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DECREASE IN THE FREQUENCY OF FOG IN CENTRAL LONDON

By I. JENKINS

Summary. Numbers of occasions with visibilities below 500, 200 and 100 metres at London Weather Centre were extracted for each of the observations at 00, 03, 06, 09, 12, 15, 18 and 21 GMT during the period July 1948 to June 1970.

At 09, 12 and 15 GMT, the number of occasions of visibility less than 500 metres was found to have decreased steadily throughout the period of the study but at 00, 03 and 06 GMT the number increased in the middle and late 1950s and only decreased in the 1960s. The ratio of the number of occasions at 06 to the number at 09 increased through unity during the period. It is suggested that these changes are connected with changes in smoke emission in central London, though not specifically with the consequences of the Clean Air Act (1956).

Introduction. A recent analysis by Brazell[1] shows that there has been a considerable decrease in the number of hours of thick and dense fog in central London and at London (Heathrow) Airport in recent years. It seemed possible that this decrease was in some way related to a decrease in pollution and it was decided to study in more detail the occurrence of fog in central London during the past 20 years or so. Observations made at London Weather Centre have been used for this study; although during the period examined the observing site was moved twice, all three sites (two in Kingsway and one in High Holborn) are within a circle of radius 200 metres, and it is believed that the fog observations have been unaffected by the moves.

Data used. The numbers of occasions when the visibility was less than 500, 200 and 100 metres (550, 220 and 110 yards) at 00, 03, 06, 09, 12, 15, 18 and 21 GMT were extracted for the years 1948 to 1970. From 1949 to 1954 the ranges in the visibility code were below 400 metres and below 600 metres but there was no code figure for below 500 metres. In this period, therefore, the numbers of occasions between 200 and 399 metres and between 400 and 599 metres were extracted separately. The number of occasions in the latter range was halved and any fractions were ignored to give an estimate of the occasions when the visibility was between 400 and 499 metres. This figure was then added to the occasions with visibilities between 200 and 399 metres to obtain the number of occasions with visibilities between 200 and 499 metres.

The period used was July to June the following year so that any foggy winter would be included in one 12-month period. Table I shows the number of occasions in each of the years examined. Five-year running means were prepared for each of the fixed hours and plotted against the middle year of the period.

Results. The graph for 09 GMT in Figure 1 is also representative of those for 12 and 15 GMT; that for 18 GMT is similar to the one for 21 GMT and that for 06 GMT resembles those for 00 and 03 GMT.

TABLE I—NUMBER OF OCCASIONS AT LONDON WEATHER CENTRE WITH VISIBILITIES BELOW CERTAIN VALUES AT FIXED HOURS, 1948–70

Time (GMT)	1948 –49	49 –50	50 –51	51 –52	52 –53	53 –54	54 –55	55 –56	56 –57	57 –58	58 –59	59 –60	60 –61	61 –62	62 –63	63 –64	64 –65	65 –66	66 –67	67 –68	68 –69	69 –70
	12-month period July to June. Number of occasions																					
(a) Below 500 metres																						
00	11	7	3	5	15	3	2	2	5	6	17	6	3	2	9	7	2	0	2	0	3	1
03	10	5	3	7	14	5	3	5	7	5	16	7	6	4	14	10	6	2	1	0	3	2
06	10	8	4	9	13	6	4	7	13	9	13	15	6	5	14	11	8	5	6	2	5	3
09	22	16	12	16	23	15	9	9	6	12	13	7	7	5	6	7	4	6	0	1	2	2
12	10	7	7	5	18	8	4	4	4	7	12	6	2	1	4	5	1	3	0	0	0	1
15	5	5	5	1	14	6	2	4	2	6	9	2	0	3	5	4	1	0	0	0	0	0
18	7	5	5	2	8	3	0	1	2	5	5	3	1	4	5	4	1	1	0	0	1	0
21	7	7	5	4	13	3	4	3	4	5	11	3	2	3	9	5	1	1	1	0	0	0
Total	82	60	44	49	118	49	28	35	43	55	96	49	27	27	66	51	24	18	10	3	14	9
(b) Below 200 metres																						
00	3	2	1	2	7	0	0	2	2	3	6	1	1	0	4	2	0	0	1	0	0	0
03	3	2	1	3	6	2	1	3	3	2	6	2	1	0	4	3	2	2	0	0	1	2
06	3	2	1	5	5	6	1	4	6	3	6	9	1	1	5	4	3	4	2	0	0	2
09	9	8	4	3	6	3	2	3	2	3	4	2	1	2	2	3	1	1	0	0	2	0
12	3	3	5	0	5	1	1	2	1	0	2	1	0	1	3	0	0	1	0	0	0	0
15	4	1	2	0	4	3	1	1	2	0	3	1	0	1	4	0	1	0	0	0	0	0
18	4	0	1	0	2	0	0	1	1	1	2	3	0	0	3	0	1	0	0	0	0	0
21	3	1	1	1	4	0	1	2	1	1	1	0	0	0	3	2	1	0	0	0	0	0
(c) Below 100 metres																						
00	3	1	1	1	5	0	0	1	1	2	4	1	1	0	4	2	0	0	0	0	0	0
03	3	0	1	1	5	2	0	0	2	1	3	2	0	0	1	1	1	0	0	0	0	2
06	2	2	1	2	2	2	0	3	4	3	2	4	0	1	2	2	1	4	0	0	0	1
09	5	5	2	2	2	2	1	3	2	2	2	1	0	0	1	1	0	0	0	0	1	0
12	2	3	1	0	4	1	1	2	1	0	0	0	0	1	1	0	0	0	0	0	0	0
15	1	1	2	0	4	2	1	0	1	0	0	0	0	1	1	0	0	0	0	0	0	0
18	3	0	1	0	2	0	0	1	1	0	0	0	0	0	3	0	0	0	0	0	0	0
21	2	1	1	1	3	0	1	1	0	0	1	0	0	0	3	0	0	0	0	0	0	0

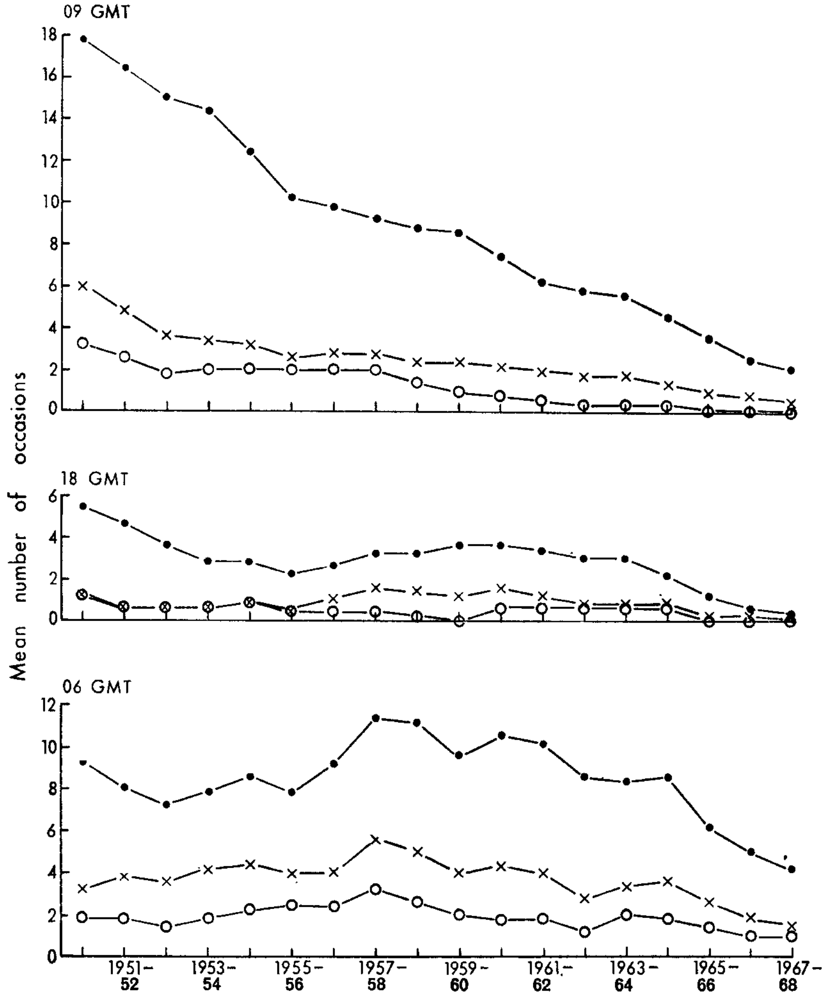

FIGURE 1—MEAN NUMBER OF OCCASIONS WITH VISIBILITY BELOW 500, 200 AND 100 METRES AT LONDON WEATHER CENTRE AT 09, 18 AND 06 GMT

5-year running means plotted on centre point of period

· ——— · below 500 m x ——— x below 200 m o ——— o below 100 m

The graphs for 00, 03 and 06 GMT show a fall in the number of occasions with visibility below 500 metres followed by a rise until the late 1950s when the number of occasions then started to fall again. The graphs for 09, 12 and 15 GMT show a steady decrease in the number of occasions with visibilities below 500 metres. The shape of the graphs for 18 and 21 GMT appears to be intermediate between those for 06 and 09, the number of occasions with visibility below 500 metres showing little change after the fall in the early 1950s until the fall in the 1960s.

The curves for visibilities less than 200 and 100 metres are broadly similar to those for visibilities less than 500 metres but the numbers of occasions are smaller.

Discussion. An investigation by Dinsdale[2] drew attention to the fact that the 5-year running means of occasions of visibility less than 440 yards at the eight synoptic hours had shown a general decrease during the 10-year period 1958–67, not only at suburban but also at rural stations. He therefore sounded a timely note of caution about interpretation of reduced fog frequencies in terms of the supposed results of the Clean Air Act (1956).

The total number of occasions of visibility less than 500 metres at the eight synoptic hours are now produced for central London (Table I). For the period 1958 to 1967, these figures are broadly similar to those produced by Dinsdale. However, examination of the detailed figures shows that the behaviour of the figures at the individual hours is not the same in each case, and the totals of the eight synoptic hours may therefore mask some important effects.

In graphs for visibilities below 500 metres at 09 and at 06 GMT (Figure 1) it is apparent that, whereas the frequency at 09 was twice that at 06 in the five-year period centred around 1950–51, by about 1956–57 the frequencies were similar. By the period centred on 1966–67 the situation was reversed and the frequency at 06 was twice that at 09. The graphs for visibilities less than 200 and 100 metres reveal a similar pattern of change, but with such small numbers the pattern is less striking. The number of occasions with visibilities below 500 metres at 06 and 09 GMT for the winter half-year (October to March) are similar to those for the complete year (Figure 2).

