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RELATION OF ATMOSPHERIC HUMIDITY AT LOW LEVELS OVER THE SEA TO WIND FORCE AND THE DIFFERENCE IN TEMPERATURE BETWEEN AIR AND SEA

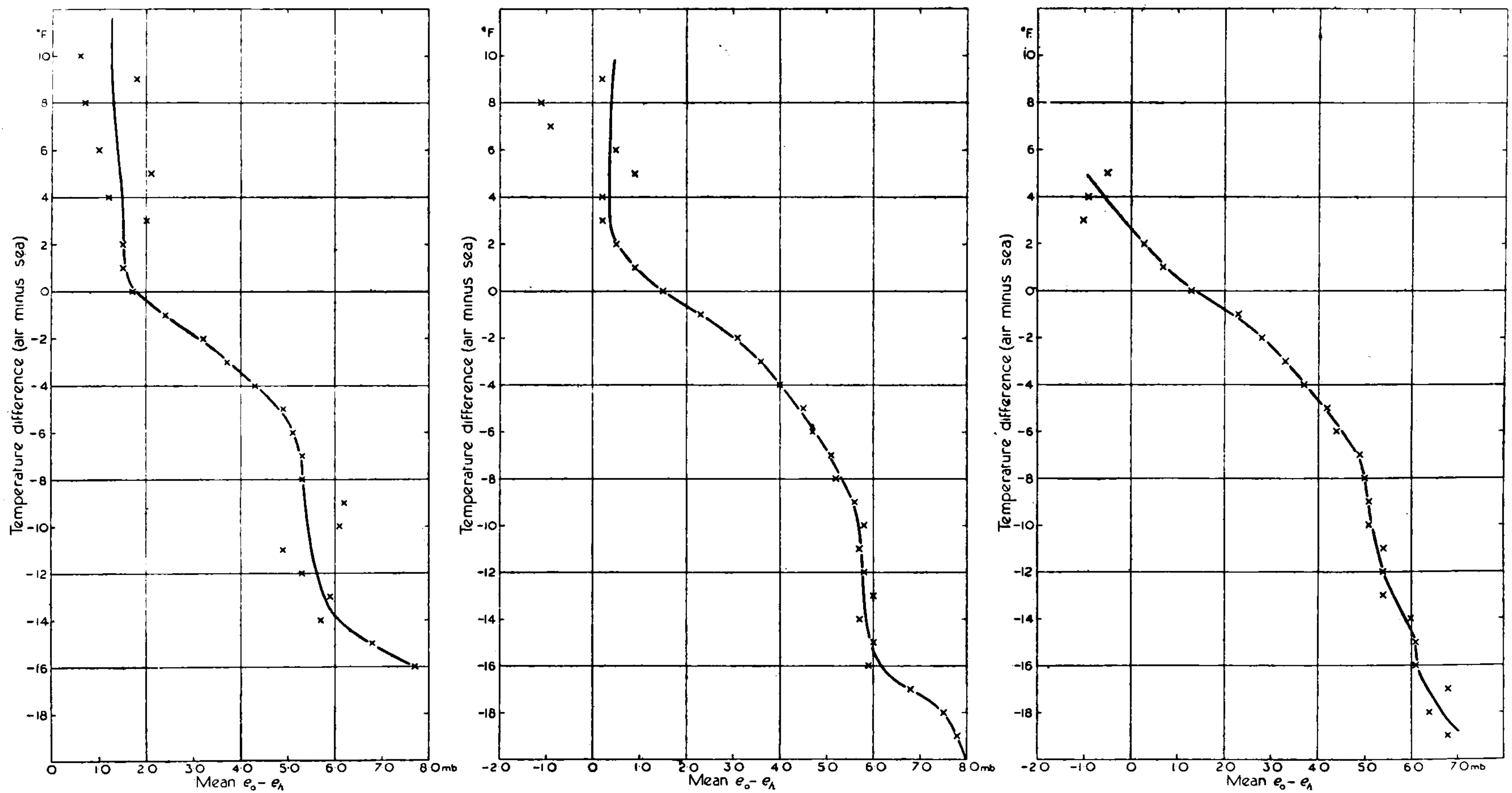
By A. H. GORDON, M.S.

The water vapour that evaporates from the surface of the sea passes first into a laminar layer about 1 mm. thick. Molecular diffusion alone transports water vapour in this layer for no turbulence exists at this level. Above this skin layer, a turbulent boundary layer extends upwards about 100 m., characterized by a logarithmic variation of wind with height and transport by eddy diffusion. Brunt[1] deduces an approximate relation for the height z to which sea-surface conditions will have diffused in time t given by

$$z^2 = 4kt$$

where k is the coefficient of eddy diffusion of the property diffused. Taylor deduced a value of 10^3 for heat diffusion under stable conditions and Brunt quotes 10^5 for "more normal conditions". With stable conditions Taylor found k increased from 1×10^3 with wind force 2 to 3×10^3 with wind force 3. The vertical transfer of heat and water vapour by eddy diffusion is therefore seen to be a function of both lapse rate and wind force.

Vapour pressure.—Tunnell[2] has derived an empirical linear relation between $e_0 - e_h$ and $T_s - T_h$ where e_0 is the saturation vapour pressure at the sea-surface temperature T_s, and e_h is the vapour pressure at the level of the ship's bridge at temperature T_h. It is obvious that these two quantities are related because they are not independent variables; e_0 is dependent on T_s and e_h is limited by its saturation value at T_h. In order to test the validity of Tunnell's linear relationship curves have been drawn (in Fig. 1) of the mean value of $e_0 - e_h$ for each individual whole degree (Fahrenheit) temperature difference (air minus sea) for the three wind-force groups 0–3, 4–6 and >6. All British ocean-weather-ship observations up to the end of 1950 have been used in this analysis. The curves for wind forces 0–3 and 4–6 are fairly similar. A relation approximating to linear occurs from 0° to −6°F. temperature difference (air minus sea) for wind-force group 0–3, and from 3° to −10°F. temperature difference for wind-force group 4–6. Beyond these limits the quantity $e_0 - e_h$ tends to change less markedly, and remains relatively constant as the sea gets increasingly cold with respect to the air. The physical basis for this empirical result can be explained on the grounds that the vertical transfer of water vapour is less under very stable conditions than under unstable conditions, since the coefficient of eddy diffusion decreases with increasing stability. Fig. 1 shows that the curve appears to approximate a linear relation



Wind-force group 0–3 | Wind-force group 4–6 | Wind-force group >6

FIG. I—RELATIONSHIP BETWEEN MEAN $e_o - e_h$ AND THE TEMPERATURE DIFFERENCE (AIR MINUS SEA) FOR 3 WIND-FORCE GROUPS more nearly for wind-force group>6 throughout the temperature-difference range, although there are no values of temperature difference greater than +6°F. to test the relation beyond that limit. This result may be explained on the grounds that strong winds so increase mechanical turbulence near the sea surface, particularly because of the roughness of the sea surface, that under stable conditions water vapour is transported vertically to a greater extent than when the wind is less strong.

Fig. 2 shows the pattern of $e_0 - e_h$ as a function of temperature difference and wind force. Mean values of $e_0 - e_h$ based on less than 10 observations have been neglected in drawing the pattern. The pattern shows that the mean value of $e_0 - e_h$ increases with increasing warmth of the sea with respect to the air and with decreasing wind force.

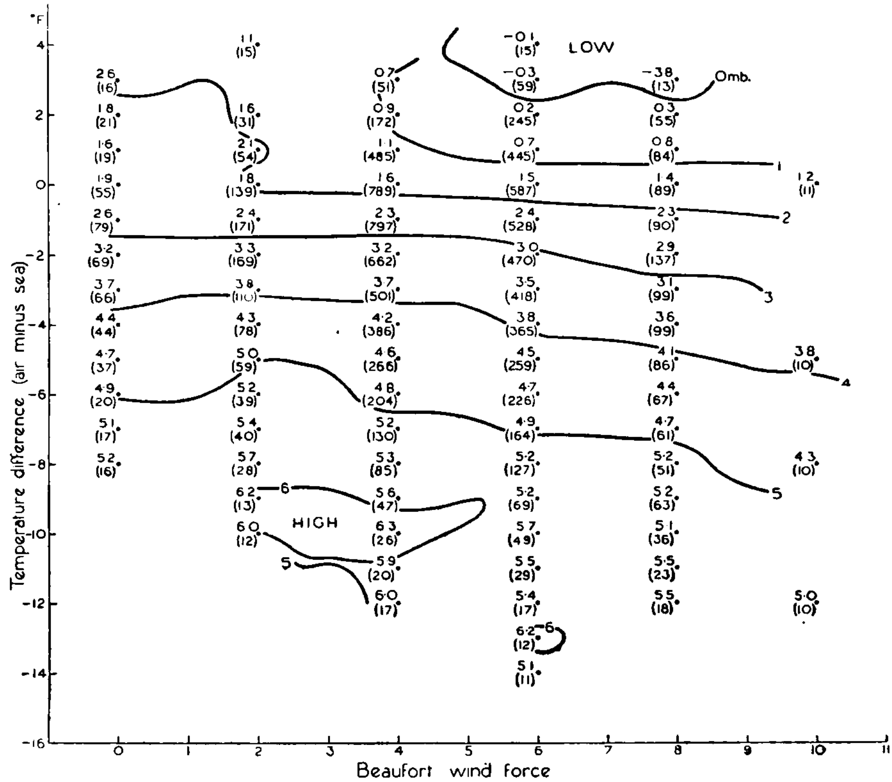


FIG. 2—MEAN VALUES OF $e_0 - e_h$ EXPRESSED AS A FUNCTION OF TEMPERATURE AND WIND FORCE

The numbers in brackets indicate the numbers of observations.

From these results it is clear that care must be exercised in using an empirical linear relation for obtaining e_h irrespective of the temperature difference or the wind force.

Tables, too bulky for publication in the *Meteorological Magazine*, have been prepared in the Meteorological Office, which give the mean vapour pressure for every combination of air and sea temperature observed at the British ocean weather stations.

Relative humidity.—An analysis was made of all British ocean-weather-ship observations up to the middle of January 1951 to determine the distribution of relative humidity as a function of the wind force and temperature difference (air minus sea). The observations were tabulated in groups comprising all combinations of wind force and one degree (Fahrenheit) temperature differences (air minus sea); 50 percentile and 10 percentile values of relative humidity were then computed for each combination and plotted. The isopleths drawn through these values illustrate a pattern of the distribution of relative humidity as a function of the two variables concerned. Patterns showing the percentage frequency of observations within specified 5-per-cent. ranges of relative humidity for each wind force and each (air minus sea) temperature difference were also drawn, together with a curve showing the frequency distribution of all observations within each 5-per-cent. range.

Previously an analysis had been made of the distribution of relative humidity as a function of wind force and wind direction only[3].

Analysis of observations.—The distribution pattern of the 50-percentile value of relative humidity aboard ship is shown in Fig. 3 as a function of wind force and air-minus-sea temperature difference. Values based on less than 10 observations have been disregarded in drawing the pattern. The pattern shows a belt of high relative humidity when the air is the same temperature as or slightly warmer than the sea. It shows a region of low relative humidity with light winds when the air is much colder than the sea, and another less well defined region with light winds when the air is considerably warmer than the sea. The relative humidity tends to increase with increasing wind strength, particularly when the temperature difference is large, either positive or negative.

Fig. 4 shows the 10-percentile frequency pattern of relative humidity also as a function of wind force and temperature difference. Maximum values

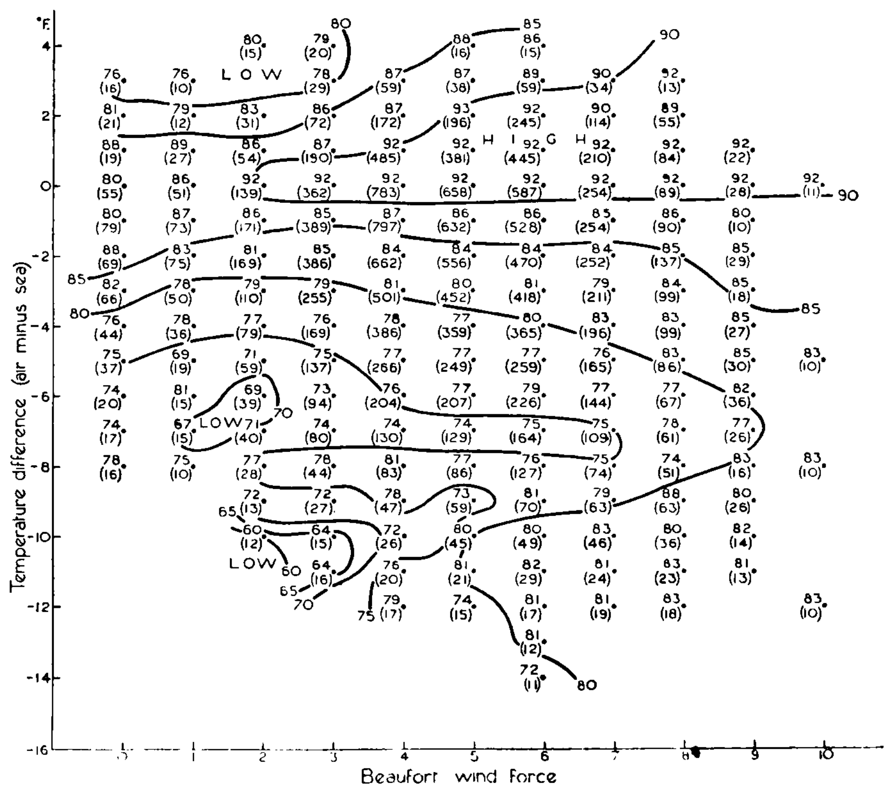


FIG. 3—DISTRIBUTION PATTERN OF 50-PERCENTILE VALUES OF RELATIVE HUMIDITY

The numbers in brackets indicate the numbers of observations.

are centred with wind force greater than 5 when the sea is colder than the air. Minimum values are found with light winds when the sea is 7°F. warmer than the air.

