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WATER-FOG POINT—A FURTHER TEST

By W. E. SAUNDERS, B.Sc.

Introduction.—A technique for forecasting the temperature at screen level at which water fog forms was described by the writer in 1950[1], and amplified by Corby and Saunders, 1952[2]. This note describes the results of a test made at a large number of United Kingdom meteorological offices during the early months of 1956.

Scope of the test.—Stations were asked to test the method on all suitable nights during the period January 1–April 15, 1956. In the selection of suitable nights the following conditions had to be satisfied:

(i) An upper air ascent representative of the air stream over the station had to be available the previous afternoon.

(ii) Water fog had actually to form during the night, or the evening conditions had to be such that the forecaster would seriously consider the risk of fog.

(iii) Visibility during the night should not be seriously affected by smoke.

The water-fog point was to be as defined by Corby and Saunders[2].

Preliminary treatment of the results.—63 stations gave details of actual fog cases, and a further 10 stations gave data for nights on which fog was considered but did not form.

Stations differed widely in their interpretation of conditions (i) and (iii) above. Cases which were reported, but with a comment that the ascent used was not properly representative, were omitted from the analysis. With regard to condition (iii), all cases reported were included in the analysis, although some were much affected by smoke. A few stations included cases which were not radiation fog, such as occasions of sea fog on coasts, and visibility falling into the fog range in precipitation, and where these cases could be identified from the accompanying remarks they were omitted.

The analysis of results is discussed in subsequent paragraphs.

Fog point as an air mass property.—The method is based on the idea, derived from observation, that the water-fog point is an air mass property—over an area in which there has been fairly uniform heating and in which the humidity distribution with height in the lowest few thousand feet shows little change from place to place, the fog point can be regarded within close limits as a fixed property of the air mass. Spatial variations in the time of onset of fog are due to differences in the cooling rate and not in the fog point.

The period of this test was not particularly suitable for illustrating this general principle, since many of the fog cases reported referred only to small localized areas. Two occasions, however, did produce fairly widespread fog, and the actual and forecast fog points on these nights have been plotted on Figures 1 and 2.

On January 16, 1956 (Figure 1) there was a light west to west-north-west air stream over southern districts. Fog was reported at 13 stations, and the forecast errors are seen to average not much more than one degree. Seven stations reported no fog, and in each case the minimum screen temperature exceeded the forecast fog point.

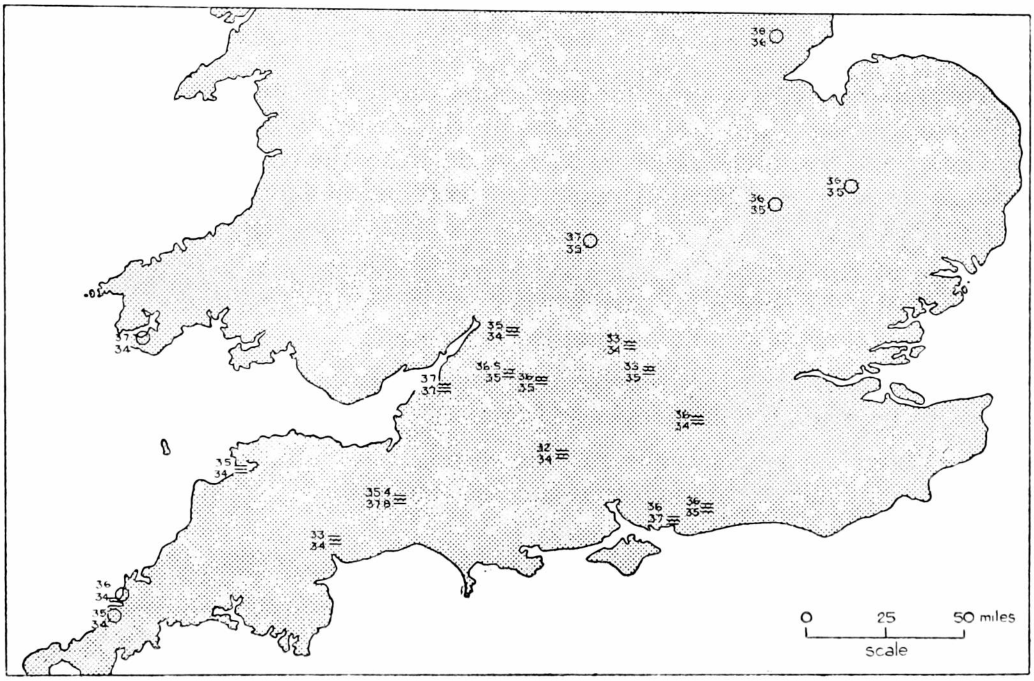

FIG. 1.—FORECAST AND ACTUAL FOG POINTS, JANUARY 16, 1956

Fog cases are plotted $\frac{T_{f'}}{T_f} \equiv$ where $T_{f'}$ is the actual and T_f the forecast fog point

Cases of no fog are plotted $\frac{T_{min}}{T_f}$ O where T_{min} is the screen minimum temperature and T_f is the forecast fog point

There was a light south-east to south air stream on March 12, 1956 (Figure 2). The actual fog points show that there were localized areas near the Thames Valley, and in north Yorkshire, with fog point 30°–31°F. Elsewhere it was mainly 27°–28°F. These differences may well have been due to variations in the length of sea track of the air mass, an effect which was appreciated and correctly allowed for in the Abingdon forecast. Three stations appeared to make forecasting errors of a type discussed below but the remaining 15 stations obtained errors averaging only a degree or so.

Variation of forecast errors.—The standard of accuracy obtained varied somewhat between stations, but 48 out of 63 obtained mean deviations not exceeding 2·0°F., and 28 not exceeding 1·0°F. The mean deviations were taken as the mean forecast errors, disregarding the signs.

In order to see the frequency of actual errors in the forecasts the records of the 48 stations referred to above were examined, and the frequencies of various errors are given in Table I.

TABLE I—FREQUENCY OF VARIOUS ERRORS IN FOG POINT FORECASTS

	Errors in forecast fog point, °F.					
	0·0–1·0	1·1–2·0	2·1–3·0	3·1–4·0	4·1–5·0	5·1–6·0
Number of occasions ...	120	36	13	7	2	2
Percentage frequency ...	67	20	7	4	1	1

Variation of forecast errors with temperature.—The forecast errors of the 48 stations were analysed according to the temperature of T_f—the forecast fog point—and the results are given in Table II. $T_{f'}$ refers to the actual fog point. Mean deviations are the forecast errors disregarding the signs, and mean errors the mean of $T_{f'} - T_f$ taking account of the signs. The small number of cases with T_f above 43° or below 20°F. were omitted.

TABLE II—VARIATION OF FOG-POINT ERRORS WITH TEMPERATURE

	Forecast fog point (T_f) °F.					
	43–40	39–36	35–32	31–28	27–24	23–20
Number of cases	19	53	48	29	21	7
Mean deviation (°F.) ...	1·3	1·0	1·3	1·3	1·4	1·5
Mean error $T_{f'} - T_f$ (°F.) ...	−0·9	−0·5	−0·1	+0·6	+0·9	+1·1

Table II shows that the forecast T_f is on average nearly one degree too high in the range 43–40°F. This error decreases with decreasing temperature, and changes sign near freezing. When the forecast T_f is below freezing it is to low, the mean error being about one degree for temperatures 27–20°F.

Variation of forecast errors with type of dew-point curve.—Stations included the type of dew-point curve used, as classified by Saunders[1]. Errors associated with each type of curve are given in Table III.

TABLE III—VARIATION OF FORECAST ERRORS WITH TYPE OF DEW-POINT CURVE

	Type of dew-point curve			
	I	II	IIIA	IIIB
Number of cases	95	36	34	10
Mean deviation (°F.)	1·2	1·2	1·1	0·7
Mean error $T_{f'} - T_f$ (°F.)	0·0	0·0	−0·5	0·0

This shows that the more general types of dew-point curve give much the same accuracy. The greatest accuracy is obtained with type IIIB, when the air is exceptionally stagnant and the afternoon dew-point is the fog point, but the proportion of cases in which this can be applied is very small.

Variation of forecast errors with state of ground.—Notes of the state of ground were included in a limited number of cases, and the forecast errors were analysed separately in these cases. The results are given in Table IV.

TABLE IV—VARIATION OF FORECAST ERRORS WITH STATE OF GROUND

	State of ground		
	Dry or moist	Frozen	Snow covered
Number of cases	37	16	11
Mean deviation (°F.)	1·2	2·1	2·1
Mean error $T_{f'} - T_f$ (°F.)	−0·1	−0·3	+0·8

Table IV shows that forecast errors increase significantly under wintry conditions with frozen and snow-covered ground.

Forecast errors following recent precipitation.—The reports included notes on precipitation at the stations, with special reference to precipitation after midday preceding fog cases. The forecast errors were considered separately for cases in which precipitation was reported at the station in the period from midday to the time of fog formation. Dew was not counted for this purpose. There were 59 such occasions, giving mean deviation 1·9°F., and mean error of $T_{f'} - T_f$, + 1·3°F.

Occasions when fog did not form.—Some stations included details of the forecast fog point and night minimum temperature—T_{min} on nights when fog was considered but did not form. These were analysed, with the state of ground, for all cases where the latter was included in the report, and the results are given in Table V.

TABLE V—RELATION OF NIGHT MINIMUM TEMPERATURE TO FORECAST FOG POINT AND STATE OF GROUND ON OCCASIONS WHEN FOG DID NOT FORM

	$T_{min} \leqslant T_f$		
$T_{min} > T_f$	Ground dry or moist	Ground frozen	Ground snow covered
	No. of occasions		
84	7	5	14

Table V shows that on most of the occasions when the fog point was reached, but no fog formed, there was snow cover.

Main sources of errors in forecasting.—Table II shows that there are small errors at low temperatures. These were, however, based on the records of the stations taken together, and will not necessarily apply at all stations. Stations who are satisfied that the mean errors are relevant to them could apply them as corrections in future work.

It is not suggested that any corrections should be made based on the results given in Tables III and IV, but Table IV emphasizes that there is some decrease in accuracy over frozen or snow covered ground.

The results mentioned earlier suggest a correction of + 1·3°F. should be made to the forecast T_f when there has been recent precipitation at the station, but this is another circumstance which leads to decreased accuracy.

Apart from the points mentioned above, which arise from the statistical tables produced, an examination was made of the larger errors reported on individual occasions, and the following appeared to be the main sources of errors:

(i) The effect of rainfall at the radio-sonde station.—Occasional large errors (forecast T_f too high) were due to the radio-sonde ascent having been made in rain, and the ascent then being used to forecast the fog

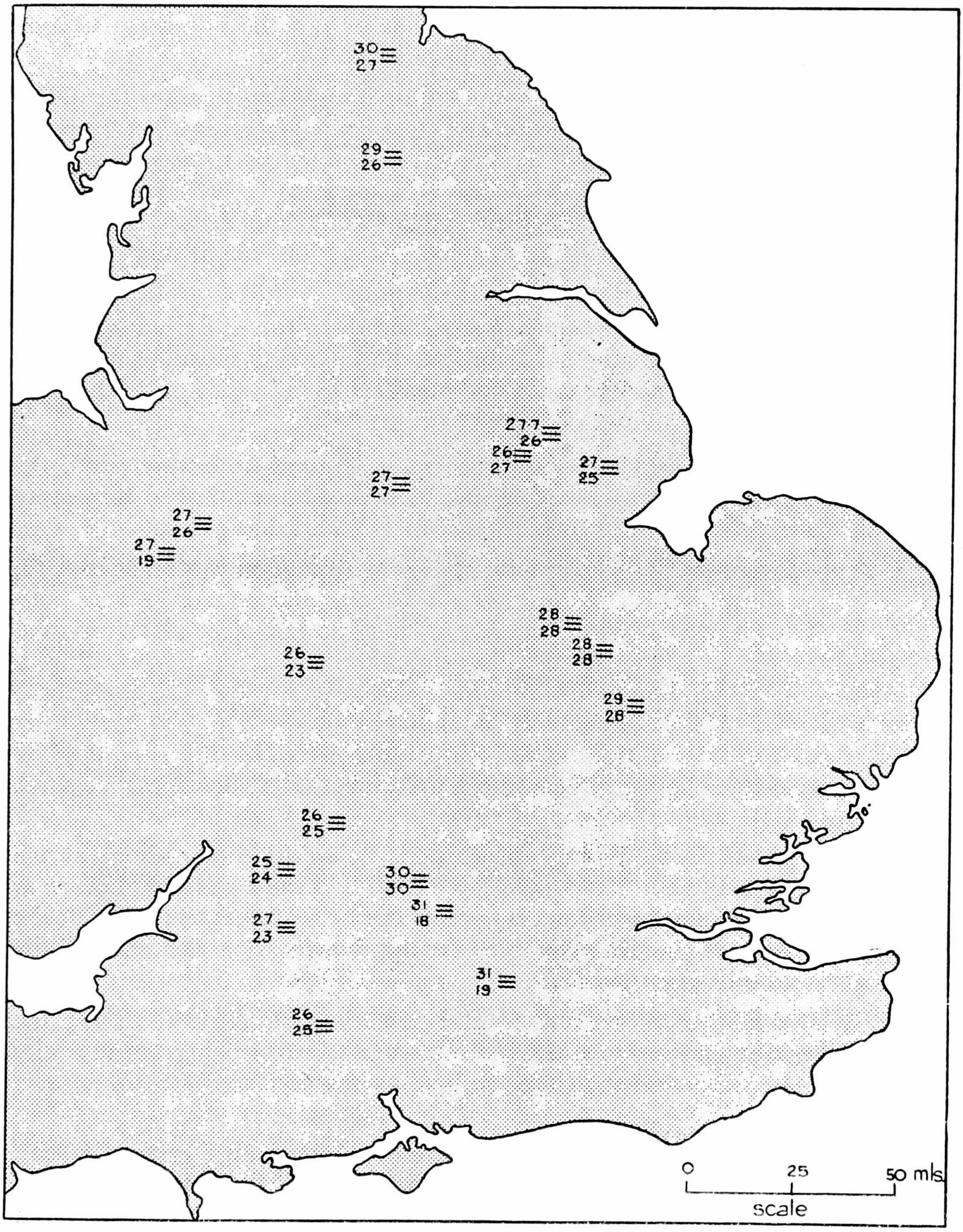

FIG. 2.—FORECAST AND ACTUAL FOG POINTS, MARCH 12, 1956

Fog cases are plotted $\frac{T_{f'}}{T_f}$ ≡ where $T_{f'}$ is the actual and T_f the forecast fog point

