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AN EXAMPLE OF VENTILATION ERROR IN THE DRY-BULB AND WET-BULB PSYCHROMETER

By R. F. ZOBEL, O.B.E.

Introduction.—Vapour pressure in the atmosphere is determined from an equation of the form

$$e_w - e = Ap\,(T - T_w) \qquad \ldots (1)$$

where e_w is the saturation vapour pressure at the wet-bulb temperature T_w, e is the vapour pressure, T is the dry-bulb temperature, p is atmospheric pressure (usually taken as constant at 1000 mb for use at the surface) and A is a constant which takes values that vary with the rate of ventilation of the wet bulb.

Meteorological Office hygrometric tables[1] use a value of $A = 7.99 \times 10^{-4}$ where T is in °C and exceeds 0°C and pressures are in millibars, for use with readings taken in a standard thermometer screen where the rate of passage of air past the wet bulb is assumed to be 1–1.5 metres per second. Humidity slide-rules used in the Office are based on the same conventions. It is specifically stated in the introduction to the tables that they (and consequently, the slide-rule) are not suitable for a psychrometer exposed in stagnant air. But there is no other recourse open to the observer if the air is, in fact, stagnant. It is the purpose of this note to draw attention, by reference to a specific example, to the rather large errors that occasionally occur due to this 'misuse' of the tables or slide-rule.

Occasions liable to produce errors.—The relative humidity U is given by

$$U = 100e/e_T \qquad \ldots (2)$$

where e_T is the saturation vapour pressure at the dry-bulb temperature.

Combination of equations (1) and (2) leads to

$$U = 100\,\frac{[e_w - Ap\,(T - T_w)]}{e_T}. \qquad \ldots (3)$$

The constant A is only appropriate to a ventilation rate of 1–1.5 m/s (2–3 knots). For a different wind speed the constant may be written $A + \Delta A$ and in particular, if the air is stagnant, $A + \Delta A_0$. In stagnant air there will be a different wet-bulb temperature (T_w') and saturation vapour pressure at T_w' (e_w'), and equation (3) becomes

$$U = 100 \frac{[e_w' - p(A + \Delta A_0)(T - T_w')]}{e_T}. \qquad \ldots (4)$$

Use of the tables however leads to a value

$$U' = 100 \frac{[e_w' - Ap(T - T_w')]}{e_T}. \qquad \ldots (5)$$

and the error in relative humidity is given by

$$\varepsilon_U = U' - U = 100 \frac{p\,\Delta A_0 (T - T_w')}{e_T}. \qquad \ldots (6)$$

The error is therefore proportional to $(T - T_w')/e_T$. Since e_T decreases as the temperature decreases, the error will be greatest at low humidities and temperatures. In the atmosphere, however, observed values of $(T - T_w')$ decrease as T (or e_T) decreases, but the insertion of a few probable values shows that the higher values of $(T - T_w')/e_T$ will occur at low temperatures. At sub-freezing temperatures the values of A and ΔA_0 are changed but it is probable that the largest errors may occur in dry, stagnant air in cold climates.

Such conditions are seldom or never experienced in the British Isles. The situations which produce the lowest humidities are warm days in June and July and the occurrence of continental air in April.[2] Although the latter may well produce the larger errors because of the lower temperature level, the example given below belongs to the former. It was brought to light because measurements from a low-flying aircraft produced dew-points which were not reconcilable with those obtained from the dry-bulb and wet-bulb psychrometer on the ground.

The physical reason for the error is that evaporation from the wet-bulb muslin produces a layer of humid air around the bulb. This is normally removed by the flow of air past the bulb. In the absence of such a flow, the moist air is removed by the slower process of diffusion, and evaporation at the wet bulb is less rapid. Consequently the wet-bulb depression is reduced.

An example.—The weather on 8 July 1959 was very hot, dry and windless over southern England, as indicated by the weather map for 1200 GMT (Figure 1).

The dew-points (after conversion from °F) recorded at Farnborough during the day are shown in Table I. Reported winds are also given.

TABLE I—HUMIDITIES AND WINDS AT FARNBOROUGH ON 8 JULY 1959

Time (GMT)	09	10	11	12	13	14	15	16	17	18
Dew-point (°C)	14.9	14.8	15.5	13.9	15.3	10.9	13.8	12.9	12.6	14.4
Wind speed (kt)	00	00	00	03	02	07	03	01	04	05

At 1400 GMT the wind was the highest and the dew-point the lowest reported during the day. This dew-point is anomalous but in fact it is the most likely to be correct because the wind was strong enough to give the ventilation rate assumed in the official tables.

Discussion.—The hair hygrograph is not subject to ventilation errors in the same way as the wet-bulb thermometer because there is no water mass associated

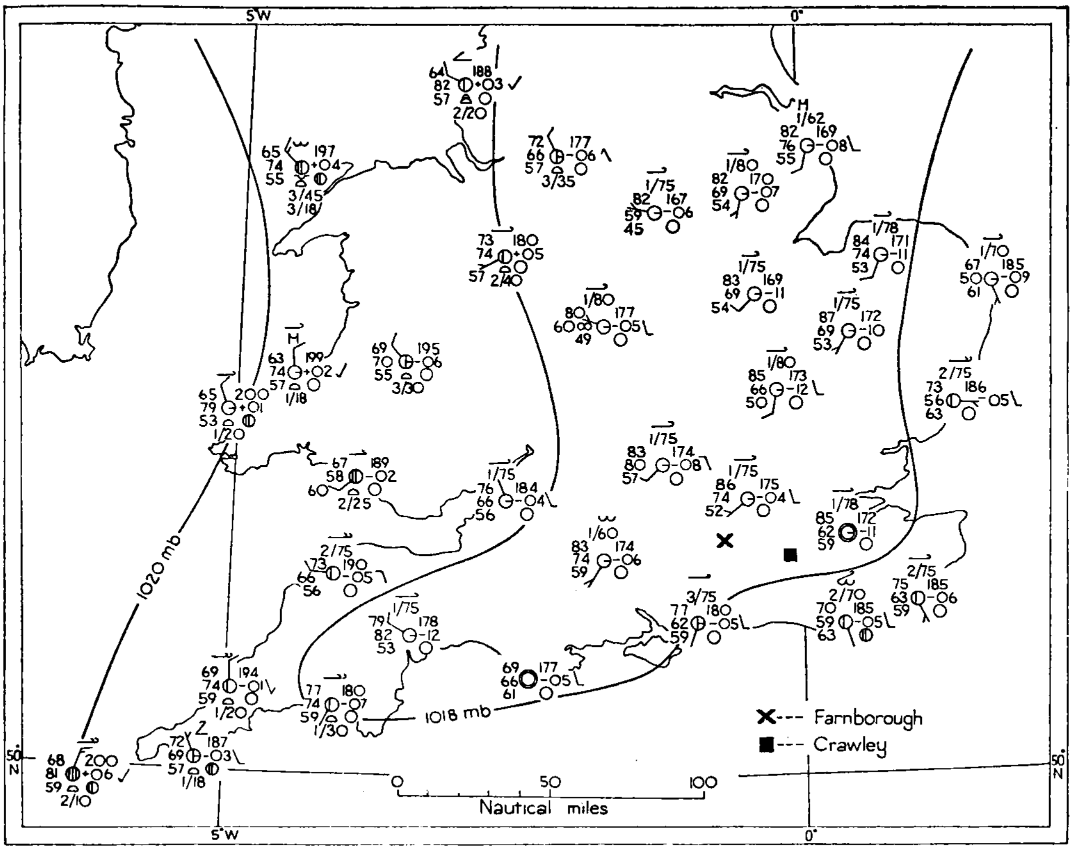

FIGURE 1—WEATHER MAP FOR SOUTHERN ENGLAND, 1200 GMT, 8 JULY 1959

with the hair. It is not, however, a highly accurate instrument and the *Handbook of meteorological instruments*[3] indicates this by saying that "errors at any point of the scale above 20–30 per cent do not normally exceed about ± 5 per cent, but the sensitivity is about ± 1 to 2 per cent." Nevertheless it will serve as a useful working standard for relative humidity U. It is possible, for this particular occasion, to estimate the likely errors of the hygrograph and so to arrive at corrected values of the errors due to lack of ventilation of the wet bulb.

Table II shows the dry-bulb temperatures for each hour corresponding to those on the hygrogram for 8–9 July 1959. The whole period of 24 hours has been considered since the winds were very light and there was a large range of humidity values. The humidities on the uncorrected hygrogram and the humidities derived by slide-rule from the dry-bulb and wet-bulb temperatures are given in columns (3) and (4) respectively, and the apparent error ε_U is given in column (5).

It will be seen that at 1400 GMT there was an apparent error of 5 in the percentage humidity which corresponds to an error in dew-point of 2.9°C. At this time the observed wind speed at 10 metres was 7 knots, which may be regarded as providing normal ventilation in the thermometer screen. The recorded humidity by dry and wet bulb can therefore be taken as correct and the hygrograph reading is thus 5 too low.

TABLE II—HUMIDITY ERROR IN RELATION TO WIND, TEMPERATURE AND HUMIDITY, 8/9 JULY 1959

Time GMT (1)	Dry-bulb temperature °C (2)	Apparent U by hygrograph per cent (3)	Recorded U by dry and wet bulbs per cent (4)	Apparent ε_U (4) − (3) (5)	ε_U corrected for hygrograph error per cent (6)	Dew-point error °C (7)	$\frac{T - T_w'}{e_T}$ (°C/mb) (8)	Wind speed *knots* (9)
8 July								
09	24.9	42	54	12	9	2.8	0.19	00
10	26.7	38	48	10	6	2.1	0.21	00
11	28.3	34	46	12	8	2.9	0.18	00
12	29.5	30	38	8	4	1.9	0.23	03
13	30.6	26	39	13	8	3.8	0.22	02
14	31.7	23	28	5	0	0.0	0.26	07
15	31.6	23	34	11	6	3.0	0.23	03
16	31.1	24	33	9	4	1.9	0.24	01
17	30.7	24	33	9	4	2.0	0.25	04
18	29.4	32	40	8	4	1.6	0.22	05
19	27.7	38	46	8	4	1.3	0.21	02
20	26.1	45	54	9	6	1.9	0.18	01
21	24.0	53	62	9	7	2.1	0.16	00
22	22.1	61	65	4	2	0.4	0.16	00
23	20.6	65	67	2	1	0.2	0.15	00
24	19.2	68	74	6	5	1.1	0.13	00
9 July								
01	19.2	69	70	1	0	0.5	0.13	01
02	18.5	73	79	6	5	0.9	0.10	00
03	16.8	80	83	3	3	0.6	0.09	00
04	16.5	84	82	−2	−2	−0.4	0.09	00
05	15.8	84	84	0	0	0.0	0.09	00
06	16.2	82	83	1	1	0.1	0.09	00
07	17.4	76	78	2	2	0.5	0.11	02
08	19.2	70	71	1	0	0.0	0.14	02

The hygrograph error at the higher humidities was estimated on the following basis. Certain editions of Kaye and Laby[4] give $A = 0.001$ for a small closed room, i.e. ΔA_0 is about 2×10^{-4}. Insertion of this value in equation (6), along with $(T - T_w')/e_T = 0.09$ (column (8) at 0300 GMT of Table II), shows that if the hygrograph was reading accurately at 80 per cent it should have read about 2 per cent below the values deduced from the dry-bulb and wet-bulb thermometers. It is clear from column (5) of Table II that this was closely the case. It has therefore been taken that the hygrogram was subject to errors of 5 per cent and 0 per cent at readings of 25 and 80 per cent respectively and that the relationship was linear. Column (6) of Table II shows values of ε_U, which are those in column (5), corrected on the basis indicated above. For the benefit of synoptic meteorologists the corresponding errors in dew-point are shown in column (7).

It is now possible, from equation (6), to obtain an average value for ΔA by plotting $(T - T_w')/e_T$ against ε_U as corrected. This should give a straight line through the origin, the slope being proportional to ΔA. This has been done in Figure 2 where the digits above the crosses denote wind speed and those beneath, in brackets, show the time. There is a good deal of scatter as is to be expected from the adoption of the hygrograph as a standard and from the fact that the wind was not always calm, but a straight line has been drawn by eye through the origin. This gives a value of $\Delta A = 2.4 \times 10^{-4}$, so giving a value of $A = 10.4 \times 10^{-4}$. This value was obtained for very low wind speeds at 10 metres; on only 5 of these 24 occasions did the wind exceed 2 knots (mean speed over 24 hours = 1.4 knots or 0.7 m/s).

