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Recent Meteorological Office Publication

Scientific Paper No. 27

The determination of the extraterrestrial constant of a Dobson spectrophotometer

By R. A. HAMILTON, OBE, MA *and* J. M. WALKER, MSC, DIC

The extraterrestrial constants of Dobson spectrophotometer No. 7 were determined by solar observations in clear weather at Lerwick in 1963, and by comparison with spectrophotometer No. 1 in 1966. The values of the constants thus determined are in satisfactory agreement with one another and with the original determinations by comparison with No. 1 in 1950.
It appears that there has been no appreciable cyclic change in the relative intensities of the ultra-violet bands of the solar spectrum which are used in the ozone measurements: such a change would be interpreted as global cyclic change in the amount of ozone. The extraterrestrial constants for moon observations were also measured.

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ESTIMATING THE DURATION OF HIGH-INTENSITY RAINFALL

By J. BRIGGS

Introduction. Statistics of high-intensity rainfall are of considerable interest to students of several problems, notably those relating to the attenuation of radio signals and to the erosion of aircraft materials. For those problems the real need is for estimates of the frequency and duration of occurrences of instantaneous rainfall rates or at least for rainfall rates measured over very short periods of time, whereas for most parts of the world the available data are usually limited to average annual, seasonal or monthly totals of rainfall. Estimates of yearly duration of rainfall at specified intensities have been based on the total duration of rainfall and the average rate of rainfall, for example McConalogue,[1] but at the highest intensities the relevant formulae become inapplicable. Where stations have been equipped with suitable recording rain-gauges, 'clock-hour' values of rainfall are usually available but these values can be very misleading as regards instantaneous rainfall, because a given clock-hour value can cover widely varying instantaneous rates and may refer either to the whole hour or to only a small part of the hour. Bussey[2] has used curves obtained from one-minute mean falls to show how instantaneous rainfall intensity distributes itself around the clock-hour value and he has thereby obtained corrections which may be applied to clock-hour figures, so as to derive estimates of duration of instantaneous rates. His adjustments show that clock-hour data considerably underestimate the short-period rainfall at high intensity and overestimate the short-period low-intensity rainfall.

Although the Bussey corrections provide improvement when figures are required for instantaneous rainfall rates, nevertheless the clock-hour data, with their widely varying basic times, remain very unsatisfactory. This note, therefore, describes an alternative method of estimating the high-intensity short-period rainfalls. This method avoids the complications of clock-hour values and may be applied whenever rain-gauge records are available which permit direct estimates of rainfall rates up to about 10 mm/h. A description of the method follows, together with an application to data for Changi, Singapore Island, for the year 1961.

Method. The pattern of build-up and decay of rainfall intensity during the passage of a shower will vary widely from shower to shower, but in general each period of light or moderate rain will include a shorter period of heavier rain, and when averaged over a large number of showers the pattern will show a smooth intensity–time profile. If this average profile can be determined then its shape will indicate the relative durations of rainfall of different intensities and figures for low-intensity rainfall will provide estimates for high-intensity rainfall. Model shower profiles are available from the Cardington rainfall experiment which has been described by Holland.[3] These profiles were based on the 15 heaviest showers occurring during the experiment. For each shower, the intensities of rainfall in two-minute intervals before and after the peak value were expressed as percentages of the peak value, the mean profile being determined by averaging the percentages at given times from the peak value over the 15 separate showers. Figure 1 illustrates the profile obtained using two-minute values at a given point.

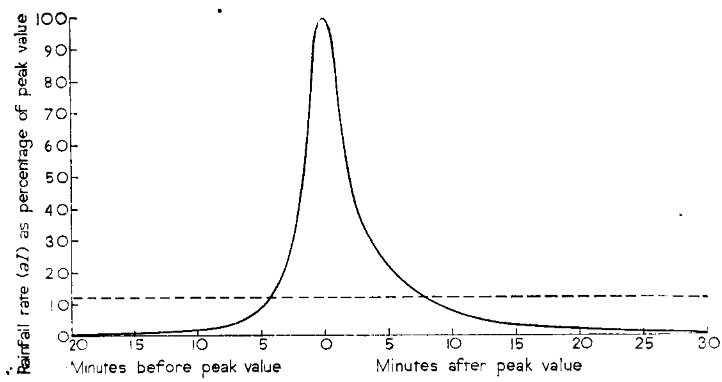

FIGURE 1—AVERAGE PROFILE OF SHOWER INTENSITY AGAINST TIME

- - - - Average rate of fall (12 per cent of peak value)

The distribution of types of rainfall varies considerably with the location concerned, but nevertheless the heaviest falls in short periods of time are usually associated with vigorous convection irrespective of the locality. Cardington is in the main thunderstorm belt of the United Kingdom, and the profile of Figure 1 being based on the 15 heaviest showers from some 150 studied may reasonably be taken as applying to heavy rainfall anywhere.

The percentages of the total shower rainfall which falls at rates equal to or exceeding given percentages of the peak intensity and also the percentage of total shower time corresponding to these rates are determinable from Figure 1 and the results are shown in Figures 2 and 3. Figure 3, together with a series of assumed values of the peak intensity, yields Table I.

TABLE I — PERCENTAGE OF TOTAL SHOWER TIME HAVING RAINFALL RATES AT OR ABOVE SPECIFIED RATES AND HAVING SPECIFIED PEAK INTENSITIES

Specified rainfall rate *mm/h*	Peak intensity (*mm/h*)											
	10	20	30	40	50	60	70	80	90	100	150	200
	percentages											
10	0	7·5	11·5	15	17·5	20	22	24	25	26	32	37
25	0	0	3·5	5·5	75	9	11	12·5	13·5	15	20	24
50	0	0	0	0	0	3·5	4·5	5·5	6·5	7·5	11·5	15
100	0	0	0	0	0	0	0	0	0	0	5	7·5

Comparison of the relative durations for 10, 25, 50, and 100 mm/h in Table I then permits the durations at 25, 50 and 100 mm/h to be expressed in terms of the duration at 10 mm/h once the peak shower intensity, I, is known.

The peak intensity is estimated as follows. Suppose the total shower rainfall is R mm and the total shower time is T h, then the average rate of fall is R/T whereas according to the profile of Figure 1 the average rate of fall is 12 per cent of I. If pR is the portion of rainfall at rates equal to or exceeding a portion aI of the peak intensity, and if qT is the corresponding portion of the shower time, then the average rate of fall at rates of aI or above is $(p/q)(R/T)$ or $0{\cdot}12Ip/q$. Values of p, q for different values of a may be determined from Figures 2 and 3 and then used to give Figure 4 which shows the average rate of rainfall at rates equal to or exceeding aI plotted against aI. If now aI is kept equal to 10 mm/h then different values of a correspond to different

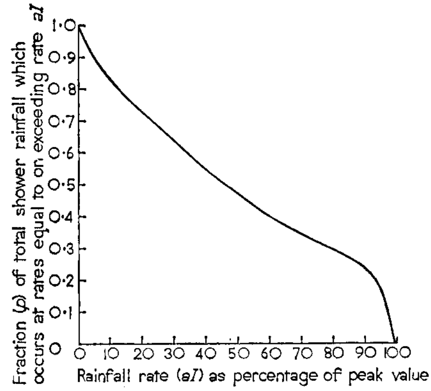

FIGURE 2 — FRACTION OF SHOWER RAINFALL AMOUNT AGAINST INTENSITY

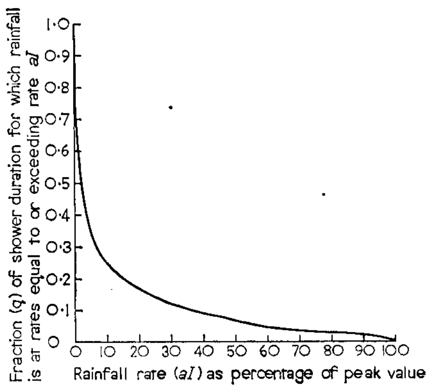

FIGURE 3 — FRACTION OF SHOWER RAINFALL DURATION AGAINST INTENSITY

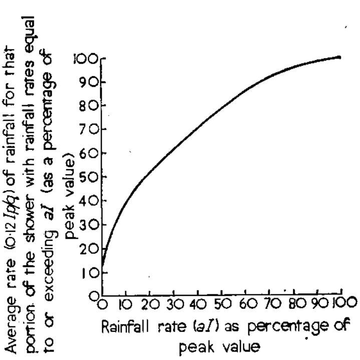

FIGURE 4 — AVERAGE INTENSITY FOR PORTION OF SHOWER EXCEEDING SPECIFIED RATES

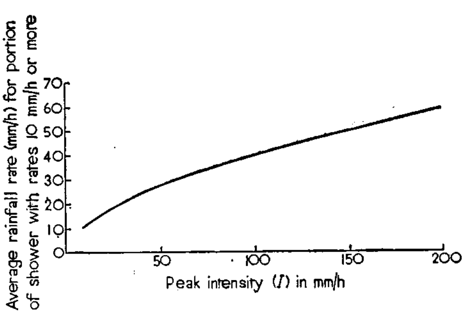

FIGURE 5 — PEAK SHOWER INTENSITY AGAINST AVERAGE INTENSITY AT RATES EQUAL TO OR EXCEEDING 10 mm/h

values of *I* and Figure 4 determines the peak shower intensity in terms of the average rate of rainfall occurring at rates of 10 mm/h or more. Figure 5 shows how the peak value varies with the average rate for rates equal to or exceeding 10 mm/h.

The amount and duration of each period of rain exceeding 10 mm/h may be determined by direct analysis of hyetograms. Figure 5 then gives the value of *I*, peak intensity, and using Table I this yields the duration of rainfall at rates of 25, 50 or 100 mm/h. In practice it is easier to use conversion factors based directly on the observed average rainfall rates and Table II shows factors which may be used to determine durations at or above 25, 50 and 100 mm/h from durations at or above 10 mm/h.

TABLE II—RATIOS OF THE DURATIONS OF SHOWER RAINFALL AT RATES EQUAL TO OR EXCEEDING 25, 50 AND 100 mm/h TO THE DURATION AT RATES EQUAL TO OR EXCEEDING 10 mm/h (RATIOS ARE GIVEN FOR SEVERAL RANGES OF OBSERVED AVERAGE RAINFALL RATE)

Specified rainfall rate *mm/h*	Observed average rainfall rate (*mm/h*)							
	<15	⩾15 and <25	⩾25 <35	⩾35 <40	⩾40 <45	⩾45 <50	⩾50 <55	⩾55
	conversion factors							
25	0	0·3	0·5	0·55	0·6	0·6	0·6	0·65
50	0	0	0·2	0·3	0·3	0·35	0·4	0·4
100	0	0	0	0	0·15	0·15	0·2	0·2

Application to Changi 1961 data. The records available were charts from a continuous-recording tilting-siphon rain-gauge of standard Meteorological Office design. Each individual rainfall occurrence shown by the records was examined and the duration and amount of each fall exceeding rates of 4 mm/h and 10 mm/h was noted. Similar direct assessment for higher specified intensities is not possible with this type of record. Discontinuities or drops in intensity to below the given values were ignored if the period involved was less than 0·1 h. If breaks exceeded 0·1 h then the falls were regarded as separate showers. Amounts were estimated to 0·1 mm and durations to 0·05 h. Table III shows the results of this direct analysis.