In the report on atmospheric pollution in Leicester[3] it was shown that during the period 1937 to 1939 the peak concentrations of smoke occur at around 08 on weekdays and 10 on Sundays and that during the hour 08 to 09 about 50 per cent more smoke was produced than at 06. If, therefore, there was a decrease in over-all smoke-emission one would expect a more marked reduction in the smoke at 09 than at 06. Pre-war Leicester and post-war London are admittedly not necessarily comparable but there is no reason to suppose that the diurnal pattern of smoke concentration is any different.

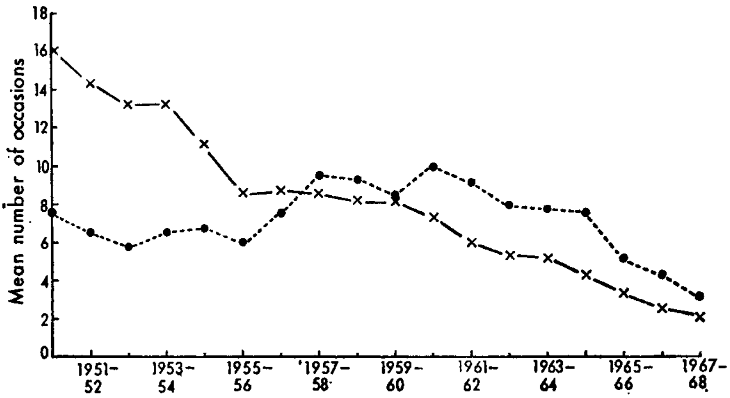

FIGURE 2—MEAN NUMBER OF OCCASIONS WITH VISIBILITY BELOW 500 METRES AT LONDON WEATHER CENTRE AT 06 AND 09 GMT FROM OCTOBER TO MARCH

5-year running means plotted on centre point of period
• - - - - - - - • 06 GMT   x ———— x 09 GMT

The variation in smoke concentration and estimated emission in London since 1952 was given in a paper by the Warren Spring Laboratory[4] from which Figure 3 is reproduced. It is apparent from this graph that there has been a general decline in estimated smoke-emission since 1954, i.e. from a date well before the Clean Air Act (1956) became effective.

With the data available it is not possible to establish any certain conclusions, but it seems at least possible that the change over the years in the ratio of fog frequency at 09 to that at 06 is connected with the changes in the amount of smoke emission.

In Figure 4 the estimated emission graph of Figure 3 is reproduced together with a graph of the ratio of fog frequency (less than 500 metres) at 09 GMT to that at 06 GMT; the similarity is apparent. There is, moreover, no doubt that one major effect of high smoke-concentration on fog is to delay fog clearance; the high frequency at 09 GMT in the early 1950s is, at least, partly due to this factor. The effect of a reduction in smoke concentration such as that which has taken place during the past 15 years will, however, be far more marked at 09 GMT (when concentrations are near the diurnal maximum) than at 06 GMT (when concentrations are much lower).

Many factors including wind, sunshine and temperature[5] may affect the frequency of fog over a period. Although there has been a general decrease in the frequency of fog at suburban and rural stations alike during the past 10 years or so, the changes cannot specifically be attributed to the Clean Air Act (1956) but it is suggested that the observed reduction in fog frequency in central London during the last 17 years has almost certainly been influenced by the reduction of smoke emission during the same period.

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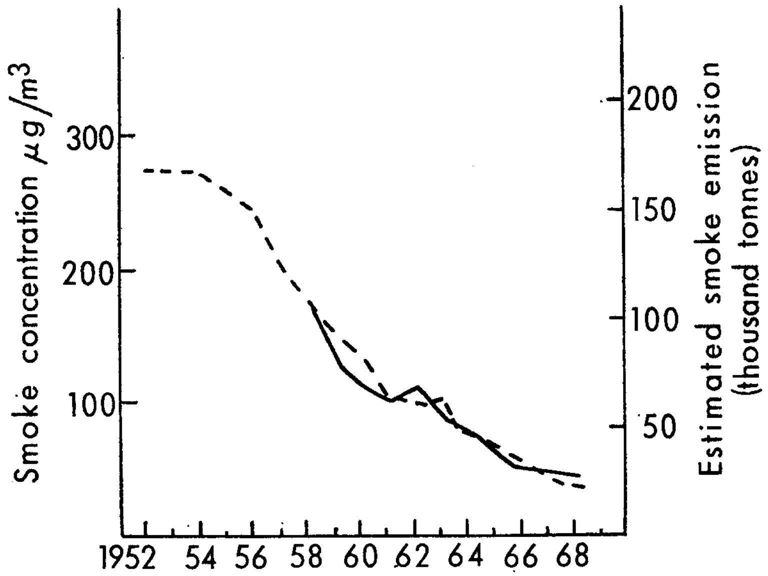

FIGURE 3—SMOKE CONCENTRATION AND ESTIMATED EMISSIONS IN LONDON

——— Average concentration - - - - - - - Emission

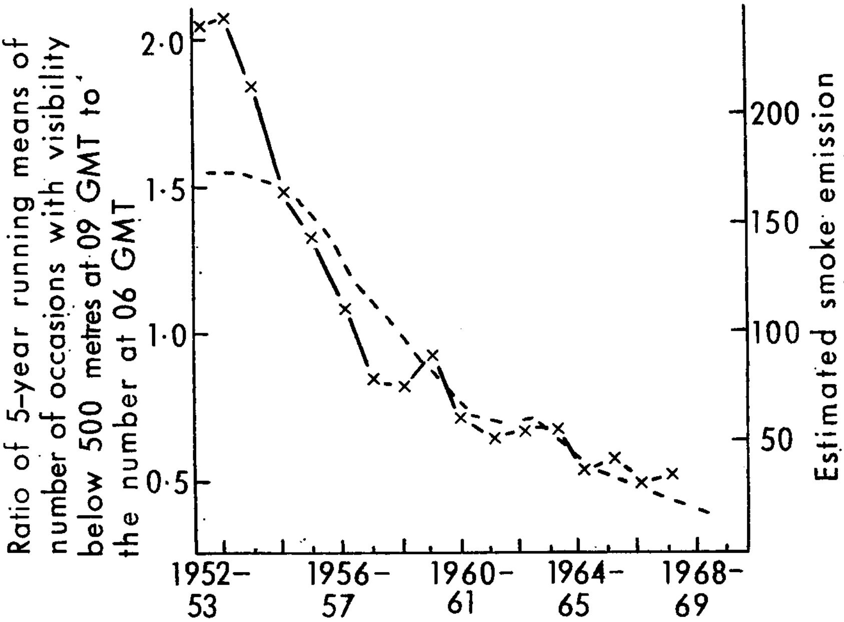

FIGURE 4—ESTIMATED SMOKE-EMISSION IN LONDON AND THE RATIO OF THE NUMBER OF OCCASIONS WITH VISIBILITY LESS THAN 500 METRES AT 09 GMT TO THAT AT 06 GMT AT LONDON WEATHER CENTRE

x ——— x Ratio of fog frequency at 09 GMT to that at 06 GMT - - - - - - - Emission

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A NOTE ON THE MEASUREMENT AND ESTIMATION OF EVAPORATION

By R. W. GLOYNE

Summary. This paper discusses the causes of the differences between the rate of water-loss from an evaporimeter and that from an extended, freely evaporating, area.

Some theoretical expressions of the evaporation rate from a strip and a circular area are examined to elucidate the problem. Attention is directed to the 'leading edge' or 'clothes-line' effect and to the 'oasis' effect and some field results quoted to illustrate these phenomena.

General considerations. It is now increasingly appreciated that, in a given *macro-meteorological* situation, the rate of water-loss per unit area from a device such as a pan, a small pond, or from an isolated small area can, and generally does, differ systematically in varying degrees from the corresponding rate of loss of water from an extensive, homogeneous vegetated surface.

Such differences can be attributed to one or more causes; amongst them are :

(i) Differences in the mechanisms of turbulent exchange operating on the contrasting surfaces.

(ii) Differences in the radiative and convective exchanges at the different surfaces; and the partitioning of available energy between these energy sinks.

(iii) Differences between the vertical and horizontal gradients of temperature, vapour density and wind impinging upon the several surfaces.

Although all three causes contribute towards the observed differences, the last, (iii), is the one on which attention is focused in this note.

Consider an idealized, extreme situation, viz. that of a shallow tank of water placed in a hot, arid desert.

(a) First, suppose that there is no horizontal air motion, i.e. no wind. The vapour pressure in the air immediately above the tank will initially be very low; that at the water surface will be the saturation vapour pressure corresponding to the temperature of the water surface. Water will be removed by molecular diffusion, the 'cylinder' of air above the tank will be increasingly enriched with water vapour at the expense of the water in the tank. Sutton[1] deals with this case under certain boundary conditions: lateral diffusion of water vapour is assumed to be negligibly small.

In practice, local convection currents will be present and transfer processes additional to molecular diffusion will be in operation.

The rate of evaporation will be proportional to the instantaneous vapour-concentration gradient. The drier the overlying air, the faster the rate of evaporation. If, as is postulated, the vapour is confined to the vertical 'cylinder' of air then, as evaporation proceeds, the vapour-concentration difference will decrease, and with it the rate of loss.

The rate of evaporation from the tank will generally not be the same as the rate of loss, if any, of water from the 'desert' surface, where the vapour gradient is quite different. However, the higher the vapour concentration over the desert surface, the higher the initial vapour concentration above the tank and the slower the evaporation from the tank.

(b) Now suppose there is a steady wind, then the vapour-enriched air above the tank will be continually removed and replaced by dry air; furthermore, if the surface area of the tank is sufficiently small — say a few square feet — the original low value of the vapour density will be continually re-established and evaporation will take place at the initial rate for as long as there is water to be evaporated. Once again, the rate of loss of water from the tank, i.e. from the 'evaporimeter' will generally not be the same as the rate of removal of water from the 'desert' surface, i.e. as the 'evaporation' from the desert. (*Note.* This is not to say that the rate of loss from various evaporimeters has no physical meaning nor practical significance in these circumstances.) This situation arises, although less dramatically, in most parts of the world after a drought. When the surface is dry because of drought there may be little or no loss of water from the parched earth or wilted vegetation — but a great deal from any nearby wet or continually dampened surface.