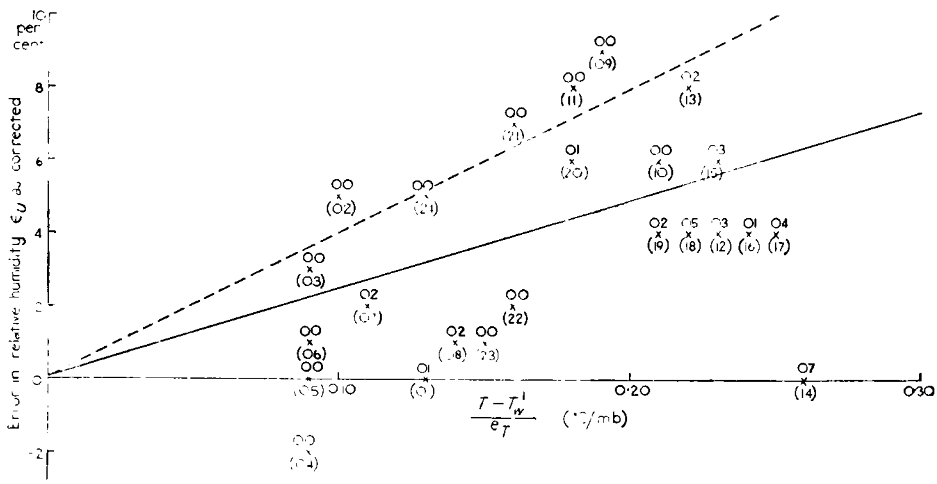

FIGURE 2—RELATIONSHIP BETWEEN THE CORRECTED ERROR IN RELATIVE HUMIDITY, $(T - T_w')/e_T$ AND WIND SPEED

The straight line corresponds to $A = 10.4 \times 10^{-4}$, the dotted line to the Austrian value of A. Digits above the crosses denote wind speed (knots), those below (in brackets) the time (GMT), see Table II.

The Kaye and Laby value of A for a small closed room can also be deduced from a paper by Powell[5], though it is possible that the Powell, and Kaye and Laby figures are based on the same observations. Another value, 12.01×10^{-4}, can be deduced from Austrian figures quoted by Penman[6] for winds of 0–0.5 m/s. The humidity errors in column (6) of Table II may therefore be regarded as serving as a reliable example of the errors which may occur as a result of inadequate wet-bulb ventilation.

Closer examination of Figure 2 shows the sensitivity of A to wind speed. It confirms that some of the scatter is due to finite wind speeds, since values of ϵ_U corresponding to the higher wind speeds tend to fall below the line, whilst above the line there are only values corresponding to the lower wind speeds. The dotted line corresponds to the Austrian value of A. It passes amongst points all of which are associated with very light winds. The Austrian value is therefore supported by the present observations as being appropriate to very stagnant conditions.

Forecasting implications.—Occasions when errors may occur in the dry-bulb and wet-bulb psychrometer are not difficult to recognize at the time. When estimating nocturnal cooling rate, or the possibility of fog formation on such occasions, forecasters may find it useful to compare surface dew-points as derived from dry bulbs and wet bulbs and from the hygrogram. The latter should be preferred if they are appreciably lower, so long as there is adequate confidence in the accuracy of the hygrograph. This means that checks, particularly at low humidities in non-stagnant air, should be made whenever possible between the two instruments. It should also be remembered that the zero of a hygrograph cannot be set accurately by reference to the dry-bulb and wet-bulb psychrometer if the wind is very light unless the relative humidity is close to 100 per cent.

Conclusions.—There are occasions, rather infrequent in the British Isles, when relative humidities and dew-points derived from dry-bulb and wet-bulb thermometers may be in error. In the data examined the error was as much as 9 per cent for humidity and 3.8°C for dew-point.

REFERENCES

1. London, Meteorological Office. Hygrometric tables, Part II, 2nd edn. London, HMSO, 1964.
2. London, Meteorological Office. Climatological atlas of the British Isles. London, HMSO, 1952.
3. London, Meteorological Office. Handbook of meteorological instruments, Part I. London, HMSO, 1956.
4. KAYE, G. W. C. and LABY, T. H.; Physical and chemical constants, 10th edn. London, Longmans Green, 1948, p. 52.
5. POWELL, R. W.; The use of thermocouples for psychrometric purposes. *Proc. phys. Soc.*, London, **48**, 1936, p. 406.
6. PENMAN, H. L.; Humidity. London, The Institute of Physics, 1955, p. 37.

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AN INDEX OF COMFORT FOR GAN

By C. N. McLEOD

Introduction.—A recent paper by Stephenson[1] examined the climate of Singapore from the point of view of human comfort using the 'effective temperature' scale devised by the American Society of Heating and Ventilating Engineers[2] and published by the Air Ministry.[3] As the results proved of considerable interest, particularly to persons stationed in or about to be posted to the Far East, it was thought worthwhile to extend the investigation to other stations in the area and this article describes the annual and diurnal variation of effective temperature at Gan. Comparison of these results with those for Singapore is of interest as, although both islands are close to the equator, Gan is near the centre of the Indian Ocean and therefore divorced from any continental effects which might influence Singapore's climate.

Summary of data used.—Climatological data for Gan for the period January 1959 to July 1964 were used to calculate the mean dry-bulb and wet-bulb temperatures and from these the mean relative humidity for each month of the year (Table I) together with mean scalar wind speeds (Figure 1).

TABLE I—MEAN DRY-AND WET-BULB TEMPERATURE AND RELATIVE HUMIDITY FOR GAN FOR JANUARY 1959 TO JULY 1964

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Mean dry-bulb temperature (°F)	81.8	82.1	83.0	82.7	82.7	82.0	81.4	81.3	81.7	81.1	81.1	81.1
Mean wet-bulb temperature (°F)	76.8	76.9	77.3	77.7	77.9	76.8	76.7	76.7	76.8	76.6	76.5	76.6
Mean relative humidity (per cent)	79	78	76	79	80	78	80	81	79	81	80	81

The corresponding mean 24-hour effective temperature, as read from the nomogram in A.P. 1269B for lightly-clad persons, together with the dry-bulb and wet-bulb values are plotted in Figure 2.

Three-hourly values of dry-bulb and wet-bulb temperatures and wind speed were then calculated for the same period, to determine the diurnal variation of the effective temperature. The variations over 24 hours for each

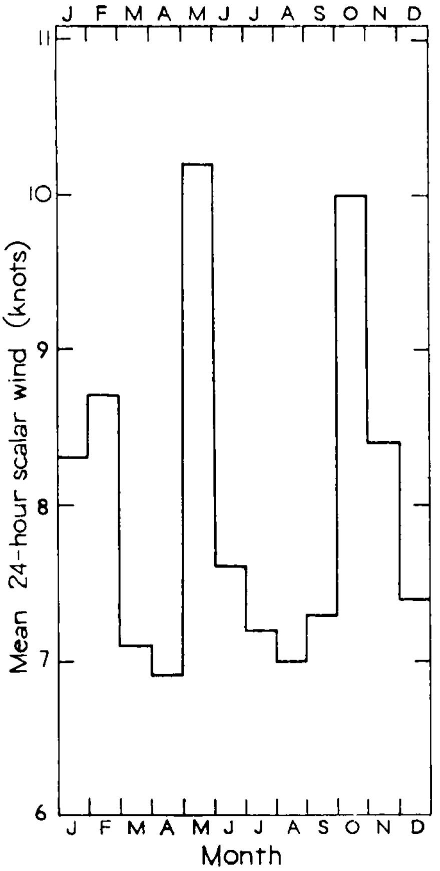

FIGURE 1—MEAN 24-HOUR SCALAR WIND AT GAN

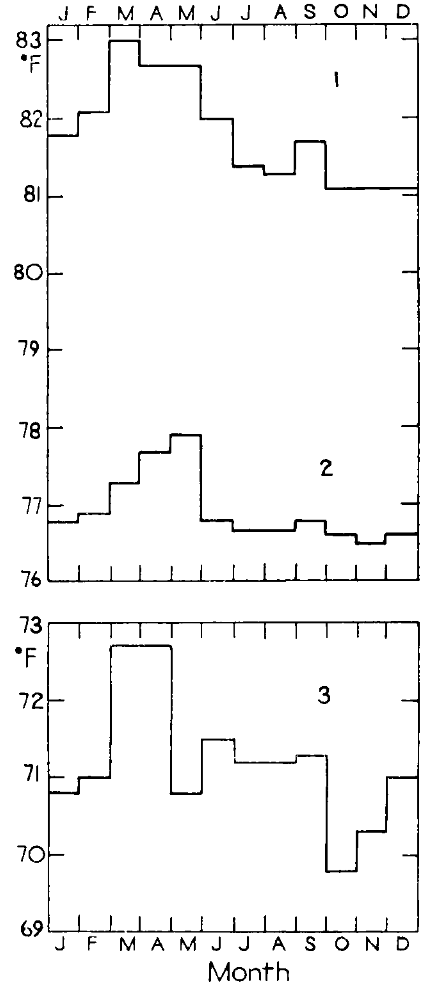

FIGURE 2—MEAN 24-HOUR TEMPERATURES AT GAN

1. Dry-bulb temperature; 2. Wet-bulb temperature; 3. Effective temperature.

Both figures are for the period January–July 1959–64 and August–December 1959–63.

of the months January, April, July and October are shown in Figure 3, whilst Figures 4 and 5 show the effective temperatures which would correspond to various wind speeds at 0500 and 1400 zone time in April (one of the hottest months) assuming that dry-bulb and wet-bulb temperatures were fixed at the appropriate average values for each of these hours.

Discussion of data.—

1. *Annual variation of effective temperature.*—Figure 2 shows that there is only a small variation in the mean effective temperature throughout the year, but the main feature is that every month falls within the optimum range for hot climates, viz. 69 to 73°F.

The figures do suggest that October and November are the most comfortable and March and April the least comfortable months, although this might not be appreciated by the individual in view of the small range of effective temperature (2.9°F). The remaining months exhibit a very small variation in effective temperature (0.7°F), suggesting that they are very much alike. It is a little unexpected to find that maximum values do not occur during the months immediately following both the equinoxes, when the sun is virtually overhead, but the stronger winds in May and October more than offset the increased effect of the sun's radiation. The result that there is little to choose between the months accords well with experience.

Table I confirms Stephenson's conclusion that relative humidity alone is not a reliable guide to comfort, since the most comfortable months in Gan are those with the highest relative humidity and one of the least comfortable months has the lowest value.

2. *Diurnal variation of effective temperature.*—Figure 3 shows that there is a marked diurnal variation of effective temperature, with the maximum in the early afternoon and the minimum around 0500 zone time. In April and July there is a suspicion of a secondary maximum around 2300 zone time but this is absent in January and October.