Fig. 5 shows the percentage frequency of observations within 5-per-cent. ranges of relative humidity as a function of the temperature difference. Outstanding features of this pattern are the high frequencies within the 83–93-per-cent. range when the sea is 16°F. warmer than the air, within the 88–98-per-cent. range when the sea is 11–14°F. warmer than the air and also within this range when the sea is from 2° warmer to 4°F. colder than the air. When the sea is 4–10°F. warmer than the air the frequencies are spread out more evenly throughout all ranges and maximum frequencies tend to occur within the 78–83-per-cent. range. The pattern thus brings out the fact that the air is most humid when the sea is more than 12°F. warmer than the air and also when it is colder than the air, and driest when the sea is 4–10°F. warmer than the air.

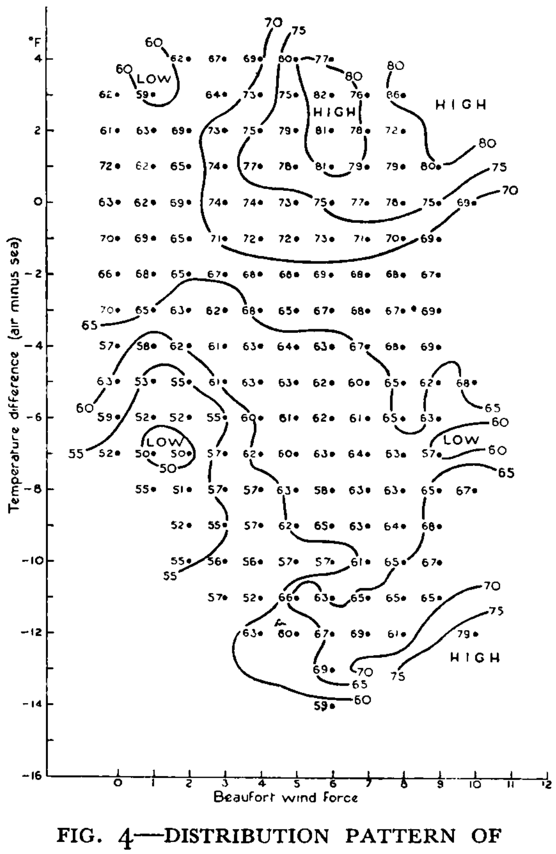


FIG. 4—DISTRIBUTION PATTERN OF 10-PERCENTILE VALUES OF RELATIVE HUMIDITY

The high humidities which are found when the sea is much warmer than the air occur because the saturation vapour pressure of the air is low relative to the sea and is quickly approached as water vapour is transported upward from the sea. The saturation vapour pressure is not approached so rapidly when the temperature difference is less great. When the sea is colder or only a little warmer than the air, the air and sea approach equilibrium conditions and relative humidities are high.

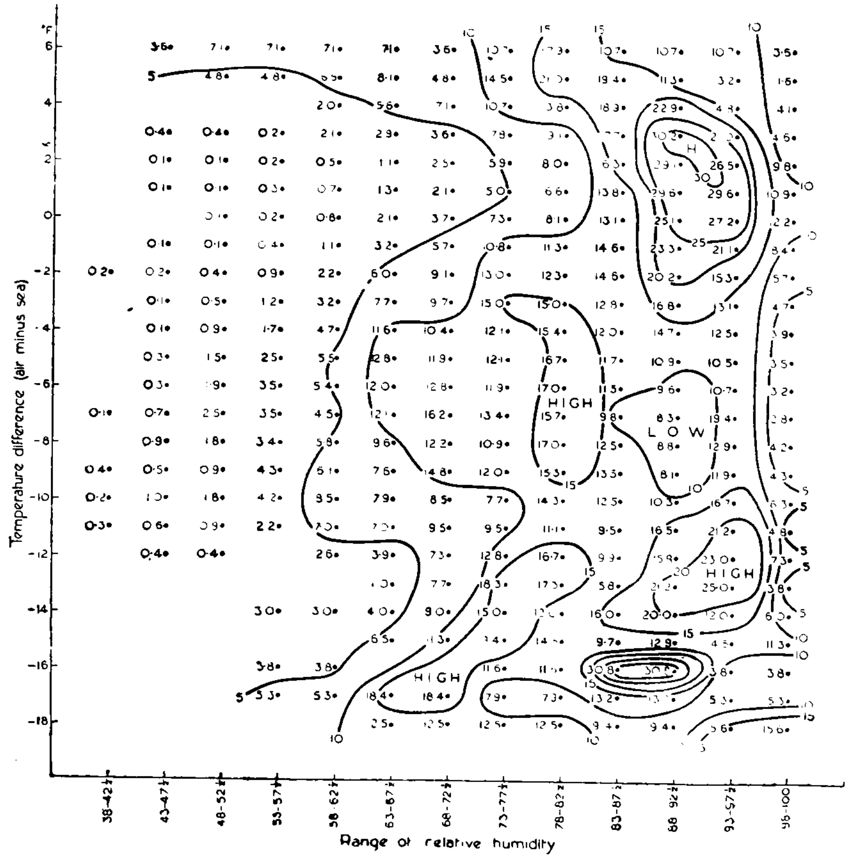


FIG. 5—FREQUENCY PATTERN OF RELATIVE HUMIDITY AS A FUNCTION OF TEMPERATURE DIFFERENCE

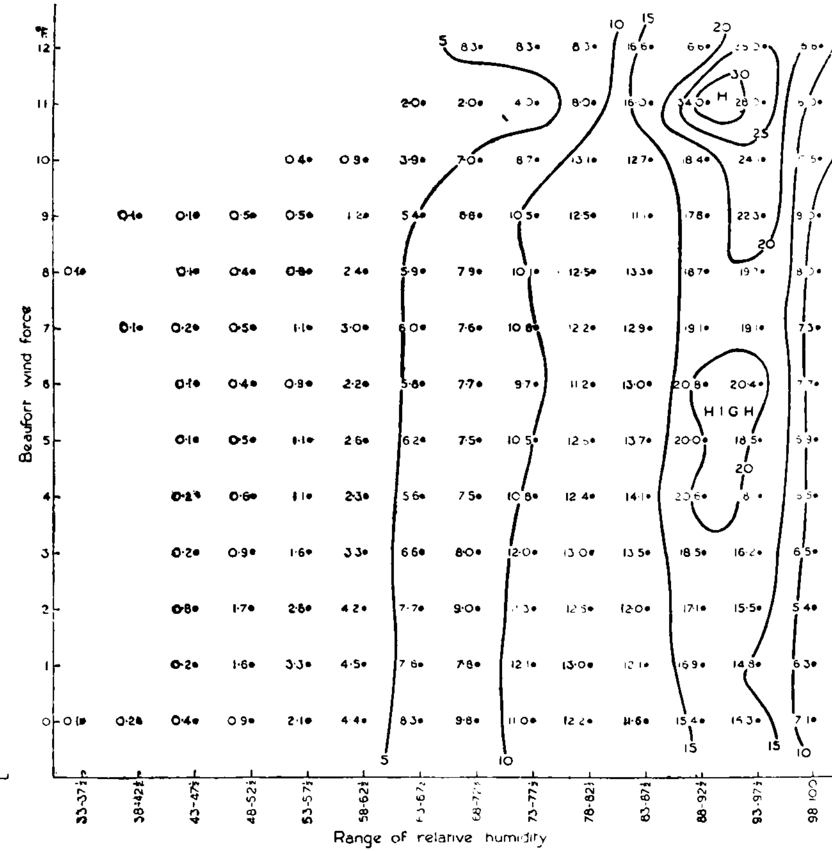


FIG. 6—FREQUENCY PATTERN OF RELATIVE HUMIDITY AS A FUNCTION OF WIND FORCE

Fig. 6 shows the frequency pattern within 5-per-cent. ranges of relative humidity as a function of wind force. Maximum frequencies are found within the 88–98-per-cent. range for all wind forces, but the frequency within this range is greater for strong winds than for light winds. As a whole, frequencies of the lower ranges are greater for light winds and frequencies of the higher ranges are greater for strong winds.

Fig. 7 shows the frequency distribution of the total number of observations within these ranges of relative humidity irrespective of other controlling variables.

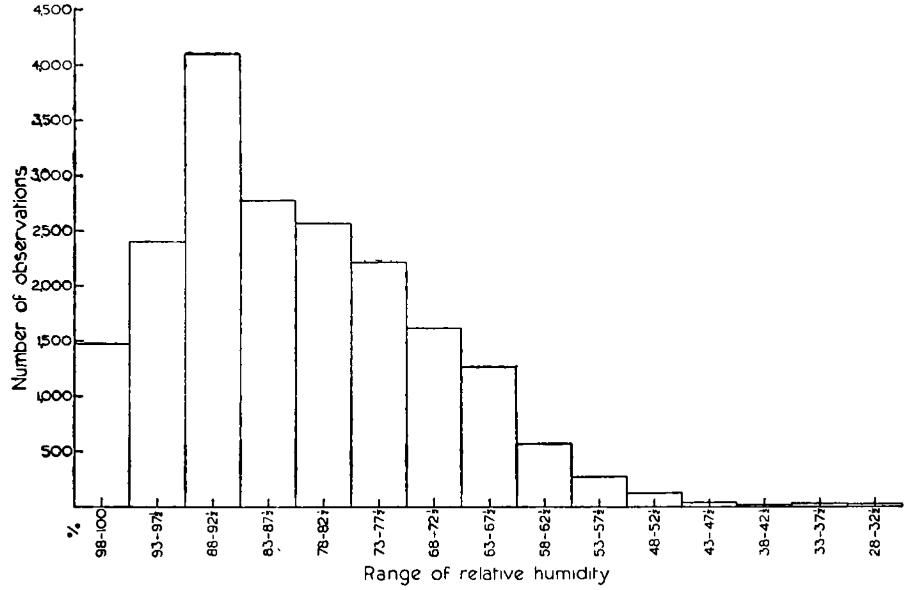


FIG. 7—FREQUENCY DISTRIBUTION OF THE TOTAL NUMBER OF OBSERVATIONS WITHIN 5-PER-CENT. RANGES OF RELATIVE HUMIDITY

Conclusions.—It is evident from the results of the analysis that the relative humidity is controlled by both the temperature difference (air minus sea) and the wind force. Relative humidities tend to be higher with strong winds than with light winds. They tend to be high when the sea is colder than the air and also when the sea is 10°F. or more warmer than the air; they tend to be low when the sea is warmer than the air by less than 10°F.

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2. TUNNELL, G. A.; Vapour pressure over the sea. *Met. Mag., London,* **81**, 1952, p. 77.
3. DURST, C. S. and GORDON, A. H.; The distribution of humidity at sea. *Met. Res. Pap., London,* No. 665, 1951.

METHOD FOR CALCULATING FROM THE TEPHIGRAM THE THICKNESS OF THE LAYER OF AIR BETWEEN ANY TWO STANDARD PRESSURE LEVELS

By S. A. CASSWELL

The methods usually employed for calculating layer thicknesses compare the plotted temperature curve with either an isotherm or a line of constant potential temperature on a tephigram. In most cases the actual curve is very different from the particular line with which it is being compared, so that it is difficult to estimate accurately the equality of the areas cut off on either side if the layer is more than 100-mb. thick.

By using any straight line the method given here allows a much greater accuracy to be obtained quickly. A correction for water vapour content is quite simple and reasonably accurate. When the height of every 100-mb. level is required this method may have little advantage, but for calculating one or two levels, or for checking figures received in teleprinter or W/T messages, it has proved useful and speedy, and forecast curves on the tephigram can quickly be checked against forecast thicknesses.

Mean temperature calculation.—Any uniform lapse rate is represented on the tephigram by a curve which is very nearly a straight line. Taking it as a straight line gives errors which are negligible, e.g. for the layer 1000–500 mb. the error in mean temperature is between zero and plus 0·15°F.

This figure has been obtained by drawing on a tephigram various lines of constant lapse rate. When the lapse rate is nil, and also when it has the value of the dry adiabatic, the lines are straight. At intermediate values there appears to be a slight deviation, but this is only just discernible on the tephigram, and the error incurred appears to be positive and not greater than 0·15°F.

In any layer of uniform lapse rate a pressure p can be found at which the temperature is equal to that of an isothermal layer of the same thickness, and this pressure varies little with variations of lapse rate and does not vary with temperature. It may be calculated as follows:—

Let I be an isothermal atmosphere of temperature T, and II be an atmosphere of uniform lapse rate β°C./m. with temperature T_0 at pressure p_0.