The discussion so far should clarify the distinction between *actual evaporation* (actual rate of loss of water from the surface exposed to atmospheric influences) and *potential evaporation* (the rate at which water would be lost, under the same atmospheric conditions, from a homogeneous, extensive surface (typically one of cropped grass), the surface having unhindered access to unlimited water). When, as is usually the case, the concern is with a vegetative surface, water moves from the soil to the atmosphere through the plant roots, stem and leaf to the atmosphere — the process of transpiration, and the term 'evapotranspiration' is commonly used. It is implicit in the above definition of potential evapotranspiration that there should be no horizontal gradient of temperature, vapour density and wind, and furthermore it is customarily assumed that the net radiant income defines this 'potential' or upper limit to water loss (for a further examination of this concept see Slatyer and McIlroy[2] or McIlroy[3]).

However, the point of immediate concern is that downwind from a boundary between surfaces having different physical characteristics (and water supply) there will be a marginal zone in which a progressive readjustment of the incident profiles of wind, temperature and humidity to those appropriate to the new surface will take place. If air moves from a dry to a moist surface then the rate of water-loss will be highest at the 'leading edge' and will decrease downwind: if the moist surface is that of an evaporimeter then such a surface may well be completely within this transitional zone. This effect has been aptly dubbed the 'clothes-line effect' by Chang.[4] A further effect — 'the oasis effect' — arises from large-scale advection of energy sources and sinks in the atmosphere, so contributing to the total energy available for evaporation at a given point (Slatyer and McIlroy, Reference 2, Chapter 3).

Quantitative discussion of some aspects of evaporation. A number of workers, e.g. Pasquill,[5] Sutton,[1] Rider, Philips and Bradley[6] have examined the effect of wind at, and beyond, the boundary between two adjacent surfaces possessing different levels of surface wetness, i.e. having different vapour concentration.

Let *AB* in Figure 1 be the boundary (extending indefinitely in either direction) between a dry region to the left and a saturated surface to the right; and suppose *pg* be a strip of unit width. Following Sutton[1] let :

u_m = the mean speed of a uniform horizontal wind blowing perpendicular to *AB*. Figure 1 shows u_m as $u(m)$.
x_0 = the downwind distance from the boundary
q_0 = the vapour concentration in the air before it reaches *AB*
q_s = the vapour concentration at the evaporating surface
E = the *total* rate of evaporation per unit cross-wind width.

Consider a rectangular 'box' of indefinite cross-wind length *AB*, of indefinite height AA' $(= z)$, but of finite downwind extent $(AD = BC = x_0)$. Under steady conditions all the water vapour leaving the horizontal surface of the elementary strip *pg* will pass horizontally through the vertical strip *gs*. Sutton shows that, in these conditions and with normal stability (adiabatic temperature lapse),

$$E = (q_s - q_0)\, B u_m^{0.78}\, x_0^{\ 0.89}, \qquad \ldots (1)$$

where *B* is a function of stability.

The effect of the progressive enrichment of the airstream by the continued evaporation of the water vapour into it is expressed by the fact that the total rate of evaporation from strips such as *pg* does not grow proportionally to the downwind distance x_0, but at a slower rate. Panofsky[7] illustrates the effect

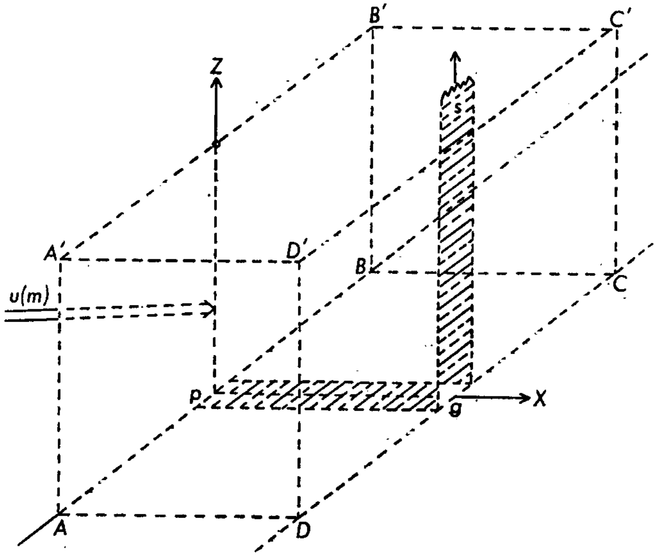

FIGURE 1—CO-ORDINATE SYSTEM FOR COMPUTATION OF EVAPORATION FROM STRIP *pg*

For additional information see text p. 324.

thus '. . . . . evaporation depends upon the 8/9th power of the fetch. This means that, if the fetch is increased by a factor of 512 (2^9), the evaporation increases only 256 (2^8)-fold.' In the limit, Sutton notes that 'if the wetted surface extends indefinitely downwind, a stage will be reached when the air over the surface is saturated and (local?) evaporation ceases'.

Pasquill,[5] amongst others, has shown that the corresponding expression to equation (1) for a wetted circular area is :

$$E = (q_s - q_o)\ C u_m^{0.78}\ r^{1.88}, \qquad \ldots (2)$$

where r is the radius of the circle.

Assuming a stationary meteorological situation the average evaporation per unit area (here written E(av)) will be :

for the strip : $E(\text{av}) \propto E/\text{area}$, i.e. E/x hence $\propto x^{-0.11}$,

for the disc : $E(\text{av}) \propto E/\text{area}$, i.e. E/r^2 hence $\propto r^{-0.12}$.

The change in evaporation rate averaged over the whole area (i.e. computed on a per-unit-area basis) with increasing size of the disc — defined by $r = 0{\cdot}01 \times 10^n$ where $n = 1$ to 7 — can be appreciated from the following figures :

n	1	2	3	4	5	6	7
r(metres)	0·1	1	10	10^2	10^3	10^4	10^5
E(av) $\propto$	7·57	5·75	4·37	3·31	2·51	1·90	1·45

An idea of the way in which additional increments of evaporating area (corresponding to increments of x in Figure 1, and increments of r for the disc) contribute to the evaporation, is indicated by the trend of the series below in which the figures are proportional to the additional evaporation averaged over the additional area.

	Increments of x or r (cm)					
	10–10^2	10^2–10^3	10^3–10^4	10^4–10^5	10^5–10^6	10^6–10^7
For the strip : increment of E(av) proportional to	0·58	0·45	0·35	0·27	0·21	0·16
For the disc : increment of E(av) proportional to	0·57	0·44	0·33	0·25	0·19	0·14

Some practical implications and evidence from field-work. The possibility of using the formula discussed above to compute the water-loss over an extended area from that lost from a small evaporimeter has been discussed by, e.g. Green [8,9] who sought a 'correction factor' to compensate for the 'oasis effect' (more strictly perhaps the 'leading edge' effect). He suggests that beyond a radius of about 200 yd ($1{\cdot}82 \times 10^4$ cm or 182 m) the rate of decrease of average evaporation changes only slowly and it may therefore be postulated that such an area represents the idealized, indefinitely large, wetted area associated with the concept of potential transpiration. On this assumption he finds that :

$$\frac{\text{evaporation rate per unit area for } r = 11 \text{ inches}}{\text{evaporation rate per unit area for } r = 200 \text{ yards}} \approx 2{\cdot}2.$$

If the 'infinitely large' area is assumed to be defined by $r = 2 \times 10^5$ cm (a 10-fold increase), the ratio becomes 2·8.

Direct field measurements of the horizontal gradient of the actual evaporation from the leading edge are few, but Rider *et alii* (Reference 6, page 529) give some derived estimates of evaporation as an airstream moves from a (dry) tarmac surface into an irrigated, grassed area. They postulate that the true evaporation rate per unit area E (say) is that required exactly to absorb all the net radiant energy impinging on the surface at a distance (x) of 1600 cm from the leading edge. If $E(0 - x)$, where x is successively 100, 400, 1600 cm, are the evaporation rates *per unit area* from strips of increasing downwind fetch of 100, 400, 1600 cm, then :

$$E(0-100) : E(0-400) : E(0-1600) : E = 3{\cdot}7 : 2{\cdot}5 : 1{\cdot}7 : 1,$$

and hence $E(0-100) : E(0-400) : E(0-1600) = 2{\cdot}2 : 1{\cdot}5 : 1.$

The corresponding ratios based upon equation (1) are 1·4: 1·2: 1·0. Millar[10] (from Australia) reports losses from lysimeters placed downwind from the leading edge of a small irrigated field adjoining a dry area; a graph in his paper indicates local evaporation rates (mm/h) averaged over about 8 hours in a single day of :

Distance from leading edge (cm)	14	167	472	1387,
Evaporation rate (mm/h)	0·78	0·74	0·71	0·70,

i.e. a much less striking contrast than that obtained by Rider *et alii.*[6] Halstead and Covey[11] computed evaporation rates for moist areas of increasing dimension situated in an otherwise completely dry area. Rather extreme initial conditions were postulated giving :

6-foot tank	0·45 cm/h
50-foot plot	0·26 cm/h
300-foot plot	0·19 cm/h
1-mile field	0·13 cm/h

Chang (Reference 4, page 141) concludes from these results that the 'clothes-line' effect extends more than 300 ft into the field. Stanhill[12] reports measurements which suggest that a 300-m fetch may be necessary (in an arid area) to avoid the 'leading edge' effect.

In his discussion of the subject Chang[4] notes research findings to the effect that the 'clothes-line' effect, even in a *humid* region, can extend to a distance of 40 times the crop height, and that an upwind 'guard-ring' of 50 metres is necessary to minimize the effect in humid climates; whilst in desert areas even a distance of 400 metres would not be too large. Referring to the 'oasis effect' proper, Chang states that this is often measurable many miles into an irrigated field in an arid climate. In Texas, Lemon, Glaser and Satterwhite[13] report an 'oasis effect' at a distance of 10 miles into an irrigated cotton field — the evaporation rate being 1·65 times that attributable to the net radiation for a 24-hour period. In a more humid climate the effect is not so great; Graham and King[14] in Ontario found that when the local surroundings of their irrigated corn were dry, the ratio between evapotranspiration and net radiation was 20 per cent higher than when the surroundings were moist.

Other research papers dealing, in particular, with the 'clothes-line' effect are by Davenport and Hudson.[15,16]

Concluding comment. The complications inherent in deriving the general evaporation (i.e. that from extended areas) from the water-loss from evaporimeters will now be obvious.

