large areas. Broad streams of fairly constant velocity persist for days and even weeks, e.g. in December 1951 and February 1952 over the east Atlantic and British Isles. During this time the wind near the tropopause may undergo large changes of direction and speed which are compensated by equivalent changes of the wind shear in the lower stratosphere. This compensation is so complete that, for periods when the wind at 100 mb. does not exceed 30–35 kt., graphs of the wind at 200 mb. against the magnitude of the wind shear 200–100 mb. reveal approximately linear proportionality. At Larkhill for February, August and September 1951, and at ocean weather station JIG for September 1951 the observations can be readily represented by the following regression equations:—

$$V_{200-100} = 0{\cdot}9\ V_{200} - 16 \text{ kt. for } V_{100} \geqslant 20 \text{ kt.}$$
$$V_{200-100} = 0{\cdot}9\ V_{200} - 5 \text{ kt. for } V_{100} < 20 \text{ kt.}$$

where V_{200} and V_{100} are the wind strengths at 200 and 100 mb. in knots and $V_{200-100}$ is the magnitude of the wind shear vector from 200 to 100 mb. Either of these relations, depending on the wind regime at 100 mb., fits the wind observations for periods of perhaps ten consecutive days and provides a useful estimate of the wind at 100 mb. from soundings which cease at 200 mb. When the winds at 100 mb. are over 30–35 kt. or when they have a considerable component across the thermal gradient in the lower stratosphere, i.e. mainly in the winter months, such relationships will not hold. During the months mentioned above the wind shear was generally about opposite in direction to the wind at 200 mb. In over 75 per cent. of cases the angular deviation from a true reciprocal was 20° or less. These small deviations, while not affecting the validity of the two relationships above, are however significant; they represent the veering or backing of the wind in the stratosphere, and further study of the data shows that the mean direction of the wind at 200 mb. for all cases of stratospheric wind veer differs significantly from that for the cases of backing.

	Mean direction of wind at 200 mb. for all cases of	
	Veering	Backing
Larkhill, August 1951	220°	276°
Larkhill, September 1951	221°	296°
Station JIG, September 1951... ...	234°	282°

These figures illustrate the decrease in amplitude of flow perturbations above the tropopause. It is of interest to note that, assuming the direction of the shear vector to be parallel to the 200–100-mb. thickness lines, this implies that the thermal patterns in the lower stratosphere mostly have a greater amplitude than the contour patterns near the tropopause.

Winds in the lower stratosphere are generally strongest in December and January, though even at this time winds of less than 20 kt. are not uncommon for quite long periods, e.g. the wind at 100 mb. at Larkhill did not exceed 25 kt. during December 10–22, 1951, and similarly light winds were being reported from other stations in the British Isles and Europe. Winds are generally light above anticyclones and slow-moving cold lows in the upper troposphere. Strong belts of flow appear to exist on the south-west side of such systems.

In the neighbourhood of travelling stratospheric warm pools in winter broad streams of 40–60 kt. occur often, with very little horizontal shear from the south of England to the Shetland Islands. This arises from the presence of the cold arctic stratosphere in the north causing a broadly westerly shear in the stratosphere to the north of the warm pools. This, together with the easterly shear to the south, removes the strong cyclonic shear at the tropopause, which is a characteristic feature of this situation.

The flow patterns change slowly, and it is often impossible to ascribe a general change in wind direction, say over the British Isles, to the bodily movement of a contour ridge or trough. In such cases it appears rather that a general change in the flow configuration over a large area has set in. As mentioned earlier, such changes take place at intervals of ten to twenty days. The stratospheric northerlies over the British Isles and north-west Europe in February 1952 were accompanied by light winds over the Atlantic, while for much of January and the first part of February 1951 there were light winds over the British Isles and north-west Europe with moderate westerlies over the west and central Atlantic. It would appear then that any month may show a large departure from a monthly or seasonal mean.

These slow changes and the broad air streams of constant direction make it highly probable that the flow at 100 mb. is nearly geostrophic. The rapid changes in thermal gradient which effect the compensation during large wind changes at the tropopause appear to be in response to dynamical causes. Thus, as a jet stream develops near the tropopause, stratospheric descent would appear to occur above the low-pressure side and perhaps ascent on the high-pressure side to produce the compensatory wind shear above the tropopause. Likewise steady ascent of the stratospheric northerly was necessary during February 1952 to maintain the thermal gradient from Greenland to France. The temperature decrease on the track of about 15–20°F. in 24 hr. is too large to be produced by radiation processes. This association of vertical motion with large-scale quasi-permanent wind configurations, and the steadiness of stratospheric winds above jet streams, provide two examples of one of the most interesting phenomena of the lower stratosphere.