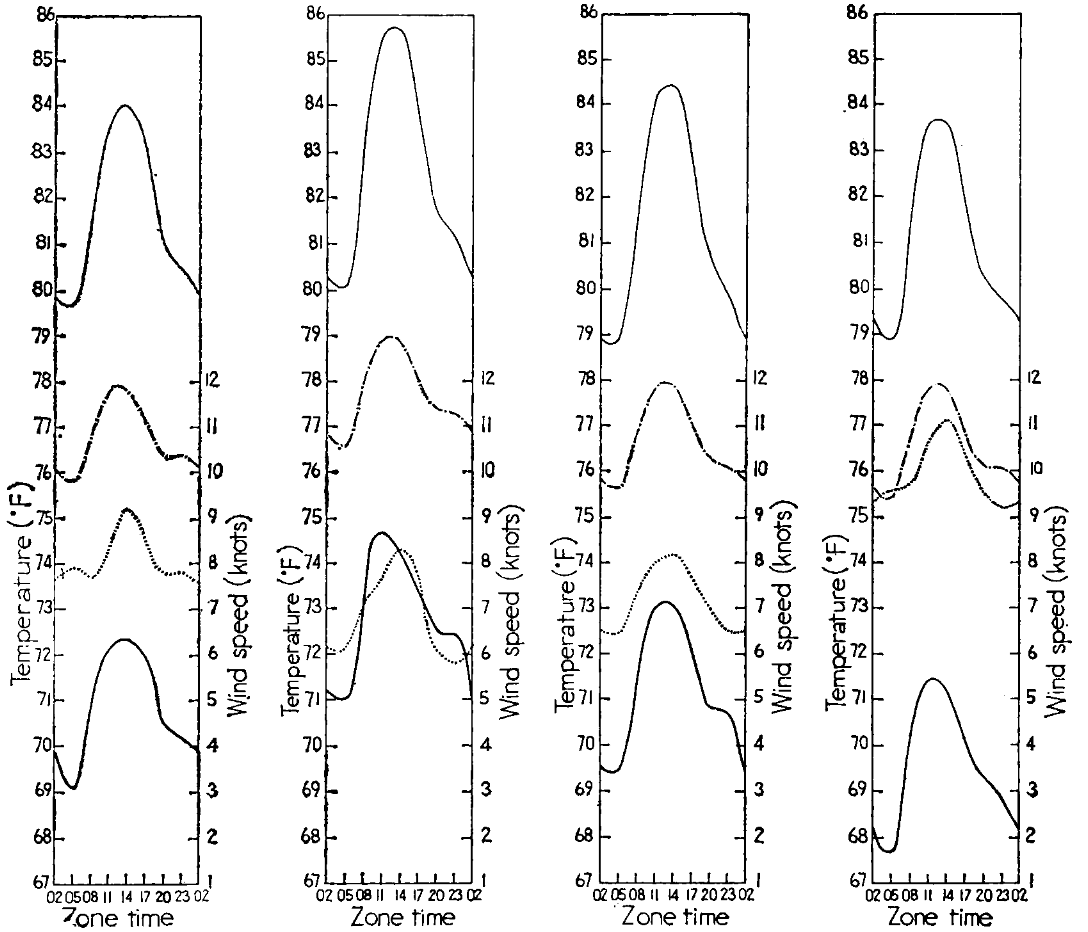

FIGURE 3—DIURNAL VARIATION OF WIND SPEED AND TEMPERATURE AT GAN

———— Dry-bulb temperature   —·—· Wet-bulb temperature

...... Wind speed   ———— Effective temperature

From left to right the diagrams are for January, April, July, and October.

Other points of interest arising from the diagrams of diurnal variation are:

(i) The time of maximum discomfort is usually an hour or so earlier than the time of maximum temperature.

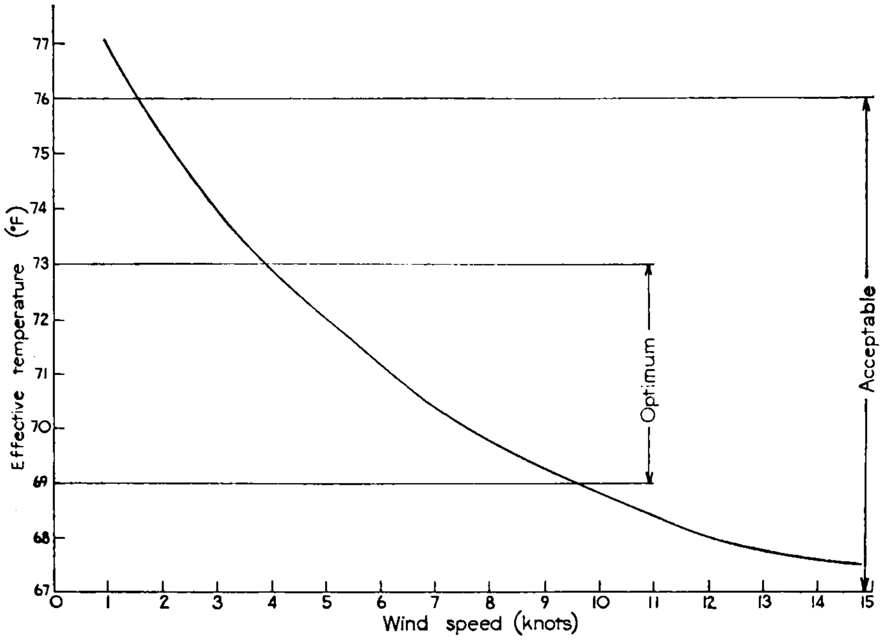

FIGURE 4—VARIATION OF EFFECTIVE TEMPERATURE WITH WIND SPEED AT GAN AT 0500 ZONE TIME FOR AN AVERAGE APRIL

Average dry-bulb temperature 80.1°F
Average wet-bulb temperature 76.6°F

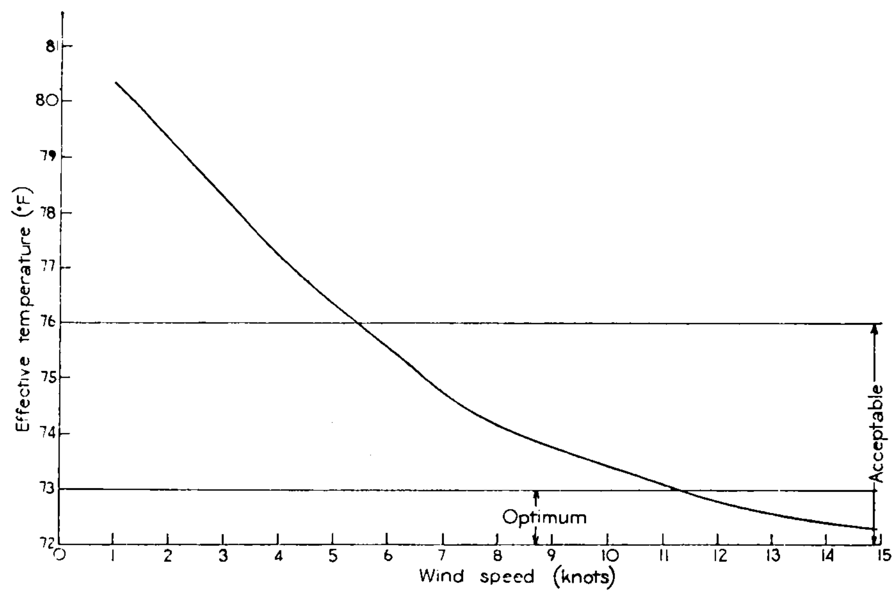

FIGURE 5—VARIATION OF EFFECTIVE TEMPERATURE WITH WIND SPEED AT GAN AT 1400 ZONE TIME FOR AN AVERAGE APRIL

Average dry-bulb temperature 85.7°F
Average wet-bulb temperature 78.9°F

(ii) The diurnal variation of the effective temperatures is not as great as that of the corresponding dry-bulb temperatures, whilst the annual variation of the former is greater than that of the latter.

(iii) Taking 69°F to 73°F effective temperature as the optimum comfort zone for the tropics, then:

(*a*) January and October are not at any time of the day too hot and during the early hours in October the effective temperature is too low for comfort.

(*b*) April is uncomfortably hot between 0800 and 1800 zone time and Figure 5 shows that on an April afternoon a wind speed of between 11 and 12 knots would be required to produce optimum comfort.

(*c*) July is uncomfortably hot between 1100 and 1400 zone time.

3. *Effect of rainfall and sunshine.*—During most periods of rain at Gan the wind is strong and squally, which combined with a temperature in the low seventies reduces the effective temperature at times to below 60°F making conditions uncomfortably cool indoors and most unpleasant outdoors. The monthly rainfall averages suggest that these conditions are most likely to occur during the period October to January and in May and June (Table II).

Gan enjoys a fair proportion of sunshine, about two-thirds of the daylight hours being sunny. Europeans, therefore, tan very easily and quickly and some form of protection against sunshine is necessary, particularly on first arrival at the island.

TABLE II—MEAN RAINFALL AND SUNSHINE AT GAN

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Rainfall (inches) Oct. 1957–July 1964	10.0	5.1	4.2	7.2	9.6	8.2	6.5	7.1	6.6	11.1	8.2	11.3
Sunshine (hours) June 1960–July 1964	231	205	270	243	218	230	216	220	223	209	238	234

Comparison with Singapore.—Table III compares the mean monthly values of effective temperature at Singapore and Gan.

TABLE III—MEAN EFFECTIVE TEMPERATURES AT SINGAPORE AND GAN

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Singapore	71.1	72.6	74.6	76.1	76.9	75.9	74.9	74.6	74.9	75.0	73.9	72.6
Gan	70.8	71.0	72.7	72.7	70.8	71.5	71.2	71.2	71.3	69.8	70.3	71.0

Inspection of this Table and of the diurnal variation, rainfall and sunshine values for the two stations reveals the following:

(i) In every month of the year Gan is more comfortable than Singapore and does not experience the latter's pronounced peaks of discomfort in May and October.

(ii) From December to February Gan and Singapore experience some of their heaviest rainfall and have very similar effective temperatures.

(iii) The diurnal variation of effective temperature is much the same at both stations, although Gan barely shows the secondary maximum found at Singapore around midnight.

(iv) Gan enjoys more sunshine than Singapore and European residents appear to tan more readily there than in Singapore.

Conclusions.—

(i) For assessing climatic comfort in the tropics the effective temperature is undoubtedly a good index, the results obtained being in accord with experience both in Gan and Singapore, whilst relative humidity values alone are misleading.

(ii) Forced ventilation by means of fans is just adequate for producing optimum comfort during the more extreme heat conditions in April whilst during rainy periods some form of protection against excessive ventilation is desirable.

(iii) Experience confirms that Gan enjoys a more comfortable climate than one would normally expect at a place near sea level in the tropics, a conclusion which is further supported by the Senior Medical Officer's statement that prickly heat is rare at Gan except amongst people whose work takes them into artificially heated areas (kitchens, power houses, etc.).

REFERENCES

1. STEPHENSON, P. M. An index of comfort for Singapore. *Met. Mag., London*, **92**, 1963, p. 338.
2. New York, American Society of Heating and Ventilating Engineers. Effective temperature chart showing normal scale of effective temperature. *Guide, New York*, 1944, p. 61.
3. Air Ministry. Handbook of preventive medicine, A.P.1269B. Air Ministry, London.

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NOTE ON THE ERRORS INVOLVED IN COMPUTING MEAN COMFORT INDICES FROM MEAN VALUES OF DRY-BULB AND WET-BULB TEMPERATURES AND WIND SPEED

By P. M. STEPHENSON and C. N. McLEOD

Recent papers by Stephenson[1] and McLeod (preceding article) presented mean values of a comfort index (effective temperature) for Singapore and Gan respectively, computed from mean values of dry-bulb and wet-bulb temperatures and mean wind speeds. The question has been raised whether such computations do give true average comfort indices or whether perhaps a correlation between dry-bulb and/or wet-bulb temperature and wind speed leads to misleading results.

A paper by Webb[2] based on measurements in Singapore, throws some light on this point. Webb calculated the partial correlation coefficients of the comfort assessment made by his subjects with temperature, vapour pressure and the square root of wind speed, and concluded that there was a "very highly significant correlation in all three cases unaffected by the correlation between temperature and air velocity." This does not completely answer the question however because, as Webb has shown, comfort correlates with the square root of wind speed and $(\Sigma\sqrt{v})/n \neq \sqrt{(\Sigma v/n)}$ unless all the values of v, the wind speed, are equal. In order to evaluate the likely maximum difference between the expressions $(\Sigma\sqrt{v})/n$ and $\sqrt{(\Sigma v/n)}$ for typical Singapore values of wind speed, their values were calculated using 3-hourly observations from Changi for January 1964, January being a month in which a large range of wind speeds is normally found in Singapore. The results were:

$(\Sigma\sqrt{v})/n = 21.5$ (feet/minute)$^{\frac{1}{2}}$ and $\sqrt{(\Sigma v/n)} = 25.5$ (feet/minute)$^{\frac{1}{2}}$ the difference being 4.0 (ft/min)$^{\frac{1}{2}}$. According to Webb the coefficient of temperature equivalent of $\sqrt{v}$ is -0.231, so that the likely maximum error in effective temperature from this source is $-4 \times 0.231 = -0.92$°F.

To take the question a stage further, the difference between an average effective temperature calculated from individual observations and one calculated from average values of temperature and wind speed also depends on the range of values of these elements and the irregularity of their distribution. In Singapore and Gan, temperatures and wind speeds only fall outside a fairly narrow range of values during periods of rain and again during calms. The average percentage of calms at Gan is 11 and at Changi is 20 whilst the average duration of rainfall is about 5 per cent of the time at both stations. Thus only a relatively small proportion of the observations would fall markedly outside the normal rather restricted range of values. The true average effective temperature would, therefore, be unlikely to differ very much from that found using mean temperatures and wind speeds.