Perhaps less immediately obvious is that in field investigations in which water vapour (and indeed most other meteorological elements) are involved, the interference of conditions in any given plot by the activity in adjacent plots can seriously vitiate conclusions. In particular, such difficulties are likely to arise when randomized layouts give rise to adjacent small plots bearing crops of different geometrical characteristics (height, density, etc).

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THE DIRECT ESTIMATION OF DERIVATIVES FROM AN IRREGULAR PATTERN OF POINTS

By R. DIXON

Summary. A method is given for the calculation of finite difference estimates of derivatives in the case where the distribution of known field values is irregular. The Laplacian of a field is used by way of illustration. A simple numerical example is given.

In numerical meteorology the need frequently arises for finite difference estimates of such quantities as $\partial/\partial x$, $\partial/\partial y$, ∇, ∇^2 etc. To take the Laplacian ∇^2, for example, the simplest and best known finite difference estimate is

$$\nabla^2 f = \frac{S_1 - 4f_0}{d^2}, \qquad \ldots (1)$$

where ∇^2 denotes the finite difference analogue of ∇^2, d is the grid length, and $S_1 = f_1 + f_2 + f_3 + f_4$ where $f_0 \ldots . f_4$ are the field values at the five regular points (Figure 1).

Another less-simple but still well-known formula which uses nine regular points (Figure 2) is

$$\nabla^2 f = \frac{S_2 + 4S_1 - 20f_0}{6d^2}, \qquad \ldots (2)$$

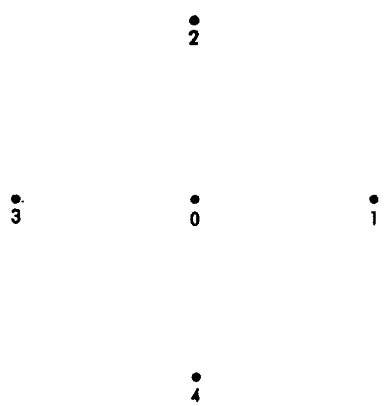

FIGURE 1—THE REGULAR FIVE-POINT PATTERN

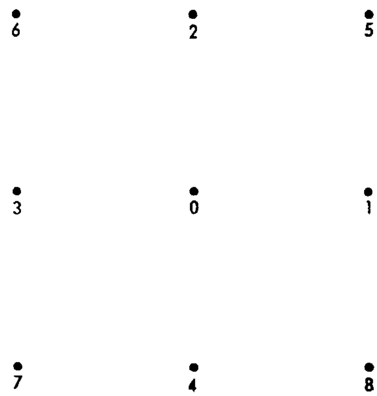

FIGURE 2—THE REGULAR NINE-POINT PATTERN

where $S_2 = f_5 + f_6 + f_7 + f_8$. S_1 and S_2 are known as the first and second symmetric sums. Other formulae involving more points may be given, but taking the nine-point pattern as a compromise between the too-simple and the too-complicated, suppose that instead of the regular pattern of Figure 2, field values are known at points of an irregular pattern (Figure 3). Such a situation might arise, for example, if the points were actual particles being followed in a fluid motion. They could be distributed regularly as in Figure 2 at time $t = 0$ and move into the pattern given by Figure 3 after an interval of time Δt. Formula (2) now no longer applies, and the problem is to obtain a formula which will serve for the irregular pattern of Figure 3.

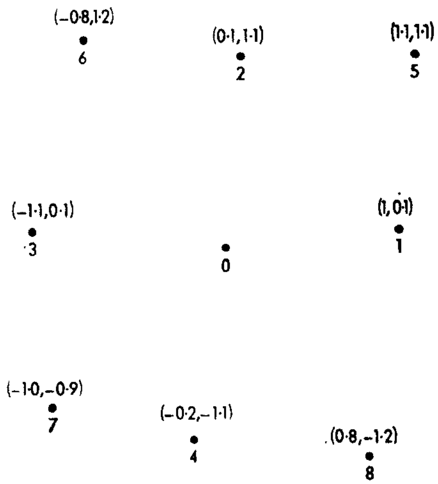

FIGURE 3—AN IRREGULAR NINE-POINT PATTERN

The method. If the point o is taken as origin then the field value f_r at any point $x_r, y_r (r = 1, 2, \ldots, 8)$ is given by Taylor's series

$$f_r\,(0 + x_r, 0 + y_r) = \left\{ \exp\left[x_r \frac{\partial}{\partial x} + y_r \frac{\partial}{\partial y}\right]\right\} f_0(0,0), \qquad \ldots (3)$$

which may be formally expanded as

$$f_r = \left\{1 + \left(x_r \frac{\partial}{\partial x} + y_r \frac{\partial}{\partial y}\right) + \frac{1}{2!}\left(x_r^2 \frac{\partial^2}{\partial x^2} + 2x_r y_r \frac{\partial^2}{\partial x \partial y} + y_r^2 \frac{\partial^2}{\partial y^2}\right) + \ldots\right\} f_0. \ldots (4)$$

Equation (4) represents a set of eight equations, by giving r the values $r = 1, 2, \ldots, 8$ in turn. Now if each equation in (4) can be multiplied by a different number such that when the set is summed the terms in $\partial/\partial x$, $\partial/\partial y$, and $\partial^2/\partial x \partial y$, which do not occur in the Laplacian, disappear, whilst at the same time the coefficients of $\partial^2/\partial x^2$ and $\partial^2/\partial y^2$ in the sum equation are equal the problem is solved. The higher terms in the series are to be regarded as consigned to an error term, as is customary.

If the set of values x_r $(r = 1, 2, \ldots, 8)$ are regarded as forming an 8-component vector, denoted by $\mathbf{x}$, with similar meanings attaching to $\mathbf{1}$, $\mathbf{y}$, $\mathbf{x}^2$, $\mathbf{xy}$, $\mathbf{y}^2$ then the problem of finding the required set of multiplying numbers is the same as that of finding an 8-component vector ψ which is orthogonal to the set of vectors $\mathbf{x}$, $\mathbf{y}$, $\mathbf{xy}$, $(\mathbf{x}^2 - \mathbf{y}^2)$. This may be accomplished as follows.

Take the vector $\mathbf{y}$ and remove from it any component in the direction of $\mathbf{x}$. Then take $\mathbf{xy}$ and remove from it any components in the directions of $\mathbf{x}$ and the modified $\mathbf{y}$. Then take $(\mathbf{x}^2 - \mathbf{y}^2)$ and remove from it any components in the directions of $\mathbf{x}$ and the modified $\mathbf{y}$ and $\mathbf{xy}$. Finally, take $\mathbf{1}$ and remove from it any components in the directions of $\mathbf{x}$ and the previously modified vectors. The resulting vector is the one required. If the modified vectors are denoted by $\boldsymbol{\varphi}_2, \boldsymbol{\varphi}_3, \boldsymbol{\varphi}_4$ then the sequence of operations may be written as

$$\boldsymbol{\varphi}_1 = \mathbf{x}, \qquad \ldots 5\,(a)$$

$$\boldsymbol{\varphi}_2 = \mathbf{y} - \frac{(\boldsymbol{\varphi}_1 \cdot \mathbf{y})}{\varphi_1^2}\, \boldsymbol{\varphi}_1, \qquad \ldots 5\,(b)$$

$$\boldsymbol{\varphi}_3 = \mathbf{xy} - \sum_{i=1}^{2} \frac{(\boldsymbol{\varphi}_i \cdot \mathbf{xy})}{\varphi_i^2}\, \boldsymbol{\varphi}_i, \qquad \ldots 5\,(c)$$

$$\boldsymbol{\varphi}_4 = (\mathbf{x}^2 - \mathbf{y}^2) - \sum_{i=1}^{3} \left[\frac{\boldsymbol{\varphi}_i \cdot (\mathbf{x}^2 - \mathbf{y}^2)}{\varphi_i^2}\right] \boldsymbol{\varphi}_i, \qquad \ldots 5\,(d)$$

$$\boldsymbol{\psi} = \mathbf{1} - \sum_{i=1}^{4} \frac{(\boldsymbol{\varphi}_i \cdot \mathbf{1})}{\varphi_i^2}\, \boldsymbol{\varphi}_i, \qquad \ldots 5\,(e)$$

in which, for example, $(\boldsymbol{\varphi}_1 \cdot \mathbf{y})$ denotes the scalar product

$$\boldsymbol{\varphi}_1 \cdot \mathbf{y} = \mathbf{x} \cdot \mathbf{y} = x_1y_1 + x_2y_2 + \ldots + x_8y_8.$$

The sequence is the classical Gram-Schmidt orthogonalization process, which in modified forms has been widely applied in several disciplines over the past decade.

The final vector $\boldsymbol{\psi}$ is orthogonal not only to $\boldsymbol{\varphi}_1$, $\boldsymbol{\varphi}_2$, $\boldsymbol{\varphi}_3$, $\boldsymbol{\varphi}_4$, but also to $\mathbf{x}$, $\mathbf{y}$, $\mathbf{xy}$, and $(\mathbf{x}^2 - \mathbf{y}^2)$ since each of these is simply a linear combination of $\boldsymbol{\varphi}_1$, $\boldsymbol{\varphi}_2$, $\boldsymbol{\varphi}_3$, $\boldsymbol{\varphi}_4$.

Thus, if equation (4) is rewritten in vector style as

$$\mathbf{f} = \left\{ \mathbf{1} + \left(\mathbf{x}\frac{\partial}{\partial x} + \mathbf{y}\frac{\partial}{\partial y}\right) + \frac{1}{2!}\left(\mathbf{x}^2\frac{\partial^2}{\partial x^2} + 2\mathbf{xy}\frac{\partial^2}{\partial x \partial y} + \mathbf{y}^2\frac{\partial^2}{\partial y^2}\right) + \ldots \right\} f_0, \qquad \ldots (6)$$

then by taking $\boldsymbol{\psi}$ through equation (6), allowing for the fact that $\boldsymbol{\psi}$ has been so constructed that $\boldsymbol{\psi} \cdot \mathbf{x} = \boldsymbol{\psi} \cdot \mathbf{y} = \boldsymbol{\psi} \cdot \mathbf{xy} = \boldsymbol{\psi} \cdot (\mathbf{x}^2 - \mathbf{y}^2) = 0$ there results

$$\boldsymbol{\psi} \cdot \mathbf{f} = \left\{ \boldsymbol{\psi} \cdot \mathbf{1} + \frac{1}{2}(\boldsymbol{\psi} \cdot \mathbf{x}^2)\left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2}\right) + \ldots \right\} f_0,$$

yielding

$$\nabla^2 f = \frac{\boldsymbol{\psi} \cdot \mathbf{f} - (\boldsymbol{\psi} \cdot \mathbf{1}) f_0}{\frac{1}{2}(\boldsymbol{\psi} \cdot \mathbf{x}^2)}, \qquad \ldots (7)$$

as the required formula. To facilitate comparisons with equation (2), (7) may be taken out of its vector guise and expressed as

$$\nabla^2 f = \frac{(\psi_1 f_1 + \psi_2 f_2 + \ldots + \psi_8 f_8) - (\psi_1 + \psi_2 + \ldots + \psi_8) f_0}{\frac{1}{2}(\psi_1 x_1^2 + \psi_2 x_2^2 + \ldots + \psi_8 x_8^2)}. \qquad \ldots (8)$$

A simple numerical example. Let the points shown in Figure 3, taken in the order 0, 1, 2, . . ., 8 have positions, with respect to the point 0 as origin, given by

(0·0, 0·0), (1·0, 0·1), (0·1, 1·1), (−1·1, 0·1), (−0·2, −1·1),
(1·1, 1·1), (−0·8, 1·2), (−1·0, −0·9), (0·8, −1·2).