Each observed duration at or above 10 mm/h was then multiplied by the factor in Table II, indicated by the observed average rate for rainfall exceeding 10 mm/h. Figures were rounded off to the nearest 0·05 h and Table IV presents the results.

TABLE III—NUMBER OF RAINFALL OCCURRENCES AT RATES EXCEEDING 4 mm/h AND 10 mm/h WHICH EXCEEDED SPECIFIED DURATIONS AT CHANGI 1961

Rainfall rate *mm/h*	Duration (*h*)										
	0·05	0·1	0·2	0·3	0·4	0·5	0·6	0·7	0·8	0·9	1·0
	number of occurrences										
4	329	248	155	105	68	49	38	26	18	16	14
10	227	157	82	54	32	21	13	8	8	6	4

Rainfall rate *mm/h*	Duration (*h*)									
	1·1	1·2	1·3	1·4	1·5	1·6	1·7	1·8	1·9	2·0
	number of occurrences									
4	12	12	9	6	4	2	2	1	1	1
10	3	2	2	2	1	1	0	0	0	0

Note : 4 mm/h average duration = 0·26 h, total duration = 87·15 h
10 mm/h average duration = 0·20 h, total duration = 46.15 h

TABLE IV—FREQUENCY AND DURATION OF RAINFALL AT RATES EQUAL TO OR EXCEEDING 25, 50 AND 100 mm/h AT CHANGI 1961

Rainfall rate (at or above) *mm/h*	Number of occurrences	Total duration *h*	Average duration *h*
25	101	14·60	0·15
50	42	5·15	0·12
100	13	1·15	0·09

The clock-hour values for Changi 1961 had already been separately analysed. A comparison of these values with the present analysis and with estimates based on the McConalogue[1] formula is of interest. This comparison is made in Table V.

TABLE V—DURATIONS OF RAINFALL AT OR ABOVE SPECIFIED RATES AT CHANGI 1961

	Rainfall rate (*mm/h*) 4	5	10	25	50	100
	hours					
Estimate on present analysis	87·1	*	46·1	14·6	5·1	1·15
Estimate from clock-hour values	*	79·1	44·0	13·8	1·4	0
Estimate using McConalogue formula	145·6	117·0	39·3	1·5	0·01	$1{\cdot}15\times10^{-7}$

* = estimates not made.

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A METHOD OF REDUCING OBSERVING AND PROCEDURE BIAS IN WIND-DIRECTION FREQUENCIES

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Summary. Surface wind-direction frequencies for some observing stations are prone to two types of error. One is procedural or clerical; the other type arises from observing bias. This paper describes an empirical method of assessing and reducing bias in individual wind-direction distributions.

Introduction. Surface wind-direction frequencies for some observing stations are prone to two particular types of error. One is a procedural error that arises when wind directions reported in tens of degrees are classified into the 16 compass points used in climatological records. Each cardinal compass direction (N, E, S and W) includes three points on the 10-degree scale, while each of the other 12 compass directions include only two 10-degree points. Thus the classified wind frequencies have a 3 : 2 bias towards the cardinal directions.

Another type of bias arises at some stations where observers have insufficient equipment, training or time to estimate wind directions accurately. At such a station it is often difficult for the observer to estimate the mean wind direction from a swinging wind vane or wind-sock, and even when the direction is fairly steady it may still be reported inaccurately if it is not aligned with a geographical direction marker, such as the fixed arms of a wind-direction indicator.

Thus the reported surface wind-direction frequencies are liable to be biased towards the directions which the observer can estimate easily and with confidence. In circumstances like this the directions most frequently reported are the semi-cardinal directions (NE, SE, SW and NW), presumably because, whatever his doubts about the precise direction, the observer can often say with confidence that the wind is between N and E, or E and S, etc., and the natural inclination is to report NE, SE, SW or NW for a wide band of actual wind directions around each semi-cardinal point. The next most confidently reported directions are the cardinal points, presumably because these directions are often indicated just below the wind vane and because these are considered as 'main' directions. The least reported directions are the minor points (NNE, ENE, etc.) that may appear to the observer as unobtainably fine sub-divisions of the direction scale.

Wind frequency records like this are too coarse for some climatological purposes; a method of reducing the bias is needed to make better use of the observations. This article describes such a method. Hypotheses used in the method are put forward with broad tentative reasoning only, as justification for them is best considered by results rather than elaborate *a priori* argument.

Adjustment for 10-degree to compass-point conversions. When wind directions in tens of degrees are classified into the 16 compass points the ranges effectively allocated to these points are :

N	345° — 015°	(30)
NNE	015° — 035°	(20)
NE	035° — 055°	(20)
ENE	055° — 075°	(20)
E	075° — 105°	(30)

where the figures in brackets give the number of degrees in each range.

The problem is to convert the histogram for these intervals into an equivalent histogram for the 22·5-degree ranges that should be allocated to each direction.

One simple method is as follows. Let n_D be the given frequency for the compass direction D. The converted value n'_D is taken to be :

(i) $n'_{\mathrm{N}} = (3/4)n_{\mathrm{N}}$, etc. for the cardinal directions.

(ii) $n'_{\mathrm{NE}} = n_{\mathrm{NE}} + (1/16)(n_{\mathrm{NNE}} + n_{\mathrm{ENE}})$, etc. for the semi-cardinal directions.

(iii) $n'_{\mathrm{NNE}} = (15/16)n_{\mathrm{NNE}} + (1/4)\left(\dfrac{n_{\mathrm{NNE}}}{n_{\mathrm{NNE}} + n_{\mathrm{NNW}}}\right)$, etc. for the minor directions.

For a purpose described in the next section of this article, we need a more general conversion scheme. First we construct a continuous frequency distribution that is compatible with the histogram; the simplest type of distribution is illustrated in Figure 1, where n_r represents the number of observations per degree in the range θ_r to θ_{r+1}, and C_r represents the constructed frequency of observations at the mid-point of the range. In each range the sum of the frequencies represented by the constructed distribution is equal to the reported number of observations; to find the required values of C we solve the 16 simultaneous equations :

$$\left(\frac{\theta_{r+1}-\theta_r}{\theta_{r+1}-\theta_{r-1}}\right)C_{r-1}+\left(2+\frac{\theta_r-\theta_{r-1}}{\theta_{r+1}-\theta_{r-1}}+\frac{\theta_{r+2}-\theta_{r+1}}{\theta_{r+2}-\theta_r}\right)C_r+\left(\frac{\theta_{r+1}-\theta_r}{\theta_{r+2}-\theta_r}\right)C_{r+1}=4n_r \qquad \ldots (1)$$

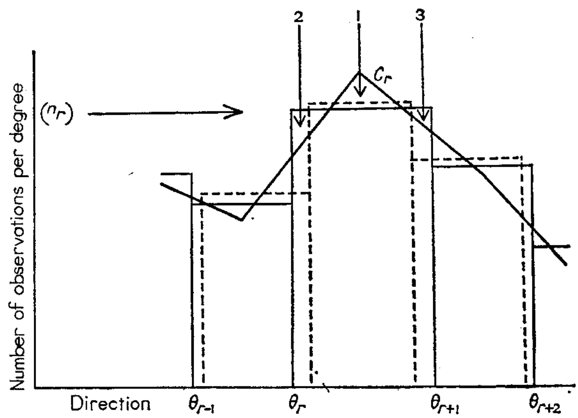

FIGURE 1—THE CONSTRUCTION OF AN EQUIVALENT HISTOGRAM

The curve through C_r shows a segment of the simplest type of continuous frequency distribution that is compatible with the histogram, a section of which is represented by the n_r observations per degree in the range θ_r to θ_{r+1}. To calculate values of C_r (r = 1, 16) it is assumed that area 1 equals areas 2 + 3, etc. Once the values of C_r are obtained a new histogram for 22·5-degree ranges can be constructed; this is illustrated by the dashed lines.

The form of these equations is particularly suitable for solution by iteration.

The final step in the adjustment process is to sum the frequencies represented by the constructed distribution for each of the required ranges.

Adjustment for observing bias. Let us suppose that an observer records as a wind direction, D, winds that are in a range of R_D degrees, and that

$$R_N = R_E = R_S = R_W = R' \quad \ldots (2a)$$

$$R_{NE} = R_{SE} = R_{SW} = R_{NW} = R'' \quad \ldots (2b)$$

$$R_{NNE} = R_{ESE} = R_{SSW} = R_{WNW} = R''' \quad \ldots (2c)$$

$$R_{ENE} = R_{SSE} = R_{WSW} = R_{NNW} = R'''' \quad \ldots (2d)$$

Let us also assume that the cardinal and semi-cardinal sectors are correctly centred on their compass points, but that the mid-points of the R''' and R'''' sectors are e''' and e'''' degrees from their correct geographical directions.

We now note a theorem illustrated in Figure 2 : if A, B, C, D are the points where the pair of mutually perpendicular lines through the origin, O, intersect an ellipse, as shown in the figure, then

$$\left(\frac{1}{OA}+\frac{1}{OB}\right)^2+\left(\frac{1}{OC}+\frac{1}{OD}\right)^2$$

is independent of the direction of these perpendicular lines.

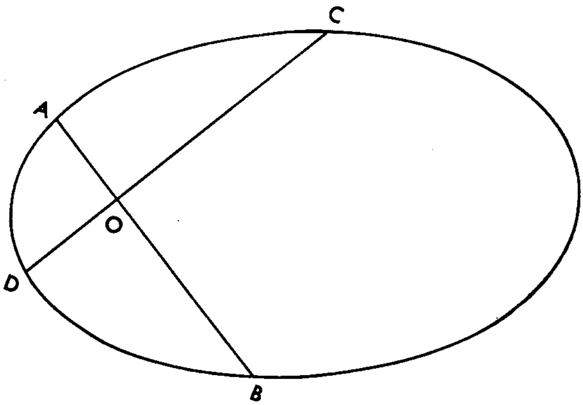

FIGURE 2—AN ELLIPTICAL DISTRIBUTION AROUND POINT O WITH MUTUALLY PERPENDICULAR LINES THROUGH POINT O

If two mutually perpendicular straight lines, AB, CD, intersect at point O and meet an ellipse at points A, B, C and D, then the value of

$$\left(\frac{1}{\mathrm{OA}}+\frac{1}{\mathrm{OB}}\right)^2+\left(\frac{1}{\mathrm{OC}}+\frac{1}{\mathrm{OD}}\right)^2$$

remains constant for any rotation of the pair of straight lines about O.

Because wind-direction frequencies are sometimes similar to elliptic distributions, we now tentatively assume that the theorem holds for wind roses. Then the number of observations per degree is n_D/R_D and we have

$$\begin{aligned}&\left[\left(\frac{1}{n_N}+\frac{1}{n_S}\right)^2+\left(\frac{1}{n_E}+\frac{1}{n_W}\right)^2\right]^{\frac{1}{2}}R'\\ &=\left[\left(\frac{1}{n_{NE}}+\frac{1}{n_{SW}}\right)^2+\left(\frac{1}{n_{SE}}+\frac{1}{n_{NW}}\right)^2\right]^{\frac{1}{2}}R''\\ &=\left[\left(\frac{1}{n_{NNE}}+\frac{1}{n_{SSW}}\right)^2+\left(\frac{1}{n_{ESE}}+\frac{1}{n_{WNW}}\right)^2\right]^{\frac{1}{2}}R'''\\ &=\left[\left(\frac{1}{n_{ENE}}+\frac{1}{n_{WSW}}\right)^2+\left(\frac{1}{n_{SSE}}+\frac{1}{n_{NNW}}\right)^2\right]^{\frac{1}{2}}R'''' \qquad \ldots(3)\end{aligned}$$

We also have that

$$R'+R''+R'''+R''''=90 \qquad \ldots(4)$$

Values of R can be determined from these equations and e''' and e'''' can be assigned values to put the centres of the minor sectors midway between the edges of the cardinal and semi-cardinal sectors. Thus, if the hypothesis is right, we have a method of estimating the sectors that the observer has virtually allocated to the cardinal, semi-cardinal and minor directions. The histogram for these estimated sectors can be converted to a new histogram for the correct 22·5-degree compass ranges by the method already described.