Cases of no fog are plotted $\frac{T_{min}}{T_f}$ O where T_{min} is the screen minimum temperature and T_f is the forecast fog point

point at a station in dry air. The humidity element of the radio-sonde is of course screened from the direct effects of rain, but the dew-points reported will correspond to the moist air in the rain. If the precipitation is of an intermittent or showery type it may be difficult for forecasters to decide whether or not the ascent was made in rain without communicating directly with the radio-sonde station. It would be helpful if radio-sonde operators would whenever possible observe whether or not the afternoon balloon passed through precipitation in the lowest 3,000 feet.

(ii) Modification of the most representative sounding to allow for differences in the surface temperature and dew-point at or up-wind from the station. The most successful results were obtained by those stations who when necessary amended the tephigram to accord with their own or other more representative up-wind temperatures and dew-points. Some rules formulated by Mr. W. L. Andrew (Abingdon) for dealing with this problem are given below:

(*a*) If conditions are fairly stagnant, and the air over the station seems likely to be representative of the air the following morning, then the most representative ascent is used, modified to take account of the 1400 G.M.T. temperature and dew-point at the station.

(*b*) If the air in which fog might form is going to be advected, the representative ascent is used, either as it stands, or adapted to a more representative up-wind surface temperature and dew-point.

A good example of type (*b*) amendment at Abingdon was on March 12, (the case illustrated in Figure 2) when forecast and actual T_f were both 30°F. The Crawley ascent had been modified to take account of reported temperatures and dew-points along the south coast and up-wind from Abingdon, which differed from those at Crawley. Another useful example of this type of adjustment was amendment of the Hemsby ascent by Stradishall to take account of the temperature at a North Sea light vessel when the air was being advected from that direction, so obtaining a correct forecast T_f.

The method of modifying an ascent is to adjust the readings at the lower heights to what they would have been had the ascent been made at 1500 hr. at the station whose fog point was being forecast, and with the assumption that the air mass over the upper air station had reached the "fog" station before 1500 hr.

Detailed analysis of the surface chart is an important aid to finding the most representative ascent, the main feature to stress being the necessity for retaining fronts on the charts so long as any surface discontinuity can be traced.

(iii) The type II dew-point construction.—A few large errors (forecast T_f too low) were noticed in cases where a type II dew-point curve was not produced upwards in the manner suggested. It should be emphasized that type II dew-point curve is not found only with an inversion of the dry-bulb temperature. It may occur when there is any decrease in the temperature lapse rate. With this distribution the hydrolapse in the upper part of the dew-point curve may be very steep, and if the lower part of the curve is not produced upwards for the fog-point construction it is apparent that large errors are readily incurred. The reason for this construction is that in this type the upper part of the dew-point curve represents air which obviously is not being mixed with the surface air, and must therefore be left out of account.

Use of the technique for forecasting the temperature of formation of stratus cloud.—In the original paper a construction was suggested for forecasting T_s, the screen level temperature at which low stratus cloud would form, when it was thought there was too much turbulence for fog at ground level[1].

A number of stations reported successful use of this construction. At Little Rissington (in the Cotswolds, 751 feet above mean sea level), owing to the altitude of the station, radiation fog is rare, but low stratus often forms on the surface. Mr. B. F. Westwater reported using T_f modified to T_s to allow for about 300 feet uplift above the surrounding countryside. On 8 occasions when there was a representative ascent the mean error was just over one degree.

The usefulness of the technique modified in this way for stratus cloud serves to emphasize that it is essentially a method for *water* fog.

Conclusion.—A number of stations commented that the period chosen for the test was unfavourable for accuracy because it included a severe wintry spell, and in some cases much smoke. In support of this view Mr. E. B. Tinney (Merryfield, near Taunton, Somerset) produced the results of a similar test carried out under local initiative during the previous autumn. This showed that for 11 cases in the period July 1–October 11, 1955 the mean error for Merryfield was about half its value for eight cases in the present test. Having seen in Table IV that the relation between mean deviations over dry or wet ground as compared with frozen or snow covered ground tended the same way, we may perhaps conclude that most stations would have obtained rather better results in an autumn period. However, the test has been a useful supplement to the autumn one described by Corby and Saunders[2], and it has suggested some small corrections which should lead to greater accuracy in future.

REFERENCES

1. SAUNDERS, W. E.; Method of forecasting the temperature of fog formation. *Met. Mag., London*, **79**, 1950, p. 213.
2. CORBY, G. A. and SAUNDERS, W. E.; Water fog point—a further test. *Met. Mag., London*, **81**, 1952, p. 225.

TEMPERATURES AND TOPOGRAPHY ON RADIATION NIGHTS

By E. N. LAWRENCE, B.Sc

Introduction.—An area forecast of minimum temperature can be interpreted satisfactorily only by the aid of formulae relating minimum temperatures to topography, especially to altitude. These formulae would be useful also for the purpose of estimating long term frost risks over areas where a sufficiently detailed network of measured observations is not available.

Method.—Ideally an investigation into the relation between topography and meteorological elements such as temperature and wind, requires a large number of meteorological stations within a small area. In the present survey, this difficulty was overcome by fitting instruments to a car, and making observations at some 70 points along a route of about 11 miles (see Figure 1) over a period of about $1\frac{1}{2}$ hours at the end of each night of the survey. This route covered three main hills and the surrounds of Aldenham Reservoir. The height variation is over 200 feet with slopes up to about one in nine. The three hills are Brockley Hill (Middlesex), Elstree Hill and the double-humped hill of Allum Lane (Borehamwood, Hertfordshire).

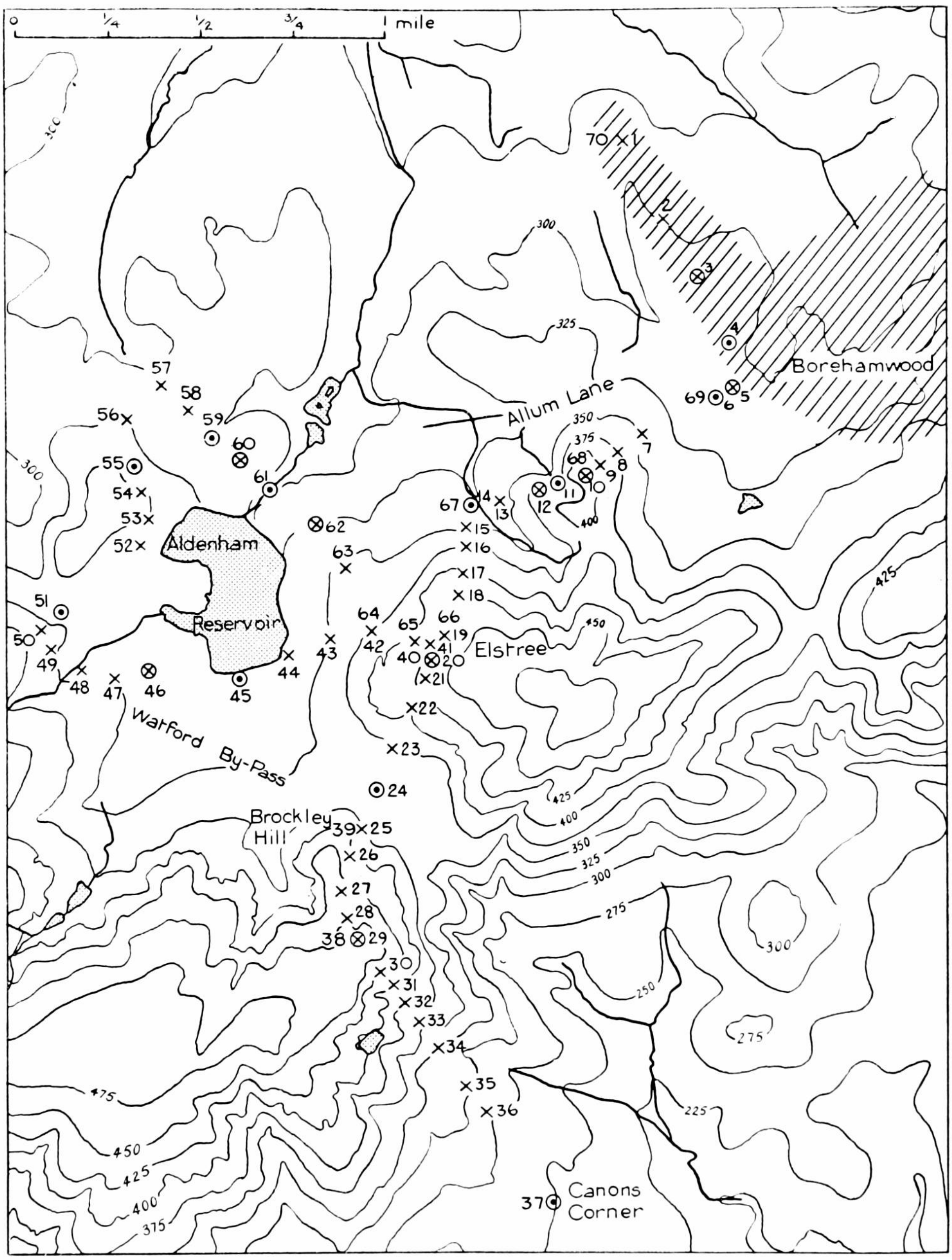

FIG. 1—AREA OF MOBILE METEOROLOGICAL SURVEY

Crosses mark points of observation.
Encircled crosses mark observations made at "main" crest points.
Encircled dots mark observations made at "main" trough points.

The instruments employed are illustrated in photographs between pp. 80–81. Temperatures were measured by means of balanced-bridge platinum resistance thermometers attached to the front of the car by means of aluminium strut supports so that the responding surfaces were at heights of 1 foot and 4 feet above the ground. Wind speed was measured with a magnetic drag hand anemometer; wind direction was measured (during the 1955 surveys) by means of streamers attached to a mast fixed to the rear of the car but later (during the 1956 surveys) wind direction was measured by means of a fine powder ejected from a flexible-ended container. Observations were made at all "main" crest and trough points, and also, where the latter points were widely separated, at intervals of 1 millibar—measured by an aneroid barometer (Mk. II). Temperature observations were made immediately before stopping the car, while wind was observed with the car at rest.

Because of the vital importance of May frosts to agriculture, the month of May was selected for experiment and several surveys were made in each of the months May 1955 and May 1956. The time of observation was during the latter end of the night so that the temperatures recorded would indicate the approximate night minimum temperatures. The nights selected were anticyclonic nights with little or no cloud and no pressure gradient—only local winds prevailing.

TABLE I—THE RELATION BETWEEN EARLY MORNING TEMPERATURE (T) IN DEGREES FAHRENHEIT AND THE HEIGHT (H), IN FEET, ABOVE MEAN SEA LEVEL, ON RADIATION NIGHTS

Date	Locations	Height–temperature correlation	Regression equations
May 22, 1955	Points 1–70 (Height range: 210 ft.)	0·66	$T = 0{\cdot}016\,H + 34$ $H = 26{\cdot}9\,T - 716$
May 27, 1956	Points 1–70 (points 33, 45 missing) = 68 points (Height range: 210 ft.)	0·33	$T = 0{\cdot}010\,H + 34$ $H = 10{\cdot}7\,T - 36$
May 27, 1956	Points 42–68 inclusive (point 45 missing) = 26 points (Height range: 120 ft.)	0·75	$T = 0{\cdot}035\,H + 24$ $H = 16{\cdot}1\,T - 230$

Results.—There was little difference between the 1-foot and 4-foot temperatures, probably due to the fact that inversions are much less marked over road surfaces because of the higher conductivity of road building materials and possibly also because of the turbulence produced by traffic. In the following results, the temperatures referred to are the means of the temperatures at the two levels; and may be regarded rather more like screen minimum temperatures than grass minimum temperatures. The mean of the extreme temperatures (average of 1-foot and 4-foot temperatures) obtained on May 22, 1955 was 40°F. while elsewhere, minima were 39°F. at Southgate, Oakwood (screen), and 35°F. at Wealdstone, Kodak (screen) with 29°F. (grass minimum). On May 27, 1956, the corresponding values were 36°F. (present survey), 37°F. at Southgate (screen), 40°F. at Wealdstone (screen) and 30°F. at Wealdstone (grass minimum).