The initial Cartesian base vectors required to find $\nabla^2 f$ are then

$$\mathbf{x} = (1{\cdot}0,\ 0{\cdot}1,\ -1{\cdot}1,\ -0{\cdot}2,\ 1{\cdot}1,\ -0{\cdot}8,\ -1{\cdot}0,\ 0{\cdot}8), \qquad \ldots (9)$$

$$\mathbf{y} = (0{\cdot}1,\ 1{\cdot}1,\ 0{\cdot}1,\ -1{\cdot}1,\ 1{\cdot}1,\ 1{\cdot}2,\ -0{\cdot}9,\ -1{\cdot}2), \qquad \ldots (10)$$

$$\mathbf{xy} = (0{\cdot}10,\ 0{\cdot}11,\ -0{\cdot}11,\ 0{\cdot}22,\ 1{\cdot}21,\ -0{\cdot}96,\ 0{\cdot}90,\ -0{\cdot}96), \qquad \ldots (11)$$

$$(\mathbf{x}^2 - \mathbf{y}^2) = (0{\cdot}99,\ -1{\cdot}20,\ 1{\cdot}20,\ -1{\cdot}17,\ 0{\cdot}00,\ -0{\cdot}80,\ 0{\cdot}19,\ -0{\cdot}80). \qquad \ldots (12)$$

There now follows a line-by-line application of equations (5) to determine the orthogonal $\boldsymbol{\varphi}$ vectors. The determination of $\boldsymbol{\varphi}_1$ is trivial, equation 5 *(a)* yielding immediately

$$\boldsymbol{\varphi}_1 = (1{\cdot}0,\ 0{\cdot}1,\ -1{\cdot}1,\ -0{\cdot}2,\ 1{\cdot}1,\ -0{\cdot}8,\ -1{\cdot}0,\ 0{\cdot}8), \qquad \ldots (13)$$

a vector with precisely the same components as $\mathbf{x}$. To obtain subsequent $\boldsymbol{\varphi}$ vectors in the sequence nothing more difficult than the evaluation of scalar products is required. Thus to get $\boldsymbol{\varphi}_2$, the scalar products $\boldsymbol{\varphi}_1.\mathbf{y}$ and $(\boldsymbol{\varphi}_1.\boldsymbol{\varphi}_1)$ are needed. From equations (10) and (13)

$$\boldsymbol{\varphi}_1 . \mathbf{y} = 1\cdot0 \times 0\cdot1 + 0\cdot1 \times 1\cdot1 - 1\cdot1 \times 0\cdot1 + 0\cdot2 \times 1\cdot1 + 1\cdot1 \times 1\cdot1 - 0\cdot8 \times 1\cdot2 + 1\cdot0 \times 0\cdot9 - 0\cdot8 \times 1\cdot2 = 0\cdot51. \qquad \ldots (14)$$

Similarly it is found that

$$\boldsymbol{\varphi}_1 . \boldsymbol{\varphi}_1 = 1\cdot0 \times 1\cdot0 + 0\cdot1 \times 0\cdot1 + 1\cdot1 \times 1\cdot1 + 0\cdot2 \times 0\cdot2 + 1\cdot1 \times 1\cdot1 + 0\cdot8 \times 0\cdot8 + 1\cdot0 \times 1\cdot0 + 0\cdot8 \times 0\cdot8 = 5\cdot75. \qquad \ldots (15)$$

Then each of the components of $\boldsymbol{\varphi}_1$ is multiplied by $0\cdot51/5\cdot75 = 0\cdot09$ and subtracted from the corresponding component of $\mathbf{y}$, yielding the vector $\boldsymbol{\varphi}_2$ where

$$\boldsymbol{\varphi}_2 = (0\cdot11,\ 1\cdot09,\ 0\cdot20,\ -1\cdot08,\ 1\cdot00,\ 1\cdot27,\ -0\cdot81,\ -1\cdot27). \qquad \ldots (16)$$

$\boldsymbol{\varphi}_3$ is obtained from 5 *(c)* in exactly the same way, the necessary additional scalar products, evaluated in the same way as (14) and (15) being

$$\boldsymbol{\varphi}_1 . \mathbf{xy} = 0\cdot62, \quad \boldsymbol{\varphi}_2.\mathbf{xy} = 0\cdot34, \quad \varphi_2^2\ (= \boldsymbol{\varphi}_2 . \boldsymbol{\varphi}_2) = 7\cdot29, \qquad \ldots (17)$$

giving, from 5 *(c)*

$$\boldsymbol{\varphi}_3 = (-0\cdot01,\ 0\cdot05,\ -0\cdot00,\ 0\cdot29,\ 1\cdot04,\ -0\cdot93,\ 1\cdot05,\ -0\cdot99). \qquad \ldots (18)$$

To get $\boldsymbol{\varphi}_4$ the required additional scalar products are

$$\boldsymbol{\varphi}_1.(\mathbf{x}^2-\mathbf{y}^2) = -0\cdot41, \quad \boldsymbol{\varphi}_2.(\mathbf{x}^2-\mathbf{y}^2) = 0\cdot05, \quad \boldsymbol{\varphi}_3.(\mathbf{x}^2-\mathbf{y}^2) = 1\cdot33, \qquad \ldots (19)$$

and $\varphi_3^2 = 4\cdot12$, the others being already known. The use of these values in 5 *(d)* then yields

$$\boldsymbol{\varphi}_4 = (1\cdot06,\ -1\cdot22,\ 1\cdot12,\ -1\cdot27,\ -0\cdot27,\ -0\cdot56,\ -0\cdot21,\ -0\cdot42). \qquad \ldots (20)$$

Finally, from the scalar products

$$\boldsymbol{\varphi}_1.\mathbf{1} = -0\cdot10, \quad \boldsymbol{\varphi}_2.\mathbf{1} = 0\cdot41, \quad \boldsymbol{\varphi}_3.\mathbf{1} = 0\cdot50, \quad \boldsymbol{\varphi}_4.\mathbf{1} = -1\cdot76, \qquad \ldots (21)$$

the required vector $\boldsymbol{\psi}$ is found from 5 *(e)* to be

$$\boldsymbol{\psi} = (1\cdot33,\ 0\cdot58,\ 1\cdot29,\ 0\cdot65,\ 0\cdot76,\ 0\cdot87,\ 0\cdot84,\ 1\cdot08)\ , \qquad \ldots (22)$$

Therefore, in (7) we have

$$\boldsymbol{\psi}.\mathbf{f} = 1\cdot33f_1 + 0\cdot58f_2 + 1\cdot29f_3 + 0\cdot65f_4 + 0\cdot76f_5 + 0\cdot87f_6 + 0\cdot84f_7 + 1\cdot08f_8, \qquad \ldots (23)$$

$$\boldsymbol{\psi}.\mathbf{1} = 1\cdot33 + 0\cdot58 + 1\cdot29 + 0\cdot65 + 0\cdot76 + 0\cdot87 + 0\cdot84 + 1\cdot08 = 7\cdot40, \qquad \ldots (24)$$

$$\boldsymbol{\psi}.\mathbf{x}^2 = 5\cdot929 \qquad \ldots (25)$$

and so, using (23), (24), (25), for this example (8) becomes

$$\nabla^2 f = \frac{(1\cdot33f_1 + 0\cdot58f_2 + 1\cdot29f_3 + 0\cdot65f_4 + 0\cdot76f_5 + 0\cdot87f_6 + 0\cdot84f_7 + 1\cdot08f_8) - 7\cdot40f_0}{2\cdot9645} \qquad \ldots (26)$$

The formula (26) may be tested by taking the pattern of points in Figure 3 to be in an exactly circular 500-mb contour height field given by the formula

$$f - 546 = 6x^2 + 6y^2. \qquad \ldots (27)$$

The exact value of $\nabla^2 f$ in this case, by differentiation of (27), is 24.
The values for $f_0, f_1, f_2, \ldots, f_8$ obtained from (27) are
$f_0 = 546\cdot00$, $f_1 = 552\cdot06$, $f_2 = 553\cdot32$, $f_3 = 553\cdot32$, $f_4 = 553\cdot50$
$f_5 = 560\cdot52$, $f_6 = 558\cdot46$, $f_7 = 556\cdot86$, $f_8 = 558\cdot46$.

Using these values in (26) the value 23·986 is obtained. Of course the field represented by (27) is a very simple and symmetric one so that the error term, which has not been discussed, can be expected to be small. In practice the f-field would be likely to be more complicated and since its analytical form would not in general be known, only experience would show if the neglected error term was acceptable.

The method is applicable for any number of points, subject to a lower limit. In the foregoing example the only difference it would make if there were n points surrounding the origin point would be that all the 8-component vectors involved would be n-component vectors instead. It should be noted, however, that the fewest number of points for which the foregoing example could be worked is five, not counting the origin point. If there were only four surrounding points then the method would involve finding a vector to be orthogonal to four independent vectors each having four components, and this is impossible. The fact that it is possible in the regular pattern case to find a formula such as equation (1) involving only four surrounding points is a bonus associated with a regular rectilinear distribution of points. It is worth mentioning that in the case where n is large, the classical formulation of the Gram-Schmidt process given by (5) should not be used, as the build-up of round-off error will be excessive. A modified form such as given by Dixon and Spackman* should be used instead.