Consider the thickness z of the layers between pressures p_0 and p_1 in these atmospheres. Let z be measured in metres, temperature in degrees Absolute, and pressure in millibars. Then, from Brunt's "Physical and dynamical meteorology", Chapter II, equations (17) and (19), we have:

$$\text{in I} \qquad z = 67{\cdot}4\, T(\log p_0 - \log p_1)$$

$$\text{in II} \quad \frac{T_0 - \beta z}{T_0} = \left(\frac{p_1}{p_0}\right)^{29\cdot 3\beta} \qquad \text{.........(1)}$$

$$\text{or} \qquad z = \frac{T_0\left\{1 - \left(\frac{p_1}{p_0}\right)^{29\cdot 3\beta}\right\}}{\beta}.$$

These thicknesses are equal when

$$T = \frac{T_0\left\{1 - \left(\frac{p_1}{p_0}\right)^{29\cdot 3\beta}\right\}}{67{\cdot}4\beta\,(\log p_0 - \log p_1)}. \qquad \text{.........(2)}$$

The height (in metres) at which atmosphere II has this temperature T is $(T_0 - T)/\beta$. The pressure p at this point is given by putting $z = (T_0 - T)/\beta$ and $p_1 = p$ in equation (1) and eliminating T by means of equation (2):

$$\left(\frac{p}{p_0}\right)^{29\cdot 3\beta} = \frac{1 - \left(\frac{p_1}{p_0}\right)^{29\cdot 3\beta}}{67{\cdot}4\beta\,(\log p_0 - \log p_1)}.$$

Application.—The straight line cutting off equal areas is assumed to have a lapse rate β. When the value of β varies between 0·01 and zero (the dry adiabatic and the isothermal) p varies little. Errors in the mean temperature for variations in the mean lapse rate are likely to be between $-0{\cdot}1^\circ$ and $+0{\cdot}1^\circ$F., when β is taken as $0{\cdot}005$ as it is in the formula:

$$\left(\frac{p}{p_0}\right)^{0\cdot1465} = \frac{1 - \left(\frac{p_1}{p_0}\right)^{0\cdot1465}}{0{\cdot}337\,(\log p_0 - \log p_1)},$$

where p_0 and p_1 are the pressures at the bottom and top of the layer respectively. The value of p for various layers is as follows:

layer 1000–700 mb..........841 mb.

layer 700–500 mb..........595 mb.

layer 1000–500 mb..........714 mb.

The conversion scale in Fig. 1 is calculated from the formula*:

$$\text{Height in feet} = 221{\cdot}1\,T(\log p_0 - \log p_1)$$

where T is the mean virtual temperature in degrees Absolute.

Correction for moisture content.—Let x be the humidity mixing ratio, then x gm. of water vapour are mixed with 1,000 gm. of air. The density of water vapour is 5/8 that of air at the same temperature and pressure.

The masses are in the ratio $x/1{,}000$; thus their pressures are in the ratio $8x/5{,}000$. Since the density of water vapour is 3/8 less than that of air, then the mixture of $8x/5{,}000$ of water vapour to one unit of air reduces the density by $3x/5{,}000$.

For dry air to have the same density as the mixture we are considering, its temperature (T in degrees Absolute) would have to be increased by this fraction. Thus the virtual temperature

$$T' = T\left(1 + \frac{3x}{5000}\right)$$

or $$T' - T = \frac{3x\,T}{5000}.$$

If $T = 278^\circ$A. (5°C.) then $T' - T = x/6$ when temperatures are in degrees Absolute or Centigrade. If $T = 290^\circ$A. (63°F.) then $T' - T = x/3{\cdot}2$ when temperatures are in degrees Fahrenheit. Taking for convenience, $T' - T = x/3$ for Fahrenheit temperatures the maximum error is $+0{\cdot}3^\circ$F. with temperatures between 40° and 80°F. when the air is saturated, and proportionately less for lower relative humidities.

Thus errors should seldom be as great as $0{\cdot}5^\circ$F., which is equivalent to 20 ft. in the layer 1000–500 mb., and no greater than the probable error of observation.

Conclusion.—The practical steps are as follows:—

(i) By means of a straight line on a transparent ruler, estimate any straight line on the tephigram such that the temperature curve between the pressure levels concerned cuts off equal areas on each side of it. The straight line may

* See BRUNT, D.; Physical and dynamical meteorology. 2nd edn, Cambridge, 1939, Chapter II, equation (16).

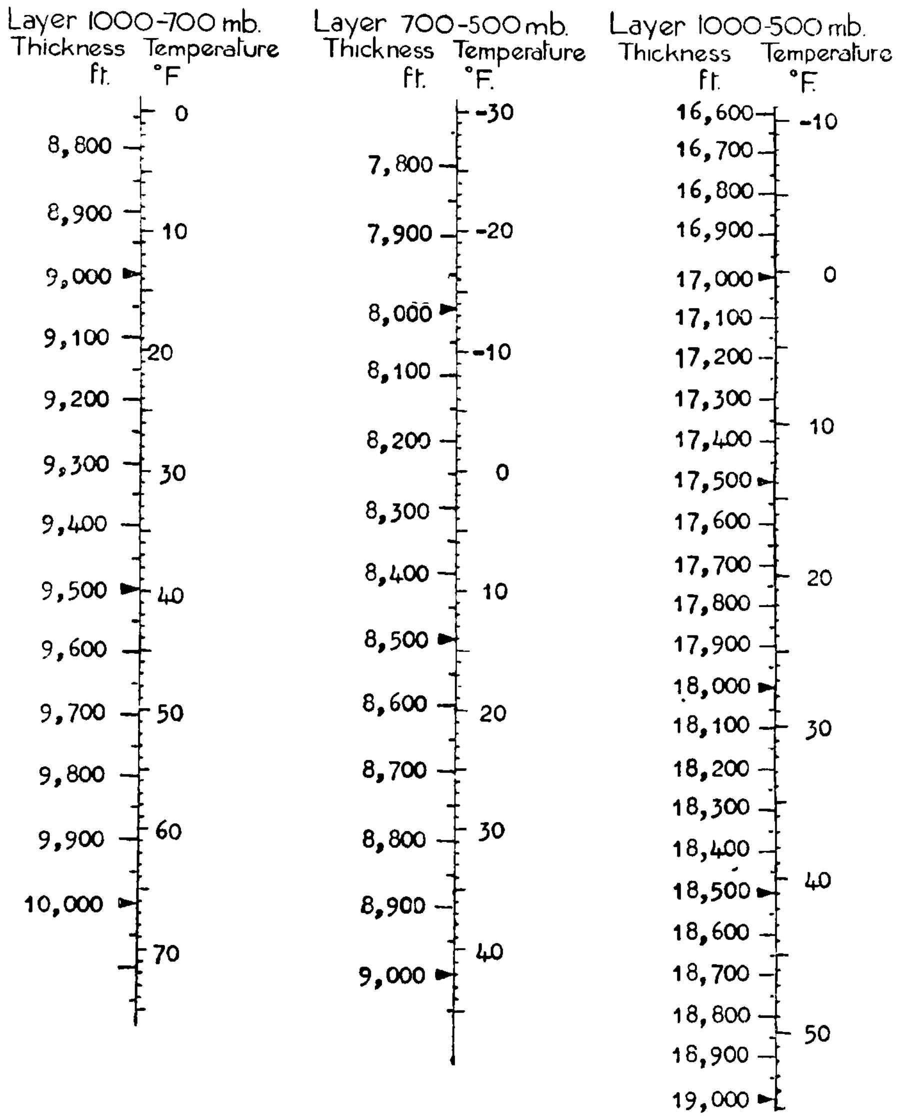


FIG. 1—CONVERSION TABLE

be in any direction, and should be taken so that the areas to be compared are as small as possible.

(ii) Note the temperature at a fixed pressure, p, on this line (for the layer 1000–500 mb., $p = 714$ mb.; for 1000–700 mb., $p = 841$ mb.; for 700–500 mb., $p = 595$ mb.).

(iii) Estimate roughly the mean moisture content of the layer in grammes per kilogramme taking the dew-point temperature instead of the dry-bulb temperature curve. Divide this figure by 3 if the temperatures are measured in degrees Fahrenheit or by 6 if in degrees Centigrade, and add the result to the temperature obtained in step (ii) to obtain the mean virtual temperature of the air column.

(iv) Read off the thickness height corresponding to this temperature on a conversion scale such as is shown in Fig. 1.

ERRATUM

August 1952, PAGE 250, lines 12–15; *delete* "There was a cold front . . . . . Derbyshire."

VERTICAL VARIATION IN TEMPERATURE AND HUMIDITY WITH ON-SHORE AND OFF-SHORE WINDS NEAR THE COAST OF SOUTH-EAST ENGLAND

By R. H. PEDLOW, B.Sc.

Summary.—Hourly values of temperature and vapour density at 1·1, 15·2, 47·2 and 106·7 m. were recorded three miles inland from the coast near Rye, Sussex, over the period July 1945 to June 1948[1]. These hourly values have been used in an examination of the effects of sea passage on the temperature and humidity structure of the atmosphere. The investigation was limited to the summer months, June, July and August, because of the infrequency of on-shore winds at other seasons.

General case of on-shore and off-shore winds.—In the first place, from tabulations of hourly anemograph readings for 10 m., all occasions of on-shore and off-shore winds were selected. Off-shore winds were defined as those between 240° and 50°, and on-shore winds as those between 135° and 210°. Hours when the wind blew from the other sectors—approximately 50 per cent.—were ignored. The first hour of calm after the cessation of an off-shore wind was regarded as being a continuation of that régime, but no similar extension of on-shore winds was made. On-shore winds were not accepted as such until the fetch of wind within the appropriate sector had reached 10 miles, which ensured a sea track of at least 5–7 miles before the air to be sampled crossed the coast; after crossing the coast, the air then had a land track of 3–5 miles, depending on its direction, before reaching the station. The number of occasions of off-shore wind at each hour varied between 110 and 134, but the on-shore winds were few, being never more than 26 at any hour and ranging between 5 and 10 for 12 hours of the day. (It is unfortunate that the commonest direction of a sea breeze at the station is in the sector 210–240° where the length of land track varies rapidly with azimuth.) Caution must therefore be used in the interpretation of the data, and the midday period must be regarded as much more significant than the night hours. As an indication of the reliability of the mean values, probable errors have been calculated for some of the 15·2 – 1·1-m. differences and are given in Table I.

TABLE I—MEAN VALUES OF DIFFERENCES OVER THE INTERVAL 15·2 – 1·1-m. INCLUDING PROBABLE ERRORS

	Temperature difference		Vapour density difference	
	On-shore wind	Off-shore wind	On-shore wind	Off-shore wind
G.M.T.	*degrees Fahrenheit*		*milligrammes per cubic metre*	
0100	+0·4±0·14	+0·9±0·07	−450±110	− 70±27
1200	−1·9±0·14	−1·2±0·08	−900± 56	−500±25

Mean hourly values of temperature, vapour density and vertical differences in these elements were found and tabulated in Tables II and III, which also give the average differences for the three height ranges for on-shore and off-shore winds for the periods 0700–1800, 1900–0600 and 0100–2400 G.M.T.

As one would expect, with few exceptions the on-shore winds show, by comparison with off-shore winds, a higher vapour density at all levels at all hours and a steeper humidity lapse rate at all levels with the difference most marked in the lowest layer. But the on-shore winds also show a generally higher temperature at all levels especially during the midday period, a higher diurnal range of temperature, a higher maximum temperature and a steeper

TABLE II—MEAN HOURLY VALUES OF TEMPERATURE AND TEMPERATURE DIFFERENCES FOR OCCASIONS OF ON-SHORE AND OFF-SHORE WINDS DURING SUMMER MONTHS

	ON-SHORE WINDS					OFF-SHORE WINDS				
	Temperature at 1·1 m.	Temperature difference* over height intervals (m.) 15·2 − 1·1	47·2 − 15·2	106·7 − 47·2	No. of hours	Temperature at 1·1 m.	Temperature difference* over height intervals (m.) 15·2 − 1·1	47·2 − 15·2	106·7 − 47·2	No. of hours
G.M.T.		*degrees Fahrenheit*					*degrees Fahrenheit*			
0100	55·8	+0·4	+0·1	+0·8	5	53·2	+0·9	+0·4	+0·4	124
0200	54·6	+0·4	+0·1	0·0	9	52·7	+0·9	+0·4	+0·6	125
0300	54·6	+0·5	+0·3	+0·3	11	52·2	+0·9	+0·6	+0·3	124
0400	54·6	+0·3	0·0	0·0	10	51·9	+1·0	+0·4	+0·5	124
0500	55·8	+0·1	−0·2	+0·1	7	52·7	+0·5	+0·4	+0·5	129
0600	56·9	−0·2	−0·3	−0·1	8	54·6	−0·1	−0·3	+0·3	132
0700	56·8	−0·6	−0·4	−0·2	8	56·6	−0·2	−0·8	−0·1	134
0800	59·4	−0·8	−0·7	−0·2	11	59·6	−1·4	−1·1	−0·4	130
0900	64·6	−1·3	−0·8	0·0	11	61·0	−1·1	−1·2	−0·5	128
1000	65·7	−2·0	−1·0	−0·2	13	61·7	−1·3	−1·2	−0·5	122
1100	69·1	−1·9	−1·2	−0·4	17	62·3	−1·4	−1·2	−0·6	117
1200	70·5	−1·9	−1·1	−0·6	25	63·0	−1·2	−1·2	−0·7	113
1300	70·3	−1·8	−1·4	−0·4	24	63·4	−1·3	−1·3	−0·5	110
1400	69·7	−1·6	−1·2	−0·4	26	63·9	−1·2	−1·2	−0·6	111
1500	69·3	−1·7	−0·9	−0·4	25	63·1	−0·8	−1·0	−0·5	114
1600	68·8	−1·6	−0·6	−0·5	22	62·8	−0·6	−1·0	−0·6	113
1700	66·3	−1·2	−0·8	−0·4	20	62·2	−0·4	−0·9	−0·5	111
1800	63·1	−0·8	−0·7	−0·4	20	60·7	−0·1	−0·7	−0·5	111
1900	59·5	−0·2	−0·4	0·0	15	58·4	+0·4	−0·4	−0·3	115
2000	57·8	+0·3	0·0	+0·5	10	56·3	+0·8	−0·1	−0·1	115
2100	57·6	+1·2	+0·3	+0·8	10	55·1	+1·0	+0·1	+0·2	113
2200	58·9	+0·5	+0·3	+1·6	6	54·5	+1·1	+0·3	+0·3	117
2300	58·6	+0·3	0·0	+1·1	7	53·9	+1·2	+0·3	+0·3	118
2400	56·9	+0·4	+0·2	+0·9	6	52·6	+1·7	+0·2	+0·5	120
12-hr. averages										
0700–1800	66·1	−1·4	−0·9	−0·3	...	61·7	−0·9	−1·1	−0·5	...
1900–0600	56·8	+0·3	0·0	+0·5	...	54·0	+0·9	+0·2	+0·3	...
24-hr. average										
0100–2400	61·5	−0·6	−0·4	+0·1	...	57·9	0·0	−0·4	−0·1	...