The results for two of the best radiation nights are given in Table I. Further detail for one of these occasions is given in Figure 2. Slope winds were fairly general during both these occasions and ground mist and fog were present (see photograph facing p. 80).

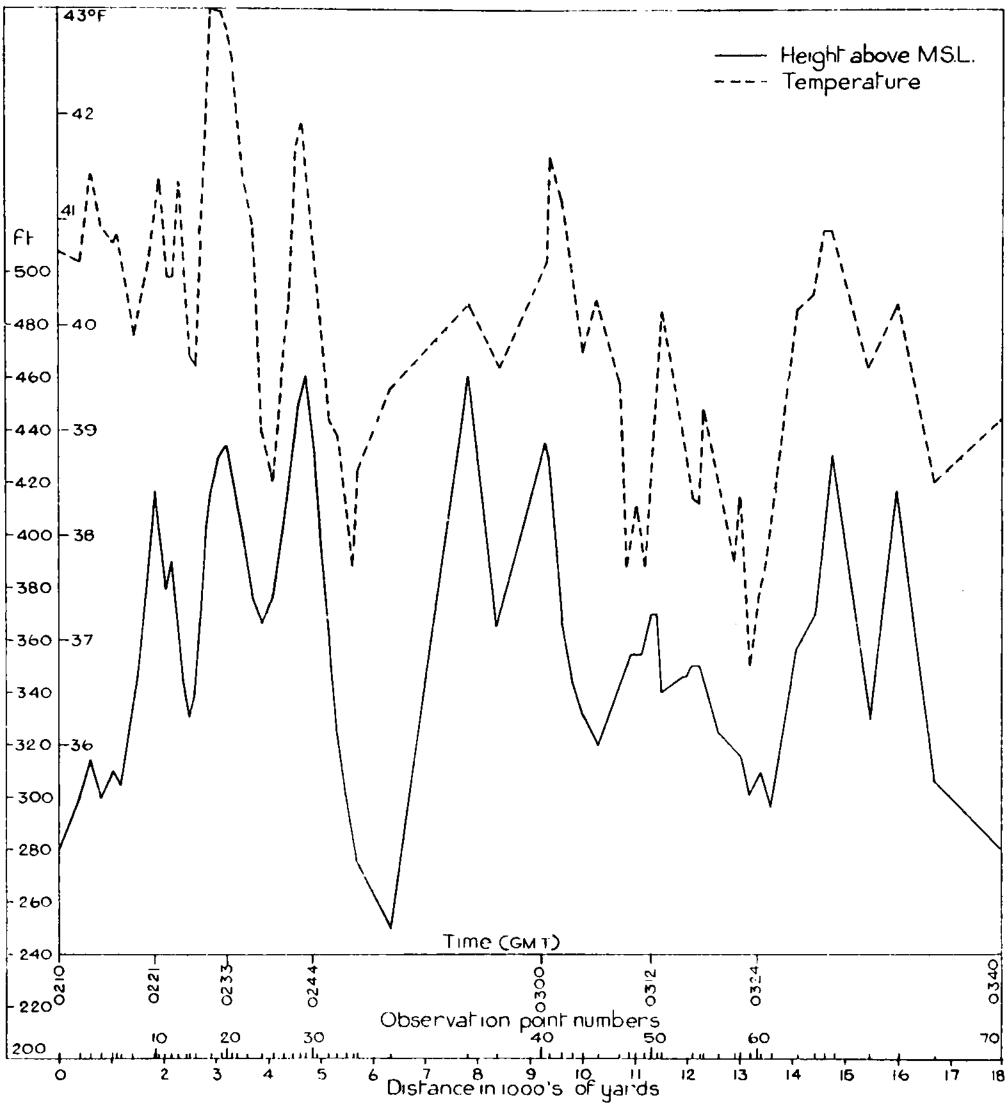

FIG. 2—RELATION BETWEEN HEIGHT AND EARLY MORNING TEMPERATURE ON MAY 22, 1955

The results show that on a radiation night, the average increase of temperature with height may be of the order of 1°–2°F. or more per hundred feet and over shorter distances (see Table I and Figure 2) very much numerically higher lapse rates may occur. For example, on the outward journey on May 22, 1955 (see Figure 2), over seven points with a height range of 75 feet on the north side of Elstree Hill, the mean rate of increase was (numerically) $4\frac{1}{2}$°F. per hundred feet; on the same outward journey, down the south side of Brockley Hill, through a height range of 160 feet, the mean rate of increase was about $2\frac{1}{2}$°F. These figures are in general agreement with other surveys: for example at Much Birch[1] in Herefordshire over eleven radiation nights in 1954 and through a height range of 20 feet, the average minimum temperature (at 4 feet above the ground) increased with height at the rate of 5°F. per hundred feet: while Geslin[2] in Champagne, on the radiation night of April 29–30, 1951, recorded up to approximately 8°F. per hundred feet through a height of 16 metres, at 40 centimetres above the ground. On the surveys carried out in Champagne, there was an indication of a "constant temperature" cold air pool in hollows. In the present survey, however, there was a fairly general temperature response to change in height, and any exceptions could usually be explained by an increase in turbulence, or by the proximity of built-up areas or of Aldenham Reservoir near which temperatures were some 1°–2°F. higher than that which would be expected from the general height–temperature pattern (see Figure 2). It is possible, however, that the "constant temperature cold pool" was not well marked because there was always a sufficient run off of cold air to lower areas surrounding the area of survey.

On the assumption that a difference of 0·5°F. in the average minimum temperature is associated with a significant difference in frost liability[3], the results of this experiment indicate that a height difference of 10 feet leads to significant differences in frost liability.

The temperature lapse rates of $2\frac{1}{2}$° and $4\frac{1}{2}$°F. per hundred feet recorded in the present survey (see above) were associated with slopes of 0·06 and 0·08 respectively. Data was insufficient to draw any firm conclusions concerning the relation between slope and either the rate of increase of temperature with height or the slope wind.

The results of the present experiment may be contrasted with the results of a previous investigation[4] in which the sites (at varying heights) were widely scattered so that the topographies were "unrelated". In the latter survey, the height–minimum temperature correlation was somewhat masked by the introduction of other variables, and whereas no firm conclusions could be drawn, a tendency for a positive correlation might have been inferred.

I am grateful to Mrs. K. Spencer and Mr. D. Tribble for help in observing and to Mr. D. Tribble for the use of his car.

REFERENCES

1. LAWRENCE, E. N.; Minimum temperatures and topography in a Herefordshire valley. *Met. Mag., London*, **85**, 1956, p. 79.

2. GESLIN, H., BOUCHET, R., DURAND, R. and NIGOND, J.; A propos des gélees de printemps nouvelles observations microclimatiques et biologiques en Champagne. *P. V. Acad. Agric. France, Alençon*, 1952.

3. LAWRENCE, E. N.; Estimation of weekly frost risk using weekly minimum temperatures. *Met. Mag., London*, **81**, 1952, p. 137.

4. LAWRENCE, E. N.; Frost investigation. *Met. Mag., London*, **81**, 1952, p. 65.

SEASONAL INCIDENCE OF RAINY CALENDAR MONTHS WITH MORE THAN AVERAGE SUNSHINE DURATION IN ENGLAND AND WALES

By E. L. HAWKE, M.A.

The *Monthly Summary* of the British *Daily Weather Report* for January 1956 contained the following statement: "This changeable month produced the unusual combination of high rainfall and an excess of sunshine." Summarized data subsequently published in the *Monthly Weather Report* indicated that over England and Wales as a whole January 1956 gave 167 per cent. of the average, 1881–1915, precipitation and 117 per cent. of the average, 1921–1950, duration of sunshine. "Changeable: wet but sunny" was the headline describing the month's general character.

Is it unusual for January to couple high rainfall with a quota of sunshine above normal? Such a combination might well be rare in summer, one would suppose, but it might seem, at first sight, no matter for special comment in winter, when anticyclonic conditions are so often associated in Great Britain with persistent canopies of low cloud and widespread fog, whereas during a predominantly cyclonic régime there are, as a rule, frequent sunny spells separating the successive intervals of rain or snow. Direct evidence on this point appears to be lacking from climatological literature. An attempt to remedy the defect has therefore been made. The material used comprised general values of monthly precipitation for England and Wales over the 40 years 1909–1948, published in the annual volumes of *British Rainfall*, and general values of monthly sunshine duration for England and Wales over the same 40 years given by D. S. Hancock[1,2]. Values for both elements are expressed as a percentage of average, the averages employed being the standard period 1881–1915 in respect of rainfall and 1909–1933 in respect of sunshine. Relevant data are set forth in Tables I and II.

TABLE I—MEAN GENERAL DURATION OF SUNSHINE OVER ENGLAND AND WALES FOR THE SEVEN WETTEST OF EACH OF THE CALENDAR MONTHS DURING THE PERIOD 1909–1948

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Percentage of 1909–1933 average	93	101	78	82	92	88	90	84	87	92*	84	98

* This value is derived from eight instead of seven months because three Octobers, 1917, 1924, and 1938, tied for the positions of sixth and seventh wettest in the period under review.

TABLE II—NUMBER OF OCCASIONS ON WHICH MARKEDLY WET CALENDAR MONTHS GAVE GENERAL SUNSHINE DURATION WITHIN SPECIFIED LIMITS ABOVE AND BELOW AVERAGE OVER ENGLAND AND WALES, 1909–1948

	Percentage							
	<61	61–70	71–80	81–90	91–100	101–110	111–120	>120
Oct.–Mar.	0	5	8	10	5	3	3	2
Apr.–Sept.	2	2	8	13	1	1	2	1

This Table shows that out of 43 markedly wet winter months during the 40-year period there were 33 with sunshine below or equal to average and only 10 with sunshine above average. In Summer the tendency for markedly wet months to give sunshine below average was decidedly more pronounced, with 38 instances against four*.

* The footnote to Table I explains why 43 winter months and 42 summer months were considered.

TABLE III—CALENDAR MONTHS FROM 1909 TO 1948 COMBINING MORE THAN AVERAGE GENERAL SUNSHINE WITH GENERAL RAINFALL EXCEEDING THE AVERAGE BY AT LEAST 40 PER CENT. OVER ENGLAND AND WALES.

Year	January Percentage of average Rainfall	Sunshine	Year	February Percentage of average Rainfall	Sunshine	Year	April Percentage of average Rainfall	Sunshine
1928	213	120	1915	200	119	1922	147	114
1930	170	106	1925	192	104			
			1910	159	125			

Year	May Percentage of average Rainfall	Sunshine	Year	July Percentage of average Rainfall	Sunshine	Year	December Percentage of average Rainfall	Sunshine
1942	177	108	1918	160	115	1914	205	108
1943	143	122				1929	188	139
						1909	147	108

This table contains evidence in support of the statement quoted from the *Monthly Summary* of the British *Daily Weather Report* at the beginning of this article. Only two Januarys between 1909 and 1948 had more than average sunshine with a general rainfall exceeding the average by at least 40 per cent. The table excludes the two wettest Januarys, the three wettest Februarys, the two wettest Mays and the second wettest December, as well as the wettest of each of the calendar months through the remainder of the year. Months of especial interest in the table are January 1928, February 1915 and December 1929, which were outstanding in the unusual class of excessively wet but notably sunny months. July 1918 was the sole example of a very wet but sunny month in high summer; it is to be noted that most of the rain over England and Wales in that month came from heavy and widely distributed thunderstorms.

Correlation coefficients for monthly general rainfall and monthly general sunshine duration over England and Wales have also been evaluated. Herein the individual data and derived averages were confined to the 25 years 1909–1933. Rigid accuracy is not ensured by the quick method which was adopted for the calculations, but the margin of uncertainty is believed to lie within about +0·03 in every case. A few misprints in the published sunshine data have been corrected after consultation with Capt. Hancock.

TABLE IV—APPROXIMATE VALUES OF THE CORRELATION COEFFICIENT BETWEEN MONTHLY GENERAL RAINFALL AND MONTHLY GENERAL SUNSHINE DURATION OVER ENGLAND AND WALES, 1909–1933.