In order to verify this conclusion and to assess the actual magnitude of the error, effective temperatures were calculated by the two methods for:

(i) June 1960 at Changi, when using observations at 0600 and 1800 GMT, the dry-bulb temperature varied from 75.2 to 91.0°F, the wet-bulb from 74.0 to 81.0°F, the wind speed from 0 to 11 knots, and the rainfall was 4.6 inches above the average of 5.5 inches.

(ii) October 1963 at Gan, when using 3-hourly observations, rain fell for 12.3 per cent of the time and was 4.2 inches above the average of 11.1 inches, and the wind was calm on 7 per cent of occasions.

(iii) April 1964 at Gan, when using 3-hourly observations, rain fell for 5.8 per cent of the time and was 1.8 inches above the average of 7.2 inches, and the wind was calm on 12 per cent of occasions.

The results, together with frequency tables of effective temperature at Gan, are shown in Tables I and II.

TABLE I—COMPARISON BETWEEN THE TRUE AND COMPUTED AVERAGE EFFECTIVE TEMPERATURE AT CHANGI AND AT GAN

		True average effective temperature	Computed average effective temperature	Error	Per cent of annual range
			degrees Fahrenheit		
Changi	June 1960	74.2	73.5	−0.7	12.1
Gan	October 1963	69.8	69.5	−0.3	10.3
Gan	April 1964	73.7	73.0	−0.7	24.1

It is concluded that mean comfort indices computed from mean dry-bulb and wet-bulb temperatures and mean wind speeds for Singapore and Gan are unlikely to differ by more than 1°F from true mean comfort indices. An error of this magnitude would not materially effect the conclusions reached in the paper on Singapore[1] as it represents only a small proportion of the annual range of effective temperatures and, in any case, the method used for calculating the wet-bulb temperature in that paper could itself lead to errors of up to 1°F, as stated in the text.

In the case of Gan, where the annual range of effective temperature is smaller, the error could be more serious. However, in all four calculations performed above, the error is of the same sign and of approximately the same magnitude so the conclusions reached in the Gan paper, which in any event did not stress the annual variation of effective temperature, are almost certainly still valid.

TABLE II—FREQUENCY OF EFFECTIVE TEMPERATURES AT GAN IN OCTOBER 1963 AND APRIL 1964

Effective temperature *degrees Fahrenheit*	Frequency October 1963	April 1964
63	15 (≤63°F)	
64	11	
65	11	
66	10	8 (≤66°F)
67	18	7
68	19	7
69	30	10
70	38	15
71	19	21
72	24	25
73	18	26
74	11	24
75	8	20
76	7	21
77	9 (≥77°F)	22
78		12
79		12
80		10 (≥80°F)
	80 per cent of the observations gave values between 65 and 74°F	80 per cent of the observations gave values between 69 and 78°F

REFERENCES

1. STEPHENSON, P. M.; An index of comfort for Singapore. *Met. Mag., London*, **92**, 1963, p. 338.
2. WEBB, C. G.; An analysis of some observations of thermal comfort in an equatorial climate. *Br. J. ind. Med., London*, **16**, 1959, p. 297.

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THE YEARLY DISTRIBUTION OF RAINFALL INTENSITIES

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Introduction.—McConalogue[1] has shown that for four British coastal stations the monthly duration, T_i, of rainfall at a rate exceeding i, can be expressed in the form:

$$T_i = T_0 \exp(-i/\bar{i}) \qquad \ldots (1)$$

where T_0 is the total duration of rainfall during the period considered and $\bar{i}$ the average rate while rain was falling. The stations for which detailed figures for T_0 are available are few in comparison with those where the total amount of rainfall is recorded; the first part of the present paper gives a method of estimated T_0 from the total rainfall (over a period of at least a year) and the location of the station.

McConalogue was concerned with low intensity rainfall only; he does not appear to have examined intensities greater than 10 mm/h (0.39 in/h), and his equation is inapplicable to high intensity rainfall. A new equation is proposed which gives a reasonable fit to experimental data from three British stations over a wide range of intensities.

Yearly duration of rainfall.—Published figures[2] for the average yearly duration with an intensity of not less than 0.1 mm/h (0.004 in/h) at a number of British stations in 1928–57 have been examined. Each point plotted in Figure 1

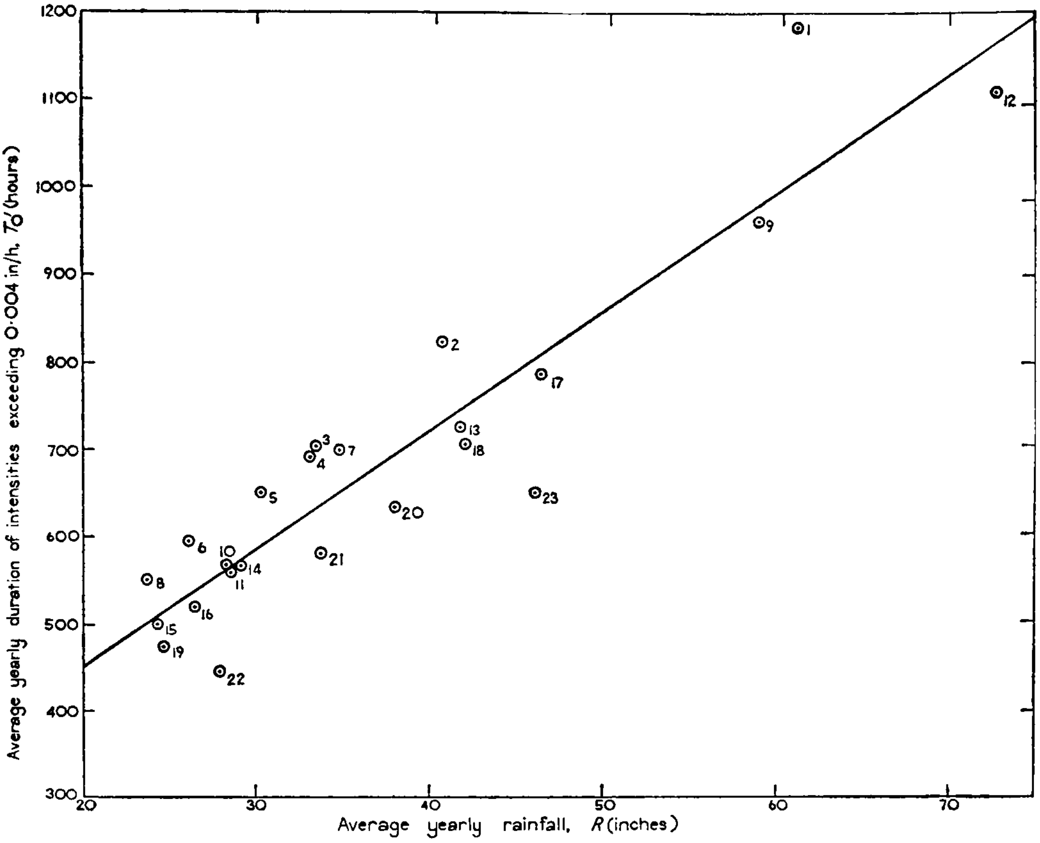

FIGURE I—RELATION BETWEEN AVERAGE YEARLY DURATION OF RAINFALL WITH INTENSITY EXCEEDING 0.004 INCHES/HOUR AND CORRESPONDING TOTAL RAINFALL

Numbers against plotted points identify stations listed in Table I; the straight line is given by equation (2).

TABLE I—IDENTIFICATION OF STATIONS USED IN FIGURE I

Number in Figure 1	Location	County	Value of A in equation (4)
1	Eskdalemuir	Dumfries	580
2	Lerwick	Shetland	438
3	Aldergrove	Antrim	400
4	Ashbourne	Staffordshire	388
5	Aberdeen	Aberdeen	383
6	Leuchars	Fife	380
7	Holyhead	Anglesey	371
8	Cranwell	Lincolnshire	366
9	Greenock	Renfrew	311
10	Birkenhead	Cheshire	298
11	Boscombe Down	Wiltshire	285
12	Cray Reservoir	Brecknockshire	284
13	Falmouth	Cornwall	281
14	Felixkirk	Yorkshire	280
15	Strood	Kent	277
16	Harpenden	Hertfordshire	265
17	Bolton	Lancashire	263
18	Cardiff	Glamorgan	247
19	St. Pancras	London	234
20	Sheffield	Yorkshire	223
21	Southport	Lancashire	218
22	Ross-on-Wye	Herefordshire	133
23	Swansea	Glamorgan	112

relates the average yearly duration in excess of 0.004 in/h (T_o')* to the average yearly total amount (R) for a particular station, a minimum of 15 (and an average of 25) years' records being used for each station; the numbers against the plotted points identify the stations which are listed in Table I. The equation of the straight line, fitted by the method of least squares, is

$$T_o' = 180 + 13.5R, \quad \ldots (2)$$

where the units of T_o' are h/year and those of R are in/year.

The departures of some of the points from the regression line in Figure 1 are not due solely to random variation but are the result of systematic differences between the pattern of rainfall at different stations. This may be seen from Figure 2 where the individual yearly data for Eskdalemuir and Swansea are plotted; the continuous line AE is that given by equation (2). The othe rcontinuous lines B, are regression lines through the two sets of data, and it is

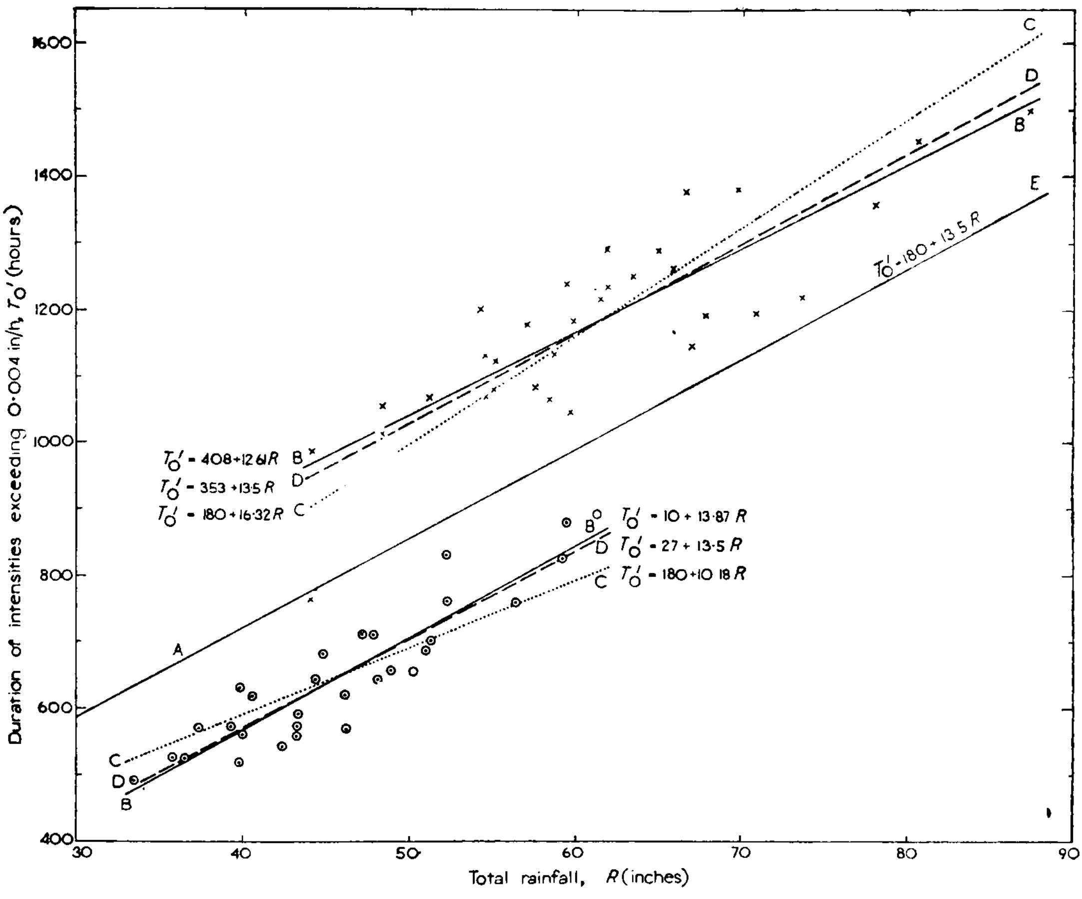

FIGURE 2—RELATION BETWEEN DURATION OF RAINFALL WITH INTENSITY EXCEEDING 0.004 INCHES/HOUR AND CORRESPONDING TOTAL RAINFALL FOR INDIVIDUAL YEARS AT ESKDALEMUIR AND SWANSEA

x Eskdalemuir o Swansea
— For derivation of straight lines see text

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*Rainfall intensities in this paper are expressed in in/h; this particular value of T_i should therefore be denoted by $T_{0.004}$ but, owing to its frequent occurrence, the symbol T_0 is used instead evident that the general form of the relation between the yearly values of T_0' and R for some 30 years at each of these stations is similar to the relation between the long-term mean values of T_0' and R for 23 different stations.