It may be noticed that the error term associated with equation (7) is of third order, whereas it is well known that the error term associated with (1) or (2) is of fourth order. This again is a bonus associated with a regular rectilinear distribution of points. A formula corresponding to (7) but having a fourth-order error term may be constructed by finding a vector orthogonal to $\mathbf{x}$, $\mathbf{y}$, $\mathbf{xy}$, $(\mathbf{x}^2 - \mathbf{y}^2)$, $\mathbf{x}^3, \mathbf{x}^2\mathbf{y}, \mathbf{xy}^2, \mathbf{y}^3$, the last four being the vectors associated with the third-order terms in the Taylor series. Note that in this case the minimum number of points, apart from the origin point, is now nine.

In working the above example on a desk calculator all numbers were carried to 10 significant digits, but for reasons of space they have been rounded and quoted to two decimal places.

Acknowledgements. I am indebted to Mr I. Jones for a valuable discussion of some mathematical points, and to Mr V. Blackman for carrying out the desk calculations.

551.577.3:551.582.2(410):551.589.1

SYNOPTIC-TYPE RAINFALL AVERAGES OVER ENGLAND AND WALES

By E. N. LAWRENCE

Summary. Long-term monthly and annual averages of daily rainfall over England and Wales (combined) for the period 1950–69 were estimated for each type of synoptic pattern of atmospheric surface pressure. The available classification of daily surface pressure patterns was as follows : north-easterly, cyclonic north-easterly, anticyclonic north-easterly; easterly, cyclonic easterly, anticyclonic easterly; etc., together with the categories, 'cyclonic', 'anti-cyclonic' and 'unclassifiable'; that is, a total of 27 categories of pressure pattern over the United Kingdom. Cols were not accorded a separate category but allocated to the most

* DIXON, R, and SPACKMAN, E. A.; The three-dimensional analysis of meteorological data. *Scient Pap Met Off, London*, No. 31, 1970.

appropriate of the 27 categories stated. The daily values of areal rainfall were estimated from a network of some 30–33 stations and a conversion factor derived from the long-term averages of annual rainfall (i) over England and Wales and (ii) for the network of rainfall stations.
Accuracy of the results was assessed by *(a)* calculating individual values of rainfall (the so-called *indirect* estimates) for each month, season and year of the period 1861–1949, using frequencies of each type of daily surface pressure pattern and synoptic-type rainfall averages and *(b)* comparing these values with the *direct* estimates based on rainfall data from a large network of stations. Corrections for the application to indirect estimates *(I)*, as percentages of the long-term average, are suggested. The corrected estimate for annual I is given by $1{\cdot}7\,I - 70$ per cent.
The monthly rainfall averages suggest that annual variation of rainfall for a particular type is related to (1) length of land- or sea-track associated with the type and (2) annual variation of sea temperature. The rainfall averages are clearly related to isobaric curvature.

Introduction. With the ever-increasing demand for water supplies, it is becoming increasingly necessary to plan for maximum efficiency in the use of water resources. In particular, there is a need for more accurate forecasts of areal rainfall from atmospheric pressure charts. The present work describes the calculation of rainfall averages over England and Wales (combined) for different synoptic patterns of atmospheric surface pressure. The accuracy and interpretation of the results are discussed. These results together with those for other pressure levels should be useful for special case-studies of drought and the associated characteristics of the general circulation.

Method. The main surface pressure pattern for each day over the U.K. was classified[1] as one of the following 27 categories : north-easterly, cyclonic north-easterly, anticyclonic north-easterly; easterly, cyclonic easterly, anticyclonic easterly, etc. together with the categories, 'cyclonic', 'anticyclonic' and 'unclassifiable'. Cols were not accorded a separate category but were allocated to the most appropriate of the 27 categories stated.

The daily (09 to 09 GMT) values of rainfall amount for each of some 30 to 33 stations on the mainland of England and Wales were extracted mainly from the *Daily Weather Report*,* for the period 1950 to 1969 (20 years). These data were used to obtain estimates of daily areal rainfall amounts for England and Wales, as follows :

Let A = average annual rainfall over England and Wales and
$r_1, r_2, \ldots, r_n$ = average annual rainfall amounts at the 'n' stations of the network and
$\bar{r}$ = average value of $r_1, r_2, \ldots, r_n$.
If T = total rainfall for the 'n' stations on a particular day and
$\bar{T} = T/n$,

then the rainfall (d over England and Wales for that day can be written

$$d = k\bar{T} = k'T,$$

where $k = A/\bar{r}$ and $k' = A/\Sigma r$.

The network and the values of k and k' were usually constant throughout any given year but varied from year to year.

These values (d) of the daily rainfall over England and Wales were then used to calculate the average daily rainfall for each synoptic type. To eliminate irregularities arising from small samples (associated with the less-frequent synoptic types), the monthly values of average daily rainfall and average frequency for each synoptic type were adjusted as follows :

Let T_m = total rainfall for the f_m days of a particular synoptic type for the month m (where $m = 1, 2, 3 \ldots 12$) during the 20-year period. Then, the

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* London, Meteorological Office. *Daily Weather Report.*

adjusted value (R_m) of the daily rainfall average of the particular synoptic type, for the month m is given by :

$$R_m = \frac{\frac{1}{4}T_{m+1} + \frac{1}{2}T_m + \frac{1}{4}T_{m-1}}{\frac{1}{4}f_{m+1} + \frac{1}{2}f_m + \frac{1}{4}f_{m-1}},$$

where the suffixes $(m-1)$ and $(m+1)$ indicate the adjacent preceding and succeeding months respectively. Adjusted frequencies (F'_m) were obtained from the formula :

$$F'_m = \tfrac{1}{4}f_{m+1} + \tfrac{1}{2}f_m + \tfrac{1}{4}f_{m-1}.$$

These values of the frequencies (F'_m) were then further adjusted to obtain the frequencies (F_m) as follows :

$$F_m = F'_m \times \frac{\Sigma f_m \text{ (all types)}}{\Sigma F'_m \text{ (all types)}},$$

so that ΣF_m (all types) $= \Sigma f_m$ (all types) and each of these latter expressions is equal to the total number of days in the month 'm' over the 20-year period, 1950 to 1969. The final monthly frequencies $(F_m/20)$ of Table I were then obtained; seasonal and annual values may be calculated from these monthly data.

Assessment of accuracy of the results. Monthly values of rainfall were estimated for each individual month of the period 1861 to 1949 (89 years) by using the calculated daily rainfall average for each synoptic type (given in Table 1) and the *actual* frequencies of each synoptic type in any given month. These estimates of monthly rainfall are referred to as *indirect* estimates *(i)* and they were compared with the *direct* estimates *(d)* obtained from observed rainfall data, as given in *British Rainfall.*† Similar comparisons were made for quarterly, half-yearly and annual data. Table II gives the long-term averages and standard deviations of both the directly estimated and indirectly estimated series of rainfall amounts and also the correlations between the two series of estimates.

Errors $(i-d)$, expressed as percentages of the direct estimates *(d)*, were calculated for each individual quarter, half-year and year. Their distributions are shown in Table III, from which it can be calculated, for example, that 92 per cent of indirectly estimated annual rainfall amounts are within 15 per cent of the direct estimates.

All estimates of rainfall amounts for the quarters, half-years and years were expressed as percentages of the long-term averages of direct estimates for the period 1861 to 1949. The distribution of indirect estimates, in five per cent ranges, was then obtained for each five per cent range of direct estimates. The distribution of *annual* rainfall estimates is shown in Table IV. The corresponding tables for quarters and half-years are similar.

It can be seen from Table II that indirectly estimated averages are very similar to the directly estimated averages but, as expected, standard deviations of indirect estimates are distinctly less than those for direct estimates. The latter relationship concerning variance results from the use of *averages* in the calculation of the indirect estimates: the inherent 'smoothing' process in the indirect estimation necessarily leads to estimates with lesser extremes, as shown in Table IV.

† London, Meteorological Office. *British Rainfall.*

TABLE I—SYNOPTIC-TYPE* AVERAGES OF (i) MONTHLY AND ANNUAL AVERAGE DAILY RAINFALL (R mm/day), (ii) FREQUENCY (F DAYS PER MONTH/YEAR) AND (iii) PRODUCT (RF mm) OVER ENGLAND AND WALES FOR THE PERIOD 1950 TO 1969 (20 YEARS)