* Increase of temperature with height is reckoned as positive.

lapse rate in the lowest layer, none of which can be ascribed to the effect of the sea.

There are two possible explanations, not mutually exclusive and probably both contributing to the effects: (i) a number of sea breezes are included in the on-shore winds during daylight hours, so that selection of occasions of on-shore winds is, in part, a selection of fine days with a high maximum temperature; (ii) those on-shore winds which are not local sea breezes but are part of a general southerly air stream, must reflect the influence not only of the sea-crossing but also of the more remote history of the air mass. Generally speaking, southerly air has a greater overall stability than northerly, and larger diurnal range and higher day-maximum temperature are consequences of that comparative stability which is perhaps discernible in the layers above 15 m., though the difference between the on-shore and off-shore winds in these layers is too near the probable error of the temperature differences concerned to be confidently quoted as evidence. The greater stability above 15 m. of the on-shore as compared with the off-shore wind—whether a consequence of air-mass characteristics or of shallow sea breezes—by retarding the convective dispersal of water vapour, must contribute to the maximum of vapour density with on-shore winds being later and higher in value than the maximum with off-shore winds, and must assist in bringing about the steep low-level humidity lapse rate which at first sight is attributable solely to the sea-crossing.

TABLE III—MEAN HOURLY VALUES OF HUMIDITY AND HUMIDITY DIFFERENCES FOR OCCASIONS OF ON-SHORE AND OFF-SHORE WINDS DURING THE SUMMER MONTHS

	ON-SHORE WINDS				OFF-SHORE WINDS			
	Vapour density at 1·1 m.	Vapour-density difference* over height intervals (m.) 15·2 − 1·1	47·2 − 15·1	106·7 − 47·2	Vapour density at 1·1 m.	Vapour-density difference* over height intervals (m.) 15·2 − 1·1	47·2 − 15·1	106·7 − 47·2
G.M.T.	*milligrammes per cubic metre*				*milligrammes per cubic metre*			
0100	9,380	−450	−400	−290	9,340	−70	−250	−160
0200	9,530	−250	−310	−330	9,170	−60	−230	−100
0300	9,570	−240	−380	−120	9,110	−50	−170	−100
0400	9,550	−330	−370	−190	9,110	−10	−150	−90
0500	9,860	−420	−480	−100	9,310	−90	−160	−80
0600	10,720	−440	−250	−140	9,780	−360	−220	−90
0700	10,590	−550	−130	−180	10,300	−520	−340	−180
0800	10,390	−580	−230	−80	10,330	−630	−260	−120
0900	11,670	−760	−240	−130	10,050	−580	−270	−40
1000	11,020	−670	−300	−140	9,840	−550	−280	−40
1100	11,450	−820	−430	−80	9,790	−490	−350	−90
1200	11,740	−900	−590	−110	9,790	−500	−310	−120
1300	11,020	−750	−400	−90	9,700	−490	−280	−100
1400	10,990	−790	−420	−140	9,890	−510	−290	−100
1500	10,660	−800	−260	−250	9,700	−430	−290	−70
1600	10,920	−940	−320	−210	9,610	−430	−250	−70
1700	10,560	−620	−250	−90	9,570	−420	−280	−60
1800	10,100	−510	−260	−90	9,510	−380	−250	−80
1900	10,090	−450	−260	+100	9,470	−340	−270	−90
2000	10,090	−300	−250	+110	9,370	−230	−270	−130
2100	10,210	−220	−470	−190	9,400	−150	−290	−150
2200	10,570	−230	−300	−190	9,390	−120	−310	−200
2300	10,440	−300	−190	−170	9,310	−70	−310	−200
2400	9,770	−530	−290	−160	9,160	−30	−260	−140
12-hr. average								
0700–1800	10,930	−720	−320	−130	9,840	−490	−290	−90
1900–0600	9,980	−350	−330	−140	9,330	−130	−240	−130
24-hr. average 0100–2400	10,450	−540	−320	−140	9,580	−310	−260	−110

* Increase of vapour density with height is reckoned as positive.

Selected occasions.—Since selection of on-shore winds is thus partially a selection of a particular air mass, the results so far discussed are applicable only to the eastern part of the south coast of England, and for that reason a different approach was made. Occasions had been noticed when sudden changes occurred in the relative-humidity traces simultaneously with changes in wind direction across the line of the coast. After elimination of occasions which were or might have been associated with precipitation or change in the general air mass, there remained 13 examples, all of which occurred during the period 0900–1800 G.M.T. In the following discussion of these 13 cases, "on shore" and "off shore" are not limited by their definition on p. 299.

Values of mean temperature and humidity were found for the 10-min. nearly steady periods immediately before and after the change (which occupied an interval of from 10 to 50 min.). Average values of temperature and humidity and of differences in these elements for the 13 occasions are given in Table IV.

TABLE IV—MEAN VALUES OF TEMPERATURE AND HUMIDITY DERIVED FROM 13 OCCASIONS OF SUDDEN WIND CHANGE IN SUMMER

	Temperature at 1·1 m.	Temperature difference over height intervals (m.) 15·2–1·1	47·2–15·2	106·7–47·2	Vapour density at 1·1 m.	Vapour-density difference over height intervals (m.) 15·2–1·1	47·2–15·2	106·7–47·2
		degrees Fahrenheit				*milligrammes per cubic metre*		
On-shore wind	65·7	−1·5	−1·0	+0·2	10,850	−660	−310	0
Off-shore wind	68·7	−1·3	−1·2	−0·3	10,070	−830	−290	−30
Difference*	−3·0±0·5	−0·2±0·2	+0·2±0·1	+0·5±0·1	780±100	+170±100	−20±80	+30±50

* on-shore minus off-shore values.

To estimate the possible influence of diurnal change on the difference in profile which we ascribe to change from land track to sea track, the mean changes in temperature and humidity over the 13 periods between the initial and final steady states were found from curves of diurnal change for clear days in summer[1]. The effect of diurnal variation in vertical temperature difference was less than 0·05°F. over all the height intervals, and in humidity difference +20 mg./m.^{3} over the 15·2 – 1·1-m. interval, and −10 mg./m.^{3} over the 47·2 – 15·2-m. and 106·7 – 47·2-m. intervals, i.e. sufficiently smaller than the change in the values of these differences from off-shore to on-shore, except in the latter two instances where the degree of uncertainty already precludes discussion.

The number of occasions is small and the scatter considerable, but as far as temperature is concerned, the changes in lapse rate between on-shore and off-shore winds were fairly uniform in sense and agree well with the model of the air over the sea, initially unwarmed compared with that over the land replacing the latter and undergoing heating in the lowest layer; whilst the undercutting of the warm air by the cold produces, soon after its inception and at a few miles from the sea, a mixing zone and inversion a little below 100 m.

On-shore winds show the expected increased vapour density at all heights; on only one day was the sea air the drier, and this was the warmest of the selected days when transpiration apparently exceeded evaporation from the sea. The contrast between on-shore and off-shore winds in respect of vertical differences of humidity is small, the scatter is large, and the sense of the average difference is reproduced in only half of the individual cases. In short, no significant pattern emerges.

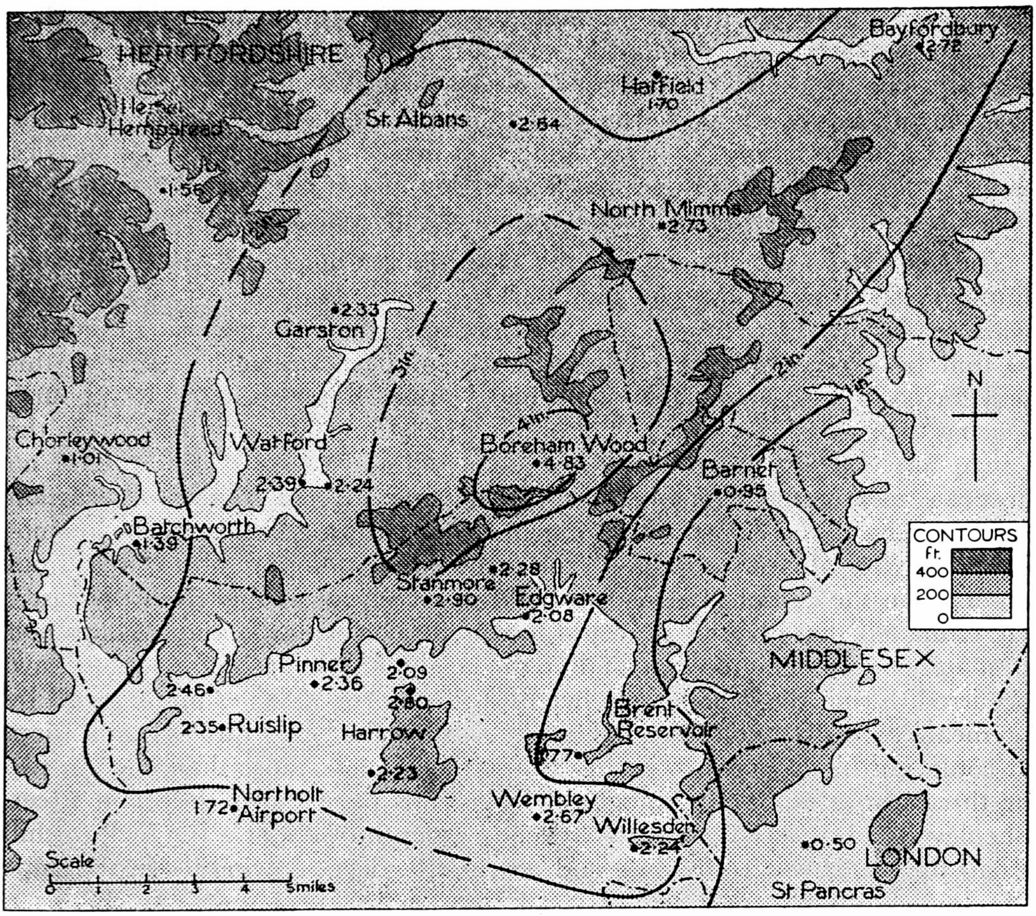
REFERENCE

1. BEST, A. C., KNIGHTING, E., PEDLOW, R. H. and STORMONTH, K.; Temperature and humidity gradients in the first 100 m. over south-east England. *Geophys. Mem., London*, **11**, No. 89 (in the press).

STORM OF AUGUST 6, 1952, CENTRED OVER BOREHAM WOOD

A very intense rainstorm accompanied by thunder and lightning occurred over an area in Hertfordshire and Middlesex on the evening of August 6, 1952. Accounts which appeared in the press, describing the damage due to flooding and lightning, indicated that the rainfall was of very unusual intensity. Moreover, the occurrence aroused particular interest among drainage engineers, since much of the precipitation, which seems to have been entirely in the form of rain, fell on built-up areas and gave rise to an exceptionally severe test of storm-water drainage systems.

In many places there were thunderstorms or thundery showers in the afternoon, but over the area under consideration the bulk of the day's rainfall, measured for the 24 hr. beginning at 0900 G.M.T. on the 6th, fell during a short time between 1800 and 2000 G.M.T. on that day. The 24-hr. totals are plotted on the accompanying map, with tentative isohyets drawn at 1-in. intervals. More than 2 in. fell in an irregular area extending from Ruislip to Ware and possibly beyond, and from Willesden to St. Albans. The area which received 3 in. or more cannot be accurately defined since, with one exception, there were no records of falls exceeding 2.90 in. The exception was the fall of 4·83 in. recorded by the gauge at Boreham Wood, which, according to reports of flooding



AREAS OF HEAVIEST RAINFALL DURING STORM OF AUGUST 6, 1952

and eye-witness accounts of the rain as it fell, must have been very near the centre of the storm. This fall exceeded any previously recorded in one rainfall day in Hertfordshire or in any of the bordering counties.

The thunderstorms developed in the central area of a small depression which moved northwards from France. During the afternoon temperature rose to 75–78° over much of southern England with a dew point about 60°F. The air at the surface and at 950 mb. could rise to the tropopause at about 37,000 ft., but the lapse rate above 850 mb. (5,000 ft.) only averaged very slightly above the saturated adiabatic. To the north of the area most affected there was less sunshine and a slightly lower temperature, and this difference became accentuated after the first storms broke out just north of the hottest region. By 1800 there was a well marked line of convergence between a light southerly wind over south-east England and a cooler ENE. wind over East Anglia and the Midlands. In the next hour or two cool NE. – N. surface winds spread over the storm area, opposing the weak south-westerly upper current in which the clouds drifted. There must have been a rapid building up of fresh cumulonimbus cells on the south-west boundary of the storm. The approach of a poorly defined cold front from south-west probably increased the convergence, producing the pincer movement characteristic of the heaviest rainstorms.