This method of using the recorded wind distribution for assessing and reducing bias will be referred to as an 'automatic symmetrical correction method'.

During preliminary trials of the complete adjustment process it became apparent that the method could be improved by two slight refinements. Subjective assessment of the results suggested that observing underestimates of minor directions do not always have the symmetry indicated in assumptions (2*c*) and (2*d*).

It appears that the lack of weight given to minor directions varies with direction in an ill-defined manner that depends on the local wind distribution and on the observer's viewpoint in relation to his wind-direction indicator. So, although the symmetrical assumptions appeared to be adequate for estimating mean values of the ranges in the two groups, a further estimate of variations of each range from the mean values was desirable. In devising a refinement it was reasoned that the smaller the number of observations in a minor direction compared to the numbers of observations in the adjacent cardinal and semi-cardinal directions the smaller the range allocated by the observer to this minor direction. This broad reasoning can be formulated empirically in several ways, one of which may be written

$$\frac{R_{\mathrm{NNE}}}{n_{\mathrm{NNE}}}\left(\frac{n_{\mathrm{N}}}{R'}+\frac{n_{\mathrm{NE}}}{R''}\right) = \frac{R_{\mathrm{ESE}}}{n_{\mathrm{ESE}}}\left(\frac{n_{\mathrm{E}}}{R'}+\frac{n_{\mathrm{SE}}}{R''}\right)$$
$$= \frac{R_{\mathrm{SSW}}}{n_{\mathrm{SSW}}}\left(\frac{n_{\mathrm{S}}}{R'}+\frac{n_{\mathrm{SW}}}{R''}\right) = \frac{R_{\mathrm{WNW}}}{n_{\mathrm{WNW}}}\left(\frac{n_{\mathrm{W}}}{R'}+\frac{n_{\mathrm{NW}}}{R''}\right) \quad \ldots (5)$$

with a similar set of equations for the other four minor directions. Instead of using assumption (2*c*) and (2*d*) we now have

$$R_{\mathrm{NNE}} + R_{\mathrm{ESE}} + R_{\mathrm{SSW}} + R_{\mathrm{WNW}} = 4R''' \quad \ldots (6)$$

and a similar equation for the R'''' sectors. Thus the values of R can be calculated.

In this article, when the automatic correction method includes the refinement for asymmetry it will be referred to as an 'automatic asymmetrical correction method.'

Another slight refinement was introduced to counter over-compensation for insignificantly small numbers of observations in any direction. In equations (3) and (5) values of n were replaced by $n + \varepsilon$, where ε is a small fraction of the average number of observations per direction. This avoids spuriously high values of $1/n$ when n is very small, but otherwise makes scarcely any difference to the results. Putting ε equal to one twentieth of the mean value of n was found to be adequate for the purpose.

Application of the methods.

Procedural correction and a check of the automatic method. There is no general proof that the conversion schemes just described are correct for all wind frequency distributions. Whenever procedural or observing bias occurs some of the basic data are irrevocably distorted. However, we can judge the usefulness of the schemes by looking at some of their effects.

Assessment of this usefulness or accuracy of the methods will be described in a qualitative way only, as there is no advantage in trying to apply statistical significance tests to wind frequencies compiled from observations for which we do not have serial correlation data.

Figure 3(*a*) and column (2) of Table I show a wind-direction distribution obtained from directions observed for 10-degree intervals and classified later

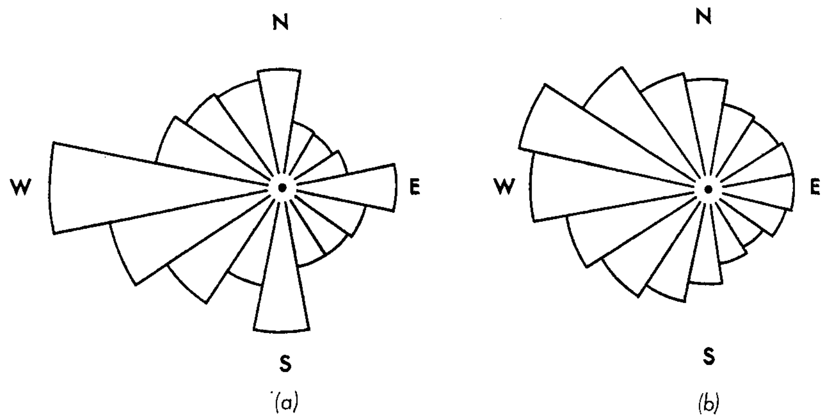

FIGURE 3—WIND ROSE FOR ISLES OF SCILLY, ENGLAND. WINDS ≥4 mile/h, 1922–27, 1930–38

(a) Recorded frequencies showing the procedural bias towards the cardinal points.

(b) Frequencies corrected for the 10-degree to compass point procedural bias. (Wind roses obtained by the automatic correction method are not shown as they differ only slightly from this illustrated distribution.)

into the 16 compass points. Conversion of this distribution by the general method described yields the wind rose of Figure 3(*b*) and the frequencies listed in column (3) of Table I.

TABLE I—WIND* DISTRIBUTION FOR ISLES OF SCILLY, ENGLAND

(1) Direction	(2) Recorded frequencies (Percentages × 10)	(3) Data in col. (2) corrected for 10-degree to compass point bias	(4) Automatic symmetrical correction applied to col. (3)	(5) Automatic symmetrical correction applied to col. (2)
NNE	40	46	45	44
NE	39	43	47	46
ENE	43	47	47	50
E	61	45	43	43
ESE	35	40	40	39
SE	28	31	32	34
SSE	30	35	35	36
S	61	46	43	43
SSW	53	58	56	56
SW	58	65	69	69
WSW	65	75	79	78
W	124	93	89	91
WNW	91	102	98	97
NW	70	79	84	82
NNW	52	59	61	59
N	75	57	54	54

* Note : Winds ≥ 4 mile/h for the period 1922–27 and 1930–38.
Frequencies in percentages × 10.

If these values in column (3) are taken to be the approximately true unbiased frequencies, then application of the automatic symmetrical correction method to these values should produce little or no change. Column (4) shows the result of applying this automatic correction method to column (3). The computed ranges virtually allocated by the values in column (3) are 24, 21 and an average of 22·5-degrees for the cardinal, semi-cardinal and minor directions respectively.

Another test of the automatic method is to see whether it reveals and corrects the procedural bias in the distribution in column (2). Applying the automatic symmetrical correction method to column (2) yields the values listed in column (5), and the automatic estimation of the sectors virtually allocated to the cardinal, semi-cardinal and minor directions are 31, 19 and an average of 20 degrees respectively. Thus the procedural bias in this example is fairly accurately assessed and eliminated by the automatic symmetrical correction procedure.

Another check of the automatic method is to apply it to a wind distribution that has been obtained from compass-point wind observations made by observers with sufficient skill and facilities to avoid bias. But it is impossible to be sure that a given set of observations have no observing bias. However, let us consider the distribution shown in Figure 4(*a*) and column (2) of Table II.

TABLE II—WIND* DISTRIBUTION FOR SHOBDON, HEREFORDSHIRE, ENGLAND

(1)	(2)	(3)	(4)
Direction	Recorded frequencies. (Percentages × 10)	Automatic asymmetrical correction applied to col. (2)	
		Virtually allocated ranges in degrees	Frequencies (Percentages × 10)
NNE	22	17·3	29
NE	38	28·6	30
ENE	24	20·3	27
E	26	23·0	26
ESE	14	13·4	24
SE	28	28·6	23
SSE	22	18·4	27
S	37	23·0	37
SSW	54	22·4	55
SW	84	28·6	67
WSW	68	18·9	81
W	108	23·0	108
WNW	70	19·2	80
NW	63	28·6	48
NNW	36	22·9	40
N	26	23·0	26

* Note : Winds ⩾ 4 mile/h for the period February – October 1943–1945 and November – January 1943–1944. Frequencies in percentages × 10.

This was obtained from compass-point observations by skilled professional observers, but they seem to include a slight bias; the average frequencies of observations in the cardinal, semi-cardinal and minor directions are 4·9, 5·3 and 3·9 per cent respectively. Figure 4(*b*) and columns (3) and (4) of Table II show the results of applying the automatic correction method to the recorded distribution.

The automatically estimated ranges virtually allocated to the compass directions suggest that, if the recorded data is in fact biased, the average error made by observers in their estimation of the ranges of the compass directions was only three degrees — which indeed indicates a high level of skill in the observing.

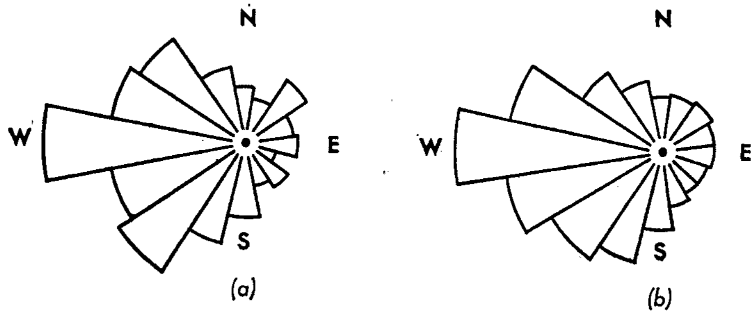

FIGURE 4—WIND ROSE FOR SHOBDON, ENGLAND. WINDS ⩾4 mile/h, FEBRUARY–OCTOBER 1943–45 AND NOVEMBER–JANUARY 1943–44

(a) Recorded frequencies showing slight observer bias.

(b) Frequencies obtained by applying the automatic asymmetrical correction method to the recorded data.

Adjustment of heavily biased data. Figure 5(*a*) and column (2) of Table III show a wind distribution obtained from compass-point observations that have a heavy asymmetrical observing bias. Indeed, the automatic correction method computes that NNE has been allocated a range of 20·9 degrees while WNW has been virtually limited to a 7·3-degree range. These virtually allocated ranges are listed in column (3) of Table III. The adjusted wind frequencies are shown in Figure 5(*b*) and column (4).

TABLE III—WIND* DISTRIBUTION FOR FINKE, AUSTRALIA

(1)	(2)	(3)	(4)
Direction	Recorded number of observations	Automatic asymmetrical correction applied to col. (2)	
		Virtually allocated ranges in degrees	Corrected number of observations
NNE	56	20·9	61
NE	113	39·0	66
ENE	39	13·7	64
E	87	27·4	71
ESE	36	8·9	95
SE	202	39·0	119
SSE	67	12·3	121
S	170	27·4	142
SSW	38	9·4	85
SW	81	39·0	42
WSW	27	13·6	42
W	62	27·4	52
WNW	20	7·3	67
NW	147	39·0	92
NNW	23	8·5	65
N	64	27·4	52

* Note : Number of observations for winds ⩾ 1 mile/h for observations at 0900 and 1500 LMT June — August 1957–1963.