	Correlation coefficient	Standard error		Correlation coefficient	Standard error
January	−0·03	0·20	July	−0·62	0·12
February	+0·08	0·20	August	−0·56	0·14
March	−0·67	0·11	September	−0·46	0·16
April	−0·71	0·10	October	−0·29	0·18
May	−0·61	0·13	November	−0·15	0·20
June	−0·55	0·14	December	−0·10	0·20

No statistical significance attaches to the coefficients for November, December, January and February, since all are smaller than their respective standard errors. Thus in any of these four months the general character of the weather as regards wetness or dryness appears to be unrelated to the general prevalence of day-time cloud. In this connexion it may be remarked that in the extremely dull December of 1890, when totals of less than ten hours sunshine were recorded over much of Britain, and less than half an hour at London stations, England and Wales as a whole had only 35 per cent. of the average precipitation. The small positive coefficient found for February, though without significance statistically, is of interest as supporting the evidence of Table I, derived from data covering a longer period, that a slight trend existed during the first half of the 20th century for marked excess of rainfall to be associated with excess of sunshine in that month. The tendency towards combination of wet weather and high prevalence of clouded skies by day appears to reach a maximum in mid-spring. Presumably the reason is that March and April are, as a rule, not only much more immune from anticyclonic cloud and fog than the winter months but also much less liable than the summer months to have their rainfall dominated by thunderstorms.

REFERENCES

1. HANCOCK, D. S.; General sunshine values England and Wales, Scotland, Ireland and the British Isles for the period 1909–1933. *Quart. J. R. met. Soc., London.* **61**, 1935, p. 45.
2. HANCOCK, D. S.; An analysis of sunshine values in the British Isles for the period 1909–1948. *Quart. J. R. met. Soc., London,* **77**, 1951, p. 127.

EXTRAORDINARY STRONG WINDS AT NORTH WEALD

By R. DALGLEISH

On January 8, 1957, between 0707 and 0717 G.M.T. extraordinary strong winds were experienced at North Weald, north-west Essex (320 feet above sea level), grossly exceeding the gradient wind and far greater than reported from any other station in southern England.

At the time of the routine observation at 0656 G.M.T., the surface wind velocity was 215 degrees 20 knots, with gusts up to 28 knots. At 0707 G.M.T. the distant reading anemometer registered a sudden gust of 56 knots from direction 265 degrees and during the subsequent 10 minutes, up to 0717 G.M.T., a mean velocity of 265 degrees 35 to 40 knots was maintained. Thereafter the wind quickly backed to 210 degrees and moderated to 20 knots. During the period of the wind increase the barograph trace showed an upward kick of nine tenths of a millibar. No significant temperature change was recorded on the thermograph in the Stevenson Screen.

No wind speed approaching the magnitude of that observed at North Weald during the 10 minutes described above was reported from anywhere in southern England, and Stansted Airport, some 12 miles to the north-north-east, did not record any speed exceeding 20 knots between 0700 and 0730 G.M.T. that morning. A mild, moist south-westerly air stream, with a well marked inversion between 850 and 900 millibars, covered all southern England and there was a fairly uniform layer of stratocumulus. Slight drizzle outbreaks were frequent along the south and west coasts and scattered inland. The gradient wind over the area was 250 degrees 30 to 35 knots.

The excess of the wind speed, during the period between 0707 and 0717 G.M.T., over the gradient wind measured from the synoptic chart and also over the wind speeds generally reported that morning was too great to be attributed simply to convectional or frictional eddies. The combination of wind veer and extraordinary increase, simultaneously with the sharp pressure rise, suggests a downdraft associated with the eastward passage of a minor cold front; the discontinuity being confined to the lowest layers.

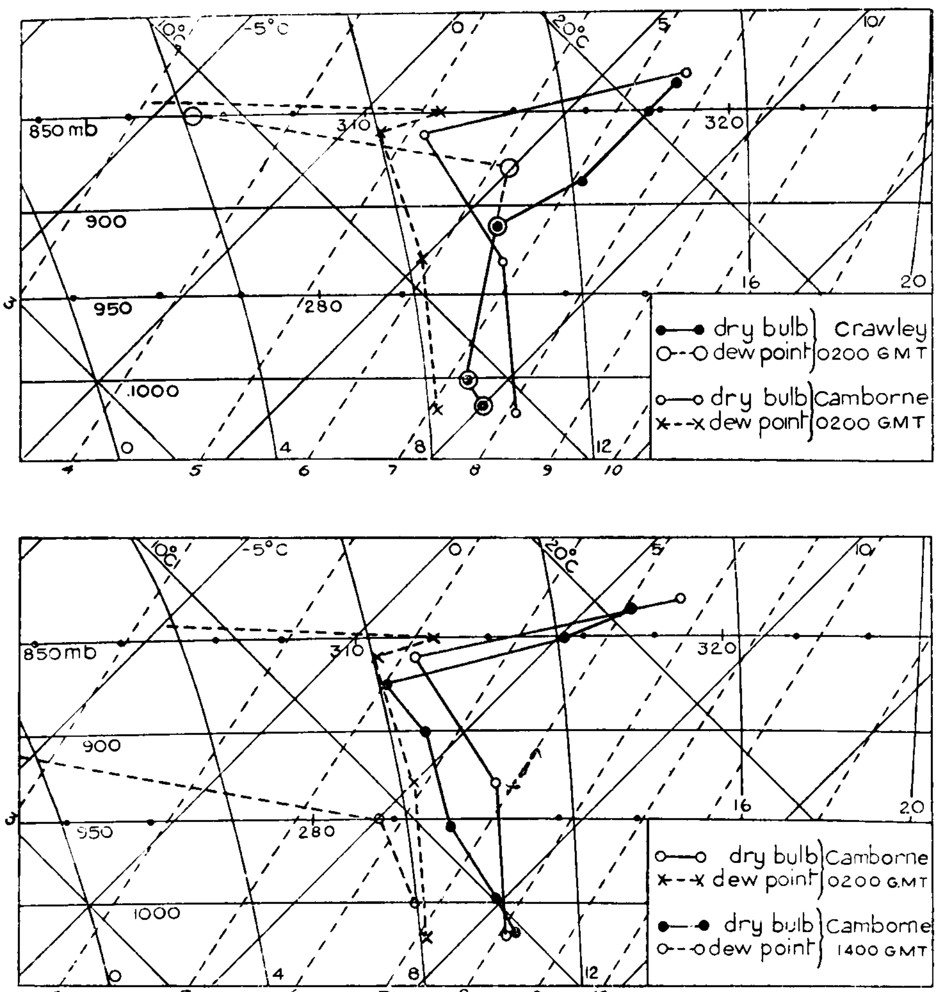

FIG. 1—UPPER AIR SOUNDINGS, CRAWLEY AND CAMBORNE, JANUARY 8, 1957

Although no clearly marked cold front or trough can be detected with any certainty from the synoptic charts the marked westward increase in conditional instability up to the 5,000-foot level is evident from the upper air soundings from Camborne and Crawley (Figure 1). The south-westerly air stream, although superficially uniform, was in fact becoming colder and less stable from the south-west in the layer below the inversion.

A further confirmation of the passage of a minor cold front is given by the Shoeburyness anemogram, (the nearest in the general direction of the wind flow to North Weald) extracts from which are given in Table 1. Positions A, B, C, and D in Table 1 correspond to the same positions in Figure 2.

TABLE I—SHOEBURYNESS ANEMOGRAM

Time (G.M.T.)	0700–0750	0750–0805	0805–0915	0915–0940
Direction (degrees)	230	250	210	230
Speed (knots)	14	18	12	12
Maximum gust	20	28	...	16
Position (Figure 2)	A	B	C	D

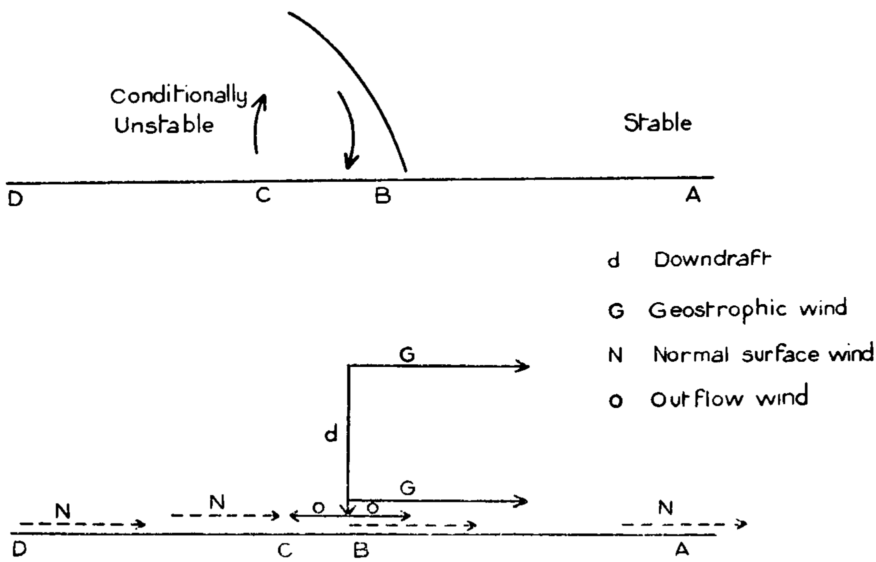

FIG. 2—EASTWARD PASSAGE OF THE MINOR COLD FRONT

Figure 2 illustrates the probable mechanism which resulted from the eastward passage of the minor cold front. The outflow following the downdraft aggravated the effect of the downward displacement of the geostrophic wind from the "frictionless" layer at position B, and momentarily reduced the normal surface wind in the "friction" layer at position C. Positions A and D are respectively well ahead of and well behind the axis of the front.

The foregoing accounts for the general sense of the phenomenon but it does not adequately explain the magnitude of the wind increase. In this respect it is postulated that a local increase in pressure gradient, undetected on the synoptic chart, uniquely coincided with the downdraft associated with the minor cold front described above.

METEOROLOGICAL OFFICE DISCUSSION

Orographic waves—form, forecasting and effect on aircraft

Opening the Meteorological Office Discussion at the Royal Society of Arts on November 18, 1957, Mr. C. E. Wallington illustrated the nature and characteristics of orographic wave flow by describing some aspects of research into the subject during the last ten years. The existence of waves had, of course, attracted attention long before this decade: plenty of stationary, lenticular

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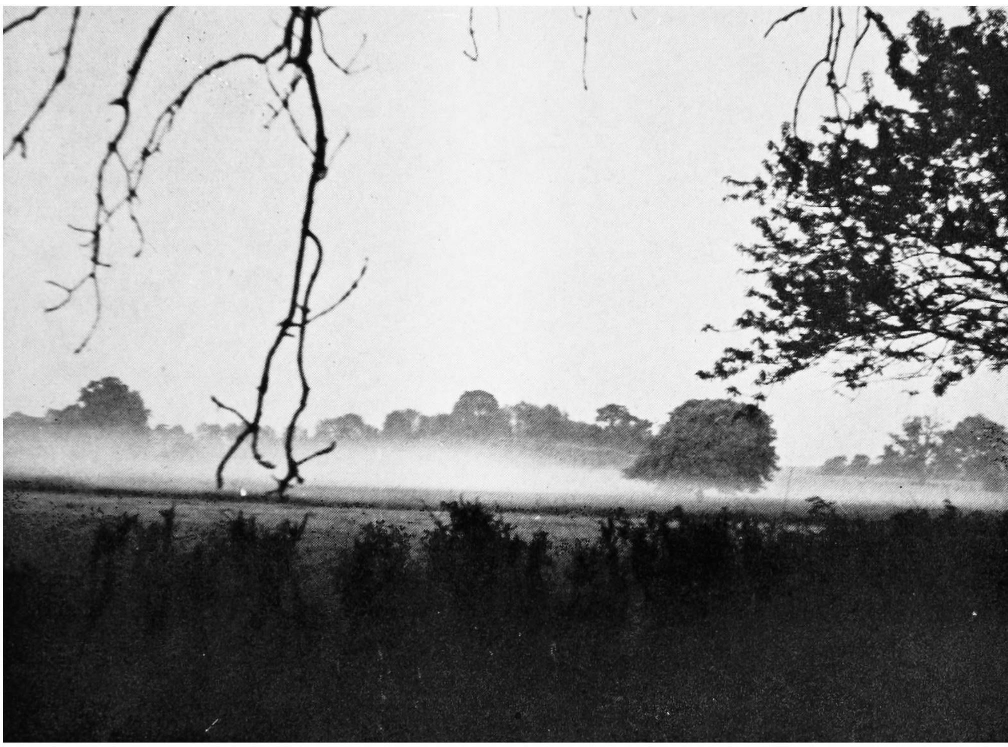

GROUND FOG AT 0330 G.M.T. ON ROUTE OF THE MOBILE METEOROLOGICAL SURVEY ON MAY 27, 1956
(see p. 74)