ROYAL METEOROLOGICAL SOCIETY

World-wide oscillations in the earth's atmosphere

The Symons Memorial Lecture for 1952 was delivered to the Royal Meteorological Society, on Wednesday, March 19, by Dr. M. V. Wilkes, Director of the University Mathematical Laboratory, Cambridge, on the subject of "World-wide oscillations in the earth's atmosphere". The President, Sir Charles Normand was in the Chair.

Dr. Wilkes began by pointing out that the principal oscillations in the atmosphere are semi-diurnal, not diurnal as might be expected. The oscillations are small in temperate zones but have an amplitude of about 1 mb. at ground level at the equator. Chapman has demonstrated the uniformity of the oscillations and their independence of local characteristics over North America. Schmidt and Simpson showed that there are two components, the principal one being a travelling sine wave in advance of the sun, and the other, a much smaller standing wave centred over the poles. The first attempt to work out a tidal theory for the atmosphere was due to Laplace who assumed isothermal variations and a temperature distribution independent of height. Attempts however to detect a lunar tidal oscillation from the data then available were not successful, and it was left to Lefroy in 1874 to be the first to discover lunar tidal oscillations from 17 months' observations at St. Helena.

In 1918 Chapman tackled the problem anew, and succeeded in demonstrating the existence of a semi-diurnal lunar tide at Greenwich of amplitude 0·01 mm. of mercury and with maxima almost in phase with the moon's upper and lower transits. Chapman also checked the temperature variations associated with the lunar semi-diurnal pressure change for Batavia, and found that the results deduced from the temperature observations agreed with those calculated from the pressure variations although the pressure variation was only 0·06 mm. and the temperature variation 0·005–0·01 °C. The fact that the solar tidal oscillations are greater than the lunar suggests that the thermal effect is predominant but the solar tide is semi-diurnal whereas the thermal variation is diurnal. To overcome this difficulty Lord Kelvin suggested that the atmosphere must possess a natural period of 12 hr.—the resonance theory. This explanation, however, would also render a thermal driving force unnecessary, and no answer has yet been given as to whether the thermal or the gravitational effect is the greater. The stratospheric low-temperature barrier would give rise to oscillations in the atmosphere, and H. Lamb showed that for resonance to occur the periodicity must be within a few minutes of 12 hr. G. I. Taylor derived this periodicity from calculations based on the spread of the pressure waves from the Krakatoa explosion of 1883 and the great Siberian meteor of 1908 and found it to be only 11 hr.—too small to give rise to resonance. Pekeris, however, showed that the existence of a temperature minimum at 50 Km., acting as a second barrier, would give an oscillation, with a node, having a period of 12 hr. provided that the temperature distribution at the top were appropriately chosen. The presence of such a temperature minimum has been confirmed from rocket ascents and anomalous sound propagation. Appleton and Weekes however, who discovered lunar tidal oscillations in the E-region of the ionosphere of amplitude about 1 Km., found these oscillations to be in phase with those at the ground instead of in anti-phase as would be required by the nodal type of oscillation. However, Martyn has demonstrated that it is easy to explain this apparent discrepancy, e.g. by taking into account second-order terms neglected at lower levels, or by assuming a hot E-region with a temperature drop above, which would produce yet a third barrier and two nodes thus bringing the lunar tidal oscillations in the E-region into phase with those at the ground. Appleton and Weekes also found that the ratio of the amplitudes of the solar and lunar tidal oscillations in the ionosphere is less than at the ground, which is confirmed, according to the "dynamo" theory, by the solar and lunar quiet-day magnetic variations. Further support for the second barrier theory is provided by the fact that the phases of the magnetic variations due to the lunar and solar tides in the E-region are out of phase with the oscillations at the ground. Martyn has also detected tidal motions in the F-region of the ionosphere, but it is uncertain whether the oscillations are initiated from the E-region or introduced directly by thermal or gravitational action. There is no evidence of lunar semi-diurnal winds in the F-region and viscous damping is considerable.

[To face p. 216

Reproduced by courtesy of Capt. H. F. Jackson

EVENING SKY AT VALENTIA, SOUTH-WEST IRELAND, SEPTEMBER 14, 1936

The clouds visible are cirrus, stratocumulus vesperalis and, in the distance, banks of cumulus over the Atlantic Ocean.