There is no unequivocal test that the converted distribution is correct, but it is undoubtedly more plausible than the biased distribution.

Another heavily biased wind distribution is shown in Figure 6(*a*). Figure 6(*b*) shows the result of applying the automatic correction method to this

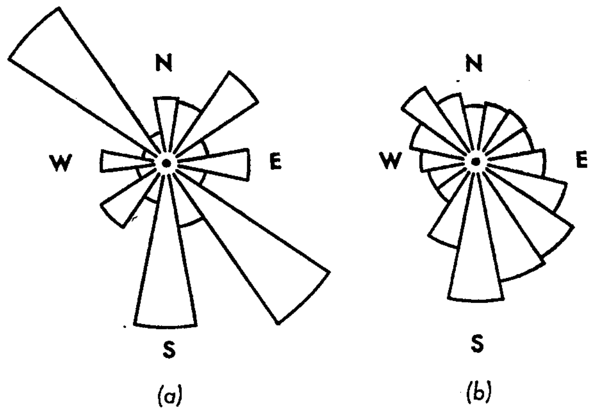

FIGURE 5—WIND ROSE FOR FINKE, AUSTRALIA. WINDS ⩾ 1 mile/h, 0900 AND 1500 LMT JUNE–AUGUST 1957–63

(a) Recorded frequencies showing heavy observer bias.

(b) Frequencies obtained by applying the automatic asymmetrical correction method to the recorded data.

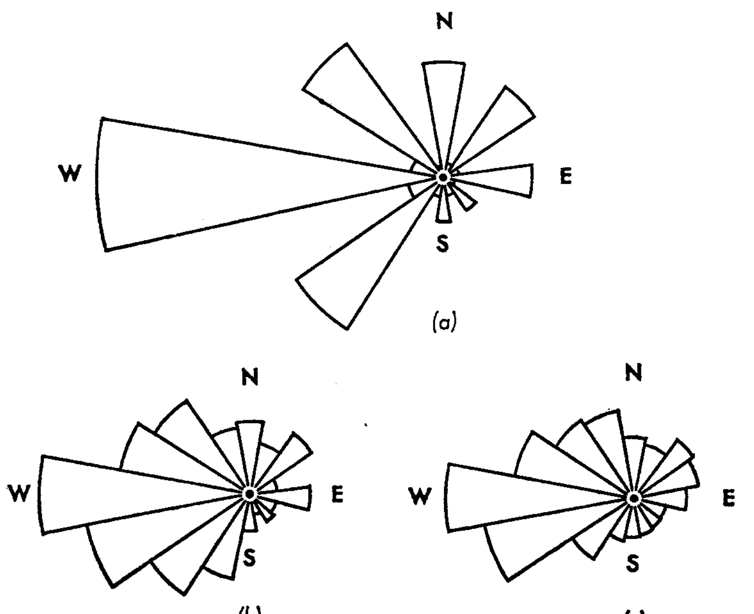

FIGURE 6—WIND ROSE FOR BRADFORD, YORKSHIRE, ENGLAND. WINDS ⩾ 4 mile/h, 1952–56

(*a*) Recorded frequencies showing heavy observer bias.

(*b*) *and* (*c*) Frequencies obtained by two successive applications of the automatic asymmetrical correction method.

distribution. The automatic asymmetrical correction method indicates the virtual ranges for the cardinal, semi-cardinal and minor directions to be 44, 38 and an average of 4 degrees respectively. The modified distribution still has unrealistic peaks in some directions, but this distribution can be further modified by another application of the automatic correction method. In fact, the correction process can be repeated until the changes between successive corrections become insignificent. In the example illustrated here the automatic method applied to the distribution of Figure 6(*b*) produced that of Figure 6(*c*). Further applications of the method yielded scarcely any changes.

Adjustment for miscellaneous bias. Bias in some wind data may also arise from miscellaneous causes associated with doubts or ambiguities in past observing and clerical procedures. The data represented by Figure 7(*a*) is known to include the 10-degree to 16-point procedural bias and an additional bias arising from past local procedures. For this type of data the automatic correction method can be used to assess and reduce the total bias; there is no need to attempt to assess the separate types of bias in the data. Figure 7(*b*) shows the wind rose obtained by one application of the automatic asymmetrical correction method.

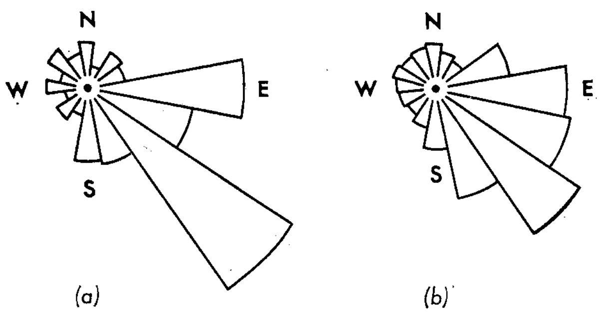

FIGURE 7—WIND ROSE FOR ALICE SPRINGS, AUSTRALIA. WINDS ⩾ 1 mile/h, 1957–63

(*a*) Recorded frequencies which include a 10-degree to compass-point bias and an additional bias arising from past local procedures.

(*b*) Frequencies obtained by applying the automatic asymmetrical correction method to the recorded data.

Conclusion. So far about 50 sets of wind frequency data have been subjected to the automatic correction technique. The experience acquired suggests that, although there is no strict test of the validity of the method for any particular distribution, it is a useful objective method of assessing and reducing bias of the types described. But even if the corrected frequencies are not required, the method of calculating probable ranges virtually allocated to each compass direction can call attention to possible local anomalies in the whole process of observing, recording and compiling wind frequency data.

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SOME PREDICTIVE RELATIONSHIPS CONCERNING SEASONAL RAINFALL OVER ENGLAND AND WALES AND SEASONAL TEMPERATURE IN CENTRAL ENGLAND

By R. MURRAY

Summary. The results of an examination of contingency tables relating monthly and seasonal rainfall (in terciles) and temperature (in quintiles) to subsequent seasonal rainfall over England and Wales and seasonal temperature over central England are presented. Some lag associations appear to give useful first approximations to seasonal rainfall and temperature predictions.

Introduction. In three recent papers[1,2,3] monthly rainfall over England and Wales and monthly mean temperature in central England have been analysed numerically; these investigations have aimed at putting certain relationships of a persistence nature in a practical form as well as at searching for potentially useful associations. In this article the main results are presented of an investigation involving seasonal rainfall and seasonal temperature. Over the period December 1873 to November 1963, seasonal rainfall (in terciles) over England and Wales was related by 5×3 or 3×3 contingency tables to (*a*) seasonal rainfall in the preceding three seasons, (*b*) seasonal temperature (in quintiles) in central England in the preceding three seasons, (*c*) monthly rainfall in the preceding three months and (*d*) monthly temperature in the preceding three months. In a similar way seasonal mean temperature (in quintiles) in central England was related to monthly and seasonal rainfall and temperature. In this paper only those associations which appear to have some predictive value are presented. The seasons are defined conventionally, e.g. winter is December, January and February and is referred to by the year in which January falls.

The tercile boundaries for rainfall and the quintile boundaries for temperature have already been given for each month.[1,2] The basic information required for obtaining the terciles of seasonal rainfall over England and Wales and the quintiles of seasonal mean temperature in central England is briefly given in Tables I and II.

TABLE I—TERCILE BOUNDARIES OF ENGLAND AND WALES SEASONAL RAINFALL FOR THE 90-YEAR PERIOD WINTER 1874 TO AUTUMN 1963

		Winter	Spring	Summer	Autumn
				inches	
3/2	⩾	10·9	7·6	10·0	12·0
1/2	⩽	8·5	6·3	7·6	9·2

Note : The figures in the row beginning 3/2 indicate the lowest value included in tercile 3 (wet) in the various seasons, and the figures in the row beginning 1/2 indicate the highest value included in tercile 1 (dry).

Regarding seasonal mean temperature in central England the quintiles are based on consideration of the seasonal mean temperature departures from 25-year moving averages, a procedure which was explained for the monthly anomalies in the paper on temperature persistence.[2] The quintile boundaries are given in Table II.

(Quintiles 1, 2, 3, 4 and 5 may be called very cold, cold, average, warm and very warm respectively.)

TABLE II—QUINTILE BOUNDARIES OF CENTRAL ENGLAND SEASONAL MEAN TEMPERATURE BASED ON DEPARTURES FROM 25-YEAR MOVING AVERAGES FOR THE PERIOD WINTER 1874 TO AUTUMN 1963

	Winter	Spring	Summer	Autumn
		degrees Celsius		
5/4 ⩾	1·1	0·8	0·7	0·8
4/3 ⩾	0·4	0·3	0·2	0·5
3/2 ⩾	−0·3	0·0	−0·2	0·2
2/1 ⩾	−1·3	−0·5	−0·7	−0·4
mean temp. 1943–1967	3·9	8·7	15·4	10·2

Note : (i) The figures in the row beginning 5/4 indicate the boundaries between quintile 5 and quintile 4 in the various seasons and give the lowest value in the (very warm) quintile 5. Likewise for row beginning 4/3, 3/2 and 2/1.
(ii) To find the quintile, first derive the anomaly of the specific season from the average of the season taken over the 25 years immediately preceding, then inspect Table II ; for example, if the anomaly is greater than or equal to 0·4 and less than 1·1 degC, the winter is quintile 4.

Summer.

(i) *England and Wales rainfall.* Chi-square tests applied to the 5×3 and 3×3 contingency tables indicate that no statistically significant (i.e. significant at 5 per cent level or less) associations exist. The best relationship (nearly significant at the 1·0 per cent level) involves April temperature as a predictor of summer rainfall (see Table III). In this case, however, the main contribution to chi-square comes from the two extreme temperature quintiles. The only other associations which might have some predictive value relate quintile 5 winters and quintile 5 springs to dry summers.

TABLE III—SUMMER RAINFALL OVER ENGLAND AND WALES ASSOCIATED WITH (a) PRECEDING APRIL TEMPERATURES IN CENTRAL ENGLAND, (b) QUINTILE 5 TEMPERATURES IN SPRING AND (c) QUINTILE 5 TEMPERATURES IN WINTER

Parameter		Summer rainfall (terciles) 1	2	3
(a) April	T_1	2	6	11
	T_2	8	4	6
	T_3	7	7	3
	T_4	6	6	7
	T_5	9	5	3
(b) Spring	T_5	9	6	3
(c) Winter	T_5	10	4	5

Note : $T_1, \ldots T_5$ are temperature quintiles for the appropriate month or season.

Using for brevity the arrow symbol (i.e. →) to mean 'tend to be followed by', we may summarize Table III as follows :

(1) Very cold Aprils → wet summers
(2) Very warm Aprils → dry summers
(3) Very warm springs → dry summers
(4) Very mild winters → dry summers.

(ii) *Central England temperature.* The April temperature and summer temperature association is probably statistically significant at the 5 per cent level. The expected number of cases in each cell of a 5×5 table is less than five when only 90 years of data are used, and this limitation of cell frequency has hitherto made the usual chi-square test inapplicable. However, recent work by Craddock and Flood[4] suggests that the chi-square statistic can be used to test the significance of such a table even when the expected number in each cell is less than five. No other contingency table is statistically significant. Nevertheless, certain rows of the tables suggest relationships which may have some limited predictive value. The best relationships are shown in Table IV.