To maintain the form of equation (2) with the minimum alteration, one or other of the two coefficients must be changed to fit the data for individual stations. If the intercept of 180 h is accepted, and the slope of the line is altered so as to pass through the centre of gravity of each of the two groups of points in Figure 2 in turn, the dotted lines C are obtained. Alternatively, accepting the slope of 13.5 h/in and altering the intercept, gives the broken lines D which are almost collinear with the regression lines B. Accordingly it is suggested that equation (2) is more satisfactory written as

$$T_0' = A' + 13.5R \qquad \ldots (3)$$

where A' varies from station to station and has a mean value of 180 h for the stations listed in Table I.

If it is assumed that equation (1) holds for intensities between 0 and 0.004 in/h, the values of T_0 may be calculated from those of T_0' by successive approximations, and equation (3) may then be replaced by

$$T_0 = A + 13.5R \qquad \ldots (4)$$

where A is given by $A - A' = T_0 - T_0'$. However, it is shown later that equation (1) is inadequate for representing the distribution of the complete range of rainfall intensities, and the values of A shown in Table I have been calculated as follows: the long-term mean values of T_0' and R from Figure 1 have been substituted in equation (3) to give a value of A' for each station, T_0 has been found from T_0' by means of the formula developed later in the paper (equation (9)), and finally $T_0 - T_0'$ has been added to A' to give the values of A shown in the table. For a station at which the yearly amount of rainfall (R inches) is known, the yearly duration (T_0 hours) may then be estimated from equation (4), the value of A being selected from Table I by consideration of the location of the particular station. Unfortunately there appears to be no systematic variation in the magnitude of A with longitude, latitude, altitude, or nearness to the coast; but an error of even 60 h in A represents an error of only about 10 per cent in the value of T_0 for a station with a yearly rainfall of 30 in, and this is probably about the limit of accuracy of equation (4). (Although equation (4) implies that A is the duration of rainfall in a year when no rain falls, this does not invalidate the equation, since within the range of yearly totals plotted in Figure 2 there is no significant curvature in a line drawn through the plotted points.) It should perhaps be mentioned that the experimental determination of values for T_0 or T_0' from recorder charts is very difficult and that the results obtained are no doubt sensitive to subjective judgement.

Distribution of rainfall intensities.—In the course of investigations on the flow and composition of storm sewage, the Laboratory installed autographic rain-gauges at Bradford and Brighouse (both in Yorkshire) and at Northampton. The recorders, which are of the type used by the Road Research Laboratory,[3] have a chart speed of 6 in/h, and the chart width of 2 inches corresponds to a rainfall of 0.2 in. Intensity distribution curves have been derived from a year's data at each of the Yorkshire stations and from 19 months' data at Northampton. The charts for Bradford were examined by means of a cursor on which were drawn lines with slopes corresponding to intensities of 0.2, 0.5, 1, and 2 in/h; the duration of each period during which these rates were continuously

Photograph by B. J. Burton

PLATE I—NOCTILUCENT CLOUD OBSERVED FROM SOUTH-WEST LONDON AT 0219 UT ON 21 JUNE 1964

See page 183.

Photograph by G. V. Black

PLATE II—NOCTILUCENT CLOUD OBSERVED FROM KINCRAIG, INVERNESS-SHIRE AT ABOUT MIDNIGHT ON 5–6 JULY 1964

See page 183.

Crown copyright

PLATE III—WINDOW DISPLAY IN THE NEW LONDON WEATHER CENTRE IN HIGH HOLBORN

PLATE IV—FORECAST ROOM IN THE NEW LONDON WEATHER CENTRE IN HIGH HOLBORN equalled or exceeded was measured from the charts, and the total duration of each fall of rain was also noted. The Brighouse charts were examined in the same way but with additional data being obtained for 0.02 and 0.05 in/h.

The Northampton records were studied in greater detail: the rainfall (to the nearest 0.001 in) during each 3-minute period was read from the charts, and the duration–intensity curve was drawn. For high intensities it was considered that 3 min was too long a period to use for accurate results to be obtained by this method; accordingly, all the periods during which the 3-min intensity exceeded 0.2 in/h were re-examined, tangents were drawn to the recorder charts at intervals of 1 min or less, and the distribution curve was determined from the results. The final distribution is shown by the points plotted in Figure 3 where the results obtained by the former method have been used for intensities up to 0.65 in/h and those by the latter for higher intensities.

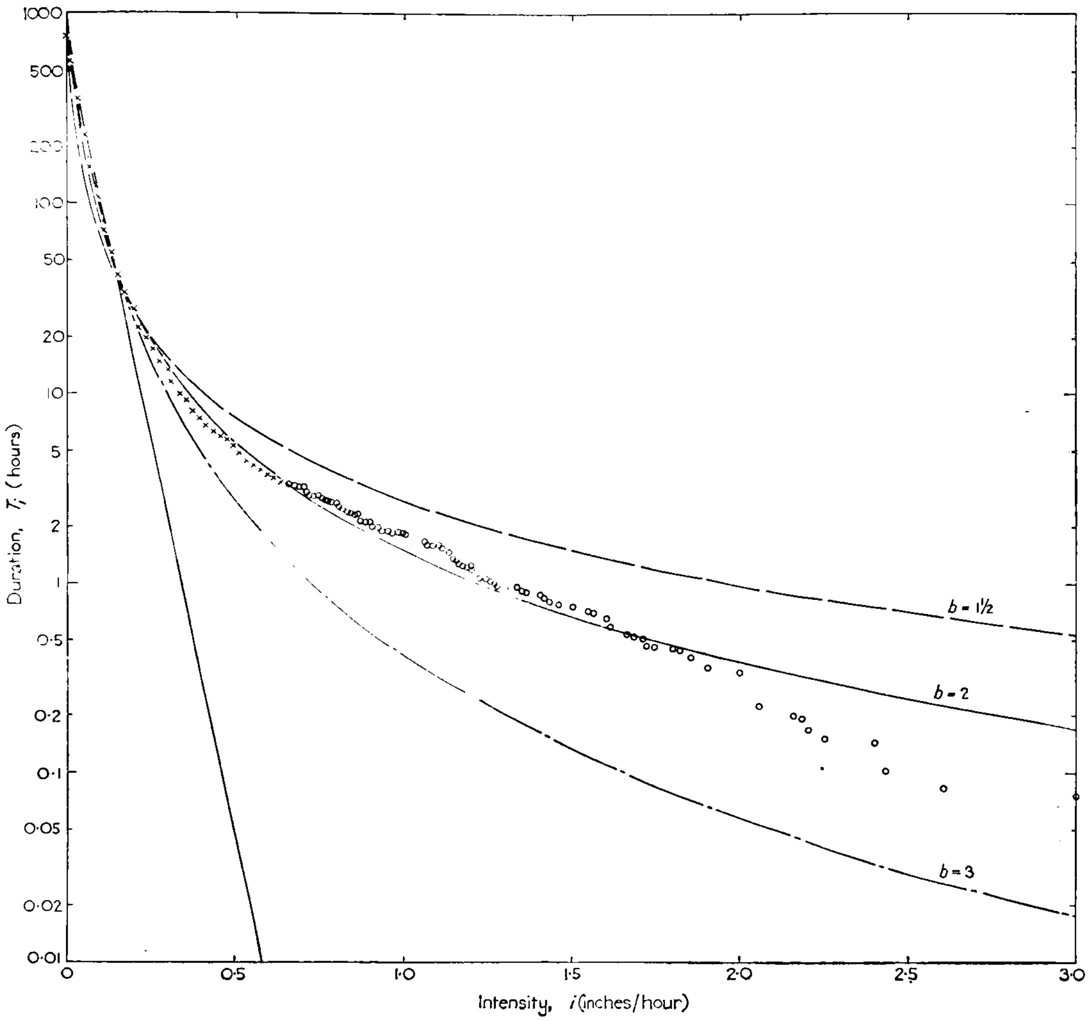

FIGURE 3—DURATION OF RAINFALL INTENSITY EXCEEDING ANY PARTICULAR VALUE AT NORTHAMPTON, JULY 1960 TO JANUARY 1962

Plotted points show observed distribution; curves are those given by equation (5) with the alternative values of b shown above each.

It may be mentioned here that the Northampton data were examined in detail because an attempt is being made to compare the observed distribution of run-off from an impermeable area of 115 acres with that calculated from the rainfall pattern. Once the 3-min rainfall totals had been read from the charts for this purpose, it seemed worthwhile to produce the distribution shown in Figure 3, and then, having found an empirical relation between duration and intensity, to make a cursory examination of the data for the other two sites to see if the relation appeared to be applicable to these sites. In fact, the data for Bradford and Brighouse could have been studied much more fully—there are nearly 3 years' records for each of five recorders—but the detailed examination is very time-consuming and it could not be justified within the scope of the Laboratory's work. However, since so little appears to have been published on the distribution of the whole range of rainfall intensities, it was felt that the results given in this paper might be of interest to other workers.

The straight line in Figure 3 is the expected distribution of intensities as given by equation (1). It is evident that this equation is inadequate for representing the whole range of intensities; it was found that the distribution could best be represented not by an exponential but by a retarded-exponential curve* of the form

$$T_i = T_0 (1 + ai)^{-b}, \qquad \ldots (5)$$

in which a and b are constant.

Integration of equation (5) must give the total rainfall during the year, thus

$$\int_0^\infty T_i \mathrm{d}i = \frac{T_0}{a(b-1)} = R. \qquad \ldots (6)$$

The mean intensity while rain is falling is

$$\bar{i} = R/T_0; \qquad \ldots (7)$$

substitution of $R/\bar{i}$ for T_0 in the previous equation then gives

$$a = 1/(b-1)\bar{i} \qquad \ldots (8)$$

so that if a particular value of b is chosen, a may then be calculated.

In Figure 3 the three curves drawn are those given by equation (5) with b equal to $1\frac{1}{2}$, 2, and 3. It should be noted that whereas this equation applies to any period†, the numerical values of A and R in equation (4) are for 1 year. The value of T_0 for substitution in equation (5) was obtained from equation (4) by using the total rainfall for 19 months at Northampton instead of the yearly total R, and by multiplying A by 19/12; the value of A was assumed to be the same as that for Harpenden which is the nearest station to Northampton listed in Table I. It is seen that with b equal to 2 the observed distribution of rainfall intensities is followed with a fair degree of accuracy over the whole range of intensities up to 3 in/h. For this particular case equation (5) reduces to

$$T_i = \frac{T_0}{(1 + i/\bar{i})^2}. \qquad \ldots (9)$$

The data obtained from examination of the charts for Bradford and Brighouse are shown by the encircled points in Figures 4(*a*) and (*b*) respectively. For

*Mr. D. J. Holland, of the Meteorological Office, has pointed out to the authors that a power law fits the higher-intensity data nearly as well as does a retarded exponential.

†This period should best be an integral number of years, as the distribution curves for summer and winter rainfall are found to be markedly different. The 19-month period used here includes roughly equal periods of summer and winter.