Reproduced by courtesy of the Public Information Division, United States Coast Guard

UNITED STATES COAST GUARD CUTTER *YAKUTAT*

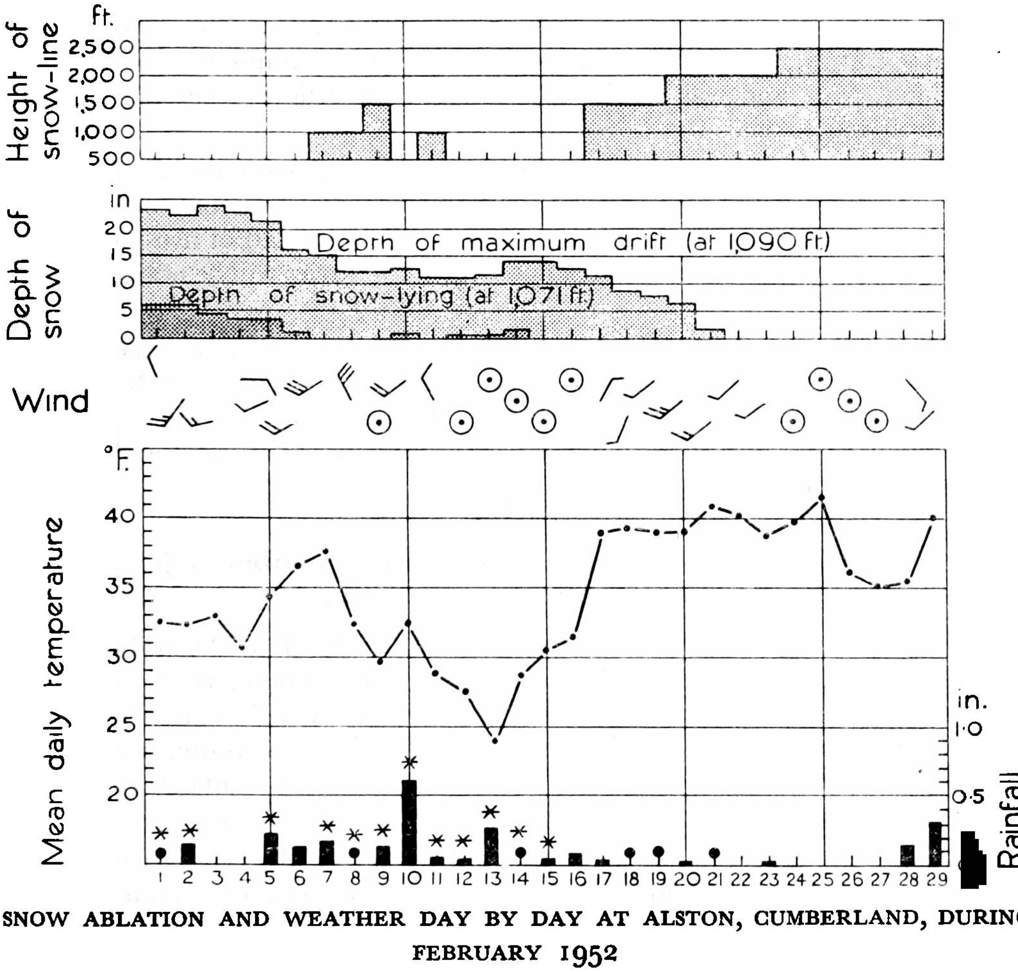
The *Yakutat*, on ocean weather station CHARLIE, being relieved by the cutter *Coos Bay*; the mail can be seen being passed from the *Coos Bay* to the *Yakutat* (see p. 218).

LETTER TO THE EDITOR

Ablation of snow deposits at Alston, Cumberland

Students of snow ablation may be interested in the following diagram showing the ablation which occurred in February 1952 at Alston. January 1952 produced a heavy accumulation of snow to which little new snow was added in February. The interest of the data for February lies in the ablation of the snow deposit laid down in January.

The three factors involved in the ablation are temperature, rainfall, and wind direction and force. Some indication of the relative value of each can be seen from the diagram. High mean temperature clearly shows a correlation with the retreat of the snow-line on the 7th and the 17th, and with the depth of the snow-drift near the observatory at Alston. From 1100 G.M.T. on the 10th heavy rain fell, but its effect on ablation was comparatively slight. This no doubt is again a reflection of mean temperature which was fairly low.



SNOW ABLATION AND WEATHER DAY BY DAY AT ALSTON, CUMBERLAND, DURING FEBRUARY 1952

The continued melting after the 7th can only be explained by the strength of the wind (SE., force 6). This was neither warm nor wet. Again the 21st showed a sudden depletion in the snow-drift at Alston after three consecutive days of moderate temperature. This seems to be the result of the strong wind (SW., force 5) of the 20th. The greater efficiency of even slight warmth caused by strong winds seems to be an important factor which needs consideration. Naturally the effect is greatest if the wind is from SW. but irrespective of direction a strong wind seems a most effective agent in the ablation process.