TABLE IV—SUMMER MEAN TEMPERATURE IN CENTRAL ENGLAND ASSOCIATED WITH *(a)* PRECEDING APRIL TEMPERATURES, *(b)* QUINTILES 1 AND 5 TEMPERATURES IN SPRING, *(c)* TERCILE 1 RAINFALL IN MARCH OVER ENGLAND AND WALES AND *(d)* TERCILES 1 AND 3 RAINFALL IN AUTUMN

Parameter		Summer temperature (quintiles)				
		1	2	3	4	5
	T_1	6	5	4	2	2
	T_2	3	6	3	3	3
(*a*) April temperature	T_3	3	4	4	1	5
	T_4	2	1	7	2	7
	T_5	2	2	1	8	4
(*b*) Spring temperature	T_1	4	7	1	2	3
	T_5	3	2	3	5	5
(*c*) March rainfall	R_1	4	2	7	7	10
(*d*) Autumn rainfall	R_1	9	8	6	3	4
	R_3	1	7	9	5	8

Note : $T_1, \ldots T_5$ are temperature quintiles and R_1, R_2, R_3 rainfall terciles for the appropriate month and season in the first column.

The useful results from Table IV are as follows, numbered in continuation of result numbers from Table III :

(5) Very cold Aprils → very cool to average summers
(6) Warm/very warm Aprils → warm/very warm summers
(7) Very cold springs → cool/very cool summers
(8) Very warm springs → warm/very warm summers
(9) Dry Marches → average to very warm summers
(10) Dry autumns → cool/very cool summers
(11) Wet autumns are rarely followed by very cool summers.

Autumn.

(i) *England and Wales rainfall.* There are no statistically significant contingency tables associated with autumn rainfall. The most useful results appear to be those listed in Table V.

TABLE V—AUTUMN RAINFALL OVER ENGLAND AND WALES ASSOCIATED WITH *(a)* TERCILE 3 RAINFALL IN SUMMER AND *(b)* QUINTILE 5 TEMPERATURES IN SPRING

Parameter		Autumn rainfall (terciles)		
		1	2	3
(*a*) Summer rainfall	R_3	5	11	14
(*b*) Spring temperature	T_5	10	4	4

In addition there is a weak indication of anti-persistence in rainfall from June to autumn. However, the main relationships are probably those contained in Table V, numbered in continuation of result numbers from Tables III and IV.

(12) Wet summers → wet/average autumns
(13) Very warm springs → dry autumns.

(ii) *Central England temperature.* The summer rainfall/autumn temperature contingency table is just significant. This contingency table and some other weak relationships are contained in Table VI.

TABLE VI—AUTUMN TEMPERATURE IN CENTRAL ENGLAND ASSOCIATED WITH *(a)* SUMMER RAINFALL OVER ENGLAND AND WALES, *(b)* WET AUGUSTS AND *(c)* QUINTILE 1 TEMPERATURES IN JUNE, JULY AND AUGUST

Parameter			Autumn temperature (quintiles)				
			1	2	3	4	5
		R_1	8	6	4	4	10
(*a*)	Summer rainfall	R_2	5	4	5	9	5
		R_3	7	10	6	7	0
(*b*)	August rainfall	R_3	10	7	6	5	4
(*c*)	June temperature	T_1	8	3	4	3	1
	July temperature	T_1	6	2	6	5	0
	August temperature	T_1	5	5	3	5	0

The main results from Table VI are numbered in continuation of result numbers from Tables III–V as follows :

(14) Wet summers are rarely followed by very warm autumns.

(15) Wet Augusts are rarely followed by very warm autumns.

(16) Very cool summer months are rarely followed by very warm autumns.

Winter.

(i) *England and Wales rainfall.* There is a significant association between autumn and winter rainfall, largely due to the tendency for wet autumns to be followed by average or wet winters. There is also a suggestion that average autumns are more likely to be followed by dry than by wet winters. This contingency table and a few other relationships are summarized in Table VII.

TABLE VII—WINTER RAINFALL OVER ENGLAND AND WALES ASSOCIATED WITH *(a)* AUTUMN RAINFALL, *(b)* DRY SUMMERS, *(c)* QUINTILE 5 TEMPERATURE IN NOVEMBER, *(d)* QUINTILE 1 TEMPERATURES IN OCTOBER, *(e)* QUINTILE 5 TEMPERATURES IN SUMMER AND *(f)* QUINTILE 5 AND QUINTILE 1 TEMPERATURES IN SPRING

Parameter			Winter rainfall (terciles)		
			1	2	3
		R_1	13	6	12
(*a*)	Autumn rainfall	R_2	13	9	7
		R_3	4	15	11
(*b*)	Summer rainfall	R_1	7	10	15
(*c*)	November temperature	T_5	10	4	2
(*d*)	October temperature	T_1	9	7	3
(*e*)	Summer temperature	T_5	4	7	10
(*f*)	Spring temperature	T_1	9	6	2
		T_5	5	4	9

The main results from Table VII are as follows, numbered in continuation of result numbers from Tables III–VI :

(17) Wet autumns → average/wet winters

(18) Dry summers → wet/average winters

(19) Very warm Novembers → dry winters

(20)	Very cold Octobers	→	dry/average winters
(21)	Very warm summers	→	wet/average winters
(22)	Very cold springs	→	dry/average winters.

(ii) *Central England temperature.* Although none of the contingency tables is statistically significant, there are some hints of trends, which are presented in Table VIII.

TABLE VIII—WINTER TEMPERATURE IN CENTRAL ENGLAND ASSOCIATED WITH (*a*) AUTUMN RAINFALL, (*b*) OCTOBER RAINFALL AND (*c*) QUINTILES 4 AND 5 TEMPERATURE IN OCTOBER

Parameter		Winter temperature (quintiles)				
		1	2	3	4	5
(*a*) Autumn rainfall	R_1	5	3	5	6	11
	R_3	6	8	9	4	3
(*b*) October rainfall	R_1	5	3	6	7	6
	R_3	8	8	7	6	2
(*c*) October temperature	T_4	1	2	6	4	3
	T_5	2	3	2	4	5

The tendencies suggested in Table VIII are not strong. October and autumn rainfall are broadly similar, and only (*a*) and (*c*) are summarized below, numbered in continuation of result numbers from Tables III–VII :

(23)	Dry autumns	→	above average rather than below average winters
(24)	Wet autumns	→	average to very cold winters
(25)	Warm/very warm Octobers	→	average to very mild winters

Spring.

(i) *England and Wales rainfall.* The association between summer temperature and rainfall in the following spring turns out to be statistically significant, but the contributions to chi-square come mainly from the peculiar frequency distributions following the warmer types of summer. There is also a suggestion of anti-persistence in rainfall from January to spring, as shown in Table IX.

TABLE IX—SPRING RAINFALL OVER ENGLAND AND WALES ASSOCIATED WITH (*a*) TEMPERATURE IN THE PRECEDING SUMMER AND (*b*) JANUARY RAINFALL

Parameter		Spring rainfall (terciles)		
		1	2	5
(*a*) Summer temperature	T_1	5	5	7
	T_2	4	4	9
	T_3	6	6	7
	T_4	9	1	6
	T_5	7	13	1
(*b*) January rainfall	R_1	7	13	10
	R_3	15	5	8

The only associations which may have some use in practice are as follows, numbered in continuation of results numbers from Tables III–VIII :

(26)	Very warm summers	→	dry/average springs
(27)	Dry Januarys	→	average/wet springs
(28)	Wet Januarys	→	dry springs.

(ii) *Central England temperature*. There is a statistically significant relationship between winter and spring temperatures; the association is essentially one of persistence, which is particularly strong after very cold winters. The association between January temperature and spring temperature is also statistically significant, although the relationship is not simply persistence. There is, however, a persistence association between February and spring temperature; this is almost significant at the 5 per cent level. The associations between winter and spring and between February and spring temperatures are clearly useful in practice, but the association involving January temperature is not readily applicable. It seemed likely that even more definite persistence relationships might exist when winter and February are both cold (quintiles 1 or 2) and both warm (quintiles 4 or 5). Examination of the individual years shows that strong persistence of cold into spring exists when both winter and February are cold. However, warm persistence is weak when both winter and February are mild. These results are shown in Table X.

TABLE X—SPRING TEMPERATURES IN CENTRAL ENGLAND ASSOCIATED WITH *(a)* WINTER TEMPERATURE, *(b)* JANUARY TEMPERATURE, *(c)* FEBRUARY TEMPERATURE AND *(d)* WINTER AND FEBRUARY BOTH COLD

Parameter		Spring temperature (quintiles) 1	2	3	4	5
(*a*) Winter temperature	T_1	7	3	5	1	1
	T_2	5	5	2	1	4
	T_3	2	4	3	8	2
	T_4	3	3	2	7	3
	T_5	1	5	3	3	7
(*b*) January temperature	T_1	5	3	4	1	6
	T_2	6	6	5	1	0
	T_3	2	2	1	10	3
	T_4	3	4	3	4	3
	T_5	2	5	2	4	5
(*c*) February temperature	T_1	4	6	4	3	1
	T_2	7	3	4	4	1
	T_3	3	5	1	3	6
	T_4	3	4	2	6	1
	T_5	1	2	4	4	8
(*d*) Winter and February temperatures	T_1 or T_2	10	6	6	2	1

Table X suggests the following 'rules', of which the most significant is probably number (29), numbered in continuation of result numbers from Tables III–IX :

(29) Cold/very cold winters and Februarys → very cold to average springs

(30) Cold/very cold winters → very cold to average springs

(31) Cold/very cold Februarys → very cold to average springs

(32) Cold (quintile 2) Januarys → cold springs

(33) Mild/very mild winters → warmer rather than colder springs

(34) Very mild Februarys → mild/very mild springs.

Another contingency table relating autumn and spring temperature is also statistically significant. However, the frequencies in the cells of the 5×5 table do not follow any simple pattern; the association is evidently complex, and the table is not reproduced since it is of little practical use.

Synchronous seasonal rainfall and temperature associations. There are of course associations between rainfall and temperature in winter and summer. The types of associations are well known, and the contingency tables which relate rainfall and temperature are statistically significant, as is shown in Table XI.

TABLE XI—SYNCHRONOUS ASSOCIATION BETWEEN RAINFALL OVER ENGLAND AND WALES (TERCILES) AND CENTRAL ENGLAND TEMPERATURES (QUINTILES) IN *(a)* WINTER AND *(b)* SUMMER

Rainfall (terciles)	Temperature (quintiles) 1	2	3	4	5
1	10	4	7	5	4
2	6	11	3	5	5
3	1	2	9	8	10

(a) Winter

Rainfall (terciles)	Temperature (quintiles) 1	2	3	4	5
1	1	4	5	6	16
2	4	7	6	7	4
3	11	7	8	3	1

(b) Summer

The spring and autumn synchronous associations are not statistically significant. There is a weak tendency for the spring associations to be like the summer associations, but the autumn relationship shows no simple pattern.

Discussion. It is of course recognized that monthly or seasonal rainfall and mean temperature cannot be regarded as adequate parameters for long-range weather forecasting. Nevertheless, these two manifestations of weather are linked to the interminable activity of the physical and dynamical processes which operate on all time-scales to maintain the general circulation of the atmosphere. It seems not unreasonable to expect some lag associations between rainfall and temperature.