		A NE	NE	C NE	A E	E	C E	A SE	SE	C SE	A S	S	C S	A SW	SW	C SW	A W	W	C W	A NW	NW	C NW	A N	N	C N	A	C	U
Jan.	R	0·4	0·8	3·9	0·5	1·8	3·9	0·3	1·4	2·7	0·1	3·2	5·5	1·1	4·2	4·2	1·0	3·8	4·6	0·8	1·6	2·3	0·7	1·4	2·5	0·5	4·9	3·7
	F	0·36	0·33	0·13	0·73	1·52	0·29	0·26	0·54	0·14	0·34	1·62	0·31	0·26	0·82	0·20	1·09	5·92	1·39	0·37	1·51	0·28	0·75	1·69	0·54	4·89	3·30	1·42
	RF	0·14	0·26	0·51	0·37	2·74	1·13	0·08	0·76	0·38	0·03	5·18	1·71	0·29	3·44	0·84	1·09	22·50	6·39	0·30	2·42	0·64	0·53	2·37	1·35	2·45	16·17	5·25
Feb.	R	0·4	1·2	1·8	0·4	1·6	3·2	0·5	1·5	3·5	0·2	3·7	6·1	0·7	3·8	4·3	0·7	3·0	4·1	0·9	1·3	2·3	0·7	1·2	2·2	0·4	4·7	4·3
	F	0·48	0·31	0·09	0·88	1·67	0·40	0·31	0·83	0·17	0·36	1·61	0·35	0·15	0·80	0·21	1·11	4·46	0·82	0·35	0·85	0·31	0·71	1·55	0·37	4·96	3·04	1·10
	RF	0·19	0·37	0·16	0·35	2·67	1·28	0·15	1·25	0·59	0·07	5·96	2·13	0·11	3·04	0·90	0·78	13·38	3·36	0·31	1·11	0·71	0·50	1·86	0·81	1·98	14·29	4·73
Mar.	R	0·2	1·3	2·1	0·3	1·9	3·1	0·6	1·6	5·2	0·3	4·0	5·3	0·1	3·6	3·5	0·5	2·7	3·1	0·6	1·3	2·0	0·5	1·1	2·3	0·3	4·5	4·0
	F	0·55	0·36	0·09	1·11	1·84	0·52	0·41	1·17	0·21	0·52	1·82	0·43	0·14	0·71	0·20	1·34	4·59	0·55	0·45	0·81	0·39	0·84	1·70	0·39	5·64	3·07	1·15
	RF	0·11	0·47	0·19	0·33	3·50	1·61	0·25	1·87	1·09	0·16	7·28	2·28	0·01	2·56	0·70	0·67	12·39	1·71	0·27	1·05	0·78	0·42	1·87	0·90	1·69	13·81	4·60
Apr.	R	0·2	1·4	2·4	0·4	2·8	3·7	1·0	2·3	6·7	0·5	3·9	4·1	0·3	3·4	3·0	0·4	2·5	3·4	0·5	1·2	1·8	0·3	1·2	2·3	0·3	4·5	3·1
	F	0·58	0·33	0·10	1·25	1·72	0·42	0·28	0·76	0·20	0·39	1·48	0·43	0·16	0·59	0·13	1·13	4·24	0·58	0·42	1·01	0·39	1·00	1·80	0·49	5·58	3·30	1·24
	RF	0·12	0·46	0·24	0·50	4·82	1·55	0·28	1·75	1·34	0·19	5·77	1·76	0·05	2·01	0·39	0·45	10·60	1·97	0·21	1·21	0·70	0·30	0·65	1·13	1·67	14·85	3·84
May	R	0·4	1·1	2·7	0·5	3·4	4·8	1·6	4·4	6·5	0·5	3·7	3·9	0·7	2·5	2·7	0·4	2·2	2·8	0·4	1·0	1·7	0·4	1·5	2·8	0·5	4·4	3·0
	F	0·58	0·34	0·08	1·37	1·61	0·37	0·23	0·55	0·15	0·24	1·18	0·37	0·24	0·51	0·06	1·11	4·38	0·87	0·46	1·07	0·34	1·04	1·88	0·48	5·59	4·46	1·44
	RF	0·23	0·37	0·22	0·69	5·47	1·78	0·37	2·42	0·97	0·12	4·37	1·44	0·17	1·27	0·16	0·44	9·64	2·44	0·18	1·07	0·58	0·42	2·82	1·34	2·79	19·62	4·32
June	R	0·6	1·5	3·3	0·5	3·4	7·6	1·1	5·4	5·5	0·5	3·5	5·3	1·3	2·6	3·8	0·6	2·0	2·6	0·3	0·9	2·0	0·4	1·7	4·4	0·7	4·6	3·6
	F	0·31	0·31	0·05	1·05	1·02	0·39	0·21	0·42	0·06	0·16	0·87	0·20	0·24	0·43	0·05	1·55	4·99	0·97	0·61	1·14	0·38	0·89	1·67	0·39	5·52	4·82	1·30
	RF	0·19	0·47	0·17	0·53	3·47	2·96	0·23	2·27	0·33	0·08	3·05	1·06	0·31	1·12	0·19	0·93	9·98	2·52	0·18	1·03	0·76	0·36	2·84	1·72	3·86	22·17	4·68
July	R	0·7	3·0	3·0	0·9	3·5	9·1	1·2	5·0	10·5	0·5	3·4	6·7	1·9	4·0	4·1	0·7	2·3	3·3	0·4	0·9	2·2	0·4	1·7	4·8	0·8	5·1	3·6
	F	0·18	0·38	0·04	0·69	0·52	0·43	0·19	0·18	0·06	0·20	0·69	0·14	0·18	0·45	0·11	1·98	5·57	1·05	0·67	1·46	0·53	0·87	1·65	0·52	5·40	5·58	1·28
	RF	0·13	1·14	0·12	0·62	1·82	3·91	0·23	0·90	0·63	0·10	2·35	0·94	0·34	1·80	0·45	1·39	12·81	3·47	0·27	1·31	1·17	0·35	2·81	2·50	4·32	28·46	4·61
Aug.	R	1·1	3·3	4·6	0·9	4·3	7·5	1·5	2·0	10·7	1·1	3·6	4·8	1·0	4·7	4·7	0·8	2·9	3·8	0·5	1·1	2·0	0·6	1·9	4·3	0·7	5·3	3·0
	F	0·33	0·43	0·05	0·48	0·45	0·34	0·23	0·25	0·11	0·32	0·91	0·23	0·15	0·54	0·15	1·83	5·61	1·23	0·53	1·30	0·42	0·62	1·52	0·58	4·89	6·03	1·47
	RF	0·36	1·42	0·23	0·43	1·93	2·55	0·35	0·50	1·18	0·35	3·28	1·10	0·15	2·54	0·71	1·46	16·27	4·67	0·27	1·43	0·84	0·37	2·89	2·49	3·42	31·96	4·41
Sept.	R	1·3	2·7	6·5	0·3	4·6	5·7	0·6	2·3	7·1	1·5	3·6	4·5	0·1	4·4	5·8	0·9	3·3	4·2	0·5	1·6	2·4	0·8	2·2	3·6	0·4	5·6	2·9
	F	0·34	0·28	0·09	0·39	0·57	0·30	0·31	0·58	0·12	0·43	1·24	0·30	0·17	0·82	0·17	1·62	5·98	1·32	0·41	1·00	0·22	0·34	1·25	0·49	5·22	4·59	1·45
	RF	0·44	0·76	0·59	0·12	2·62	1·71	0·19	1·33	0·85	0·65	4·46	1·35	0·02	3·61	0·99	1·46	19·73	5·54	0·21	1·60	0·53	0·27	2·75	1·76	2·09	25·70	4·21
Oct.	R	1·6	1·9	6·9	0·4	3·5	5·8	0·1	2·5	4·8	1·5	3·4	5·1	0·1	4·1	5·8	1·0	3·5	4·5	0·5	1·8	3·7	0·6	1·9	3·0	0·4	6·6	3·3
	F	0·33	0·16	0·09	0·47	0·78	0·38	0·38	0·71	0·17	0·44	1·49	0·32	0·18	1·08	0·20	1·65	6·25	1·25	0·36	1·09	0·22	0·37	1·41	0·36	5·81	3·77	1·28
	RF	0·53	0·30	0·62	0·19	2·73	2·20	0·04	1·77	0·82	0·66	5·07	1·63	0·02	4·43	1·16	1·65	21·87	5·63	0·18	1·96	0·81	0·22	2·68	1·08	2·32	21·88	4·22
Nov.	R	1·7	1·0	6·8	0·8	2·5	5·3	0·1	2·3	4·6	1·2	3·4	5·5	0·5	4·1	5·2	1·0	4·1	4·4	0·7	1·8	3·3	0·5	1·6	3·0	0·4	6·7	3·3
	F	0·38	0·27	0·09	0·49	0·98	0·42	0·32	0·48	0·20	0·41	1·31	0·36	0·20	0·86	0·17	1·29	6·14	1·20	0·34	1·47	0·28	0·41	1·63	0·43	4·88	3·75	1·24
	RF	0·65	0·27	0·61	0·39	2·45	2·23	0·03	1·10	0·92	0·49	4·45	1·98	0·10	3·53	0·88	1·29	25·17	5·28	0·24	2·65	0·92	0·21	2·61	1·29	1·95	25·13	4·09
Dec.	R	1·1	0·7	6·5	0·7	2·1	4·6	0·1	1·4	3·6	0·5	3·2	5·2	1·0	4·4	4·0	1·0	4·3	4·5	0·8	1·9	2·6	0·6	1·6	3·1	0·5	5·7	3·3
	F	0·33	0·39	0·11	0·53	1·21	0·34	0·28	0·43	0·16	0·44	1·37	0·34	0·29	0·68	0·16	1·06	6·68	1·48	0·39	1·85	0·29	0·57	1·69	0·57	4·38	3·50	1·48
	RF	0·36	0·27	0·71	0·37	2·54	1·56	0·03	0·60	0·58	0·22	4·38	1·77	0·29	2·99	0·64	1·06	28·72	6·66	0·31	3·51	0·75	0·34	2·70	1·77	2·19	19·95	4·88
Year	R	0·73	1·69	4·33	0·52	2·65	5·32	0·65	2·39	5·53	0·73	3·57	5·13	0·79	3·90	4·43	0·76	3·13	3·91	0·55	1·40	2·27	0·51	1·48	3·23	0·49	5·16	3·40
	F	4·75	3·89	1·01	9·44	13·89	4·60	3·41	6·90	1·75	4·25	15·59	3·73	2·36	8·29	1·81	16·76	64·81	12·71	5·36	14·56	4·05	8·41	19·44	5·61	62·81	49·21	15·85
	RF	3·5	6·6	4·4	4·9	36·8	24·5	2·2	16·5	9·7	3·1	55·7	19·1	1·9	32·3	8·0	12·7	202·9	49·7	2·9	20·4	9·2	4·3	28·8	18·1	30·8	253·9	53·9

* A = anticyclonic, C = cyclonic, U = unclassifiable.

TABLE II—DIRECT AND INDIRECT ESTIMATES OF THE AVERAGES AND STANDARD DEVIATIONS OF MONTHLY, SEASONAL AND ANNUAL RAINFALL OVER ENGLAND AND WALES DURING THE PERIOD 1861 TO 1949 AND CORRELATIONS BETWEEN THE SERIES OF DIRECT AND INDIRECT ESTIMATES

	No. of terms	Estimates of average		Estimates of standard deviation		Correlation
		Direct	Indirect	Direct	Indirect	
		millimetres				
Jan.	89	87·6	85·2	35·5	20·8	0·80
Feb.	89	66·9	65·9	33·4	21·1	0·85
Mar.	89	63·4	66·7	30·6	19·3	0·79
Apr.	89	56·4	61·7	22·0	17·4	0·74
May	89	60·3	65·0	24·7	17·3	0·75
June	89	60·4	62·3	26·4	17·8	0·85
July	89	75·4	79·6	33·0	20·6	0·87
Aug.	89	83·3	84·7	34·6	20·9	0·78
Sept.	89	75·2	76·5	35·1	21·9	0·80
Oct.	89	99·2	91·6	39·2	22·9	0·76
Nov.	89	92·2	89·8	37·4	24·9	0·82
Dec.	89	94·5	93·2	41·2	22·0	0·85
Jan.–Mar.	89	217·9	217·8	55·3	35·7	0·79
Apr.–June	89	177·0	189·1	42·6	31·8	0·84
July–Sept.	89	233·9	240·7	58·3	33·8	0·82
Oct.–Dec.	89	285·9	274·6	70·8	41·3	0·79
Apr.–Sept.	89	410·9	429·8	81·7	49·7	0·83
Oct.–Mar.	88	503·1	492·1	95·4	56·5	0·81
Apr.–Mar.	88	915·3	922·6	126·3	74·5	0·77