Since little exists in the way of data of wind force on mountain sides could not this factor easily confuse inferences made about the effects of related phenomena, such as temperature and rainfall, which are more regularly measured?

W. E. RICHARDSON

South Tyne House, The Brewery, Alston, Cumberland, March 17, 1952

NOTES AND NEWS

Ocean weather ships of the United Stated Coast Guard

The photograph facing p. 217, for which we are indebted to the Public Information Division, United States Coast Guard, shows the United States Coast Guard cutter *Yakutat* on duty at North Atlantic ocean weather station CHARLIE (52°45'N., 35°30'W.). The ship had been at sea a month from her base at Portland, Me., and was receiving mail from the relieving cutter when the photograph was taken.

Yakutat has a displacement of 2,592 tons compared with the 1,400 tons of British ocean weather ships. She carries a Coast-Guard crew of 8 or 9 officers and 117–120 men and a United States Weather Bureau staff of five meteorologists. The balloon-filling shed and balloon-release gantries will be noticed on the boat deck.

Mr. R. K. Pilsbury writes that the ship T.S.S. *Bayano* on which he was returning from Jamaica passed near *Yakutat*, then on duty at station DOG (44°N., 41°W.) on the evening of July 25, 1951. He was able to send the message, "The Meteorological Officer, Jamaica, sends his compliments to the Weather Officer," and receive greetings in return.

Meteorological observations on a flight by a Canberra jet aircraft from England to Australia

Before the flight of a Canberra aircraft from England to Australia at the beginning of August 1951 discussions were held with the pilot, Wg Cmdr D. R. Cuming, Royal Australian Air Force, who was provided with information regarding meteorological conditions to be expected over the route, particularly equivalent headwinds and temperature at various levels, heights of tropopause and weather conditions likely to affect the flight.

Wg Cmdr Cuming offered to make meteorological observations whenever possible during the flight, and it was suggested that observations of temperature and wind at flying height, cloud type and height of cloud tops, visibility, icing and turbulence would prove very useful.

The route followed was Lyneham—El Adem (Libya)—Habbaniya (Iraq)—Mauripur (Karachi)—Negombo (Ceylon)—Changi (Singapore)—Darwin—Melbourne. The following useful observations were included in the reports given by the pilot and navigator to meteorological officers at stopping places on the route:—

(*a*) information regarding up-currents experienced at a height of 39,000 ft. east of Sardinia, which may have been associated with a jet stream with its axis considerably above 40,000 ft.

(*b*) reports of cloud tops much above the expected heights; cirrus cloud at and above 45,000 ft.; cumulonimbus cloud building up to 45,000 ft. in many places on the west side of the mountains of Sumatra with anvil cirrus above blowing westwards for about one hundred miles before dispersing

(*c*) reports of frequent moderate to heavy turbulence experienced in clear air above cirrus cloud over the sea around 20°N. on the flight from Mauripur to Negombo, the turbulence being in the nature of very frequent hard bumps for a period of 15 min.; intermittent moderate turbulence in clear air over cumulonimbus cloud between 12° and 10°N. in the nature of an occasional drop in a generally rising current or an occasional rise in a generally descending current; moderate turbulence from Ceylon to Sabang at about 45,000 ft. when flying in the same plane as 2 oktas banded cirrocumulus, for periods of 3–4 min. at 10-min. intervals, the effect on the aircraft suggesting turbulence rolls continuous with cirrocumulus rolls seen off track with their axes at right angles to the track.

A most interesting and instructive letter was received in December 1951 from Wg Cmdr Cuming who has agreed to the reproduction of the following extracts:—

"Cloud forecasts were the weakest section of the forecasts, not from the point of locality but in the estimation of the cloud tops. This was most noticeable as far as cumulus and cumulonimbus were concerned. Across India and as far as Canberra in Australia the estimates of the cumulonimbus tops were generally about 10,000–15,000 ft. too low. Where reports gave the tops at 25,000 ft. they were generally about 35,000–40,000 ft. Over those portions of the trip we were flying at 45,000 ft. and these clouds were well above us. On the direct route between Ceylon and Singapore, when we went through, it would have been impossible to have completed the trip without going through the cumulonimbus over Sumatra. There was a solid area of cumulonimbus right down the west coast of the island and there did not appear to be any breaks in the cloud below 50,000 ft. Fortunately our route was via Sabang and so we passed round the northern tip of this cloud mass.