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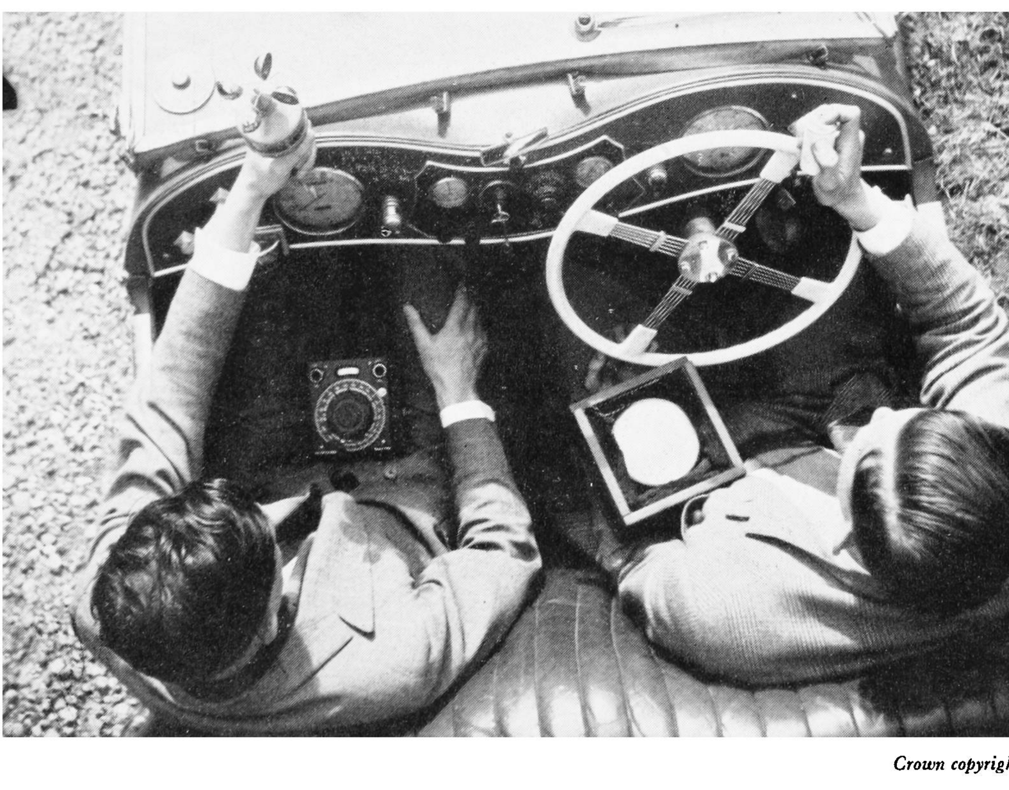
METEOROLOGICAL INSTRUMENTS USED IN A MOBILE METEOROLOGICAL SURVEY



DISPOSITION OF METEOROLOGICAL INSTRUMENTS IN A MOBILE METEOROLOGICAL SURVEY

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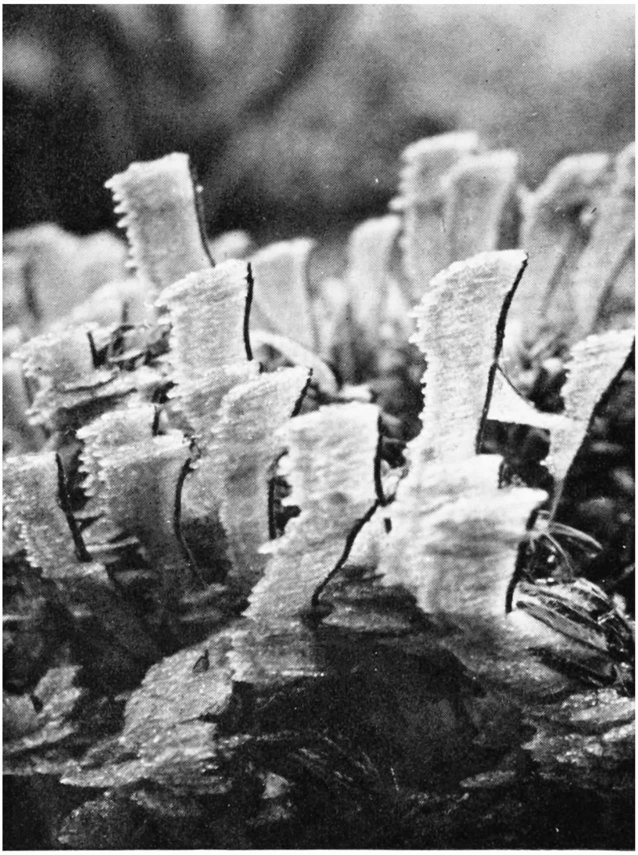

Photograph by J. M. Bayliss

RIME ACCRETION

(see p. 90)

clouds had been observed; glider pilots had soared to great heights in waves and Professor Manley, the late Terence Horsley and others had written graphic accounts of wave phenomena[1,2]. But it was Scorer's theoretical study published in 1949 that provided the frame within which all these divers observations could be fitted into a coherent pattern of lee-wave flow[3].

The "natural wavelength".—When discussing wave flow it is often expedient to describe the wind and stability characteristics of an air stream in terms of a particularly relevant parameter. A function of wind speed, U, temperature, T, the lapse rate, $\partial T/\partial z$, and the acceleration due to gravity, g, this wave flow parameter, denoted by λ, is defined by the equation

$$\lambda = 2\pi\left[\frac{g}{U^2T}\left(\frac{\partial T}{\partial z} + \Gamma\right) - \frac{1}{U}\frac{\partial^2 U}{\partial z^2}\right]^{-\frac{1}{2}}$$

where Γ denotes the appropriate adiabatic lapse rate. (λ is another version of a parameter denoted by l in much of the literature on lee waves.) The last term in the formula is often small and its omission reduces the equation to form

$$\lambda = 2\pi U\sqrt{\frac{T}{g\left(\frac{\partial T}{\partial z} + \Gamma\right)}}.$$

The significance of the stability factor may be appreciated by considering the buoyancy force on a parcel of air displaced vertically from its equilibrium level in a stable environment. It can be shown that for small displacements this force would cause the parcel to oscillate about its equilibrium level with a period of oscillation equal to

$$2\pi\left[\frac{T}{g\left(\frac{\partial T}{\partial z} + \Gamma\right)}\right]^{\frac{1}{2}}.$$

The greater the stability the shorter the period.

Now vertical oscillation plus horizontal motion leads to a wave-like flow whose wavelength is the period of oscillation multiplied by the horizontal wind speed, in other words the wave length is equal to λ. Thus λ may be regarded as the natural wavelength of the layer of air in which it is measured.

A real air stream usually contains several natural wavelengths; for example, λ may be large in a low-level layer of small stability, small (say about 2 miles) in a layer of great stability with light winds and large (say 15 miles) in a high layer of lesser stability and strong winds. In wave-flow parlance such an air stream as this is called a "three layer" air stream—three separate layers can be distinguished by values of λ . If this air stream is disturbed by crossing a mountain ridge the three layers do not oscillate up and down independently on their own natural wavelengths; this type of motion would not satisfy conditions for physical continuity at the boundaries between the layers. The wavelength of the motion which does maintain this continuity at the boundaries is a complicated function of the distribution of λ with height.

Lee-wave flow.—In 1949 Scorer devised a method of calculating not only the wavelength on which oscillations could take place in an airstream but also the two-dimensional pattern of stream-lines in an air flow crossing a mountain ridge. He computed that a train of lee waves could form downwind of the ridge provided that λ increased with height over some depth of the atmosphere. Observations by Turner[4] and others showed lee-wave effects to be commonly associated with air streams comprising stable air sandwiched between two layers of lesser stability, or more precisely, a three layer troposphere with λ smallest in the middle layer (Figure 1). These observations confirmed Scorer's criterion for the existence of lee waves but it was difficult to make quantitative tests of the calculated flow pattern itself.

A start was made by focussing observational attention on several of the distinctive features which could arise from the motion illustrated in Figure 1. Further deductions relating to diurnal variations in wave flow were made from the theoretical study.

Diurnal variations.—Theoretical study showed that when an early morning inversion was gradually transformed by insolation into an unstable layer at low levels then the lee wavelength of the air stream would increase and that subsequent cooling by radiation during the late afternoon and evening would lead to a decrease in wavelength. It could also be deduced that lee waves would be most pronounced during the morning and evening and relatively weak, or even non-existent during the early afternoon. These deduced diurnal tendencies were supported by many observations made by glider pilots and others whose business or pleasure kept them acutely aware of waves and their habits (see, for example, evidence by Manley and Roper[1,5]).

The effect of synoptic changes.—An investigation by Wallington showed that, ahead of a well marked warm front, lee waves were likely to be significant in two zones[6]. Ahead of the warm front featured in this investigation lee waves were calculated and observed to be particularly pronounced at low levels in a zone between about 150 and 250 miles ahead of the surface position of the front. Pronounced lee-wave flow was also possible at both high and low levels at distances between about 400 and 600 miles ahead of the front. Between these zones short lee waves were possible but their amplitudes would not have been significant.

This study drew attention to the short-comings of the lee-wave criterion; an increase of λ with height denoted the possibility of lee waves forming but gave no indication of the magnitude of the waves. The next step, therefore, was to examine more closely the factors controlling lee-wave amplitude in the hope that some more useful forecasting rules could be evolved. But a study by Corby and Wallington revealed the wave flow to be even more sensitive to synoptic changes than had been supposed and no simple criteria for large amplitude waves could be formulated[7].

The effect of mountain shape and size.—The study by Corby and Wallington also investigated the effect of mountain size and shape. To ease computing problems it is convenient to study lee-wave flow downwind of a long ridge whose height, h, at horizontal distance, x, from its summit is given by

$$h = \frac{Hb^2}{b^2 + x^2},$$

where H denotes the height of the ridge and b is a width parameter. The lee-wave amplitude may then be considered as the product

$$\left[Hb \exp\left(-2\pi\frac{b}{W}\right)\right] \times \left[\begin{array}{l}\text{an air-stream factor determined entirely}\\ \text{by upper winds and temperatures}\end{array}\right]$$

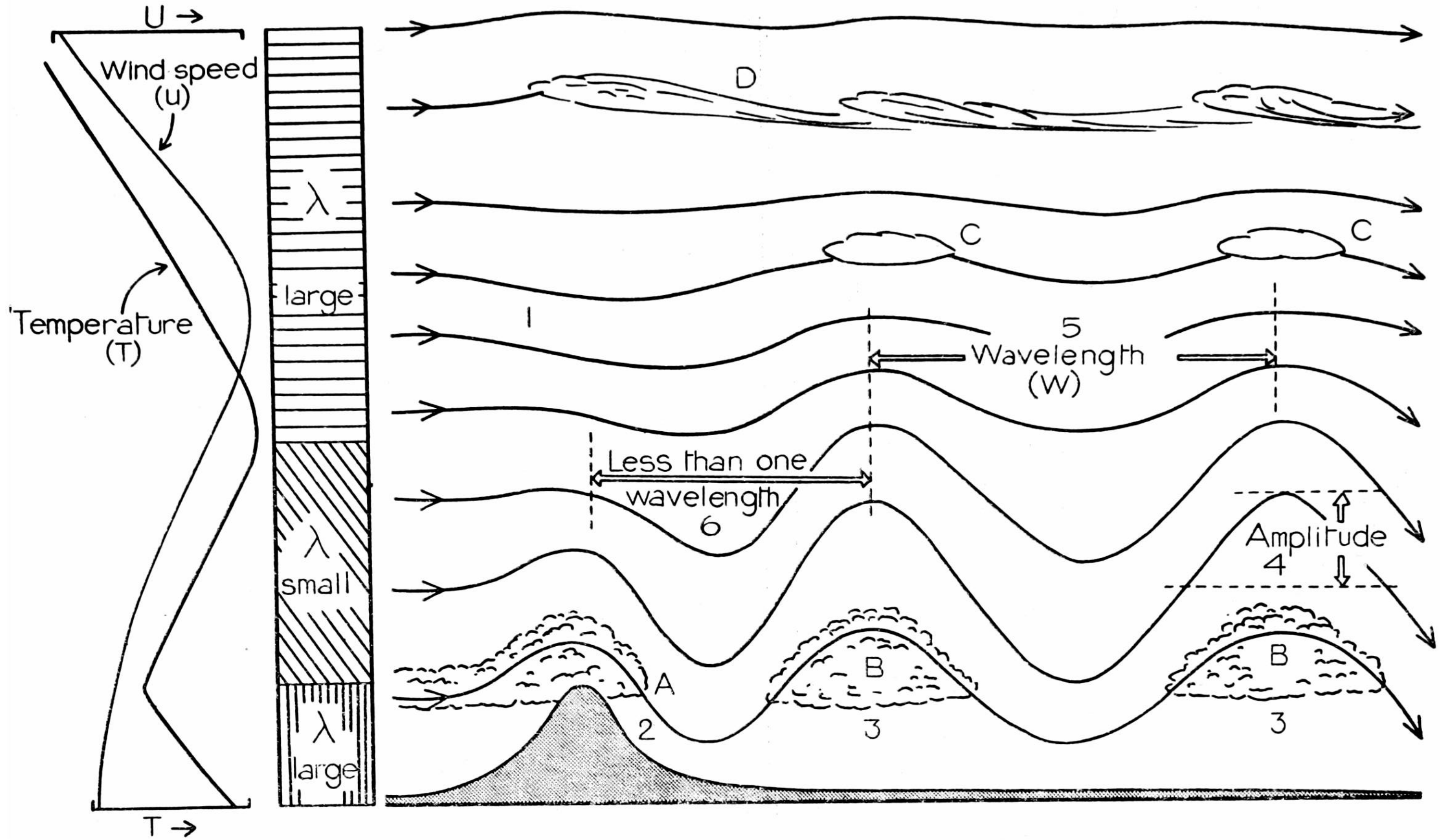

FIG. 1—FEATURES OF AIR FLOW ACROSS A LONG MOUNTAIN RIDGE

"Three layer" troposphere

1. Down draught may occur at some levels to windward of ridge. 2. Strong surface wind down lee slope. 3. Variable surface wind. 4. Maximum amplitude in stable layer. 5. Order of wavelengths: 2–20 miles. 6. First wave crest usually less than one wavelength downstream of ridge. A. Föhnwall. B. Roll cloud. C. Altocumulus lenticularis. D. Cirrus.