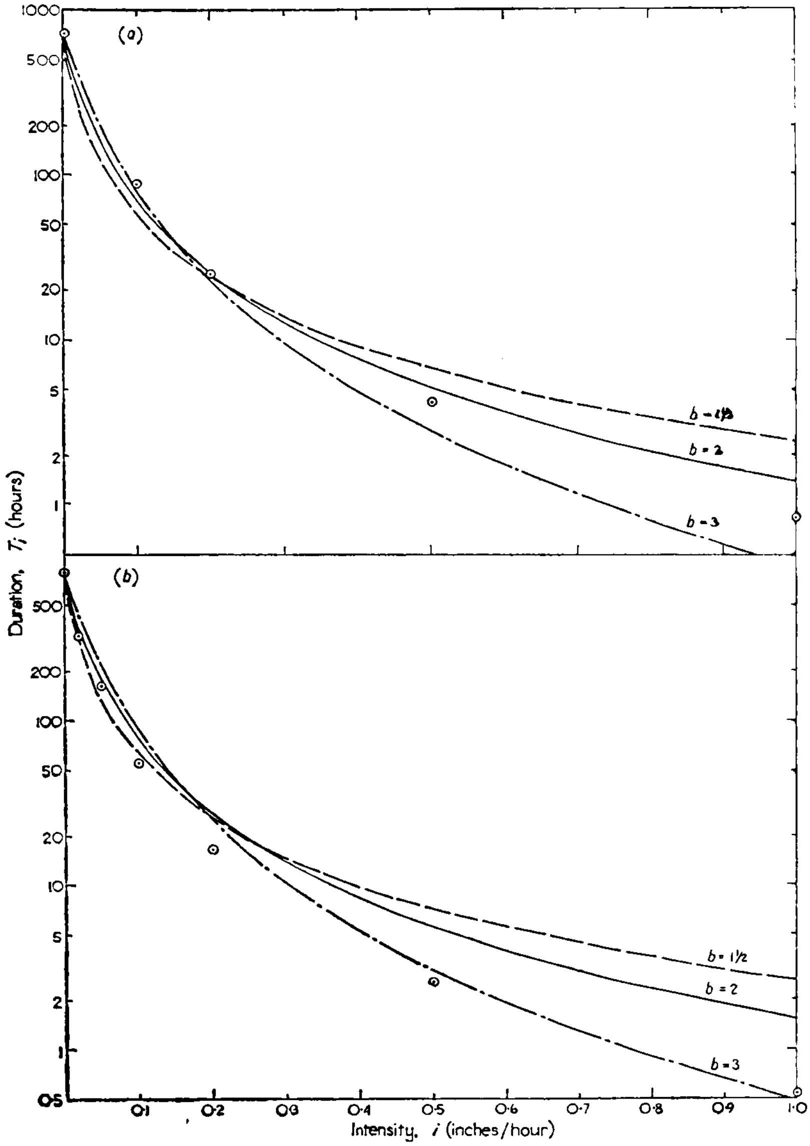

FIGURE 4—DURATION OF RAINFALL INTENSITY EXCEEDING ANY PARTICULAR VALUE AT BRADFORD, FEBRUARY 1961 TO JANUARY 1962 AND AT BRIGHOUSE, JANUARY TO DECEMBER 1960

Plotted points show observed distribution; curves are those given by equation (5) with the alternative values of b shown above each; the straight line is given by equation (1).

(a) Bradford (b) Brighouse

each of these sites the value of A for use in equation (4) has been taken as the mean of the values for the three nearest stations listed in Table I. The three curves in each of these diagrams correspond to those shown in Figure 3. For Bradford it is seen that with b equal to 2 the experimental data are fitted reasonably well, but at Brighouse the curve for b equal to 3 is distinctly better for the two highest intensities plotted—though none of the curves can be considered to fit the whole range of data very satisfactorily.

Discussion.—Figures 3 and 4 show that equation (9) (that is, equation (5) with b equal to 2) gives a reasonable approximation to the distribution of intensities at the three sites studied. For intensities up to 1 in/h the ratio of the observed to the calculated durations at Northampton lie within the range 0.78–1.25; the corresponding ranges for Bradford and Brighouse are 0.60–1.25 and 0.35–1.19. Although these last two ranges indicate large errors in the predicted values, the range of durations covered is very great, the largest duration being over a thousand times the smallest. At Brighouse—the station giving the greatest errors in prediction—the observed and calculated values of T_0 (the total duration of rainfall) were 784 and 658 h respectively, whereas the corresponding values of T_1 (the duration of intensities exceeding 1 in/h) were only 0.5 and 1.5h; at Northampton—for which site the data for a longer period (19 months) were examined—the observed and calculated values of T_0 were 763 and 973 h respectively, and those of T_3 were 10 and 4½ min.

No simple equation can reasonably be expected to give greatly better predictions than does equation (9): statistical fluctuations in high intensity rainfall must give rise to corresponding variations in the yearly duration of such rainfall even at a particular station in two years with substantially the same total rainfall.

Conclusion.—It is suggested that, when information is required concerning the probable yearly duration, T_ih, of rainfall intensities exceeding any particular value, i in/h, at a station where the annual rainfall is R in, it can be obtained approximately from the equation

$$T_i = \frac{T_0}{(1 + i/\bar{i})^2}$$

where $\bar{i} = R/T_0$, and $T_0 = A + 13.5R$, the value of A being selected from Table I.

Acknowledgements.—Miss J. M. Threlfall carried out the detailed examination of the Northampton rainfall records and I. C. Hart assisted in much of the subsequent work.

REFERENCES

1. MCCONALOGUE, D. J.; On the distribution of rainfall rates at some coastal stations in the British Isles. *Met. Mag., London*, **82**, 1953, p. 304.
2. London, Meteorological Office. *British Rainfall.* London, HMSO (particularly annual volumes for 1948 p. 30, and 1957 p. 33).
3. LEWIS, W. A. and WATKINS, L. H.; Investigation into the accuracy of four types of rainfall recorder. *Quart. J. R. met. Soc., London*, **81**, 1955, p. 449.

551.593.653

NOCTILUCENT CLOUDS IN 1964

By J. PATON

The accompanying Table I contains an analysis in summary form of displays of noctilucent clouds that were visible over western Europe and the Atlantic during 1964.

The geographical situation of the clouds was determined by the method described in an article in the *Meteorological Magazine*[1]. Those occasions when the cloud mass was seen to be illuminated to its southern border at some time during the night are recorded in the table. The extension in longitude is given to the nearest 5°.

The most striking displays occurred during the nights of 20–21 June, 30 June–1 July, 5–6, 11–12, 15–16 and 19–20 July. The last of these displays became spectacular only during the latter part of the night after 0045 Universal Time (UT). The changes in blue and green coloration and the rapid variations in fine structure and form recorded by observers accord with the theory that these are ice clouds, in fact, very high cirrus, formed on nuclei of cosmic origin. If this is so, then the formation of the clouds is largely controlled by the temperature at the mesopause. The fact that the frequency of occurrence of the clouds during the year of sunspot minimum, 1964, is the greatest recorded since systematic observations began, suggests therefore that the temperature at the mesopause reaches a minimum at the time of sunspot minimum. From observations at the extensive network of stations that he has organized over North America, Benson Fogle of the University of Alaska reports that during 1964, noctilucent clouds were seen as early as 1 April and as late as 31 August, and that during the period 28 June–4 August, the clouds were seen somewhere over North America on every night except 2–3, 3–4, 9–10, 14–15, 18–19 and 19–20 July. It will be noted that on three of these nights—2–3, 9–10 and 19–20 July—the clouds were seen over western Europe.

TABLE I—DISPLAYS OF NOCTILUCENT CLOUDS OVER WESTERN EUROPE AND ATLANTIC IN 1964

Date—night of	Times UT	Approximate geographical position: Latitude*	Longitude	Notes by observers
9–10 June	2310–0140	57°	5°E–20°W	Silvery streaks and patches, blue edges.
10–11	0020–0035		0°	Seen through temporary break in overcast sky at elevation 9° above northern horizon in latitude 56°.
14–15	0010		0°	Bluish streaks seen through break in cloud at elevation 4° in latitude 56°.
15–16	0200–0405		30°W–55°W	Reports from two aircraft over the Atlantic. Long bluish streaks with fine ripples. Elevation 5° in latitude 52°.
20–21	2245–0235	< 51°	5°E–15°W	Very bright display with long and closely-packed parallel filaments and fine rippled structure. Portions very blue at times (see Plate I).
24–25	2355–0120	60°	10°E–10°W	Weak and isolated patches just perceptible in very clear and cloudless conditions.
27–28	2300–0235	< 60°	10°E–20°W	Compacted fine streaks, portions of strong blue colour.
28–29	0030		0°	Seen in gap in low cloud at elevation 11° in latitude 56°.
29–30	2215–0400	< 57°	20°E–55°W	Long streaks of pearly-white cloud tinged with blue. Reports from western Atlantic to Denmark.
30 June–1 July	2310–0345	53°	5°E–60°W	Faint streaks and patches at first. Brighter and complicated ripple patterns after 0100 UT. Two observers independently report colour as greenish-white.
2–3 July	0010–0100		5°W–10°W	Reports from two aircraft. Elevation 10° in latitude 56°.

*Of southern borders when measurable.

TABLE I—DISPLAYS OF NOCTILUCENT CLOUDS OVER WESTERN EUROPE AND ATLANTIC IN 1964—*contd.*

Date—night of	Times UT	Approximate geographical position Latitude*	Longitude	Notes by observers
4–5	0005–0040		0°	Very faint streaks to elevation 8° in latitude 56°.
5–6	2120–0420	< 55°	0°–70°W	A brilliant display, situated to the west of longitude 0°, visible in the north-west from Denmark. Long straight band extending overhead from just west of the outer Hebrides, in a direction a few degrees to east of north to 250 km west of Shetland. This band, occasionally splitting in parts and showing fine wave structure, persisted from 2220–0040 UT moving slowly westwards. The band was described by many observers as remarkably like an aeroplane condensation trail, bluish in colour. A mass of chaotic streaks, aligned approximately north-south, overhead north of latitude 57° (probably lower) in the region bounded by longitudes 0° and 3°W, at 2220, also moving slowly westwards; this weakened after 2340 and had vanished by 0020 UT. By 0050, the noctilucent cloud over western Europe had vanished. Observing conditions remained good at several stations until 0230, but no further cloud was seen. The cloud was later reported by Lufthansa officers over the western Atlantic to Nova Scotia.
6–7 July	2300–2325		0°	Aircraft in latitude 55° report two streaks at elevation 5° and 7°, bluish-silvery-white in colour. Earlier at 1855–1910 UT a pilot from the same squadron, flying at 44,000 ft above Leuchars (56°N) reported two thin silvery streaks, one at 8° elevation, the other at 10° elevation. This was, of course, in bright daylight, the sun being at an elevation of 20°.
9–10	2225–2255		15°E–10°E	Report of short-lived display from Denmark. Nil visible in the U.K. in good observing conditions.
10–11	2210–2300		15°E–5°E	Streaks up to elevation 12°, visible from Denmark (56°N 9°E)
11–12	2245–0140	52°	15°E–15°W	Silvery-white streaks, tinged with blue, almost as bright as moonlit cumulus. Areas of fine complex wave structure in almond-shaped patches. Turbulent in eastern portion of display.
12–13	2310 and 0440		5°E and 70°W	Seen through broken cloud, elevation 15° in 56°N 5°E, and to elevation 10° from aircraft in 50°N 70°W.
15–16	2110–0140	< 56°	15°E–25°W	Mainly in lenticular patches, silvery white, occasionally with bluish tinge and herring-bone structure. General movement westwards. Several observers reported greenish colour in later stages. Brightest at 0040 UT.

Date–night of	Times UT	Approximate geographical position Latitude*	Longitude	Notes of observers
19–20	2230–0240	55°	5°E–10°W	Faint until after 0045 UT, developing thereafter into widespread compacted mass of moderately bright clouds, showing complicated wave patterns.
25–26 July	0050–0220 and later over mid-Atlantic		5°E–40°W	No trace of cloud until 0050 UT when weak filaments became visible in latitude 56° to 12° elevation. Faint and pale blue in colour. Aircraft in 56°N 38°W and 60°N 25–30°W reported noctilucent cloud without giving details.
30–31	0125–0230		5°E–0°	Faint clouds seen up to elevation 16.5° in latitude 58°.
2–3 Aug.	0300–0330		25°W–35°W	Noctilucent cloud observed to 10° elevation from aircraft in latitude 58°.
6–7	2355–0145		20°W	Noctilucent cloud observed in Reykjavik (64°N), Iceland. No details.

*Of southern borders when measurable.

The clouds have never been seen from stations in central Scotland later than 3 August. They have been regularly seen at later dates in higher latitudes, for example on 6–7 August in Reykjavik in 1964. This northwards recession of the clouds in early August may indicate that the temperature at the mesopause in the lower latitudes has now begun to increase from the normal summer minimum[2].