A number of autographic records are available for analysing the timing of the storm, and in addition some observers with standard gauges made special readings covering the period of most intense rain. From the evidence thus brought together it appears that in several places the falls merit the duration-intensity classification of "very rare", which describes a fall such as is likely to occur at any one station not more than once in 160 yr.[1] At other places the falls were "remarkable", corresponding to a frequency of not more than once in 40 yr. The following notes give a selection of the most intense individual falls for which the records can be accepted as fully reliable:—

Boreham Wood.—Mr. Court, rainfall observer at Furzehill Road, wrote that thundery showers occurred in the afternoon from about 1430 to 1700 G.M.T. Rain ceased for about 45 min. and then began again with increasing intensity, so that by 1800 it was "exceedingly heavy and continuous", lasting in this way for 90 min. or more. By 2000 it had "abated to an ordinary downpour". During the storm it was noted that about 4 in. of rain had accumulated in the gauge but efforts were concentrated on avoiding loss by overflow, and no accurate measurement was made until the time for the routine observation next morning. Mr. Court also commented that "during the storm the anemometer slowed almost to a stop, the wind vane pointing north, but from observation the cumulus seemed to build up overhead mainly from the east". He estimated that about 1 in. could have fallen before 1800 and perhaps half that amount after 2000 so that a fall in the neighbourhood of 3·25 in. must have occurred during the 2 hr. at the height of the storm. This estimate seems by no means excessive and such a fall lies well within the "very rare" classification. It could not be expected to occur, at any one station, more than once in two or three centuries. The photograph facing this page shows the main street, Shenley Road, where flood-water reached a depth of about 2 ft. In Furzehill Road the water was 15 ft. wide and nearly 1 ft. deep, flowing down the slope "fast enough to make it difficult to walk through".

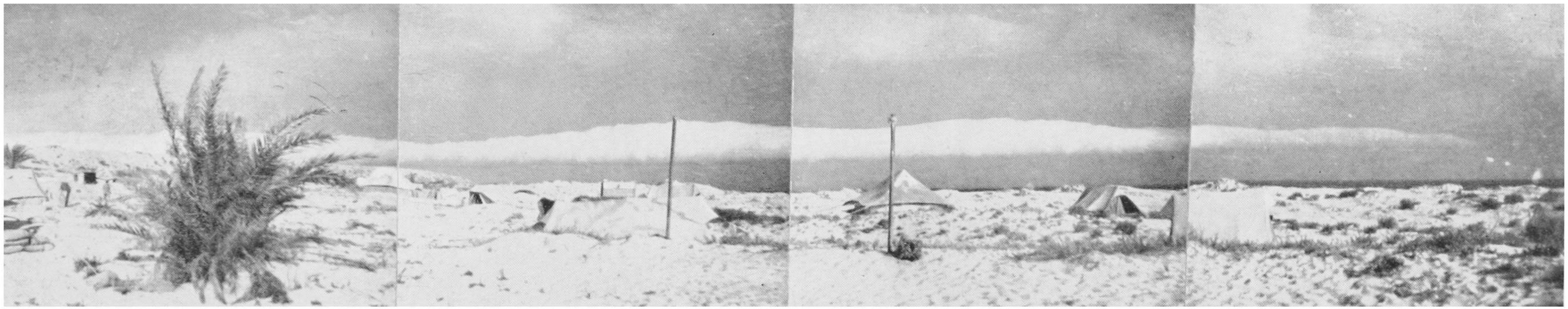
Harrow.—Mr. Hyla Greves, Welldon Crescent, recorded a "very rare" fall of 2·80 in. in 2 hr. between 1840 and 2040 G.M.T. This observation was supported by another reading of 2·87 in. in the same time only a short distance away.

Wembley.—The gauge at the Town Hall recorded 2·67 in. for the rainfall day. There was no preliminary shower in the afternoon at Wembley, and the chart from the autographic gauge shows a "very rare" fall of 2·00 in. in 30 min. from 1910 to 1940 G.M.T.

Stanmore and Edgware.—A fall of 2·70 in. at Harrow Council Offices, Stanmore, has been widely reported as having occurred in 45 min. duration, this having been obtained from a first reading of the chart. This would have qualified for the classification "very rare". Examination of the autographic chart showed,

Reproduced by courtesy of H. T. Court

FLOODING AT SHIRLEY ROAD, BOREHAM WOOD, HERTS., AUGUST 6, 1952
The water is above the bottom of the bus radiator; it was still raining when the photograph was taken (see p. 302).



Reproduced by courtesy of E. A. Lunson

LINE SQUALL AT SANYET EL QUTEIFIYA ON THE COAST OF THE WESTERN DESERT, EGYPT, APRIL 1942.

On this particular morning the weather was overcast and squally. The photograph was taken about 0800 and shows the long cloud over the beach and running out to sea. About 20–25 min. later the squall hit the encampment, and although no damage was done it was very gusty and squally for about 15 min. with local rising sand and sudden wind shift. A similar squall, which occurred about 2100 led to local sandstorms.

Photos by R.A.F.

1428 G.M.T.

1435 G.M.T.

ROLL CLOUD WITH PASSAGE OF LINE SQUALL OVER SOUTH FARNBOROUGH, NOVEMBER 6, 1947

(see p. 316)

EDDIE STRUCTURE OBSERVED TOWARDS THE NORTHERN EDGE OF A CUMULONIMBUS CELL, LOOKING NORTH-WEST FROM TENGAH AIRFIELD
(see p. 314)

Reproduced by courtesy of J. Waling

ROLL CLOUD PHOTOGRAPHED FROM T.E.V. *Beaverlake* AT 2155, JULY 14, 1951 AT 52°01′N., 53°40′W.
(see p. 317)

however, that the pen had not recorded correctly throughout the storm, and the timing of the fall has had to be re-estimated from other evidence. Instrumental records from Stanmore (Meteorological Office Training School) and Edgware were used, together with eye-witness accounts of the storm. The revised estimates are:—

> 24-hr. fall 2·90 in., of which 2·60 in. fell during the evening storm, probably in 1½–2 hr. beginning at 1830 G.M.T.; about 90 per cent. of this, say 2·35 in., probably fell in 1 hr. 15 min. beginning at 1845 G.M.T.

This is a "remarkable" fall which just fails to reach the "very rare" classification. The records from the Meteorological Office Training School and from Edgware both showed "remarkable" falls, the former 2·00 in. in 1 hr. 15 min. starting at 1845 G.M.T. (24-hr. total 2·28 in.) and the latter 2·08 in. in the same time starting at 1830 G.M.T., with 1·75 in. of this amount in the first 40 min.

Garston, near Watford (Department of Scientific and Industrial Research Building Research Station).—From a fall of 2·34 in. in 5 hr. beginning at 1630 G.M.T., 1·61 in. fell in 45 min. between 1740 and 1825 G.M.T. The most intense part of the fall ranks as "remarkable".

Other "remarkable" falls were reported from Brent Reservoir, Ruislip, and Eastcote Lane, Harrow. Among the larger falls in 24 hr. were 2·73 in. at North Mimms, which is known not to have included a "remarkable" fall, and 2·72 in. at Bayfordbury.

This account has been assembled with the aid of records contributed by official Meteorological Office stations, other official and public bodies, and many voluntary private observers, some of whom, on realizing that the storm would be of unusual interest, were able to take special and careful note of events as they occurred.

REFERENCE

1. BILHAM, E. G.; Classification of heavy falls in short periods. *Brit. Rainf. 1935, London*, 1936, p. 262.

FREQUENCY OF SPELLS OF LIGHT WIND

By A. F. JENKINSON, B.A.

The average number of spells of light wind (Beaufort force less than 4 at all reported observations) in a period of N days that last for x or more days can be expressed in the form $Nf^{x+1} \log_e(1/f)$, where f is the average frequency of light winds.

The average monthly frequencies of spells of light wind at Brindisi were obtained from data for the period 1935–37 and 1939 (observations at 0700 and 1800), and the average monthly frequencies during the winter and summer months at Malta (Luqa) were obtained from hourly records for the period July 1947–February 1952. The lengths of spells were measured in units of hours. Spells of length ⩾ 24 hr., ⩾ 48 hr., etc., were then recorded as ⩾ 1 day, ⩾ 2 days, etc. The average percentage frequencies of light wind, from the same observations, were:—

	%
Brindisi, average during the year	72
Luqa, average during winter (December–February) ...	52
Luqa, average during summer (July–August)	83

The frequencies are plotted on a logarithmic scale against the length of spell in Fig. 1, and it will be seen that the points obtained lie on straight lines with slopes of 0·14 ($= \log_{10} 1/0{\cdot}72$) for Brindisi, 0·28 ($= \log_{10} 1/0{\cdot}52$) for Luqa in winter and 0·08 ($= \log_{10} 1/0{\cdot}83$) for Luqa in summer.

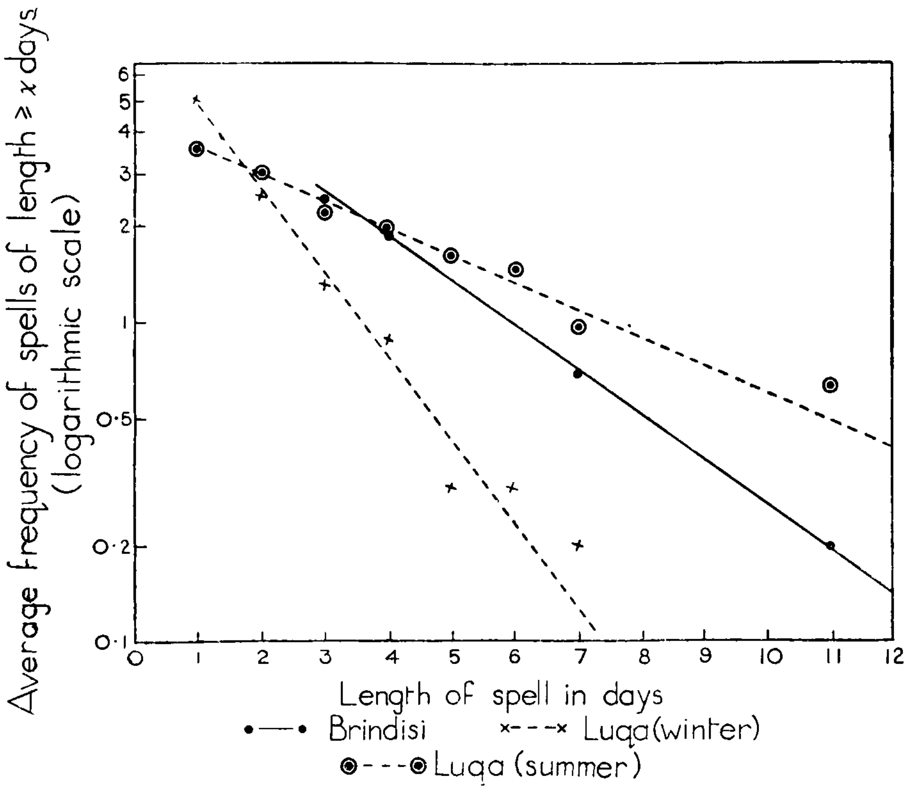


FIG. 1—RELATION BETWEEN THE NUMBER OF SPELLS PER MONTH WITH LENGTH GREATER THAN OR EQUAL TO x DAYS, AND x

This leads one to propose the statistical model

$$f' = kf^x,$$

where f' is the frequency in a period of N days of spells of light wind lasting for x or more days and f is the average frequency of light winds (k is a constant).

Then the number of days taken up by spells of x to $x + dx$ days is

$$- x \frac{d}{dx} (kf^x)\, dx$$

Therefore

$$Nf = \int_0^\infty - x\, d(kf^x)$$

$$= \int_0^\infty kf^x dx$$

$$= \frac{k}{\log_e \frac{1}{f}}$$

Therefore $k = Nf \log_e \frac{1}{f}$

i.e. $f' = Nf^{x+1} \log_e \frac{1}{f}$

Taking $N = 30$ days for a monthly interval, Table I gives the number of spells of 3, 4–6, 7–10, 11–20, and > 20 days for $f = 0{\cdot}40, 0{\cdot}45, 0{\cdot}50 \ldots\ldots\ldots 0{\cdot}90$, together with the number of spells of duration three days or more and the length of spell which is most likely to occur once. Table II gives a comparison of observed and theoretical frequencies for Brindisi and Luqa.