The first factor of the product, the mountain factor, which incorporates the lee wavelength W, reveals that the higher the ridge the bigger the wave amplitude. But the width is also important; the parameter b is incorporated in the mountain factor in such a way that, if H is kept constant, the term has a maximum when $2\pi b = W$. This means that if an air stream passes over a number of ridges all of the same height then the biggest waves will occur in lee of the ridge whose width parameter is equal to $W/2\pi$. Narrower or broader ridges will produce waves of lesser amplitude. There is, in fact, a resonance effect between the air stream and the mountain width, and on occasions this resonance even swamps the effect of mountain height. The height of a large mountain will be of little use in setting off lee waves if the mountain width is too great for resonance with the wavelength in force.

Observations of wave phenomena.—Theoretical study directed observational effort to better effect and by 1955 Pilsbury had collected and analysed 66 reports of wave phenomena encountered in flight by British European Airways pilots[8]. His analysis showed these wave effects to be associated with:

(i) a high lapse rate from ground level to at least 2,000 feet,

(ii) a stable layer (depth 800 to 10,000 feet) above the less stable air,

(iii) an upper layer of low stability,

(iv) a wind speed of at least 15 knots at the 950-millibar pressure level,

(v) a wind direction almost constant up to the top of the stable layer.

The wave effects occurred in a variety of synoptic situations. Wavelengths were of the order of 3 to 8 miles below 10,000 feet with indications of longer waves at higher levels. Vertical speeds were often 300–500 feet per minute, occasionally 700–900 feet per minute and on one occasion over 2,000 feet per minute was reported. Slight turbulence was noted on one third of the cases and moderate turbulence in two out of the 66 reports.

Some pilots gave particularly detailed accounts of the wave phenomena they encountered. A contribution of special interest was made by Captain Mason who encountered orographic wave effects with vertical speeds of more than 1,000 feet per minute over Spain[9]. The air flow containing these effects was a north-north-westerly stream with an isothermal layer from 8,000 to 11,000 feet.

In America men and equipment were available for exploring the frequently observed wave flow in lee of a Rocky Mountain range called the Sierra Nevada[10]. Using gliders, powered aircraft, radio-sonde and radar equipment this intensive field project not only supported much of the theoretical study into the subject but also revealed the order of magnitude at several features of the flow. One of the features explored by the Sierra Wave Project was the turbulent region sometimes found at low levels at wave crests. Wave cloud in this region looks like ragged stratocumulus but it harbours severe turbulence. Turbulence associated with wind shear and the variation with height of wave amplitude also occurs at high levels but this type is not usually so severe as the low-level variety.

In the British Isles intensive field study was not a practical proposition but Corby used routine radio-sonde observations for detecting wave flow[11]. His investigation strengthened the growing conviction that waves are often associated with a shallow stable layer in the lower half of the troposphere and that the vertical speeds were at a maximum in this stable layer. Furthermore he was able to deduce the wavelength of waves affecting the balloons during their ascent.

In addition to the British European Airways pilots' reports, the Sierra Wave Project, and the radio-sonde study, a number of local investigations added to the observational data collected by 1955. Turner reported an example of severe turbulence in low-level wave cloud over the Inner Hebrides; Ward described the effects of lee waves on the surface winds at Ronaldsway[12,13]. Studying the low-level turbulence in lee waves in Czechoslovakia, Förchtgott noted the tendency for some wave clouds to move slowly downstream, covering about 1 mile in 5 minutes before jumping back up stream to their initial positions[14]. Harrison illustrated this periodic movement by time lapse films taken near Denver, U.S.A.[15]

Numerical study.—With abundant observations available it became worth while to undertake the mathematical labour of a numerical study of the lee wavelength and air stream amplitude factors of a wide variety of air streams. At Dunstable a numerical study of two-dimensional flow is shedding more light on the relationship between lee wavelength and amplitude and upper winds and temperatures and on the effect of the stratosphere on lee waves in the troposphere[16].

Forecasting wave effects.—The details of orographic wave flow are very difficult to predict but forecasters can to some extent be prepared for their occurrence by recognizing the conditions favourable for wave flow in general. Broadly these conditions are those implied by the analysis of the British European Airways reports. In routine forecasting there are several observational aids which can be used to confirm the presence of wave flow but these aids cannot prove the non-existence of waves. A forecaster can say with reasonable confidence that waves associated with a stable layer will be most effective in that layer and that if waves occur in the presence of marked wind shear, such as in a jet stream, then there will probably be some turbulence. Probably the best way of attempting more than this is to calculate values of λ (using a special scale[17]) at several levels in situations of particular interest and to build up some experience at assessing the relationship between these values and the observed effects.

In addition to attempting to predict the likelihood of wave effects the forecaster can do aviators a great service by explaining to them the nature and characteristics of lee-wave flow in general. Besides producing wave cloud, turbulence, variable winds and increased icing risk, orographic wave flow can also cause fluctuations in airspeed and lead to difficulties in maintaining vertical separation of aircraft in air lanes. Altimeter errors can occur in wave flow but usually they are small and insignificant compared to the effects of vertical motion and turbulence.

The Chairman, *Dr. Stagg* opened the subsequent discussion by asking outstation forecasters to relate some of their experiences in coping with orographic wave problems.

Mr. F. Davis described the hazards to parked aircraft of sudden and erratic changes of surface wind which had been noted at Sealand. It appeared likely that these changes were due to wave flow. Was there a method of predicting the time and duration of such changes? Mr. Wallington replied that while forecasters had a reasonable chance of recognizing the general types of conditions favourable for such effects there was, at present, no practical way of predicting details.

Dr. Stewart asked what was the nature of the airflow when no waves were present. The reply suggested that waves could exist in many, if not most, air streams. When they did not occur the air stream was either convectively unstable or slow moving.

Dr. Scorer emphasized the danger of turbulence in "roll" cloud by calling attention to the exceptionally large instability which can be produced in the overturning motion in the turbulent region. He also discussed the distinction between the eddies which sometimes form on lee slopes and the "rotors" which require a stable layer for their formation.

Mr. Gloyne wondered whether hill shape and in particular the steepness of the lee slope determined the likelihood of lee eddies. Was there some steepness criterion with which to predict steady or eddying flow down the lee slope?

Mr. H. H. Lamb remembered seeing high-level wave cloud over Scotland; the position and orientation of these clouds bore no simple relationship to the topography or to the low-level winds. There appeared to be rather long waves at these high levels which may have been associated with the broad features of the high ground rather than with the smaller and more recognizable ridges.

Mr. Findlater, in reply to a query by Dr. Stagg, said that modern views on mountain air flow are mentioned in various Training School courses, the main purpose being to acquaint trainees with the nature and effects of mountain air flow.

Mr. Lee asked whether Comets flying at 55,000 feet over the Central Massif and the French Alps would be affected by orographic wave flow. In reply to this Mr. Wallington said that wave effects, including turbulence, had been reported as high as 44,000 feet in the Sierra Wave Project. Evidence suggested that long waves may not be uncommon in the stratosphere but this evidence was based mainly on theoretical study and more actual observations were needed to support or modify these deductions. The French Meteorological Service have carried out field studies of air flow over the French Alps and a preliminary report has just been published[18].

Mr. Sawyer reminded the meeting that real atmospheres and real topography are not so simple as most of the models used for numerical study. It may be impossible to set an upper limit to vertical currents when all conditions are favourable.

Mr. C. V. Smith enquiring about the effect of wave flow on contour height was told by Mr. Sawyer that variations of about 50 feet at the 500-millibar level might be expected from wave effects.

Mr. Jacobs drew attention to local wind effects near Edge Hill which would probably be worth investigating.

Mr. Richardson, asking whether or not convection could take place from the top of cloud in the wave crests, was told that such a process had been observed.

Mr. L. Jacobs wondered what had become of the model experiments. Were they now out of fashion? Mr. Wallington replied that it was practically impossible to achieve strict similarity between model experiments and a real air flow extending over appreciable vertical depth. The numerical study now being carried out could be considered as a type of model experiment in which conditions were easily controlled. Dr. Scorer added that model experiments sponsored by the Meteorological Office are being conducted at Imperial College.

Mr. Gold suggested that an elaborate field survey of the air flow across the Welsh Mountains or across the Pennines in just a few synoptic situations would be useful.

Dr. Stagg replied that a scheme such as this had been considered and rejected as economically impractical some years ago. He then summed up some of the points raised and thanked Mr. Wallington for opening the discussion.

REFERENCES

1. MANLEY, G.; The helm wind at Crossfell. *Quart. J. R. met. Soc., London,* **71,** 1945, p. 197.
2. HORSLEY, T.; New light on the standing wave. *Aeronautics, London,* **11,** 1945, p.38.
3. SCORER, R. S.; Theory of waves in lee of mountains. *Quart. J. R. met. Soc., London,* **75,** 1949 p. 41.
4. TURNER, H. S.; Standing waves and powered flight. *Met. Mag., London,* **80,** 1951, p. 106.
5. ROPER, R. D.; Evening waves. *Quart, J. R. met. Soc., London,* **78,** 1952, p. 415.
6. WALLINGTON, C. E.; Lee waves ahead of a warm front. *Quart. J. R. met. Soc., London,* **81,** 1955, p. 251.
7. CORBY, G. A., and WALLINGTON, C. E.; Airflow over mountains: the lee-wave amplitude. *Quart. J. R. met. Soc., London,* **82,** 1956, p. 266.
8. PILSBURY, R. K.; Preliminary analysis of standing-wave reports received at Northolt during the winter of 1953–54. *Met. Mag., London,* **84,** 1955, p. 313.
9. MASON, D.; Hill standing waves and safety heights. *Weather,* **9,** 1954, p. 45.
10. HOLMBOE, J., and KLIEFORTH, H.; Investigations of mountain lee waves and the airflow over the Sierra Nevada. University of California, Department of Meteorology. Final report of contract AF 19(604)—728. Los Angeles, 1957.
11. CORBY, G. A.; A preliminary study of atmospheric waves using radio-sonde data. *Quart. J. R. met. Soc., London,* **83,** 1957, p. 355.
12. TURNER, H. S.; Severe turbulence over the Inner Hebrides. *Met. Mag., London,* **81,** 1952, p. 239
13. WARD, F. W.; Helm-wind effect at Ronaldsway, Isle of Man. *Met. Mag., London,* **82,** 1953, p. 234.
14. FÖRCHTGOTT, J.; The active turbulent layer in lee of mountain ridges. *Schweiz. Aerorev., Berne.,* **32,** 1957, p. 324.
15. HARRISON, H. T.; Synoptic features of the mountain wave at Denver, Colorado. *United Air Lines Met. Circ., Denver,* **41,** 1956.
16. WALLINGTON, C. E., and PORTNALL, J.; A numerical study of the wavelength and amplitude of lee waves. *Quart. J. R. met. Soc., London,* **84,** 1958, p. 38.
17. WALLINGTON, C. E.; A lee-wave scale. *Quart. J. R. met. Soc., London,* **79,** 1953, p. 545.
18. BÉRENGER, M., and GERBIER, N.; Les mouvements ondulatoires à Saint Auban-sur-Durance. *Monographie de la Météorologie Nationale, Paris,* 1957.

LETTERS TO THE EDITOR

Night cooling under clear skies at Wittering

Further study of the temperature graphs produced by Mr. Pollard in Fig. 1 of his article[1] suggests that his conclusion that there is no evening temperature discontinuity at Wittering is not entirely correct. If the temperatures for these occasions are plotted from mid-afternoon instead of from 1700–1800 G.M.T., as in Fig. 1, it is obvious that on two of the occasions there was a discontinuity (approximately 4°F./hr. changing to 2°F./hr.). The time was 1800 G.M.T., the recognized time for early October.