This analysis has been compiled from observations made (*a*) at Malin Head and by staff at Meteorological Office stations at Lerwick, Wick, Kinloss, Dyce, Tiree, Shanwell, Leuchars, Renfrew, Carlisle, Acklington, Manby, Ronaldsway, Linton-on-Ouse, Leeming and Exeter and in O.W.S. *Weather Surveyor*; (*b*) by the following voluntary observers—R. J. Livesey, Newton Mearns; C. F. Priestley, Dunoon; C. Wilson, Dr. H. Lang and C. M. Christison, Newton Stewart; Dr. D. A. R. Simmons, Aberdeen; K. B. Hindley, Douglas; J. W. Noble, Leuchars; F. J. Acfield, Northumberland; G. V. Black, Inverness-shire; B. J. Burton, London; P. C. Knowles, Whitstable; Miss H. L. Tuer, Oxford; P. Puxty, Folkestone; J. R. Randall, Pickering; J. O. Oleson and G. Persson, Denmark; and Dr. T. Saemundsson, Iceland; and (*c*) by observers in aircraft—Flight Lieutenants Fletcher, Steele-Morgan, Penfold and Quantrill, and Flight Sergeant Faulkner of the Royal Air Force; Captain Miles and Lee, B.O.A.C.; Captain Mountney, B.E.A.; and Captains Tinbergen, Ebert and Arzinger and Navigators Liegnitz and Kuppert of Lufthansa. Dr. F. E. Volz of the University of Tübingen collected and sent the observations from Lufthansa aircraft. Some observations of particular displays were received from observers, mainly in aircraft, who did not give their names. Photographs were supplied by G. V. Black, Dr. H. Lang, B. J. Burton, C. Wilson and C. M. Christison (see Plates I and II). We wish to thank all who have taken part in this work either by organizing or making the observations.

These synoptic studies will continue and we invite the co-operation of observers who may wish to join in contributing to them. Notes on observation and photography of the clouds can be obtained from the Balfour Stewart Laboratory, The University, Drummond Street, Edinburgh 8.

REFERENCES

1. PATON, J.; Noctilucent clouds. *Met. Mag., London,* **93**, 1964, p. 161.
2. MURGATROYD, R. J.; Winds and temperatures between 20 km and 100 km—a review. *Quart. J. R. met. Soc., London,* **83**, 1957, p. 417.

551.524.36

PHENOMENAL TEMPERATURE OSCILLATION IN ADEN

By G. FROUDE and J. SIMMONDS

Large temperature changes occur from time to time in a number of different parts of the world, and some of the areas and circumstances in which these changes take place have been indicated in a memorandum by Dods and Dinsdale.* Although the examples quoted in the memorandum record temperature rises (or falls) much greater than in the instance described in the present note, there is no mention of a case where a sudden temperature change was followed in a very short time by a return to near the former value, and the details given below may, therefore, be of some interest.

On 29 June 1964, the temperature recorded at the Main Meteorological Office, RAF Khormaksar, (13°N 45°E), reached a typical maximum of about 98°F (37°C) in the middle of the day, and subsequently the usual fairly sharp diurnal fall set in to reduce the temperature to about 88°F (31°C) by 1630 GMT, by which time it was already dark. (Times in this note are GMT; to obtain Aden local time add three hours.) The surface wind had been light easterly for some time. At 1700 GMT, however, in a 'hot blast' of air the temperature rose almost instantaneously to 107°F (42°C) as measured by the maximum thermometer in the screen. About the same time, the wind backed from 090 degrees 5 knots to 220 degrees 5 knots, subsequently increasing sharply to about 20 knots and veering to a mean north-westerly direction (but with fluctuations between 230 and 040 degrees) with a gust of 32 knots at 1703 GMT. Within five minutes, the dry-bulb temperature had fallen again to 87°F (31°C), while the surface wind veered once more to 090 degrees 10 knots.

The synoptic charts for the day showed a depression over Persia, with a trough to the east of Djibouti, and the intertropical convergence zone, though very ill defined, seemed to lie a little to the south of Aden at 1800 GMT. A thunderstorm had been reported during the afternoon in the Thumeir area, about 50 miles north of Aden, but the upper winds between 12,000 and 18,000 feet observed on the midday Khormaksar ascent could have advected the storm towards Aden.

It is thought possible that a trough or squall line associated with the Thumeir thunderstorm may have swung round and approached Aden from the north-west shortly before the 'hot blast' occurred, especially as there was an increase of medium cloud and a little rain about that time. Two aircraft found severe turbulence at 2700 to 3500 feet between 11 nautical miles west of Khormaksar and about the same distance east of the aerodrome, one aircraft also reporting

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* DODDS, L. and DINSDALE, F. E.; Air temperature and its variability. *Invest. Div. Memor.* No.96, 1964 (unpublished, copy available in the Meteorological Office Library).

heavy rain. The 'hot blast' was likened by a forecaster, coming on duty, to the sudden opening of an oven door. It was also felt at Steamer Point, some 6 miles away.

A plausible explanation substantiated by the turbulence report given below, is that a down draught associated with the supposed squall line forced air in the layer 850 to 900 mb, down to the surface. Such air descending adiabatically from 850 mb to 1000 mb would warm to about 44°C (111°F) with a wet-bulb temperature of 20°C (68°F). Consideration of the 2330 GMT ascent for 29 June (Figure 1) shows that the 850 mb wet-bulb potential temperature was 21°C as compared with a surface wet-bulb temperature of 28°C.

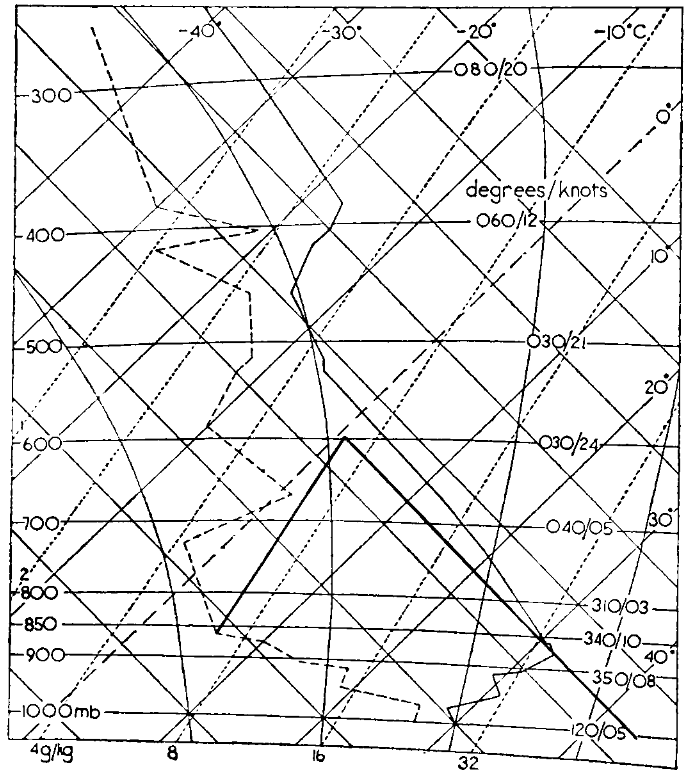


FIGURE 1—UPPER-AIR ASCENT FOR KHORMAKSAR AT 2330 GMT ON 29 JUNE 1964

——— Dry-bulb temperature — — — Dew-point

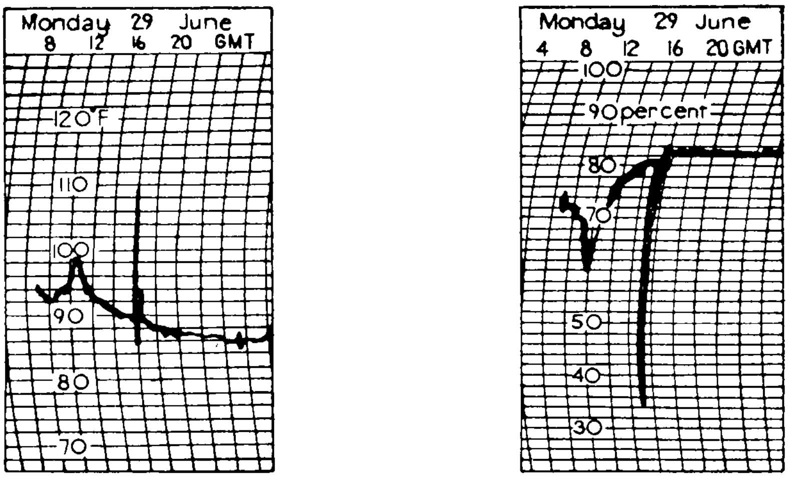
Bold construction lines show that the wet-bulb potential temperature at 850 mb is 21 C

The maximum temperature reached on this occasion has been exceeded in Aden, though it may well be a record for this time after sunset. The highest maximum between 0600 and 1800 GMT since 1946 was 44°C (111°F) in 1961 during a sandstorm on 29 June—strangely enough on the same date as the recent oscillation.

Turbulence report.—A pilot flying an Argosy aircraft near Little Aden at a distance of 10 to 15 nautical miles from Khormaksar and heading east towards Khormaksar shortly before 1700 GMT reported very severe turbulence. The aircraft, flying at 3500 feet, had just encountered a little rain and some dust which temporarily obscured the windscreen, but at no time was the aircraft in cloud. The aircraft suffered a 'terrific jolt' and suddenly dropped from 3500 to 2700 feet in altitude.

The pilot made an immediate attempt to regain his previous altitude but because of continuous very severe turbulence he had extreme difficulty in maintaining control. The indicated airspeed fluctuated between 140 and 195 knots. On reaching the airfield beacon at Hiswa, about 5 miles from Khormaksar, the aircraft was 'carried up' to about 3500 feet once more. The surface wind speed over the airfield at the time was 2 knots.

Autographic records.—The bimetallic thermograph and hair hygrograph in the instrument screen at Khormaksar responded well to the short-lived changes in temperature and humidity as shown in Figure 2. The records from the mercury-in-steel wet- and dry-bulb thermometers (Figure 3) located in a small screen 20 yards distant from the main instrument screen, and separated from it by the hydrogen shed, showed marked differences which are most likely due to the lag of this instrument. The mercury-in-steel instrument



(a) Thermogram (b) Hygrogram

FIGURE2—AUTOGRAPHIC RECORDS FOR KHORMAKSAR ON JUNE 29 1964

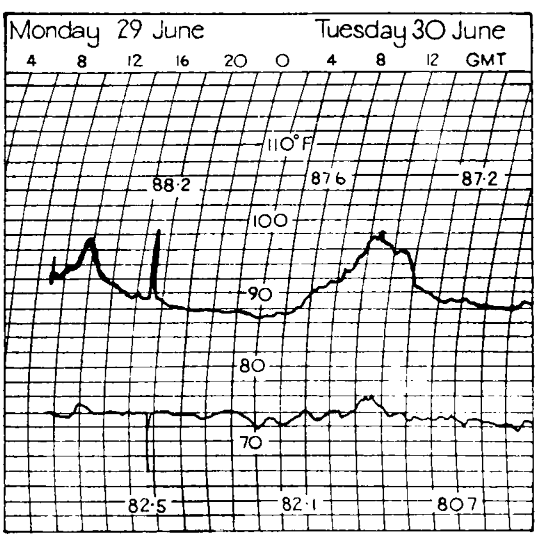


FIGURE 3—THERMOGRAM FROM THE MERCURY-IN-STEEL RECORDER AT KHORMAKSAR ON 29–30 JUNE 1964

Upper curve gives dry-bulb temperatures, lower curve (set 10 low) gives wet-bulb temperatures recorded a rise in temperature of 9°F (5°C) to 98°F (37°C) and a fall in wet bulb of 8°F (4°C) to 75½°F (24°C) (corrected values), giving a relative humidity of 33 per cent. This agrees closely with the adjusted reading of the hair hygrograph of 31 per cent, as the hygrograph may also be expected to lag considerably under the circumstances. However, assuming a fall in wet-bulb temperature of 8°F (4°C), and an actual maximum dry-bulb temperature of 107°F (42°C), then the relative humidity fell to about 20 per cent for a brief period.

METEOROLOGICAL OFFICE DISCUSSION

The work of the Central Forecasting Office

The Monday Discussion held in January 1965 was opened by Mr. V. R. Coles. He described the international and national aspects of the work of the Central Forecasting Office (CFO), stressing the services provided for the Meteorological Office outstations. The recently revised land-line facsimile programme was described in some detail. Mention was made of the land areas and shipping forecasts provided for the BBC and for the national Press as well as the variety of other services provided by CFO such as the summer fine-spell notification service for farmers.