"The forecast heights of cirrus were not bad, but again the estimated height was invariably too low. The highest cirrus we saw was between Ceylon and Singapore and this was above 45,000 ft.

"Visibility under cloudless conditions varied considerably. Oblique visibility seems to depend on the time of the day, direction of view relative to the position of the sun, haze and, from the point of view of picking up detail, the type of country flown over. Assuming that the atmosphere is clear it was found that for about an hour after sunrise and before sunset it was only possible to pick up such detail as coastlines, large rivers and mountain ranges. This was from 45,000 ft. Of course lakes were also prominent. It was quite hopeless to look for towns especially when the surrounding country was timbered. In other words, it is necessary to have a large degree of contrast in order to pick up detail. As the sun rises higher the situation improves somewhat but even under good conditions with the sun overhead it is still difficult to pick out average sized towns. Dirt roads are far easier to pick up than bitumen roads or railway lines.

"Visibility distance obviously depends on the haze and detail wanted. Coastlines and large mountains are the easiest things to see and, from 45,000 ft., we were able to see up to about 200 miles on the route from Singapore to Darwin. In fact we could see Timor at the same time as we could see the coast at Darwin, and on trips to Melbourne it is often possible to see Port Philip Bay from 170 miles. Looking up sun, if the sun is low on the horizon, it is generally hopeless and the visibility is reduced to about 40 miles. In this case the amount of haze is the predominant factor, and in the Canberra at times it reduces the visibility up sun to zero.

"On the trip from England to Australia we experienced turbulence at high altitude on every leg. However, no severe turbulence was experienced. It was invariably associated with cirrus, especially cirrus with mares' tails and cirrus that lay in lines across the sky. Flying at the same level and across these lines was reasonably bumpy. Turbulence was always noticed on the climb when passing through inversions and when passing through the tropopause. There was more turbulence, generally speaking, when going through the tropopause than through inversions. During our flying in Australia we found a considerable amount of high-altitude turbulence when flying between Brisbane and Melbourne. This is the worst route. We flew across several jet streams in this area, and on one occasion the turbulence was so severe that the navigator could not work or read some of his instruments accurately. This occurred when entering a jet stream from the polar side. The first warning that we got under these conditions was a falling off of airspeed and a few small bumps. Going in the opposite direction we noticed an increase in airspeed. Obviously the changes in airspeed must be due to fairly rapid changes in the wind speed.

"In Australia we find it useful for the tropopause to be plotted along our route because at some part of our route we invariably have to fly through it. As an example of what I mean, the tropopause at Amberley (Queensland) may be 47,000 ft. and the tropopause at Melbourne may be only 35,000 ft. Our cruising height may be 42,000 ft. and thus we get a certain amount of turbulence at the stage of the route where the tropopause falls to 42,000 ft."

R. P. BATTY

Bibliography for the second International Polar Year, 1932–33

The second International Polar Year was organized by a special commission of the International Meteorological Organization under the presidency of Dr. D. la Cour, Director of the Danish Meteorological Institute. After the end of the Year itself the labours of the Commission changed from the organization of the observing expeditions and their equipment to ensuring that the observations and registrations were made available for the benefit of science. The Commission was supported in this work by funds provided by the International Meteorological Organization, the International Association for Meteorology of the International Geodetic and Geophysical Union, and the Rockefeller Foundation.

The work of the Commission was seriously delayed by the war and by Dr. D. la Cour's death in 1942 and was not completed when the pre-war commissions were formally dissolved at the International Meteorological Organization meetings held in 1946. To complete the work the International Meteorological Organization then set up the Temporary Commission for the Liquidation of the Polar Year 1932–33. Dr. J. A. Fleming, United States, became the President of this Commission; Dr. J. M. Stagg, who had been in charge of the British Polar Year station in northern Canada, represented Great Britain; and Dr. V. Laursen of the Danish Meteorological Institute was placed in charge of the Central Bureau of the Commission situated at that Institute as Executive Secretary of the Commission.

The Temporary Commission arranged for completion of the central archives of the Polar Year at the Danish Meteorological Institute, for the completion of the publication of the weather maps of the northen hemisphere for the Polar Year* drawn by the Deutsche Seewarte, and finally for the publication of the Bibliography of the Polar Year.