It is also noted that the temperatures at this time would have been readily predictable by the discontinuity method, as shown overleaf:—

Date	T_{max}	T_d at time of T_{max}	T_r (calculated)	1800 G.M.T. temperature
	°F.	°F.	°F.	°F.
October 8, 1955	69·0	58·0	62·5	61
October 10, 1955	67·0	51·0	58·0	58
October 12, 1955	64·0	52·5	57·2	57

In this table T_r was calculated using the Mildenhall equation $T_r = \frac{1}{2}(T_{max} + T_d) - 1{\cdot}0$°F., on the assumption that Wittering and Mildenhall might not differ materially. The Daily Aerological Records show that the three afternoons were "non-inversion" having regard to Wittering. The case of October 12, 1955 shows that the forecast T_r was reached at 1800, despite the fact of having no marked discontinuity at screen level.

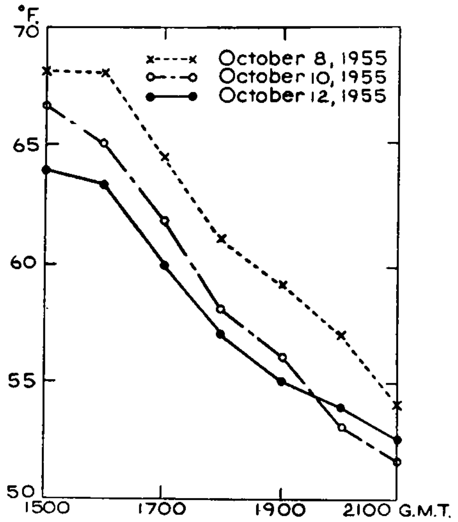

FIG. 1—EVENING TEMPERATURES AT WITTERING

It is thought the difficulty at stations like Wittering is not that the discontinuity does not occur, but that in the screen-level observations it often appears insignificant compared with some of the random irregularities which are liable to occur later in the night due to air-mass heterogeneities. At Exeter hourly readings are being made of a thermometer (with the bulb screened) exposed at the grass level. These confirm that the evening change in cooling rate is much more pronounced at grass level than in the screen. Although at Exeter the discontinuity is generally clearly recognizable at screen level, there are a few occasions when it is only shown at grass level. An example is given in Fig. 2. This shows that the discontinuity (from 12°F./hr. to 2°F./hr.) occurred at grass level at the time for early September given by the published Exeter curve[2], although there was no corresponding change at screen level. As in the case of October 12, 1955 at Wittering, the screen-level temperature at the time of the grass-level discontinuity corresponded very closely with the theoretical value (forecast T_r 59·9°F., actual 1900 G.M.T. temperature 60·2°F.). This suggests that if at some sites the discontinuity cannot readily be discerned at screen level it may still be quite pronounced nearer the ground. Whether or not there is a marked change of rate in the screen, the screen temperature at that time is significant for forecasting purposes, because a different set of conditions becomes operative near the ground.

In the forecasting technique proposed by Mr. Pollard it is considered that the adoption of constants, which give the best fit for Wittering and which vary seasonally, improves McKenzie's formula. Allowing for this, the McKenzie method still seems open to two criticisms. It does not provide for the fact that the lower the initial temperature of a period of cooling the smaller, in general, is the amount of cooling. In the T_r/T_{min} cooling curves this is brought out by the shape of the curves, e.g. at Northolt in winter, if T_r is 50°F. the subsequent

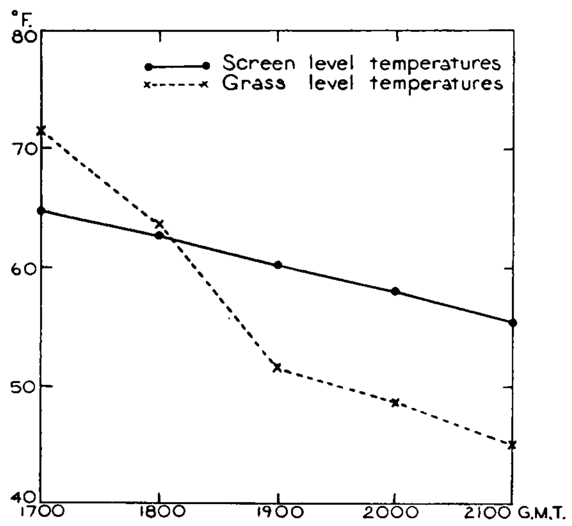

FIG. 2—EVENING TEMPERATURES AT EXETER, SEPTEMBER 7, 1955

cooling is on average 18°F.; if T_r is 30°F. it is only 11°F. Secondly, McKenzie's formula does not allow for the difference between cases in which a subsidence inversion is or is not present near the ground. In the T_r/T_{min} method this is allowed for in the regression equations for T_r, and also, at some stations, in the curves expressing the T_r/T_{min} relations. Since the inversion case dealt with here is obviously identical with the inversion fog case reported at Cardington by K. H. Stewart[3], in which early night cooling affects a deeper layer than usual and in which vertically thick fog forms suddenly, it is not a matter which the aviation forecaster can ignore.

With regard to the results quoted by Mr. Pollard in Table II, it is only possible to make comparisons by using the mean square difference between the forecast and actual T_{min}. At Northolt, using Northolt curves,[4] a test on thirty clear nights gave mean square difference 1·28°F. At Weston Zoyland, using Exeter curves[2] together with the correction:— T_{min} (Weston Zoyland) = T_{min} (from Exeter curves) − 0·9°F., a test on thirty-two clear nights gave mean square difference 1·40°F. The difference between these results and Mr. Pollard's mean square difference 2·15°F. is presumably due to the parameters mentioned above which McKenzie's method does not take into account.

It is considered that, now that the general form of the regression equations for T_r and the shape of the T_r/T_{min} curves has been well established, the main requirement for local study appears to be in marginal matters such as the effective dates for introduction of winter and summer curves on different sites. For use in fog forecasting there is much scope for preparation of curves similar to those of Mr. Pollard's Fig. 2, but covering the period from the time of the evening discontinuity to sunrise for the separate seasons, and for different ranges of gradient wind speed (gradient wind in preference to surface wind). There should be no need to separate according to wind direction, since with an on-shore wind the effects of relatively warm or cold sea should be taken into account at the outset, in the selection of the most representative maximum temperature and the corresponding dew-point.

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REFERENCES

1. POLLARD, K.; A preliminary study of night cooling under clear skies at Wittering. *Met. Mag., London*, **87**, 1958, p. 12.

2. SAUNDERS, W. E.; Night cooling under clear skies, Exeter Airport. *Met. Mag., London*, **83**, 1954, p. 9.

3. STEWART, K. H.; Radiation fog. Investigations at Cardington, 1951–54. *Met. Res. Pap., London*, No. 912, p. 8.

4. SAUNDERS, W. E.; Some further aspects of night cooling under clear skies. *Quart. J. R. met. Soc., London*, **78**, 1952, p. 603.

Rime accretion

The accompanying photograph of rime accretion on the dead flower stalks of a rock plant was taken at 1000 G.M.T. on December 22, 1956 at Bedale in the North Riding of Yorkshire. At this time the rime had grown to a length of 1 inch on the south-eastern sides of the stalks, which were 3–5 inches high and averaged one sixteenth of an inch in diameter. The rime, which was dirty white in colour due to industrial smoke mixed with the fog, was firm and hard, probably due to the fluctuation of the temperature about the freezing point, thus causing alternate partial melting and freezing.

The freezing fog which caused this accretion had been persistent since the evening of December 18, with visibility in the range 30–100 yards for the majority of the time; the air temperature being between 27 and 33 degrees Fahrenheit. The surface wind velocity varied from calm to 10 knots from between 090 and 170 degrees.

The photograph was taken on a Soft Gradation Panchromatic plate and was given an exposure of 2 seconds with lens aperture f.11.

J. M. BAYLISS

NOTES AND NEWS

The Abnormal Summer of 1956 at Bahrain

There were several features of the weather at Bahrain during the summer of 1956 which were unusual and deserve recording.

May was a cold month: it was the coldest since systematic daily records began at Muhurraq Airport in 1946; the average temperature was $4\frac{1}{2}$°F. below the normal for the ten-year period 1946 to 1955. It was also the windiest on record, with abnormally strong north-westerly winds—gusts of 30 knots or more being recorded on seven days. The period of strong north-westerly winds, known locally as the 40-day Shamal, usually starts in June and continues into July.

June was 3°F. colder than normal, but the outstanding feature of the month was the thick dust haze during the first week. This thick dust haze originated from duststorms over southern Iraq and persisted over Bahrain and the Persian Gulf area from the 2nd to the 6th. Towards the end of the period the dust cloud extended from southern Iraq as far south as the southern coast of Arabia and as far east as Karachi. This exceptional spell, according to local residents, was the worst in living memory.

July was characterized by light and variable winds instead of the usual north-westerlies and by abnormal cloud amounts (daily average 3·2 oktas compared with an average of 0·7 oktas for the previous ten years). These clouds were of the altocumulus–altostratus or altocumulus castellanus types. No rain was actually recorded at the Meteorological Office, but a little rain fell at Manama some three miles away at 4 a.m. on July 30. No rain has ever been recorded during the summer months since observations began at the Airport. August was normal in all respects except that the maximum temperature of 113°F. on the 5th was the highest ever recorded. September was apparently normal in all respects.

It is probable that the weather during the summer of 1956 was abnormal over a large part of the neighbouring region of the Middle East. Certainly there were some interesting and unusual aircraft reports received during July. A selection of these is given.

July 23, R.A.F. Pembroke (Flying Officer Watt), flight Sharjah to Ibri (40 miles north-east of Fahoud), p.m.: Cumulonimbus whole route with heavy rain. Flood water on the desert isolated the airstrip at Ibri.

July 16, Aryana, flight Bahrain to Kabul: Towering cumulonimbus in all directions around Kandahar, tops generally 13,000 feet, many thunder heads above.

July 25, British Overseas Airways Corporation, Cairo to Bahrain p.m., flight level 15,500 feet: At 28°N. 43°E. 5 oktas layered altocumulus with isolated cumulonimbus top 23,000 feet. 8 oktas altostratus and rain at 28°N. 44°E.

It is difficult to give any satisfactory explanation of these events other than to say that they were due to the unusually early onset of the Indian Monsoon, and to its penetration far northwards into the subtropical belt to an extent hitherto unrecorded.

F. E. DINSDALE

[The unusual amount of rainfall at Sharjah, Oman, Persian Gulf in the summer of 1956 was described, with a photograph of a line of cumulonimbus clouds, by Mr. E. W. Smith in the May 1957 number of the *Meteorological Magazine*. Ed. M.M.]

REVIEWS

Empire Forestry Review, **36**, 1957, No. 1, London.

The March 1957 number of the *Empire Forestry Review* includes two articles of meteorological interest. Mr. M. V. Laurie, Chief Research Officer, Forestry

Commission, writes on the effect of forests in water catchment areas on the water losses by evaporation and transpiration and Mr. A. Bleasdale of the Meteorological Office on the physicist's approach to problems of water loss from vegetation. Mr. Laurie is satisfied that Penman's evaporation formula is accurate over wide areas of mixed vegetation but considers that experiments are highly desirable for water supply planning to ascertain the differences in the evapo-transpiration from different types of vegetation, notably the differences between the water loss from forests and from areas of short vegetation. He states that it has been suggested that evapo-transpiration is 10 per cent higher from trees than from grass, a very large difference to the water engineer.

The methods suggested are:

(i) comparison of rainfall, run-off etc. from two similar areas neither of which is forested, and then growing trees on one of them and comparing rainfall and run-off again, and

(ii) exact measurement of the water balance of two areas covering rainfall, fog drip, run-off, accumulation of water in the soil with lysimeters. As Mr. Laurie remarks these are costly in time and effort and uncertain in result.

Mr. Bleasdale agrees that there can never be a comprehensive instrumental comparison between the hydrological balance of forested and open spaces since measurements of the terms of the water balance equation, in particular of the evaporation loss, must be based on sampling methods. He accordingly devotes his paper to a review of the existing information on the physical factors concerned. The experimental evidence is contradictory, some workers in different countries and climates having found little difference between types of vegetation cover and others appreciable differences. Mr. Bleasdale points out the opposing factors concerned such as the larger area of exposed surface at the windward side of a forest followed by a reduction of evaporating power in the damper air as it moves inward, and the "fog drip" in fog or cloud on the windward edge followed again by a downwind compensating effect of higher evaporation into air cleared of fog. He believes that the methods of calculating evapo-transpiration based on Penman's work (with energy balance consideration dominating the broad-scale results) will remain valid over large forested areas but that there may be scope for arranging vegetation types to take advantage of the edge processes.

G. A. BULL

Geophysical Institute, Faculty of Sciences, University of Zagreb, Yugoslavia.

We have received three papers written in this Institute as follows:

Geoph. Inst. Papers, IIIrd Series, No. 5. On the discontinuity in the curve of the fall of temperature on cloudless nights. By Ivo Penzar.

Geoph. Inst. Papers, IIIrd Series, No. 7. Microclimatological investigations of the Geophysical Institute made at Krizevci in 1953. By Ivo Penzar.