Lag relationships were examined in 96 and synchronous associations in 4 contingency tables. The examination of 100 contingency tables implies that 5 might be expected by chance to satisfy a 5 per cent significance test. In fact 9 contingency tables are significant at the 5 per cent level. However, in most cases only particular rows in the statistically significant as well as in the statistically non-significant tables suggest relationships which might have a real basis. It is synoptically reasonable that the more extreme categories of rainfall or temperature, as indicated broadly by the relevant rows of the contingency tables, might be characteristic of certain large-scale circulation patterns, which appear to have a built-in tendency to persist or to evolve in one way in preference to another at certain times in the year. Thus a contingency table which is strictly non-significant taken as a whole, might still contain a relationship which is indicative of the existence of associations between complex physical processes in the atmosphere.

The 34 'rules' listed in this paper must be regarded as no more than statistical trends. Clearly not all of the trends are equally strong. A perusal of the statistics will readily give some idea of the reliability to be expected. For example, 'rules' (10) and (11) have not a strong statistical foundation but they seem worth including since complementary trends are suggested (see *(d)* in Table IV). On the other hand, 'rules' (1) and (2) are examples which appear to have a sound statistical foundation, even though the 5×3 contingency table (see *(a)* in Table III) is not statistically significant. Moreover 'rules' (1) and (2), which are also complementary, are based on two frequency distributions which are significantly different from each other in the statistical sense; also, these different frequency distributions follow radically different broad-scale synoptic patterns. It is outside the scope of the present article to examine the synoptic patterns associated with the statistical relationships. However, it is worth pointing out that numbers (1) and (2), which relate April mean temperature in central England to summer rainfall agree with work of Hay.[5] In Hay's paper, summer rainfall over England and Wales was shown to be significantly related to centres of positive and negative temperature anomaly in April in certain regions of western Europe and North America. The temperature-anomaly centres in the two regions were taken by Hay as indications of anomalous positions of the American and European cold trough in the troposphere.

There is some further evidence to support the belief that many of the 'rules' are likely to have some synoptic physical basis. In the four years of independent data since 1963 there were 26 cases of application of these 'rules'; on 19 occasions they were verified in the event (i.e. about 73 per cent success). This may be compared with a reasonable estimate of the number likely to be correct by chance, namely 50 to 60 per cent.

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A COMPARISON OF EFFECTIVE TEMPERATURES AT BAHRAIN AND SHARJAH

By G. A. WATT

Introduction. A previous paper by Watt[1] discussed the summer climate of Bahrain from the point of view of human comfort, an assessment of which was obtained by working out values of effective temperature.

Although Sharjah is often hotter than Bahrain in summer, and certainly has considerably higher absolute maxima of dry-bulb temperature, it is considered by most people with experience of both places that Sharjah's summer is rather less unpleasant than that of Bahrain. This paper extends the investigation of effective temperature to Sharjah and compares the results with those of Bahrain. While the differences appear to be small, it is nevertheless suggested that they are significant.

All times quoted in this paper are zone times (zone time = GMT + 4 h).

General background. Sharjah is located at the south-eastern end of the Persian Gulf on the coast of the Trucial States, while Bahrain is an island situated half-way down the Gulf and about 15 miles from the nearest mainland (see Figure 1).

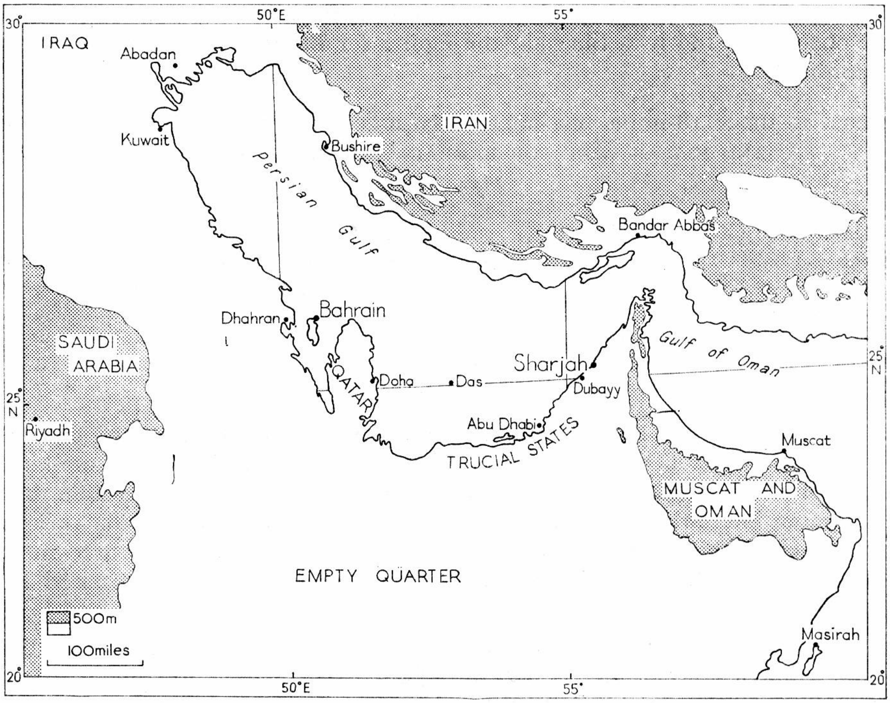

FIGURE 1—MAP OF PERSIAN GULF SHOWING RELATIVE POSITIONS OF BAHRAIN AND SHARJAH

The climate of Sharjah is largely similar to that of Bahrain except that at Sharjah it is usual to have a land or katabatic breeze from between east and south during the latter part of the night and early morning until about 1000 to 1200 h, the humidity remaining quite low. After this time the north-westerly sea-breeze sets in, the temperature drops somewhat but the humidity rises. The strength of the sea breeze is usually between 12 and 17 knots and this has the effect of keeping the effective temperature down to a more tolerable level, though still remaining high.

During the summer months cumulonimbus clouds frequently form over the mountains to the south-east of Sharjah in Muscat and Oman. Sometimes these storms are in association with an active intertropical convergence zone. Now and then the downdraughts from these clouds penetrate as far as Sharjah. The normal flow of the sea breeze is disrupted and can be replaced by very hot desert air, sometimes causing a secondary maximum temperature to be recorded between 1700 and 1900 h. The desert air is very dry and can cause noticeable smarting of the eyes.

Data extracted. Similar data to that extracted for Bahrain were taken from the daily registers of Sharjah over the six summer months. Three-hourly values of temperature and wind speed were noted from 0300 to 1800 h for the 5-year period 1962 to 1966 inclusive. Means of dry-bulb, wet-bulb and effective temperature were calculated and are shown in Table I, which also includes corresponding values for Bahrain. Since no values were available for 0000 and 2100 h at Sharjah, the figures for Bahrain have been adjusted accordingly.

TABLE I—MEAN 18-HOUR DRY-BULB, WET-BULB AND EFFECTIVE TEMPERATURE AND SCALAR WIND FOR BAHRAIN AND SHARJAH, 1962–66

		May	June	July	Aug.	Sept.	Oct.
Mean dry-bulb temperature (°C)	Bahrain	28	33	34	35	33	30
	Sharjah	29	31	34	34	31	28
Mean wet-bulb temperature (°C)	Bahrain	23	26	28	29	27	25
	Sharjah	23	25	27	28	26	24
Mean effective temperature (°C)	Bahrain	21	25	27	28	26	23
	Sharjah	22	24	26	27	25	22
Mean scalar wind speed (knots)	Bahrain	10	11	10	8	7	8
	Sharjah	10	9	9	8	8	7

Table I shows that Bahrain experiences mean values of effective temperature from June to October about 1 degC above those for Sharjah. At these high levels of effective temperature a difference of 1 degC is very noticeable, but even more interesting is a comparison of the diurnal variation of the various parameters. This is illustrated graphically in Figure 2 for the three most trying months. The Sharjah values for 0000 and 2100 h are assumed by extrapolation.

Figure 2 reveals a greater diurnal variation at Sharjah not only of the three temperature parameters but also of wind speed. In particular it shows the relatively pleasant period of 'acceptable' effective temperature (below 24·5°C (76°F)) during the period of the morning land breeze. This is further emphasized in Tables II and III which give, for different times of the day, the number of days per month when the effective temperature exceeds 24·5°C (the upper 'acceptable' limit) and 29·5°C (85°F) (the 'critical' value) respectively for the two places. At 0600 h in August the effective temperature exceeds 24·5°C almost every day in Bahrain while at Sharjah the frequency is just less than half. In September the difference is even more striking with 21 days at Bahrain and only 4 at Sharjah.

TABLE II—AVERAGE NUMBER OF DAYS ON WHICH THE EFFECTIVE TEMPERATURE ≥ 24·5°C (76°F) AT BAHRAIN AND SHARJAH, 1962–66

		00	03	06	09	12	15	18	21
July	Bahrain	30	28	24	30	31	31	31	31
	Sharjah	—	17	12	30	31	31	31	—
August	Bahrain	31	31	30	31	31	31	31	31
	Sharjah	—	24	14	29	31	31	31	—
September	Bahrain	28	25	21	26	30	30	29	27
	Sharjah	—	10	4	18	30	29	29	—

TABLE III—AVERAGE NUMBER OF DAYS ON WHICH THE EFFECTIVE TEMPERATURE ≥ 29·5°C (85°F) AT BAHRAIN AND SHARJAH, 1962–66

		00	03	06	09	12	15	18	21
July	Bahrain	4	3	1	3	5	4	2	4
	Sharjah	—	1	1	2	10	6	4	—
August	Bahrain	7	6	5	7	11	12	8	8
	Sharjah	—	2	1	5	10	4	5	—
September	Bahrain	3	1	0	1	2	3	1	1
	Sharjah	—	0	0	1	2	1	0	—