The Bibliography is in three parts. Part I is a history of the organization of the second Polar Year. Part II is a bibliography arranged by countries but opening with a bibliography of the relevant publications of the International Meteorological Organization. The entry under each country begins with a statement of that country's Polar Year expeditions and continues with a list of books and articles relating to the Polar Year published in that country arranged under subjects. Part III is a subject bibliography for the whole world. The arrangement under each subject in both Parts II and III is by author's name. The title page is appropriately preceded by a page bearing only the photograph of Dr. D. la Cour.

The entries in the Bibliography were compiled, first from the collection of documents formed by Dr. D. la Cour and secondly from returns sent to Dr. Laursen by national meteorological services, institutes, observatories and individuals to whom he applied for information.

It is advisable to consult the introductions to each part before searching in the main entries, as some classes of document are given in Part II only.

The Bibliography is very clearly printed in large type. It will constitute an indispensable work of reference for all students of the wealth of observations made during the second Polar Year.

Lunar halo complex, Guernsey, April 14, 1952

Mr. S. G. Tew, a meteorological observer at the Airport, Guernsey, reports a rarely observed lunar halo complex as seen between 0250 and 0315 G.M.T. April 14, 1952. The complex varied from time to time but in all Mr. Tew observed:—

(i) the upper half of the 22° halo
(ii) the two paraselenae of the 22° halo
(iii) the paraselenic circle through the moon to beyond the paraselenae
(iv) short light pillars above and below the moon.

The paraselenae were perfectly clear and only slightly less bright than the moon itself.

The phase of the moon was three days past full.

*London, Meteorological Office. I.M.O. Northern-hemisphere Polar-Year charts. *Met. Mag., London*, **80**, 1951, p. 139.

Kodaikanal Observatory Jubilee

The first fifty years of scientific work at the Kodaikanal Observatory, south India, were celebrated at the observatory on September 18, 1951, when the Governor of Madras, in the presence of the Deputy Minister of Communications and the Director General of Observatories, formally inaugurated a new ionospheric observatory and a new 20-in. telescope for stellar spectroscopy.

BOOKS RECEIVED

Annual Reports for 1940, 1941, 1942. Christchurch Magnetic Observatory. $9\frac{1}{2}$ in. × 6 in., pp. xvi + 152, New Zealand Department of Scientific and Industrial Research, Wellington, *s.a.*

Annual Reports for 1943, 1944, 1945. Christchurch Magnetic Observatory. $9\frac{1}{2}$ in. × 6 in., pp. xviii + 150, New Zealand Department of Scientific and Industrial Research, Wellington, *s.a.*

The night sky 1952. 10 in. × 7 in., pp. 26, *The Times* Publishing Company Limited, London, 1951. Price: 2*s.* 6*d.*

METEOROLOGICAL OFFICE NEWS

Ocean weather ships.—*Weather Explorer* reported that on March 2, 1952, "the wind increased rapidly from force 4 to force 11 after the passage of a cold front and continued at or near force 11 for almost three days". For most of the time the vessel was forced to run before the wind, the sea being so high that it was not found practicable to heave her to. Radio-sondes had to be abandoned in these circumstances, the balloon shelter being in the after part of the ship. The meteorological office was partially flooded more than once.

When the wind did ease down sufficiently for the vessel to turn into the wind it was found that she was 168 miles from the centre of her station "grid". The station grid is an area 200 nautical miles square, in the centre of which is the station and an ocean weather ship is classified as being "on station" provided she is within the grid; so on this occasion *Weather Explorer* was literally "blown out of her grid".

WEATHER OF MAY 1952

Mean pressure during May was above normal in a large area extending from Greenland, with 1023 mb. which was 8 mb. above normal, to Scandinavia and western Europe, with values generally around 1017 mb. which were 2 mb. above normal. Mean pressure was below normal over the North Atlantic, between 35°N. and 50°N., the deficit at the Azores with 1017 mb. reaching 5 mb.

Mean temperature was generally 3–4°F. above normal in western Europe and about 2°F. below normal in eastern Europe; in the Mediterranean region mean temperature was about normal. The values of mean temperature varied from 40–50°F. in Scandinavia, 50–60°F. in Europe to 60–70°F. in the Mediterranean.

In the British Isles the weather was very warm for the time of year; at Kew Observatory it was the warmest May since records began in 1871, at Greenwich the warmest since 1848 and at Oxford since 1868. Broadly speaking the month was dry in Northern Ireland and over most of Scotland and northern England but very wet in parts of south-west England, south Wales and the south Midlands. Local thunderstorms occurred frequently during the first three weeks.