Rad jug. Akad. Znam. Umj. **302,** 1956. A method of reducing the barometer to mean sea level. By B. Maksic.

They are all in Croat with long German summaries.

The first of these is of most interest. The author compares the differences in occurrence of times of the evening "cooling curve" discontinuity at three stations, one the Zagreb Observatory on rising ground at Gric, height 162·5 metres, one in the Botanic Garden in the plain 1 kilometre away at 116 metres, and the third the mountain observatory at Sljeme, 999 metres. The discontinuity occurred at Sljeme at most ½ hours, in the Botanic Garden ¾ to 1½ hours, and at Gric an hour or more after sunset. The difference between the Botanic Garden and Gric is ascribed to the nocturnal fall of temperature beginning earlier in the plain than on small hills. It is stated that thermographs used in the microclimatic investigation at Krizevci showed that discontinuity occurred earlier in valleys than on slopes or hills. It was also found at Krizevci that the discontinuity occurred 8 minutes later in the layer up to 1 metre above the ground than on the surface but in the layer 1 to 2 metres the delay was only 6 minutes. This effect may play a part at Gric where the thermograph is on a north wall 4 metres above the surface. Formulae are given for computing the temperature at the time of discontinuity from midday temperatures and humidities and the night minimum from the "discontinuity" temperature. The writer rejects the dew-point and transpiration theories of the discontinuity but has no alternative to offer.

G. A. BULL

Fortschritte in der meteorologischen Forschung seit 1900. By B. Neis. 9 in. × 6 in., pp. xviii + 238, *illus.*, Akademische Verlagsgesellschaft M.B.H., Frankfurt am Main, 1956. Price: 28 *DM.*

This book, based on a course of lectures given in 1953–54 at the Free University of Berlin, is stated in the preface to be an account of those researches of the present century which have contributed to the development of meteorology as a branch of mathematical physics. Papers are quoted in the book to 1953.

The two major previous histories, those of Sir Napier Shaw in Volume I of the *Manual of Meteorology* (1931) and K. Schneider Carius in *Wetterkunde Wetterforschung* (1955), began with the Babylonians and so could devote only a relatively small part of their texts to the 20th century. Dr. Neis's book is naturally much fuller than theirs.

Dr. Neis describes the history of each part of the subject more or less separately. The book is divided into four parts covering subjects as follows:

Part I: General state of physics and meteorology in 1900 and changes in basic physical ideas (causality etc.) since then.

Part II: Aerology and its methods, aerosols, synoptic models, wind structure and turbulence, physics of radiation.

Part III: Weather as the process of transformation of solar radiation into other forms of energy covering matters such as radiative equilibrium theory, vorticity, general circulation.

Part IV: Weather forecasting, climatology and climatological services.

There are good photographs of eighteen eminent meteorologists including Sir Napier Shaw and W. H. Dines.

1900 is a good time to start a history as it was just before the first flowering of upper air observation with its discovery (1902) of the tropopause. The author has well succeeded in his enormous task of giving an account of the development of meteorology from, as Sir D. Brunt has said, an arithmetical exercise to a branch of physics. Some sides are more thoroughly covered than others. Radiation and aerology are thoroughly treated but the post-1945 history of cloud physics is scarcely touched on. In dynamical meteorology the account extends to Rossby's constant-vorticity and Sutcliffe's development theorems but there is no mention of Charney. There is a tendency to give more space to German than foreign meteorologists. Thus the history of ozone research makes no mention at all of Dobson's work.

There are numerous references to accounts of the state of knowledge of various parts of the subject. Thus for numerical forecasting there is a reference to a review by K. Hinkelmann and others published in 1952.

G. A. BULL

HONOURS

The following awards were announced in the New Year Honours List, 1958:

O.B.E.

M. H. Freeman, M.Sc., Principal Scientific Officer, Meteorological Office.

M.B.E.

W. R. Hanson, B.Sc., Senior Experimental Officer, Meteorological Office.

METEOROLOGICAL OFFICE NEWS

Retirement.—*Mr. H. T. Smith*, Chief Experimental Officer, retired on 28 January, 1958. He joined the Office as a Boy Clerk in April 1914 in the Administrative Division. He was transferred to the Marine Division in May 1915 but shortly afterwards he joined the Civil Service Rifles for service during the First World War. On his return to the Office in February 1919 he resumed duty in the Marine Division where he remained for the next 22 years. In 1941 he was posted to the Instruments Division and he served in that Division until his retirement. From December 1956 he was Head of the Branch dealing with instruments supply.

Obituary.—*Miss D. K. Lamport.*—We regret to learn of the death on 20 January, 1958 of Miss D. K. Lamport who until 1937 was a temporary assistant in the British Climatology Division.

THE WEATHER OF NOVEMBER, 1957

Northern Hemisphere

A broad trough of low pressure in mid-Atlantic extended from the Icelandic depression, which was in the normal position, to latitude 40°N. Pressure was higher than average over an area which extended from Iceland across the Faroe Islands into central Europe. These higher pressures were associated with blocking anticyclones to the west and north of the British Isles during the period from the 8th to the 15th of the month and near Spain from the 17th to the 29th. The low pressure area centred near Spitsbergen, although less deep than usual, extended into northern Russia. The main Siberian anticyclone was divided; one centre being just east of the Sea of Aral and the other in eastern Siberia. The Azores anticyclone was apparent only as a ridge and the area of maximum pressure was further to the south than usual. The North Pacific high was a little further east than the normal position and extended into the United States.

The largest pressure anomalies were + 8 millibars over Scotland and southern Norway. In North America the mean pressure distribution for the month was near normal. There were, however, areas of positive pressure anomaly in the west of the United States and Canada and also in the Baffin Island area. A slight negative pressure anomaly in the Great Lakes region was associated with an eastward displacement of the anticyclone normally situated a little to the south. The pressure distribution over the Arctic during November was nearly normal but the central pressure of the anticyclone extending north from north-east Siberia was + 8 millibars above normal.

In the Atlantic–European sector, blocking produced meridional rather than zonal flow and the normal westerly flow across the Atlantic between latitudes 40°N. and 60°N. was interrupted.

The largest area of negative temperature anomaly was in north Siberia. Centres of positive temperature anomaly of 3°C. occurred in Russia at the southern extremity of the Ural Mountains, over the west of Hudson Bay, in New Mexico and in the West Indies. The mean temperature for the month was more than 5°C. above normal in Alaska, Manchuria, Baffin Island and the Kamchatka Peninsula.

Precipitation exceeded the normal over northern Europe and also over some Mediterranean lands. Rainfall was greater than normal over most parts of North America although the weather was drier than usual along the west coasts of the United States and Canada. In India rainfall was generally less than average except in coastal regions and in West Pakistan.

WEATHER OF JANUARY 1958

Great Britain and Northern Ireland

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

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Percentage of average	No. of days difference from average	Percentage of average
	°F.	°F.	°F.	%		%
England and Wales ...	61	−3	−0·9	98	−1	108
Scotland	62	−7	−1·7	100	0	110
Northern Ireland ...	56	9	−1·1	100	−1	128

RAINFALL OF JANUARY 1958

Great Britain and Northern Ireland

County	Station	In.	*Per cent of Av.	County	Station	In.	*Per cent of Av.
London	Camden Square Gdns.	2·26	100	*Carm.*	Pontcrynfe	4·56	67
Kent	Dover	3·80	136	*Pemb.*	Maenclochog, Ddolwen B.	4·73	67
,,	Edenbridge, Falconhurst	3·87	122	*Radnor*	Llandrindod Wells	4·38	96
Sussex	Compton, Compton Ho.	5·21	123	*Mont.*	Lake Vyrnwy	6·83	85
,,	Worthing, Beach Ho. Pk.	4·38	149	*Mer.*	Blaenau Festiniog	9·29	73
Hants.	St. Catherine's L'thouse	4·48	133	,,	Aberdovey	3·64	84
,,	Southampton, East Pk.	4·64	135	*Carn.*	Llandudno	2·66	90
,,	South Farnborough	2·41	89	*Angl.*	Llanerchymedd	3·21	75
Herts.	Harpenden, Rothamsted	2·76	102	*I. Man*	Douglas, Borough Cem.	5·45	109
Bucks.	Slough, Upton	2·82	117	*Wigtown*	Newton Stewart	5·40	95
Oxford	Oxford, Radcliffe	3·54	150	*Dumf.*	Dumfries, Crichton R.I.	5·23	110
N'hants.	Wellingboro' Swanspool	2·55	111	,,	Eskdalemuir Obsy.	6·45	85
Essex	Southend W.W.	2·03	109	*Roxb.*	Crailing	1·62	67
Suffolk	Ipswich, Belstead Hall	2·51	115	*Peebles*	Stobo Castle	3·68	84
,,	Lowestoft Sec. School	2·19	99	*Berwick*	Marchmont House	1·91	66
,,	Bury St. Ed., Westley H.	2·40	103	*E. Loth.*	N. Berwick	0·85	40
Norfolk	Sandringham Ho. Gdns.	2·86	114	*Midl'n.*	Edinburgh, Blackf'd H.	1·37	56
Dorset	Creech Grange	4·95	118	*Lanark*	Hamilton W.W., T'nhill	4·43	99
,,	Beaminster, East St.	4·94	113	*Ayr*	Prestwick	3·32	90
Devon	Teignmouth, Den Gdns.	3·57	95	,,	Glen Afton, Ayr San.	7·54	109
,,	Ilfracombe	3·92	95	*Renfrew*	Greenock, Prospect Hill	7·27	93
,,	Princetown	9·06	84	*Bute*	Rothesay, Ardencraig	7·65	127
Cornwall	Bude	3·48	94	*Argyll*	Morven, Drimnin	7·63	112
,,	Penzance	6·06	121	,,	Poltalloch	6·33	99
,,	St. Austell	6·74	120	,,	Inveraray Castle	8·06	77
,,	Scilly, St. Mary	4·02	113	,,	Islay, Eallabus	6·51	113
Somerset	Bath	2·60	87	,,	Tiree	5·73	121
,,	Taunton	2·42	81	*Kinross*	Lock Leven Sluice	2·26	60
Glos.	Cirencester	3·25	97	*Fife*	Leuchars Airfield	1·68	68
Salop	Church Stretton	3·08	87	*Perth*	Loch Dhu	10·41	103
,,	Shrewsbury, Monkmore	1·72	72	,,	Crieff, Strathearn Hyd.	4·23	95
Worcs.	Worcester, Diglis Lock	1·96	77	,,	Pitlochry, Fincastle	2·51	60
Warwick	Birmingham, Edgbaston	2·61	88	*Angus*	Montrose Hospital	3·46	140
Leics.	Thornton Reservoir	2·72	102	*Aberd.*	Braemar	3·77	92
Lincs.	Cranwell Airfield	2·14	103	,,	Dyce, Craibstone	3·52	116
,,	Skegness, Marine Gdns.	1·99	95	,,	New Deer School House	5·07	163
Notts.	Mansfield, Carr Bank	2·64	99	*Moray*	Gordon Castle	3·19	135
Derby	Buxton, Terrace Slopes	5·38	98	*Inverness*	Loch Ness, Garthbeg	3·20	67
Ches.	Bidston Observatory	2·45	96	,,	Fort William	7·69	77
,,	Manchester, Ringway	3·00	100	,,	Skye, Duntulm	7·24	124
Lancs.	Stonyhurst College	3·53	71	,,	Benbecula	7·74	164
,,	Squires Gate	3·30	103	R. & C.	Fearn, Geanies	1·78	95
Yorks.	Wakefield, Clarence Pk.	2·49	98	,,	Inverbroom, Glackour	6·59	104
,,	Hull, Pearson Park	2·17	92	,,	Loch Duich, Ratagan	10·89	118
,,	Felixkirk, Mt. St. John	2·50	89	,,	Achnashellach	11·83	133
,,	York Museum	2·24	96	*Suth.*	Stornoway	6·74	161
,,	Scarborough	2·96	117	*Caith.*	Lairg, Crask	...	...
,,	Middlesbrough	1·58	74	,,	Wick Airfield	4·10	140
,,	Baldersdale, Hury Res.	2·88	73	*Shetland*	Lerwick Observatory	5·61	124
Nor'l'd	Newcastle, Leazes Pk.	1·67	67	*Ferm.*	Belleek	5·39	115
,,	Bellingham, High Green	2·51	69	*Armagh*	Armagh Observatory	3·40	104
,,	Lilburn Tower Gdns.	2·71	93	*Down*	Seaforde	3·62	83
Cumb.	Geltsdale	2·96	85	*Antrim*	Aldergrove Airfield	3·45	94
,,	Keswick, High Hill	6·31	94	,,	Ballymena, Harryville	4·34	101
,,	Ravenglass, The Grove	4·50	102	*L'derry*	Garvagh, Moneydig	5·27	127
Mon.	A'gavenney, Plâs Derwen	3·94	77	,,	Londonderry, Creggan	5·25	117
Glam.	Cardiff, Penylan	4·23	92	*Tyrone*	Omagh, Edenfel	4·03	93

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