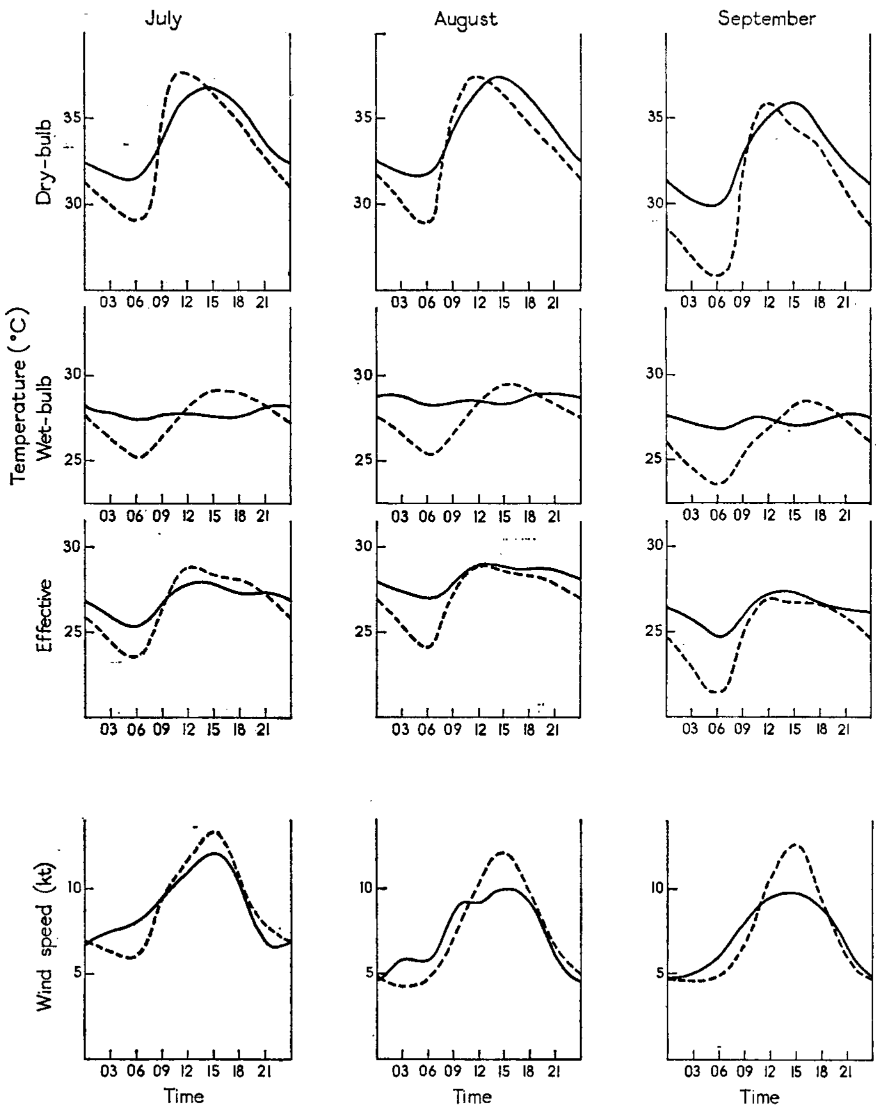

FIGURE 2—DIURNAL VARIATION OF WIND SPEED AND TEMPERATURES AT BAHRAIN AND SHARJAH

——— Bahrain - - - - - - Sharjah

This morning spell at Sharjah of relatively low effective temperature is usually quite stimulating. Even although it does not last very long it provides a most welcome respite from the normally enervating combination of high temperature and high humidity which is typical of the Gulf summer. It should be mentioned, however, that on occasions when the katabatic 'fails', the mornings can be equally (occasionally more) unpleasant than at Bahrain.

In the afternoons in summer there is usually not much to choose between the two places though in July Sharjah's effective temperatures usually exceed those of Bahrain. This is because the Shamal is still evident in the Gulf for the greater part of July bringing dry continental air from the north-west into Bahrain. By the time the air reaches Sharjah, however, it has a greatly increased moisture content due to the longer sea track. During August and September, however, the Shamal no longer prevails, the air becomes much more stagnant over the Gulf and the effective temperatures attain similar values during the afternoon at both localities, in spite of the greater average wind speed at Sharjah. This means that it can be more uncomfortable at Sharjah in places not ideally exposed to the wind and excessive exercise could overheat the body dangerously and cause serious dehydration. Effective temperatures of 32°C or more were recorded on five occasions at Sharjah, which is comparable with the six occasions at Bahrain during the 5-year period.

One further very noticeable factor is the absence of waste smell at Sharjah compared with Bahrain. This is because at low tide a good deal of sand is laid bare around Manama, the capital of Bahrain, and the nearby Muharraq island. This prevents sewerage and other waste matter from being carried out to sea. This is hardly a meteorological factor but necessarily one which adds to the discomfort especially when accompanied by high humidities.

Conclusions.

(i) Sharjah has a slightly more pleasant climate than Bahrain during the summer months because of the prevalence of a dry katabatic wind during the morning.

(ii) Conditions during the afternoon are largely comparable at both places in spite of a greater average wind speed at Sharjah.

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FOG FREQUENCIES AT INLAND STATIONS

By F. E. DINSDALE

A number of articles have been written in recent years[1-5] drawing attention to the decrease in fog frequencies and improvement of general visibility at a selection of sites in England. These articles have, in the main, attributed these changes to the implementation of the Clean Air Act of 1956 in different cities. Whilst there can be no doubt that this Act has done much to remove the murk from our largest centres of population — and the results at

Finningley have been well demonstrated by Corfield and Newton[1] — any changes in fog frequencies at a particular site for a specified period should be viewed against the general pattern of fog occurrence over the country as a whole.

Figure 1 shows the annual incidence of fog for four different thresholds at Abingdon and at London/Heathrow Airport during the 12 years 1956–67. Values plotted are the yearly totals of reports at the four climatological hours and give a good indication of total fog frequency. The resemblance between the two diagrams is quite striking, yet it should be borne in mind that Abingdon is a wholly rural station, little affected by smoke, whilst Heathrow is a suburban aerodrome on the western edge of London.

Looking at a broader field it can be seen that there has been a general decline in fog frequencies over the country during the past 10 years — since the peak years of 1958 and 1959 — and it is against this general decline that

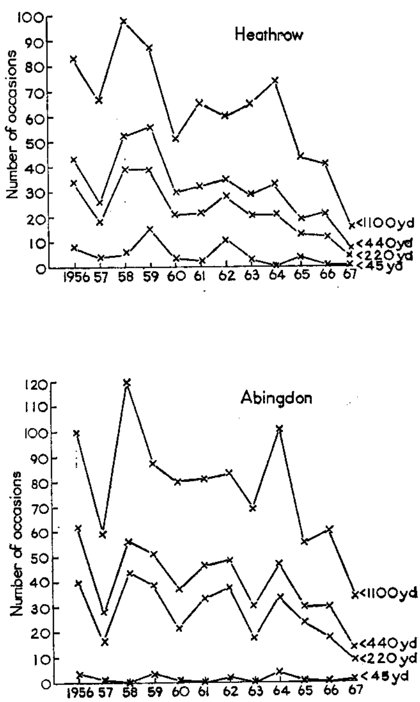

FIGURE 1—NUMBER OF OCCASIONS PER YEAR WITH VISIBILITY BELOW SPECIFIED LIMITS (BASED ON THE FOUR CLIMATOLOGICAL HOURS 0300, 0900, 1500 AND 2100 GMT) 1956-67

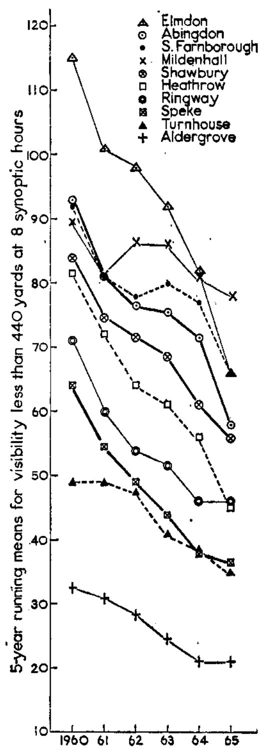

FIGURE 2—FIVE-YEAR RUNNING MEANS OF OCCASIONS OF VISIBILITY LESS THAN 440 yd AT THE EIGHT SYNOPTIC HOURS. PERIOD 1958–67

statistics at a particular site should be measured. Figure 2 shows for 10 well-known stations in the British Isles the five-year running means of visibility less than 440 yd as reported at the eight synoptic hours during the period 1958 to 1967. The figures for South Farnborough 1966 and 1967 were adjusted to allow for missing observations at 2100 GMT. Five-year running means obscure the inherent 'peakiness' of fog statistics but they are visually more satisfactory when studying trends. The means are plotted against the mid-years of each five-year period. These ten airfields comprise five suburban stations and five rural stations, spread from the south of the Thames valley to Northern Ireland and the Scottish Lowlands. There is clearly scope for wider investigations to include coastal sites although here the annual incidence of fog is normally low.

One of the simplest of fog statistics is the number of days of fog, (visibility less than 1100 yd), at the morning hour, which since 1945 has been 0900 GMT. Five-year running means of the annual totals at four stations in southern England are shown in Figure 3. This diagram exhibits a curious convergence at the year 1956 which is due to the substantial falls at both Kew and South Farnborough during the first half of the 1950's. This fall is not related, presumably, to the Clean Air Act of 1956, but may of course be the result of a change of domestic habits during the earlier years. Ross-on-Wye shows a small but steady decline in fog occurrence over the 23 years, but Rothamsted, an exception to what is believed to be a common trend, has remained broadly

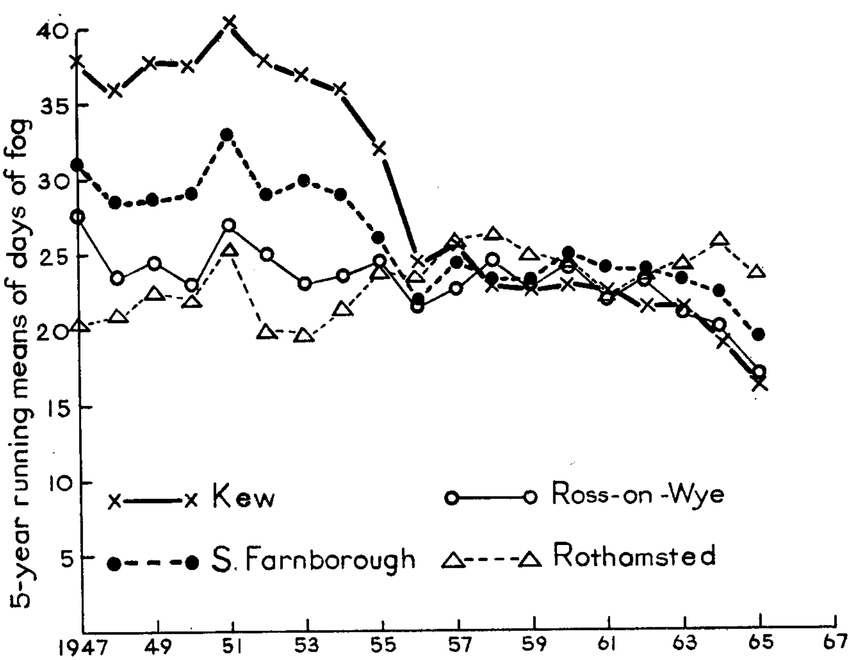

FIGURE 3—FIVE-YEAR RUNNING MEANS OF DAYS OF FOG AT 0900 GMT. PERIOD 1945–67

unchanged — indeed an examination going back to 1925 revealed that the level of fog frequency at this station was remarkably constant for the whole 40 years or so with a five-year mean value between 20 and 25 days per year.

There is obviously much scope for further studies of visibility variation at both rural and suburban sites in relation to the changes of atmospheric pollution, but it is felt that in such studies the broad-scale long-term variation — which may be the result of synoptic patterns — should not be overlooked.

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REVIEW

The theory of rotating fluids, by H. P. Greenspan. 22 cm × 15 cm, pp. xii + 327, *illus.*, Cambridge University Press, Bentley House, 200 Euston Road, London, N.W.1, 1968. Price £5.

Geostrophic motion is characterized by a balance between Coriolis forces and pressure forces, and satisfies the thermal wind equation when the fluid is baroclinic, which reduces to the celebrated 'Proudman — Taylor' theorem when the fluid is barotropic. Laboratory experiments and experience with geophysical systems such as the oceans and atmosphere indicate that in very rapidly rotating fluids, quasi-geostrophy is attained nearly everywhere. Unfortunately, the equations of geostrophic motion are mathematically degenerate and ageostrophic effects must, therefore, be taken into account in any acceptable theoretical procedure.