In the opening days a depression westward of Ireland moved south-east to the north-west of Spain, while associated troughs of low pressure affected southern districts of the British Isles causing rain, heavy in places in the south-west, and local thunderstorms. At Westbury in Wiltshire 2·01 in. was measured and at Bath 1·57 in. on the 1st. On the 3rd and 4th the depression moved north-east and became less deep; further rain and scattered thunderstorms occurred in southern districts and some rain fell also in the north (1·25 in. at Coventry on the 4th). On the 5th a depression over the North Sea moved north and turned west northward of Scotland, subsequently moving southward to a position south-west of Ireland. This system, with its associated troughs or secondary depressions, dominated conditions over the British Isles until the 13th, with rain or showers and local thunderstorms but long sunny periods. Rainfall was heavy locally at times, for example 2·21 in. at Borrowdale, Cumberland, on the 8th and 1·38 in. at Tenby on the 10th. On the 13th and 14th an anticyclone situated over Spain and south-west France moved north; meanwhile a trough to an Atlantic depression moved north-east across the British Isles causing appreciable rain at some places in the north of Scotland. The anticyclone continued to move north and fair, very warm weather prevailed, apart from scattered thunderstorms, until the 19th. Temperature exceeded 75°F. at many places, chiefly inland but also at some coastal stations, from the 16th to the 18th, while 80°F. was reached or somewhat exceeded locally (86°F. at Camden Square, London, on the 18th). Temperature continued very high in eastern and midland districts of England also on the 19th. On the 19th and 20th a shallow trough of low pressure moved very slowly westward over the British Isles; thunderstorms occurred locally and heavy rain caused floods in places, but the heavy rain was very local (2·56 in. at Cotleigh House near Honiton, Devon, in less than 50 min. and 2·34 in. at Kidlington, Oxfordshire, on the 19th). At Tibshelf, Derbyshire, a small tornado occurred on the 19th causing considerable local damage. Subsequently an anticyclone over Scandinavia moved south-south-west and anticyclonic conditions, with fair, though somewhat cooler weather, prevailed in most parts until the 26th. Thereafter a depression off north-west Iceland moved slowly east-south-east giving rain in Scotland on the 26th and scattered rain or showers on the 27th. In the rear of this depression, cool north-westerly winds brought a fall in temperature, with scattered, mainly slight, rain or showers, but long sunny periods in many places. During the closing days an almost stationary depression was centred westward of Ireland and an associated trough moved north over England and Wales. Rain or showers occurred in many places on the 30th and throughout the country on the 31st; rainfall was rather heavy locally on the 31st, particularly during the following night.

The general character of the weather is shown by the following provisional figures:—

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Per-centage of average	No. of days difference from average	Per-centage of average
	°F.	°F.	°F.	%		%
England and Wales ...	86	28	+3·7	111	−1	109
Scotland	80	25	+3·1	89	−2	98
Northern Ireland ...	79	30	+2·5	66	−3	96