Mr. Coles detailed the allocation of duties to the team of forecasters at CFO before describing changes in the CFO routine that would be effected in the relatively near future. The first and most important of these will be the introduction into the CFO routine of numerical forecasts which will be prepared twice a day after the new computer COMET has been installed. Another development that is expected during 1965 and early 1966 is the introduction of automatic plotting for the hourly charts of the weather of the British Isles which are transmitted to the outstations on the land-line facsimile circuit. The automatic plotter will plot two stations a second and will operate on the teleprinter tapes as received at Bracknell from the principal and main meteorological offices. It is hoped that it will be possible to transmit these charts to the outstations at least 20 minutes earlier than is now possible. Mr. Coles' next reference was to equipment which would enable direct read-out of satellite cloud pictures to be made at Bracknell. It is hoped that it will be possible to broadcast these pictures on the facsimile circuits. Finally Mr. Coles described the development by which it is hoped to broadcast two isopleth charts on the facsimile circuits in 5 minutes. These charts will be received at the outstations on a scale of 1:30,000,000.

During the general discussion, which ranged over many topics, officers from the outstations had an opportunity to express their opinions of the work of the Central Forecasting Office and several useful suggestions were put forward which will be of assistance in future planning.

NOTES AND NEWS

London Weather Centre moves to High Holborn

The London Weather Centre had been accommodated since 1959 at the southern end of Kingsway in Princes House. This is an old building of eight storeys whose roof exposure had been suitable for both eye and instrumental weather observations.

Length of tenure was in doubt and then, in 1962, it was learnt that an adjacent building was to be demolished and replaced by a new building at least 50 feet taller than Princes House, the roof of which would then no longer be suitable for instruments and, in particular, weather radar. This made it necessary for new accommodation to be sought.

This was no easy matter for the Ministry of Public Building and Works because the new accommodation had to satisfy certain conditions. In particular, the roof should be suitably exposed for instruments and observations and high enough so that future development would not impair the suitability of the site for observations. Moreover, it should be within easy reach of Fleet Street. Eventually the Ministry came up with part of a new building at 284–286 High Holborn, opposite State House. As the roof of the Weather Centre building is overshadowed by State House, instruments have been installed on State House, with cabling under High Holborn to recording and indicating instruments in the Weather Centre. Although the roof of State House was considered suitable for meteorological instruments, present and future building development in London made it suspect as a site for weather radar. This led to the exciting use of the GPO tower in Bloomsbury as a site for the radar scanner, thanks to the co-operation of the Postmaster General.

The new accommodation which was occupied on 9 January 1965 has a contemporary shop front in keeping with the general style of the building itself (see Plates III and IV). A large magnetic chart showing weather over the British Isles, the near continent and adjacent seas occupies a considerable proportion of the window display. Near it are three charts showing the synoptic situation of yesterday, today, and tomorrow. An additional display of topical interest occupies part of the window together with details of sunrise and sunset times and moon data. There is an open-scale barograph and dials showing wind speed and direction, temperature and relative humidity as measured on the roof of State House. In an adjacent window details of the weather at a number of British and continental holiday resorts are displayed.

Immediately behind this window and next to the 'shop' is the broadcasting studio. This room, from which the morning 'Metcast' and other broadcasts are made, is soundproofed and designed for easy conversion for use as a television studio should the need arise. Nearby are two small rooms, one housing duplicating equipment, and the other, radio and television monitoring and recording equipment.

Adjoining these rooms is the forecast room which is dominated by the forecasters' and plotters' bench. At this large and complex piece of furniture 8 to 10 people are able to cope with the stream of inquiries from the general public. In the Kingsway Office the bench had 6 positions with a 10-line key and lamp unit at each. The number of calls dealt with has more than doubled in the last 6 years and on some occasions the calls have been too numerous to deal with (Figure 1). The new bench provides 8 positions at which 4 forecasters and 4 assistants may carry out their routine work as well as answering telephone calls on the 20-line key and lamp unit provided for each. Eleven of these 20 lines handle calls from the general public on Temple Bar 4311 while the remaining 9 provide direct links with Ministry of Defence exchanges, Central Electricity

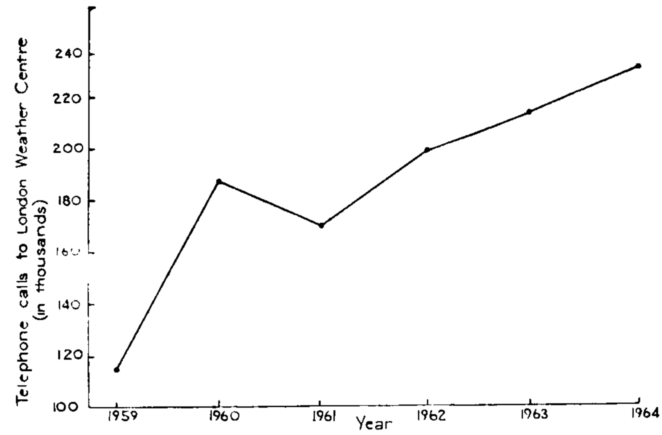


FIGURE 1—NUMBER OF TELEPHONE CALLS TO THE LONDON WEATHER CENTRE 1959–1964

Generating Board Control Rooms and the GPO. The last is used to provide the GPO with forecasts for London and the coasts of south-east England for use in the Automatic Telephone Weather Service.

A new instrument console has been designed, incorporating a distant-reading temperature recorder, a high-speed anemograph and a precision aneroid barometer. The instrument panel is above a desk at which the observer records readings in the *Daily Register*. Nearby is Meteorological Office data logging equipment for recording solar radiation. Also in this room is the display unit of the weather radar. Next to this room, with easy access, are the teleprinter room and the typing pool.

At the rear lies the 'Climate' room. Here are housed records and other information for the weather of the past century. Tables are provided at which visitors may work when extracting items from the records. In this room records are maintained for a number of stations throughout Great Britain, and here the summaries of weather are prepared and issued weekly and monthly.

J. GEORGE

REVIEWS

Heat transfer in the soil by A. F. Chudnovskii (translated from Russian). 9½ in × 6¼ in, pp. iv + 164, *illus.*, Israel Program for Scientific Translations, Jerusalem. (Distributed by Oldbourne Press, 121 Fleet Street, E.C.4), 1962, Second impression 1963. Price: 48*s*.

This book, unlike its companion translations[1,2] from the Russian, is not an introduction to the subject for the beginner; nor is it indeed a textbook, like *Physics of Plant Environment*,[3] because it is not a comprehensive and integrated exposition of the subject. Here is an account of the practical and theoretical contributions to research on the subject of heat transfer, both in the soil and in the air near the air-soil boundary, by an author who is an experienced micro-meteorologist and soil physicist.

The first two chapters (about one third of the book) contain theoretical discussion of the surface energy balance with special reference to soil heat transfer but little or no discussion on the 'minor' processes, such as percolation or heat transfer in the vapour phase.

Chapter 3 (another third of the book) discusses the classical methods of obtaining soil diffusivity and the problem of more general (non-periodic) surface temperature variation; field and laboratory measurements of soil temperature, using plate and cylindrical rod, isothermal and instantaneous heat sources; and the theoretical derivation of soil thermal conductivity ('calometric conductivity') and soil diffusivity ('thermometric conductivity').

Chapter 4 deals with the dependence of soil thermal characteristics on soil physical and chemical properties, soil temperature and humidity; and the following chapter gives a mathematical derivation of soil temperature as a function of depth.

The final chapter (6) describes two practical applications: (i) the determination of soil moisture content from thermal characteristics and (ii) of special interest to meteorologists, the forecasting of minimum night-time radiation frost temperature using temperatures at sunset and at 7 p.m., the radiation balance, wind speed and soil humidity and constants which depend on the time and place of observation. The radiation balance parameter is obtained from tables, using air temperature, humidity and cloud cover; soil humidity is broadly classified as 'dry, slightly moist or moist.' If a forecast is regarded as successful when the difference between the observed and calculated minimum temperature is $\leqslant$ 2°C, half-successful for larger differences $\leqslant$ 3.4°C and unsuccessful for difference $\geqslant$ 3.5°C, then the success of these forecasts is claimed to be 80 per cent or more for all days, and 90 per cent or more for all days excepting days with advection.

The account includes considerable mathematical detail and in Chapter 3, experimental techniques are dealt with at length.

The book was originally published (in Russian) in 1948 and is therefore somewhat out of date. This is apparent, for example, from the references to the state of research on the mechanism, measurement and calculation of evaporation (p. 19), the lack of suitable maximum and minimum soil thermometers (p. 59) and the section relating soil diffusivity, etc. to soil humidity (pp. 123–128). Also since 1948, there has been important development in the direct measurement of all the major terms of the surface energy balance—soil heat flux, atmospheric fluxes of heat and water vapour and net radiative flux.

The presentation suffers from the lack of an index and of bolder-typed sub-headings and from a number of misprints or omissions, mainly obvious but sometimes disconcerting. Non-Russian references are limited and some references in the text are omitted from the bibliography.

Despite the faults mentioned, the book is a useful contribution by a valuable translation service and its acquisition should benefit any science library catering for soil physics or micrometeorology.

REFERENCES

1. VENTSKEVICH, G. Z.; Agrometeorology. Leningrad, 1958. Israel Program for Scientific Translations, Jerusalem. 1961.
2. VITKEVICH, V. I.; Agricultural meteorology. Moscow, 1960. Israel Program for Scientific Translations. Jerusalem, 1963.
3. VAN WIJK, W. R.; Physics of plant environment. North-Holland Publishing Company, Amsterdam, 1963.

E. N. LAWRENCE

Climatology—an introduction, by J. Bucknell. $8\frac{3}{4}$ in × $5\frac{3}{4}$ in, pp. xii + 163, *illus.*, Macmillan & Co. Ltd., St. Martin's Street, London, W.C.2, 1964. Price: 18*s*.

This book is aimed at sixth form pupils and others studying climatology at post "O" level stage. No doubt the author envisages its use by the teacher working with the class; it might prove rather indigestible to the student working on his own at this level.

Chapter I—Factors of Climate—forms a useful introduction to the subject, though a more quantitative approach might be enlightening. For example the idea of insolation is introduced, but the word is never defined nor are any suitable units of measurement suggested. Diagram 1.1 illustrates how short-wave radiation from the sun is reflected, scattered and absorbed by the earth–atmosphere system, but gives no idea of what proportion is reflected or is available for heating the ground. In the second chapter the general circulation is described briefly and the idea of stability of an air mass introduced. Here a lot of ground is covered though, of necessity, the treatment is somewhat cursory. This is no doubt adequate as a reminder to the student with a sound basic knowledge of meteorology but the less well-prepared reader will almost certainly need to refer to a suitable textbook on elementary meteorology.

The third chapter provides a short but clear account of the historical approach to the problem of climatic classification, finishing up with a description of the classification due to Professor Miller. The following eight chapters, comprising some two thirds of the total text, take the reader through examples of the various types of climate recognized in Miller's classification. Virtually the whole land surface of the earth receives some mention. It would be helpful here if, in a subsequent edition, the author were to include a few worked examples showing how, from statistics of temperature and rainfall, any particular station can be assigned a climatic classification. The reader would then be in a position to construct his own climatic atlas from the tabulated data normally available. The reviewer would also prefer to see latitude, longitude and altitude quoted for each station mentioned in the diagrams rather than a vague location stated such as "Congo basin" or "West Africa." A short final chapter relates climate to vegetation; this relationship is essential to the idea of climatic classification and the chapter could with advantage be placed earlier in the book.

The text is well illustrated by close on 200 diagrams. Those including a map would be even more helpful if a grid of latitude and longitude were added. The book cannot be considered easy reading, containing, as it does, a mass of information, but any reader who works his way through chapters 4 to 11, supplementing his reading from regional textbooks will emerge with a sound knowledge of the distribution of climatic types over the globe. A set of questions and exercises is included, but not the answers, as stated on the book jacket. A useful bibliography and an adequate index are also provided.

H. HEASTIE

OBITUARY

Mr. H. W. L. Absalom, O.B.E.—It is with deep regret that we heard of the death of Mr. H. W. L. Absalom on 7 April 1965. An appreciation of his many years of service in the Meteorological Office appeared in the August, 1959 (page 248) issue of this magazine. Our deepest sympathy is extended to his widow and family in their sad loss.

D.J.W.