TABLE I—THEORETICAL FREQUENCY OF SPELLS OF LIGHT WINDS IN PERIODS OF 30 DAYS

f	Spells of duration, days 3	4–6	7–10	11–20	>20	≥3	Most probable longest spell
	Number of spells in 30 days						*days*
0·40	0·42	0·26	0·02	0	0	0·70	2·6
0·45	0·54	0·40	0·04	0	0	0·98	3·0
0·50	0·65	0·57	0·08	0·01	0	1·31	3·4
0·55	0·73	0·75	0·14	0·01	0	1·63	3·8
0·60	0·79	0·93	0·22	0·03	0	1·97	4·3
0·65	0·79	1·07	0·33	0·07	0	2·26	4·9
0·70	0·77	1·18	0·47	0·12	0	2·54	5·6
0·75	0·68	1·18	0·59	0·26	0·01	2·72	6·4
0·80	0·55	1·01	0·66	0·41	0·02	2·65	7·2
0·85	0·38	0·83	0·63	0·55	0·05	2·44	8·1
0·90	0·21	0·50	0·45	0·58	0·15	1·89	9·0

TABLE II—FREQUENCY OF SPELLS OF LIGHT WINDS AT BRINDISI AND LUQA

BRINDISI $f = 0{\cdot}72$ Length of spell	Observed frequency	Theoretical frequency	LUQA (winter) $f = 0{\cdot}52$ Length of spell	Observed frequency	Theoretical frequency	LUQA (summer) $f = 0{\cdot}83$ Length of spell	Observed frequency	Theoretical frequency
days			*days*			*days*		
≥ 3	2·6	2·5	≥ 1	5·0	5·3	≥ 1	3·6	3·6
≥ 4	1·8	1·9	≥ 2	2·6	2·7	≥ 3	2·3	2·5
≥ 7	0·7	0·7	≥ 3	1·3	1·4	≥ 7	0·9	1·1
≥11	0·2	0·2	≥ 4	0·9	0·8	≥11	0·8	0·5
≥21	0	0	≥ 5	0·3	0·4	≥21	0·1	0·04
			≥ 6	0·3	0·2			
			≥ 7	0·2	0·1			

A STANDING WAVE AT DUNSTABLE

By G. H. LEE and O. W. NEUMARK

Introduction.—The top of the hill above the London Gliding Club site at Dunstable is about 250 ft. above the ground to the north-west, and the average slope is about 1 : 2½. The slope faces about 15° north of west. Launches by winch to over 800 ft. can now be obtained by gliders in easterly winds, whereas previously power cables prevented launches of more than 300 ft. above the site. Only once, until recently, was lift found to the lee of the slope in a south-easterly wind, and then, in 1937, with a wind direction of 160° on the surface veering to 225° at 2,500 ft. Neumark observed a visible standing wave three times in 1947 in easterly winds, before the higher launches could be made; and then, as on the occasion described below, there was a temperature inversion at less than 3,000 ft. Twice there was a bank of fog on top of the ridge which dissolved and reformed again in a line parallel to the ridge, and once there was a haze layer at about 1,500 ft. whose undulations became visible and there was a darkening of the haze over Totternhoe. It is now well known that standing waves occur at Dunstable far more frequently than was once supposed; most often they are marked by clear breaks in an overcast sky.

Flight of September 22, 1951.—The early part of the day was sunny but towards the end of the afternoon a layer of what appeared to be thin medium cloud gradually thickened. No appreciable thermal activity was noticed at all by Lee during the day in several flights with pupils in a T.21B 2-seater glider. The launch was towards the hill and directly in the lee of it, and nothing especially remarkable was noticed until about 1700 G.M.T. when it was observed that a pupil practising turns near the Tring Road lost less height than was expected.

Later, at about 1730, the phenomenon was investigated by another pupil by flying a few beats up and down the Tring Road. In this case reduced sink, corresponding to an upward air velocity of 2 ft./sec., was found (taking the sinking speed of the T.21B as 3 ft./sec.).

The surface wind at 1800 was about 110°, 10–12 kt., and had increased, and at 1805 Lee and Neumark were launched in J. E. Furlong's *Dragonfly*. The light was already waning. The cable was released at 900 ft., and it seemed that there was an appreciable strengthening of wind between 700 and 1,000 ft. above the site. At 1,500–2,000 ft. the wind appeared to have veered to about 140–150°, 15–20 kt., but even so all the radio-sonde winds at Downham Market and Larkhill at 1500–2100 G.M.T. showed a much more southerly wind, and it seems cannot be taken as representative of the winds near Dunstable, for the Chilterns appear to deflect the wind from its general direction on many occasions.

After flying directly down wind, lift was found after crossing the Tring Road, and several beats at heights between 1,500 and 2,200 ft. were made up and down to find the extent of the area of lift, which is shown in Fig. 1. The magnitude of the lift was steadily increasing during the flight, and the vertical air velocity reached about $5\frac{1}{2}$ ft./sec. at a height of 2,200 ft. above the launching point, i.e. at about nine times the height of the hill.

A sharply defined haze layer could be seen and was estimated to lie at about 2,500 ft. above the launching point, but no undulation in the haze top could be detected from 2,200 ft. In spite of the continuous lift it was necessary to break off the ascent because of approaching darkness. Descent was made mainly in tight circles in the down-current over the slope, and the landing was assisted by car headlights at 1840.

A Tutor sailplane, flown by A. Doughty, landed one minute later after reaching 1,500 ft. from a later launch.

The following is extracted from an account of the phenomenon by A. Doughty:—

"I had never heard of a wave before but had often heard the Club's ground engineer, Mr. Walker, talk about being able to fly right out to Totternhoe at sundown without much loss of height when the katabatic wind begins to blow. On this particular day shortly after 1700 G.M.T. the wind-sock was hanging limply round the mast; about 20 min. later it started to fill out again

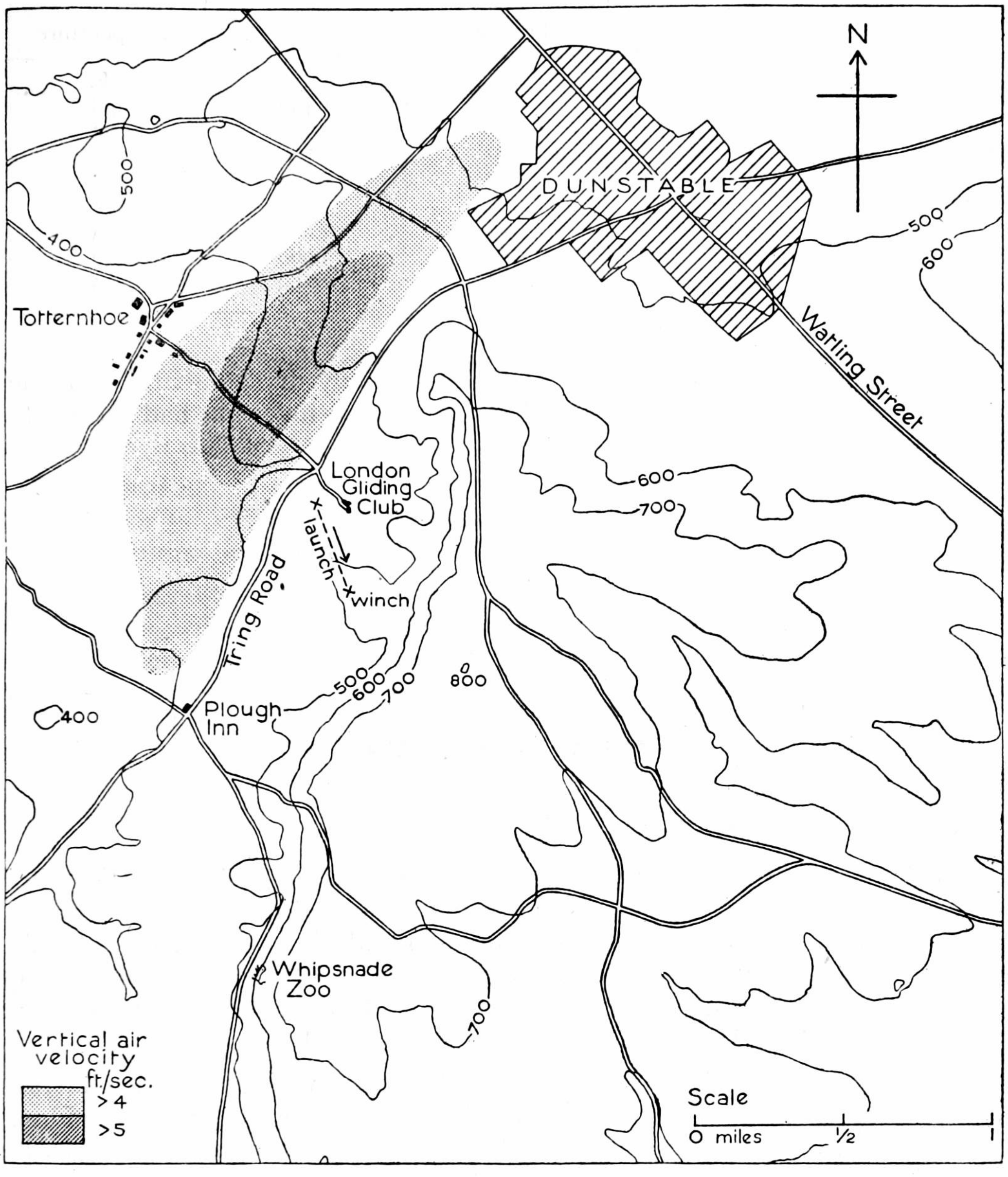


FIG. 1—MAP SHOWING AREA OF BEST LIFT ON SEPTEMBER 22, 1951
Contour heights are given in feet

as the wind freshened . . . I landed after 28 min. in the air and found that the wind had freshened to about 20 m.p.h. and two small lenticular clouds had formed above Totternhoe. By 1930 the wind had dropped and the clouds had cleared away."

[The synoptic charts for Saturday, September 22, 1951, show a depression centred west of Ireland and an anticyclone over Germany with south-east England in a south-easterly air stream.

The observations at Larkhill and Downham Market of the inversion giving the haze layer observed by the authors at about 2,900 ft. above M.S.L. (the height of the gliding club site is 450 ft. above M.S.L.) over the Dunstable area at 1800 G.M.T. are set out in the following table:—

	Time	Pressure	Height above M.S.L.	Temperature
	G.M.T.	mb.	ft.	°F.
Larkhill ...	1500	862	4,450	58
		922	2,600	52
Downham Market	1500	900	3,300	56
		940	2,140	52
Larkhill ...	2100	865	4,250	56
		903	3,050	52
Downham Market	2100	878	3,900	57
		933	2,250	55

The air above the inversion was very dry.

In the afternoon the lapse rate was approximately dry adiabatic from the ground to the base of the inversion, but by 2100 an inversion had formed in the layer below as follows:—

		Pressure	Height	Temperature
	G.M.T.	mb.	ft.	°F.
Larkhill ...	2100	956	1,510	56
		968	1,150	54
Downham Market	2100	970	870	58
		1006·8 (surface)	120	53

Ed. *M.M.*]

OFFICIAL PUBLICATIONS

The following publications have recently been issued:—

Climatological atlas of the British Isles.

This is the first reasonably complete climatological atlas of the British Isles to be published. The Atlas contains the results of the collection of the records of weather data made by thousands of climatological observers. These include not only those connected with the Meteorological Office and some Local Authorities and other interested bodies but also very many voluntary observers to whose enthusiasm British climatology is greatly indebted.

The Atlas is divided into ten sections, each dealing with one of the climatological elements: pressure, wind, temperature, rainfall, snow, thunder, humidity, fog and visibility, sunshine, and cloud. Every section is complete in itself. All except that on cloud have plates of maps and diagrams of average and extreme conditions. The distribution of an element is superimposed on a map as bold lines and in most instances is emphasized by colour-shading, e.g. red for temperature, green for humidity. Maps of average conditions are mostly for the 30-year period, 1901–30, selected by the International Meteorological Organization. Each section also has an introduction describing the methods of making the observations and correcting the data, interesting items concerning extreme values or comparison with long-period averages and, where necessary, tables and diagrams to supplement the plates. Information about the plates and a bibliography are included in the sections. There is a preface by the Director of the Meteorological Office, Sir Nelson Johnson, and a general introduction containing a gazetteer and a map of the stations mentioned in the Atlas. A coloured map, showing the orographical features of the British Isles, to aid the reader to understand the distribution of the elements, forms the frontispiece.

No. 106.—Occurrence of high rates of ice accretion on aircraft. By A. C. Best, M.Sc. Measurements of liquid-water content in strongly convective cloud at great heights in America are compared with theoretical values and good agreement is found. The same method of computing the amount of liquid water in clouds with much higher temperatures at the base is thus justified. After taking account of the variation with drop diameter of the temperature of spontaneous freezing of small drops, the probability of an aircraft encountering various concentrations of supercooled liquid water in strongly convective cloud in low latitudes is assessed.

METEOROLOGICAL RESEARCH COMMITTEE

The 21st meeting of the Synoptic and Dynamical Sub-Committee of the Meteorological Research Committee was held at Dunstable on July 3, 1952.

The Chairman, Sir Charles Normand, announced with regret the resignation of Professor G. C. McVittie as a member of the Sub-Committee consequent upon his taking up an appointment in the United States.

The Committee considered papers by Mr. R. Murray and Miss S. Daniels[1] on the transverse flow at the entrance and exit to jet streams, by Miss E. E. Austin[2] on upper winds over Aden, and by Mr. J. K. Bannon[3] on the classification of temperatures in the upper troposphere and lower stratosphere according to tropopause pressure.

Other matters discussed included (i) a preliminary analysis of the errors in forecasting fog and (ii) sea-surface temperature in the eastern North Atlantic.

ABSTRACTS

1. MURRAY, R. and DANIELS, S.; Transverse flow at entrance and exit to jet streams. *Met. Res. Pap., London,* No. 690, S.C. II/99, 1952.

The wind components across the jet axis were found from 200 mb. below to 100 mb. above maximum wind levels in 1948–50. A component of 8 kt. from right to left (looking down stream) was found at the entrance, 6 kt. from left to right in centre, and 12 kt. from left to right at exit. Mean pressure levels were 279 mb. at entrance and 306 mb. at exit. The probable circulations are shown schematically.

2. AUSTIN, E.; Upper winds of Aden. *Met. Res. Pap., London,* No. 729 (revised) S.C. II/100, 1952.

Radar winds at Aden, August 1948–December 1950, are summarized for levels of 900 to 100 or 60 mb. and discussed. Points noted include sharp transition from westerlies to easterlies at 200 mb. in May and back to westerlies in October, and persistent easterlies in July (55 kt. at 100 mb.). An addendum by C. S. Durst gives winds between Cairo and Entebbe in July 1951.

3. BANNON, J. K.; Classification of temperatures in the upper troposphere and lower stratosphere according to tropopause pressure. *Met. Res. Pap., London,* No. 731, S.C. II/111, 1952.