RAINFALL OF MAY 1952

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	1·07	61	*Glam.*	Cardiff, Penylan ...	3·81	156
Kent	Folkestone, Cherry Gdn.	1·21	72	*Pemb.*	Tenby, The Priory ...	4·58	211
„	Edenbridge, Falconhurst	1·26	68	*Radnor*	Tyrmynydd	3·88	113
Sussex	Compton, Compton Ho.	3·20	144	*Mont.*	Lake Vyrnwy	3·58	111
„	Worthing, Beach Ho. Pk.	1·79	108	*Mer.*	Blaenau Festiniog ...	3·53	62
Hants.	Ventnor Cemetery ...	2·11	121	„	Aberdovey	3·33	133
„	Southampton, (East Pk.)	3·03	151	*Carn.*	Llandudno	1·81	102
„	Sherborne St. John ...	3·18	164	*Angl.*	Llanerchymedd ...	2·32	99
Herts.	Royston, Therfield Rec.	2·42	125	*I. Man*	Douglas, Borough Cem.	2·71	108
Bucks.	Slough, Upton... ...	2·31	137	*Wigtown*	Newton Stewart ...	2·24	85
Oxford	Oxford, Radcliffe ...	2·23	119	*Dumf.*	Dumfries, Crichton R.I.	3·43	125
N'hants.	Wellingboro' Swanspool	3·45	178	„	Eskdalemuir Obsy. ...	2·81	85
Essex	Shoeburyness	1·24	95	*Roxb.*	Kelso, Floors	1·67	87
„	Dovercourt	1·12	81	*Peebles*	Stobo Castle	2·14	94
Suffolk	Lowestoft Sec. School...	...	...	*Berwick*	Marchmont House ...	2·02	82
„	Bury St. Ed., Westley H.	1·00	55	*E. Loth.*	North Berwick Res. ...	1·95	98
Norfolk	Sandringham Ho. Gdns.	2·34	128	*Midl'n.*	Edinburgh, Blackf'd. H.	1·70	83
Wilts.	Aldbourne	3·39	172	*Lanark*	Hamilton W. W., T'nhill	1·79	75
Dorset	Creech Grange... ...	2·87	141	*Ayr*	Colmonell, Knockdolian	1·85	72
„	Beaminster, East St. ...	3·06	149	„	Glen Afton, Ayr San. ...	2·83	94
Devon	Teignmouth, Den Gdns.	2·42	132	*Renfrew*	Greenock, Prospect Hill	1·98	61
„	Cullompton	2·78	129	*Bute*	Rothesay, Ardencraig...	1·97	65
„	Ilfracombe	3·26	158	*Argyll*	Morven (Drimnin) ...	2·06	64
„	Okehampton Uplands...	3·37	125	„	Poltalloch	1·51	52
Cornwall	Bude, School House ...	2·45	133	„	Inveraray Castle ...	1·75	45
„	Penzance, Morrab Gdns.	2·06	93	„	Islay, Eallabus... ...	1·88	71
„	St. Austell	3·14	130	„	Tiree	1·39	56
„	Scilly, Tresco Abbey ...	1·88	111	*Kinross*	Loch Leven Sluice ...	1·57	64
Glos.	Cirencester	2·68	130	*Fife*	Leuchars Airfield ...	1·90	97
Salop	Church Stretton ...	2·82	111	*Perth*	Loch Dhu	...	...
„	Shrewsbury, Monksmore	1·63	84	„	Crieff, Strathearn Hyd.	1·96	79
Worcs.	Malvern, Free Library...	3·49	162	„	Pitlochry, Fincastle ...	3·29	155
Warwick	Birmingham, Edgbaston	2·58	121	*Angus*	Montrose, Sunnyside ...	2·90	142
Leics.	Thornton Reservoir ...	2·36	117	*Aberd.*	Braemar	2·99	126
Lincs.	Boston, Skirbeck ...	2·73	155	„	Dyce, Craibstone ...	2·52	99
„	Skegness, Marine Gdns.	1·46	86	„	New Deer School House	1·99	91
Notts.	Mansfield, Carr Bank...	2·38	112	*Moray*	Gordon Castle	1·63	77
Derby	Buxton, Terrace Slopes	2·62	85	*Nairn*	Nairn, Achareidh ...	1·37	77
Ches.	Bidston Observatory ...	1·84	97	*Inverness*	Loch Ness, Garthbeg ...	2·99	120
„	Manchester, Ringway...	1·81	85	„	Glenquoich	4·43	81
Lancs.	Stonyhurst College ...	2·83	99	„	Fort William, Teviot ...	2·48	63
„	Squires Gate	2·22	107	„	Skye, Duntuilm ...	2·47	87
Yorks.	Wakefield, Clarence Pk.	1·50	76	„	Skye, Broadford ...	3·63	86
„	Hull, Pearson Park ...	1·18	61	*R. & C.*	Tain, Tarlogie House ...	1·28	62
„	Felixkirk, Mt. St. John...	1·61	86	„	Inverbroom, Glackour...	3·79	126
„	York Museum	1·48	74	„	Achnashellach	3·68	87
„	Scarborough	1·28	67	*Suth.*	Lochinver, Bank Ho. ...	3·10	122
„	Middlesbrough... ...	1·05	55	*Caith.*	Wick Airfield	1·81	87
„	Baldersdale, Hury Res.	2·05	83	*Shetland*	Lerwick Observatory ...	3·83	183
Norl'd.	Newcastle, Leazes Pk....	1·58	80	*Ferm.*	Crom Castle	2·18	78
„	Bellingham, High Green	2·03	85	*Armagh*	Armagh Observatory ...	1·11	47
„	Lilburn Tower Gdns. ...	1·76	76	*Down*	Seaforde	1·90	72
Cumb.	Geltsdale	1·58	61	*Antrim*	Aldergrove Airfield ...	1·19	52
„	Keswick, High Hill ...	3·28	103	„	Ballymena, Harryville...	1·50	52
„	Ravenglass, The Grove	2·62	94	*L'derry*	Garvagh, Moneydig ...	1·88	73
Mon.	Abergavenny, Larchfield	4·34	163	„	Londonderry, Creggan	1·60	61
Glam.	Ystalyfera, Wern House	4·64	133	*Tyrone*	Omagh, Edenfel ...	1·83	71