Three types of ageostrophic effect occur in general, associated respectively with changes in flow pattern, with the acceleration of fluid particles relative to the rotating frame, and with viscous friction. The first step in any theoretical study is the ranking of ageostrophic effects in order of importance (a procedure fraught with the kind of problems Dr Johnson must have had in mind when complaining of the 'difficulty of establishing the precedence of a louse over a flea'). If either friction or time-variations in the flow pattern predominate then the mathematical problem can usually be linearized and treated analytically. More commonly, however, particle accelerations predominate and the resulting mathematical equations are non-linear and generally intractable, except by numerical methods.

Several years ago, largely through pioneering studies by meteorologists and oceanographers, the number and variety of available rigorous and elegant solutions to linear problems in the hydrodynamics of rotating fluids reached the level at which it became possible to offer a course on the subject that would satisfy graduate students in applied mathematics. The most successful part of Professor Greenspan's book is the outcome of such a course, given by him and by Professors Pedlosky and Barcilon at the Massachusetts Institute of Technology. The stated objective of the book is to give a comprehensive account of the theory of rotating fluids. The mathematical development is illustrated by laboratory demonstrations, one or two of which are described for the first time.

In the first chapter (27 pages), the Introduction, a few simple laboratory demonstrations (Taylor columns, etc.) are described, the equations of motion are presented and the rudiments of vorticity theory and boundary layer theory are outlined.

In Chapter 2 (105 pages), linear phenomena in a barotropic fluid in a rigid container are considered (with a short section at the end on the effects of density stratification). The theory of the Ekman boundary layer is treated at some length. As meteorologists discovered long ago, Ekman-layer suction is the dominant viscous process in the vorticity-balance equation, a process brilliantly analysed by Professor Greenspan under the title of 'Spin-up'. According to the theory, the typical interval of time required for friction to bring about substantial changes in vorticity is the geometric mean of the viscous diffusion time (typically several months at least for the atmosphere) and the rotation period (a 'day'). 'Spin-up' is a recurring theme throughout the book.

A rotating barotropic fluid is capable of supporting inertial oscillations with frequencies less than twice the angular speed of basic rotation. Rossby-Haurwitz waves comprise that class of inertial oscillation with which the meteorologist and oceanographer are particularly familiar. These waves are but one phenomenon due essentially (in a barotropic fluid) to the spatial variation of the axial distance between the upper and lower surfaces of the fluid ; 'western boundary currents', e.g. the Gulf Stream, and 'Taylor columns', e.g. Jupiter's Red Spot (?), are others. Linear theories of these phenomena are treated in detail.

Chapter 3 (52 pages) is a valuable review of investigations (often by aerodynamicists) of systems akin to some of those treated in Chapter 2 but with the difference, in some cases crucial, that non-linear effects cannot be neglected, and Chapter 4 (40 pages) deals with both steady and time-varying motions in unbounded fluids.

In Chapter 5 (46 pages), entitled 'Depth-averaged equations : models for the oceanic circulation', Rossby-Haurwitz waves, including an important class of inertial oscillations that are trapped near the equator, and western boundary currents are discussed in further detail and some numerical studies are outlined. Finally, in Chapter 6 (29 pages), experimental and theoretical investigations of the stability of various barotropic and baroclinic flows are reviewed, with the greatest emphasis on the instabilities that arise when the Reynolds number of the flow in an Ekman layer exceeds a certain critical value. Baroclinic instability, the process responsible for the conversion of potential energy due to solar heating of the atmosphere into kinetic energy of large-scale atmospheric motions, is also treated, but only in vague outline.

The book carries a detailed notation guide, a bibliography and author index and a subject index, and is fairly lavishly illustrated, which may account for its high price. This reviewer was aware of only one or two errors, towards the end of the book, which were only minor (though some of them indicate that the author may not always have been able to consult the cited reference). The book will constitute a useful addition to the libraries of mathematically inclined geophysicists, meteorologists, oceanographers and engineers, and will undoubtedly lead to further work by applied mathematicians on the hydrodynamics of rotating fluids.

R. HIDE

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NOTES AND NEWS

Training Seminar on Agricultural Meteorology, Wageningen, Holland, May, 1968

The first Regional Training Seminar on agricultural meteorology in Europe was held at Wageningen from 13 to 24 May, 1968. It was sponsored by the World Meteorological Organization (WMO) and the Netherlands Government, and was organized by the Agricultural University and the International Agricultural Centre at Wageningen, by the Meteorological Institute, De Bilt, and by the WMO. The Technical Director of the seminar was Dr P. M. A. Bourke, Director of the Meteorological Service of Ireland.

Participants numbered well over 50, most of whom attended for two weeks, and nearly all of the countries in Europe were represented together with several in the Middle East. The seminar was formally opened by the Rector Magnificus of the Agricultural University at Wageningen, Professor Dr Ir F. Hellinga.

The first week was devoted to lectures on agricultural pests and diseases; the main speakers were from Holland, Ireland, Israel and the United Kingdom. Subjects included many animal diseases for which links had been established between disease incidence and the weather, and also several plant diseases such as potato blight and apple scab, for which similar relationships with the weather had been shown to exist. One full day was devoted to a special session on lysimetry and evaporation, with the Dutch hosts as the main speakers.

The work of the second week was very different in nature. A fresh team of experts lectured on the problems of investigations into local climates. The main contributions, again international in character, were presented by speakers from Norway, Switzerland, the United Kingdom and the Federal Republic of Germany. The lectures, which covered a wide field, ranged from the philosophical approach to the problems of agrometeorological investigation on the one hand, and on the other, to the actual techniques (with full detail) of mounting particular experiments.

During the second week a most interesting day was spent in visiting the Polders where the use which the Dutch people have made of land reclaimed from the sea was indeed impressive. It was almost impossible to realize, while motoring across horizonless, intensively cultivated level ground, with some shelter-belt trees and attractive farm-houses, that this area had been 20 feet under the Zuyder Zee only a few years ago.

The training seminar ended on the afternoon of 24 May, with a closing address by Dr M. W. F. Schregardus, Director of the Royal Netherlands Meteorological Institute at De Bilt, and sincere expressions of gratitude to the hosts and to the organizers, notably Ir A. J. W. Borghorst, by Dr Bourke and by Mr Milton L. Blanc of the WMO. There can be no doubt of the value of this seminar to agricultural meteorology in Europe. Although meteorologists predominated, scientists from many other disciplines were present, especially among the representatives from the Republic of Ireland, the United Kingdom and Holland. The success of the seminar could be judged by the active and intelligent discussion which followed every paper. It was very rare indeed for the Chairman of the day not to have to choose from several would-be contributors to the discussion, and it was frequently clear, from the particular issues being raised from the floor, that the delegates were very well informed indeed.

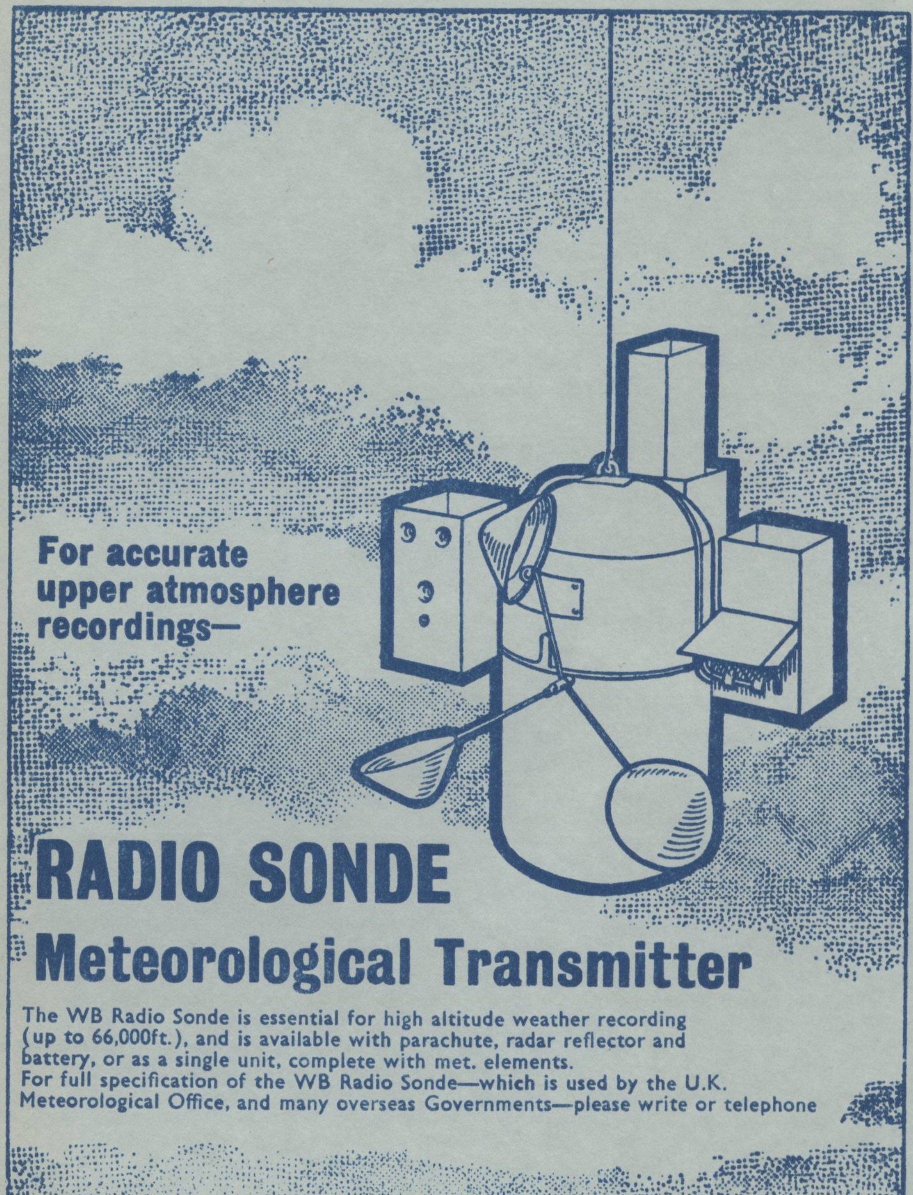
Such seminars are obviously of the greatest value to agriculture and meteorology and the number of delegates who attended on this occasion was probably near the ideal — large enough for the message to be carried far, small enough still to achieve a certain element of informality. The only improvements for future sessions which occur to the author are the inclusion, if possible, of rather more agricultural and biological researchers with the meteorologists, and perhaps slightly more of a 'workshop' approach. The audience was obviously interested in the philosophy of local climatology: it was clearly fascinated by applications to practical problems.

G. W. HURST

OFFICIAL PUBLICATION

The following publication has recently been issued : *London weather*. London, HMSO, 1968, Price 55*s*.

Weather, especially comparison of the present with the past, is reputed to be one of the main subjects of conversation in Britain. This book is the successor to W. A. L. Marshall's *A century of London weather*, and its aim is to cover the main aspects of weather in Greater London and environs from the earliest times up to the present. It presents details of the weather over the period 1841 to 1964 in a form suitable for quick reference and comparison, so that the reader can see how London's climate has changed and can pick out record values of temperature, rainfall and sunshine. The book also deals with outstanding weather from Roman to early Victorian times, and it includes chapters on London Fogs, Droughts and Floods, Weather Trends and Persistence, and Weather Lore.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