Both upper air temperature and tropopause pressure (P_c) are functions of advection and vertical motion. For 20-mb. steps of P_c, mean pressure-temperature curves 500–100 mb. are drawn for Larkhill (England) in January, April, July and October, 1948–50. Lapse rates are discussed and causes of variation examined, and several significant correlations found. A high mean lapse rate in lower stratosphere in autumn is related to the autumn minimum of ozone. Suggestions are made for future investigation.

BOOKS RECEIVED

Aktinometrische Untersuchungen während des Internationalen Polarjahres 1932/1933 auf dem Jungfraujoch (3471 m). By W. Mörikofer and W. Schüepp. *Arch. Met. Wien,* B, **2,** 1951, pp. 397–426.

Untersuchung über die Wirkungsweise des Solarigraphen Moll-Gorczynski. By P. Bener. *Arch. Met. Wien,* B, **2,** 1950, pp. 188–249.

ROYAL METEOROLOGICAL SOCIETY

Visit to London Airport

This year the annual summer meeting of the Royal Meteorological Society was held at London Airport on July 16.

From the roof of the air traffic control building it was possible to obtain a view of the whole airport, whilst listening to the Aerodrome Controller talking by radio-telephone to pilots of aircraft on landing or preparing to take-off. Meantime, on the floor below the Approach Controller was, again by radio-telephony, dealing with aircraft approaching the airport. On the ground floor of the same building was the flight information room wherein were diagrams covering the whole of western Europe and the Mediterranean, showing information on aviation matters other than weather, i.e. serviceability of airports, danger zones and the state of navigation aids.

The Society inspected a Hermes air liner, with its 40 supercomfortable seats, and were impressed with the complicated array of dials and equipment in the cockpit on the one hand and the tiny all-electric kitchen on the other. A tour of the airport perimeter was also enjoyed, passing the "airstop" for helicopters, and the maintenance units of many of the 23 operating companies using the airport. A Comet aircraft could be seen undergoing maintenance inspection, and Mr. Housego, the Chief Public Relations Officer, gave details of performance and comparative times of flight on the South African route where, at present, there are three Comet flights per week.

Of greatest interest, however, was the visit to the meteorological office where a roster of 5 forecasters and 12 assistants is maintained continuously. The senior forecaster is normally engaged on forecasting for the Atlantic routes, three others deal respectively with Mediterranean, European and local routes, and the fifth draws the upper air charts and prepares the upper air analyses. For other than short flights, forecasts are issued in the form of a vertical cross-section accompanied by the composite surface chart for the flight, and in the case of North Atlantic flights composite upper air charts, on the basis of which the tracks across the ocean are planned. The hourly position and weather reports made by aircraft crossing the North Atlantic are plotted in the meteorological office. Continuous watch is kept on the development of the synoptic situation and amendments of forecasts are signalled to the aircraft as necessary. Similar information issued by foreign meteorological services and received from in-coming pilots was exhibited, and showed the reports of the weather entered by the crew as experienced during the flight.

Synoptic surface and upper air charts are drawn to cover the whole area of operations, based on information received by 8 teleprinters and 2 W/T receivers. The charts are hourly, three-hourly and six-hourly, dependent upon the purpose for which each is required.

A special organization is required for Comet flights as their flight plan demands an initial climb to height, then relatively level flight until near destination, followed by rapid descent to the terminal. Because of the high consumption of fuel at low levels particular stress is laid on accurate landing forecasts, as any diversion due to weather (or any other cause) should be decided before the aircraft descends. For the flight itself forecast winds are required at levels up to 40,000 ft.

The observational equipment is of normal standard except for the addition of a photo-electric visibility meter which was described to the visitors by Dr. K. H. Stewart. A distant-reading cup generator anemometer and a direction indicator are connected to dials in the observers' room and in air traffic control.

After tea, Mr. W. M. Witchell, a Vice-President of the Society, thanked the Airport Commandant, Air Marshal Sir John D'Albiac, for permission to visit the airport, and drew comparisons between the present-day London Airport and Croydon on the occasion of the Society's visit there in 1934. Sir John, in reply, stressed the importance of meteorology in the economics of flight planning and, above all, in the safety of aircraft.

INDUSTRIAL PHYSICS CONFERENCE AND EXHIBITION

The Institute of Physics held its fourth Industrial Physics Conference in the Royal Technical College, Glasgow, from June 25 to 28. On the first morning after the formal opening by The Rt. Hon. Lord Bilsland (President of the Scottish Council) there were lectures and discussion on "Physics in the service of metallurgy", opened by Sir Andrew McCance, F.R.S. (Deputy Chairman, Colvilles Ltd.), and "Meteorology in industry", opened by Sir Robert Watson-Watt, F.R.S. Someone remarked that the only connexion seemed to be the difficulty in pronouncing either of the words. It was interesting to learn how completely physical techniques, the spectrograph, ultra-sonic waves and isotope tracer elements, had ousted the slow and cumbersome chemical analysis methods in metallurgical processes.

Opening the discussion on meteorology in industry, Sir Robert Watson-Watt pointed out that although there was no means of assessing the value of long-period forecasts four or five weeks ahead, it must be a very appreciable percentage of the national income. Thirty years ago L. F. Richardson had reached the discouraging conclusion that an excessive number of computers could only forecast tomorrow's weather from today's observations in many weeks' work. Electronic computing machines of today encouraged one to believe that attempts of this sort were now worth while. Sir Robert went on to say that he believed it essential that some meteorologists should be directly employed by industry. These meteorologists should be of as high a standing as the best in the State Service.

Sir Nelson Johnson, Director of the Meteorological Office, said he felt that he should give a warning that long-period forecasts were not, in his opinion, "just round the corner". Electronic brains could only evaluate clearly formulated problems, and we were far from being able to feed into a machine material in a form which would enable the machine to supply forecasts. Before this could be done it was first necessary to establish mathematical equations which took account of all the factors involved. These equations would then have to be simplified to make their solution possible—the difficulty here being to know which terms to retain and which to omit. And thirdly there was the problem of the boundary conditions to be assumed.

Mr. R. A. Watson, Superintendent of the Edinburgh Meteorological Office, agreed with Sir Robert that it was only when the industrialist and the meteorologist had frank discussions on their problems that the meteorologist could play his proper part. He thought the state meteorologist had access to far more information, published and unpublished, than the private consultant could command. Multiplication of private enterprise would raise questions of the protection of the public. We already had weather prophets claiming divine inspiration.

Other discussions of interest, but not touching meteorological subjects, took place throughout the meeting, and visits were arranged to laboratories and works in the neighbourhood. The social side of the meeting was well catered for with functions of various kinds, including steamer and coach tours. On the whole the weather was kind.

An exhibition of instruments, apparatus and books had been arranged in the Technical College. A large number of firms and research organizations were represented, and it was impossible to do more than nibble at the fare provided. An interesting exhibit was a working model of a heat pump which used a large tub of soil as a source of low-grade heat to produce hot water "by the consumption of only a fraction of the electrical energy that would have been used by an immersion heater". The quotation is from the description issued by the Electrical Research Association. Meteorologists are required to collaborate more and more with engineers in dissipating colossal stores of low-grade heat in cooling towers. Even a small fraction of this waste would be of account in world economics. The National Physical Laboratory had diagrams and photographs of smoke plumes from chimneys and funnels. The casual visitor was left with the impression that the only property of the atmosphere of importance in dissipating smoke was the ratio of the wind speed to the vertical velocity of the smoke as it leaves the top of the chimney. Probably a talk to the demonstrator would have removed this false impression but this was not possible.

R. A. WATSON

LETTERS TO EDITOR

Eddy structure at the base of a cumulonimbus cloud

An opportunity was offered at Tengah, Singapore, during the morning of March 12, 1952, for photographing a particularly good example of eddy structure at the base of a cumulonimbus cloud. This structure, although not common, has been observed by the writer on other occasions, but seldom with such definition.

At 0915 zone time (G.M.T. + 7) a cumulonimbus cloud was observed at a distance of about four miles on a bearing of 290° from the station. The well defined eddy structure of the base could be seen towards the northern edge of the cloud, and it persisted for a quarter of an hour or so with little or no apparent change.

The surface wind at the time was 330°, 5 kt., having backed just previously from NE. Altocumulus castellatus was present to the north and north-east of the station, together with some high-level cumulus based between 5,000 and 6,000 ft.

Rain could be seen (extreme left of upper photograph facing p. 305) falling from the cumulonimbus which was moving fairly quickly towards Tengah. A shower commenced at the the station at 0929 when the surface wind backed to 260°, 5 kt. The rain became moderate at 0945 and ceased at 1010 when the shower cloud had moved eastwards across the station.

The mammatus formation also seen in the photograph was neither extensive nor well defined.

P. G. RACKLIFF

R.A.F. Station, Tengah, Singapore, April 21, 1952.

Unusual condensation trails

At about 1710 G.M.T. on June 4, 1952, near Stanwell, Middlesex, with the sun behind me, I noticed at an angle of elevation of about 30° a condensation trail which had just been formed from the north and running in a roughly north-south direction. The aeroplane although audible was not seen; from its steady note I judge that it was not in a violent climb or dive. At its junction with a tenuous cloud the trail became "negative" and continued as such (i.e. as a dark grey lane) along the course through the cloud until it petered out. There was no apparent change of direction between the two parts of the trail, the whole track being straight or possibly gently curved. Although I made no direct estimates at the time I think that each part subtended an angle of about 5°.

Over the subsequent 5–10 min. the course of events was as follows. The normal portion of the trail took on the common pendulous, beady appearance and then was spread out, apparently westwards, developing as a cloud. On the other hand the "negative" trail did not widen noticeably, retaining roughly its original width with, however, a few small dark (i.e. "negative") beads developing. After about 5 min. the normal trail at its junction with the negative was about 4 times the width of the latter. The tenuous cloud itself slowly dispersed, the negative trail of necessity disappearing with it. In the end the white, short dense cloud formed from the "positive" trail alone remained of the features described.

I would be interested to know what conditions along the track could account for the effects observed. At any rate it seems that there must have existed a marked variation of humidity, but it is not easy to account for the striking contrast in behaviour of the two parts of the trail as time progressed.

H. G. HOPKINS

Radio Research Station, Slough, Bucks., June 16, 1952

[The nearest meteorological station, London Airport, reported 1 okta cumulus at 3,500 ft. and 4 oktas cirrus at the time of Dr. Hopkins's observation. The Larkhill ascent at 1500 showed a wind of from 220°, 10 kt. in the lowest layers veering and increasing with height to 244°, 46 kt. at 250 mb. (35,000 ft.) in the upper part of the troposphere.

The ascent showed an inversion of 2° F. between 864 mb. (4,700 ft.) and 838 mb. (5,500 ft.). Otherwise there was a fall of temperature to the tropopause (−78°F., 222 mb., 37,100 ft.). Temperature rose to −59°F. in the stratosphere. The humidity was low at all points to the highest observation of that element at 350 mb. (27,000 ft., dry bulb −33°F., dew point −43°F.), with differences between dry bulb and dew point of the order of 10° except from the low inversion to 14,000 ft. where the differences exceeded 30°.

The Mintra-level curve crossed the temperature curve at 350 mb., but as noted above the air was not saturated at that level. The cirrus clouds were presumably higher.

A similar phenomenon*, except that the cloud formation took place some ten minutes after the aircraft had passed, was observed over the sea near Lübeck, Germany, at midday on August 8, 1938. The aircraft responsible was proved to be flying along a very sharp inversion (temperature 38°F.) at 3 Km. with very dry air above. The cloud through which the aircraft cut a lane was a thin sheet spreading out along the inversion from cumulus over the land.

It is very unlikely that the aircraft responsible for the effects observed by Dr. Hopkins was flying along the inversion at 5,000 ft. because the air was dry above and below, no cloud was noted at that level, and he would probably have seen the aircraft at so low a level.—Ed., *M.M.*]

Ablation of snow deposits at Alston, Cumberland

I was very interested in Mr. Richardson's illustrated note on the above in the July issue of the *Meteorological Magazine*. There is no doubt that wind velocity must play a large part in the ablation of snow cover, but the measurement or estimation of its velocity over snow beds in corries must be rather difficult.

In steep-sided corries, such as those among the buttresses of Ben Nevis, the direction of the ambient wind must greatly modify the effect, however great the speed. The increase in speed of winds blowing into the corries, due to funnelling, must greatly increase the ablation. On the other hand, snow beds in corries to the lee of the wind, apart from lee-side eddies, would probably be little ablated by wind alone. If accompanied by rainfall, however, the ablation might be accelerated even in lee-side corries.

D. L. CHAMPION

47 Norrys Road, Cockfosters, Herts., July 28, 1952

NOTES AND NEWS

Line squall at South Farnborough, Hampshire

The photographs in the centre of this Magazine were taken during the passage of a line squall over South Farnborough. The squall, which gave very little rain (only a trace being measured during 12 hr.), was associated with a cold front from a depression which formed south of Newfoundland on November 6, 1947.

This depression moved eastwards but did not begin to occlude until it reached the mid Atlantic on the 10th, when its easterly movement increased rapidly. The centre of the depression crossed north Scotland about 0300 G.M.T. on the 12th, and the cold front passed over South Farnborough at 1428 when these photographs were taken.

Roll cloud

The photograph of the roll cloud facing the lower part of p. 305 was taken from 52°01′ N., 53°40′W. at 2155 on July 14, 1951, by Mr. J. Waling 3rd Officer (and one of the observers) of T.E.V. *Beaverlake* on a voyage from London to Three Rivers on the St. Lawrence. The elongated round formation of cloud, extending from horizon to horizon, was observed in an otherwise cloudless sky. As the cloud, moving in an east-south-easterly direction at about 600 ft., passed over the ship the wind veered from WSW. force 4 to W. force 6 and the pressure rose sharply from 1011·4 to 1012·8 mb. Immediately after the

*KUHLBRODT, E.; Flugzeug bewirkte auf seiner Bahn gleichzeitig Wolkenauflösung und Wolkenbildung. *Z. angew. Met., Leipzig*, **55**, 1938, p. 346.

transit the wind backed to WSW. force 4 as previously, and shortly afterwards the formation decayed into a line of cumulus cloud. Maximum visibility was experienced during the whole period and the air temperature was constant at 53°F. The photograph was taken just after the cloud had passed over the ship and just before it began to decay.

OBITUARY

Dr. Robert Edward Watson.—Dr. R. E. Watson, formerly a Principal Scientific Officer in the Meteorological Office, died suddenly on May 28, 1952, little more than a year after his retirement at the end of his 62nd year. The news came as a shock to the many who knew him. Deep sympathy is felt for Mrs. Watson and family.

Dr. Watson was born in Yorkshire. He became a student at University College, Nottingham, graduated in London University in 1911 and then lectured in mathematics and physics at Halifax Technical College. He served with the Royal Garrison Artillery during the First World War, 1914–18, and was twice wounded in France in 1917.

As an invalided officer Dr. Watson joined the Meteorological Office in March 1918, but after about a year at Kew Observatory and Falmouth Observatory relinquished the appointment for private reasons. On re-appointment as Senior Professional Assistant in July 1920 he returned to Kew Observatory. During almost nine years, under Dr. C. Chree and later Dr. F. J. W. Whipple as Superintendent, Dr. Watson's fondness and aptitude for instrumental work found scope in most of the Observatory's activities. His first *Geophysical Memoir* discussed the results of comparisons of the pyrheliometers used in measuring solar radiation at Kew. In another field, Dr. Watson was responsible for preparing, installing and generally supervising the magnetographs used in 1923 at the Sandwell Park Colliery, near Birmingham to obtain continuous records of magnetic declination and horizontal force 1,800 ft. underground, and of declination above ground. These mine records were the first of their kind obtained in this country. They and records from the permanent observatories were used in an investigation, arising from the requirements in mine surveying, to determine how far regular and irregular magnetic changes registered at one observatory were representative of changes at the same time in other parts of the country. The subject was discussed by Chree and Watson in a Royal Society paper and a *Geophysical Memoir.* Dr. Watson took a prominent part in the installation of the Galitzin seismographs when they were transferred to Kew from Eskdalemuir Observatory towards the end of 1925.

Perhaps Dr. Watson's chief personal interest was in atmospheric electrical measurements. He made extensive experiments with mercury micro-voltameters in the hope that they could be used to measure the air-earth current. A characteristically thorough investigation of the technique of determining the electrical conductivity of the air and of the electrical potential gradient by means of the Wilson universal electrometer was published as a *Geophysical Memoir*, and led a few years later to the construction of an underground laboratory to enable measurements to be made over a flat surface free from near obstructions. This has now been standard procedure at Kew for more than twenty years. Relationships between atmospheric pollution and electrical potential gradient at Kew were discussed by Chree and Watson in a paper to the Royal Society. Dr. Watson was awarded the Ph.D. of London University in 1927.

In mid 1929 Dr. Watson, in the grade of Assistant Superintendent, moved to Eskdalemuir to take charge of the Observatory which had been established among the Dumfriesshire moors twenty years earlier with magnetic work as a primary commitment. During his tenure of this post, a Schuster-Smith coil magnetometer was acquired for the measurement of horizontal force.

The increasing provision which was being made for meteorological services to civil and military aviation led to Dr. Watson's transfer to that very different sphere of work at the beginning of 1934. After a few months of acclimatization at Lympne to the fresh type of duties, he went on to the Royal Air Force Headquarters (later No. 1 Group) at Abingdon. From this point his career lay with the Royal Air Force, advising senior officers and supervising the work of subsidiary meteorological offices at airfields. To him, as to many of his colleagues, the Second World War, 1939–45, brought changes in location and long interruption of home life. Early in the war it fell to him to investigate and report on the war-time requirements for the meteorological instruction of members of aircrew. Following periods with the School of Air Navigation and at a Group Headquarters in Inverness he occupied the post of senior or chief meteorological officer at Headquarters Fighter Command 1941–44, at Headquarters No. 3 Group, and finally, from 1948, at Headquarters Bomber Command. He became Wing Commander R.A.F.V.R. (Meteorological Branch) in 1944. "Doc." Watson was widely known in the Royal Air Force and was well liked. It is known that his services were highly appreciated.

The care for securing precision in measurement and observation displayed by Dr. Watson while at Kew, Falmouth and Eskdalemuir Observatories was in harmony with neatness of personal appearance and habits. He was very sociable, keenly interested in sporting affairs and devoted to golf. It is sad that he has gone so soon.

WEATHER OF AUGUST 1952

During the first half of the month pressure was high between the Azores and Greenland and Iceland; in the second half of the month, high pressure developed from the eastern United States to south-west Europe. Mean pressure generally over Europe, the North Atlantic and North America differed very little from normal; over most of Europe it was about 2 mb. below normal; mean pressure in Finland fell to 1006 mb. which was 5 mb. below normal.

Mean temperature was generally 2–5°F. above normal in Europe and North America, but in Scandinavia, mean temperatures of 45–50°F. were 2–5°F. below normal; in southern Algeria a mean temperature of 99°F. was recorded.

In the British Isles the weather during the first 19 days was unsettled, with severe rainstorms at times, particularly in the south. The storm in the south-west on the 15th will long be remembered for the great destruction and heavy loss of life sustained at Lynmouth. Over much of the country fair weather prevailed from the 20th onwards but in the north of Scotland considerable rain fell at times after the 23rd.

In the opening days of the month a complex depression covered the British Isles; rainfall was fairly heavy in places, and there were widespread thunderstorms on the 2nd. From the 6th to the 8th shallow depressions to the south-west of the British Isles and over northern France moved slowly north giving thunderstorms and heavy rain, notably on the 6th in the London area and the Home Counties where some flooding occurred and 4·83 in. of rain was registered at Boreham Wood, Hertfordshire. On the 9th a deep depression off the south of Ireland moved north-north-east over the country causing strong winds in England and Wales and widespread rain, heavy locally, particularly in Northern Ireland, south-west Scotland and the Isle of Man. Subsequently a belt of rather low pressure extended from south-west of Ireland to Norway, while pressure was relatively high on the continent; rain fell in most districts except the south-east on the 11th, but mainly fair, warmer weather prevailed over much of England and Wales from the 12th to the 14th. On the 15th a small depression moved slowly from a position near Brest east-north-east across southern England and was associated with severe thunderstorms and exceptionally heavy rainfall in the south of England; locally in north Devon and north Somerset more than 7 in. of rain fell in the 24 hr. ending at 0900 on the 16th, while a fall of 9·00 in. was registered at Longstone Barrow, Exmoor. Floods occurred over a wide area, notably at Lynmouth where the water rushing down from the moors washed away the bridges and almost destroyed the town; many people lost their lives. On the 18th a deep depression off southern Ireland moved south-east to west France and later turned north-east to west Germany; more heavy rain fell in parts of southern England (2·47 in. at Hastings, the heaviest fall there in 24 hr. since 1875). The 18th was a very cold day for the time of year; at Marlborough the maximum temperature, 54·7°F., was the lowest recorded there in August since records were first taken in 1864. On the 19th a ridge of high pressure off our north-west coasts moved slowly south-east and the weather improved; apart from some rain in the north of Scotland mainly fair weather prevailed until the 26th. On that day troughs associated with a deep depression over Iceland moved south-east and rain fell over Scotland, north Ireland and the extreme north of England. Thereafter pressure was high in a ridge from an anticyclone north of the Azores to central Europe and low to the north of the British Isles. Strong winds and local gales occurred in Scotland on the 27th and 28th and rain occurred, chiefly in the north-west and north. In the early hours of the 30th a shallow depression over Brittany spreading north-east was associated with rain in the Channel Islands and locally on the south coast of England. On the 30th and 31st a depression south of Iceland moved slowly north-east and associated troughs crossed the British Isles giving heavy rain in the north of Scotland on the 30th and mainly slight rain in the west and north of the British Isles on the 31st. A gale occurred in north Scotland on the 31st. The last week was warm except in the north of Scotland.

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 ...	81	35	+1·0	126	−1	101
Scotland	75	27	+0·4	115	−1	93
Northern Ireland ...	72	37	+0·5	124	−2	89

RAINFALL OF AUGUST 1952

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	2·54	115	*Glam.*	Cardiff, Penylan ...	6·02	142
Kent	Folkestone, Cherry Gdn.	4·09	171	*Pemb.*	Tenby	4·95	130
„	Edenbridge, Falconhurst	3·55	135	*Mer.*	Aberdovey	4·01	90
Sussex	Compton, Compton Ho.	2·90	94	*Radnor*	Tyrmynydd	5·70	106
„	Worthing, Beach Ho. Pk.	2·04	90	*Mont.*	Lake Vyrnwy	5·47	103
Hants.	Ventnor Cemetery ...	2·01	99	*Mer.*	Blaenau Festiniog ...	7·75	69
„	Southampton (East Pk.)	4·06	155	*Carn.*	Llandudno	2·75	98
„	Sherborne St. John ...	2·49	103	*Angl.*	Llanerchymedd ...	4·04	112
Herts.	Royston, Therfield Rec.	5·02	195	*I. Man*	Douglas, Borough Cem.	5·16	135
Bucks.	Slough, Upton... ...	2·57	118	*Wigtown*	Newton Stewart ...	3·34	80
Oxford	Oxford, Radcliffe ...	4·27	187	*Dumf.*	Dumfries, Crichton R.I.	3·93	97
N'hants.	Wellingboro' Swanspool	3·27	137	„	Eskdalemuir Obsy. ...	4·49	87
Essex	Shoeburyness	3·07	173	*Roxb.*	Kelso, Floors	4·75	161
„	Dovercourt	2·12	118	*Peebles*	Stobo Castle	4·24	119
Suffolk	Lowestoft Sec. School...	4·31	196	*Berwick*	Marchmont House ...	3·54	107
„	Bury St. Ed., Westley H.	3·33	128	*E. Loth.*	North Berwick Res. ...	2·18	69
Norfolk	Sandringham Ho. Gdns.	2·24	83	*Midl'n.*	Edinburgh, Blackf'd. H.	4·53	141
Wilts.	Aldbourne	5·53	209	*Lanark*	Hamilton W. W., T'nhill	3·56	104
Dorset	Creech Grange... ...	2·74	96	*Ayr*	Colmonell, Knockdolian	5·68	142
„	Beaminster, East St. ...	5·04	161	„	Glen Afton, Ayr San. ...	3·89	72
Devon	Teignmouth, Den Gdns.	3·88	172	*Renfrew.*	Greenock, Prospect Hill	5·93	115
„	Cullompton	5·59	183	*Bute*	Rothesay, Ardencraig...	6·56	135
„	Ilfracombe	7·51	209	*Argyll*	Morven (Drimnin) ...	6·42	122
„	Okehampton Uplands...	10·54	249	„	Poltalloch	5·79	118
Cornwall	Bude, School House ...	7·44	264	„	Inveraray Castle ...	7·28	111
„	Penzance, Morrab Gdns.	3·57	113	„	Islay, Eallabus... ...	5·29	121
„	St. Austell	4·61	127	„	Tiree	3·53	84
„	Scilly, Tresco Abbey ...	3·56	129	*Kinross*	Loch Leven Sluice ...	3·99	104
Glos.	Cirencester	3·60	120	*Fife*	Leuchars Airfield ...	3·49	113
Salop	Church Stretton ...	2·79	84	*Perth*	Loch Dhu	5·19	77
„	Shrewsbury, Monksmore	2·03	73	„	Crieff, Strathearn Hyd.	4·71	112
Worcs.	Malvern, Free Library...	4·73	164	„	Pitlochry, Fincastle ...	3·34	94
Warwick	Birmingham, Edgbaston	3·66	135	*Angus*	Montrose, Sunnyside ...	2·25	81
Leics.	Thornton Reservoir ...	3·72	133	*Aberd.*	Braemar	3·17	93
Lincs.	Boston, Skirbeck ...	2·61	109	„	Dyce, Craibstone ...	4·69	155
„	Skegness, Marine Gdns.	1·67	68	„	New Deer School House	4·16	141
Notts.	Mansfield, Carr Bank...	2·22	80	*Moray*	Gordon Castle	4·15	131
Derby	Buxton, Terrace Slopes	2·64	60	*Nairn*	Nairn, Achareidh ...	3·55	146
Ches.	Bidston Observatory ...	2·21	72	*Inverness*	Loch Ness, Garthbeg ...	5·46	168
„	Manchester, Ringway...	1·28	39	„	Glenquoich	8·57	104
Lancs.	Stonyhurst College ...	7·62	151	„	Fort William, Teviot ...	5·92	95
„	Squires Gate	3·23	94	„	Skye, Broadford ...	6·06	94
Yorks.	Wakefield, Clarence Pk.	1·24	48	„	Skye, Duntuilm ...	5·03	113
„	Hull, Pearson Park ...	1·23	42	*R. & C.*	Tain, Tarlogie House ...	4·27	158
„	Felixkirk, Mt. St. John...	2·25	79	„	Inverbroom, Glackour...	4·07	97
„	York Museum	1·67	66	„	Achnashellach	6·43	102
„	Scarborough	1·81	65	*Suth.*	Lochinver, Bank Ho. ...	4·78	143
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