Errors resulting from this loss of variance may be corrected by the application of simple linear correction factors. For example, in each row of Table IV, if the value of D is compared with the median value of I in the row (I_M say), it can be seen that the difference of I_M from 100 is approximately half the difference of D from 100. This would be expected from the ratio (0·59) of the standard deviations of the indirect and direct estimates of annual rainfall in Table II. The value of 0·59 is also the ratio of the sum of the deviations,

TABLE III—PERCENTAGE DISTRIBUTION OF ERRORS* EXPRESSED AS PERCENTAGES OF DIRECT ESTIMATES OF ANNUAL AND SEASONAL RAINFALL AVERAGES OVER ENGLAND AND WALES FOR THE PERIOD 1861 TO 1949

	Negative errors *per cent*											Positive errors *per cent*						
	55–50	50–45	45–40	40–35	35–30	30–25	25–20	20–15	15–10	10–5	5–0	0–5	5–10	10–15	15–20	20–25	25–30	30–35
	Percentage frequency																	
Jan–Mar	0·0	0·0	1·1	2·2	1·1	1·1	4·5	3·4	7·9	14·6	14·6	14·6	10·1	5·6	6·7	4·5	5·6	2·2
Apr–June	0·0	0·0	0·0	0·0	0·0	1·1	1·1	2·2	6·7	9·0	11·2	11·2	20·2	4·5	15·7	7·9	5·6	3·4
July–Sept	0·0	0·0	0·0	1·1	1·1	3·4	2·2	5·6	5·6	7·9	13·5	13·5	11·2	6·7	12·4	11·2	2·2	2·2
Oct–Dec	1·1	0·0	0·0	1·1	3·4	5·6	6·7	9·0	7·9	10·1	10·1	13·5	9·0	10·1	5·6	6·7	0·0	0·0
Apr–Sept	0·0	0·0	0·0	0·0	1·1	0·0	0·0	2·2	9·0	7·9	13·5	14·6	14·6	18·0	9·0	7·9	2·2	0·0
Oct–Mar	0·0	0·0	0·0	0·0	0·0	4·5	4·5	8·0	6·8	9·1	17·0	20·5	14·8	9·1	4·5	1·1	0·0	0·0
Apr–Mar	0·0	0·0	0·0	0·0	0·0	0·0	1·1	1·1	13·6	6·8	22·7	20·5	19·3	9·1	4·5	1·1	0·0	0·0

* Indirect estimates minus direct estimates.

TABLE IV—FREQUENCY OF DIRECT AND INDIRECT ESTIMATES OF THE ANNUAL (APRIL TO MARCH) RAINFALL OVER ENGLAND AND WALES EXPRESSED AS PERCENTAGES OF THE DIRECTLY ESTIMATED AVERAGE FOR 1861/62 TO 1948/49

*D**	Indirect estimates (*I*) *per cent*							
	85–90	90–95	95–100	100–105	105–110	110–115	115–120	120–125
				frequency				
70–75	1							
75–80	2		1					
80–85	1	7	3	1				
85–90		4	1					
90–95		3	5	3	2			
95–100		2	5	2	2			
100–105		2	4	7	1	1		
105–110		1	3	1	3	1		
110–115			1		4	1		
115–120			1	1	1	1	1	
120–125					1			1
125–130					1	2	1	
130–135							1	1

**D* = direct estimates, per cent.

from 100 per cent, of *I* estimates of annual rainfall to that for the *D* estimates (Table IV data), all deviations being regarded as positive. Thus a corrected estimate for *I* is given by: $I + (I - 100)$, that is $(2I - 100)$ or with a greater average accuracy, by: $100 + (I - 100)/0{\cdot}59$, that is $(1{\cdot}7\,I - 70)$.

Clearly, also, part of the error of indirect estimates may be the result of long-term climatic change in synoptic-type averages. The averages for the period 1950 to 1969 may not be representative of the years from 1861 to 1949. Such long-term changes are suggested, for example, by the slightly lower indirect estimates of average monthly rainfall from October to March and the slightly higher indirect estimates of average rainfall from April to September, as compared with direct estimates (Table II).

If it is assumed that the errors (for example, as reflected in Table IV and in the averages of Table II) result only from a general long-term change in average rainfall of all synoptic types, then the average excess error in indirect estimates will be about $100\,(M - L)/L$ per cent, where L and M are the average rainfall amounts (direct estimates) in the periods 1861 to 1949 and 1950 to 1969, respectively. For example, this formula gives a value of about one per cent for annual rainfall, and the percentage excess of the indirect estimate over the direct estimate of mean annual rainfall in the period April 1861 to March 1949 (Table II) is about the same value. The magnitude of such errors is within the limits of accuracy of any of the estimates.

Part of the 'error' in the indirect estimates may be due also to errors in the direct estimates of rainfall, which are calculated from networks of rainfall stations that increased from about 58 stations in 1861 to about 70 stations around 1950. Such errors are particularly liable to occur with very low rainfall.[2]

Annual variation. The cyclonic type shows an annual wave with the driest part, on average, in spring (March to May) and the wettest part in October and November.

Westerly and westerly cyclonic types are driest (on average) around June and wettest in winter. The corresponding south-westerly and north-westerly types are driest around May and June but are wettest in late summer and autumn. North-easterlies have a somewhat similar tendency but easterlies and south-easterlies tend to be generally wetter in summer.

These patterns would appear to be related to the land–sea orientation. Atlantic types or types with long sea-track usually show a tendency to have the driest months around the time of minimum sea temperature and the wettest around the time of maximum, while those types with a longer land-track are generally wetter in summer when thermal convection is usually greater.

Isobaric curvature. The difference in wetness between cyclonic types and anticyclonic types is reflected not only in the rainfall averages for the cyclonic and anticyclonic categories but also in the decrease in rainfall within each 'directional' group of categories, from 'cyclonic' to 'straight' isobars to anticyclonic curvature.

Concluding remarks. The distribution of errors suggests that an improvement in the indirect estimates is likely to be obtained from a more detailed classification of synoptic types which would break down the more dominant, prevalent categories into smaller groups.

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REVIEWS

Biometeorological methods, by R. E. Munn. 225 mm × 152 mm, pp. xi + 336, *illus.*, Academic Press Inc. (London) Ltd, Berkeley Square House, London W1X 6BA, 1971. Price: £5·85. (Paperback edition £3·25.)

In the preface, the author defines biometeorology as the study of relationships between weather and life; he quotes examples from the fields of meteorology, hydrology, physiology, ecology, biology, medicine, geography, forestry, agronomy, engineering and, most frequently, air pollution. Whilst undoubtedly this last topic is one which falls within the very broad definition of biometeorology, it has already been discussed by A. C. Stern in the three volumes which constitute the first of this series of Interdisciplinary Monographs.

The book contains 14 chapters which review the broad subject of biometeorological methods and form an introduction to the subject. An interesting feature is the Appendix which lists 50 problems designed to test the reader, to encourage further work and to stimulate thought, but these are presented without preamble so their purpose is not immediately clear. The list of 481 references covers all the topics discussed and alone forms a valuable guide to methods. There is no mention of two important references WMO Technical Note No. 65 'A survey of human biometeorology' edited by F. Sargent and S. W. Tromp, published in 1964 and 'Medical biometeorology' by S. W. Tromp in co-operation with 26 contributors, published by Elsevier in 1963. In discussing international aspects, there is no mention of the International Society of Biometeorology and its Journal.

After an introductory Chapter 1, atmospheric sampling techniques, time and space variations and network and instrumental sampling problems are outlined in Chapters 2 and 3 largely using air pollution studies to illustrate concepts of concentration, dosage and flux. The design of biometeorological experiments in Chapter 4 is a good summary of the methods but, in the 62 pages of Chapters 5, 6 and 7, only brief descriptions of methods of using tables, graphs, charts and statistics are given. In particular, the discussions of eigen vectors and spectrum analysis give the impression that the author included these because they are fashionable and not because they are directly of use in biometeorology. Models and indices are discussed in Chapters 8, 9 and 13. These chapters are informative and useful mainly because they are illustrated by examples from human biometeorology. Apart from their use in comparison work, the value of indices in increasing our understanding of biometeorology has still to be proved. There is no doubt that the tracking methods described in Chapter 10 are invaluable tools in explaining the distribution of airborne bodies over an area and that certain conditions of ill health can be associated with certain weather events on a short time-scale of a few days. The review of evapotranspiration and water balance in the atmosphere and soil given in Chapter 11 is a handy summary of the methods but the study of past climates in Chapter 12 could have been omitted as it contributes little to the general theme of the book. Chapter 14 discusses the engineering applications in a mere 1½ pages and ignores the architectural problems altogether, whilst the four pages on economic studies merely whet the appetite for more information.

Because the topics discussed range so widely, the treatment is often superficial and uncritical. For the ordinary reader, however, it is a useful introduction to the subject and the research worker will find it valuable to have handy for the references. There are a few errors in the formulae but the book is well presented in clear type with good diagrams.

N. C. HELLIWELL

World survey of climatology, Volume 5, Climates of northern and western Europe, edited by C. C. Wallén. 300 mm × 215 mm, pp. x + 253, *illus.*, Elsevier Publishing Co. Ltd, 22 Rippleside Commercial Estate, Ripple Road, Barking, Essex, 1970. Price: £13.

This is the fifth (but the fourth, not in order of the volumes, to appear) of the 15 volumes of the World Survey of Climatology being published under the direction of Professor H. C. Landsberg. The four main chapters discuss in turn the climates of Scandinavia, the British Isles, France and the Benelux countries and the Iberian peninsula. Central and southern Europe will be covered in a later volume (Volume 6).

In an introductory chapter C. C. Wallén describes the general radiation conditions and air and sea circulations affecting the region, together with the resulting temperature and precipitation distributions. There is a muddle over Figures 5 and 6 which are maps of the frequency of cyclones with central pressure less than 1000 mb. The text leads the reader to expect winter and summer maps, respectively, but in fact Figure 5 is a summer map which is labelled 'annual'', while Figure 6 is an annual map which is labelled 'summer'. These maps were originally published in 1924 and it is surprising that more recent ones could not have been found, or prepared. Their periods are not stated, nor are those of the mean temperature map (which has isotherms at unequal intervals) or the precipitation map.

The chapter on the climate of Scandinavia is written by T. W. Johannessen of the Norwegian Meteorological Institute. In 40 pages of text he gives a detailed description of the climates of Norway, Sweden, Finland and Denmark. It is interesting to learn that the 'heating season' in these countries normally begins when the mean daily air temperature falls below 11°C and ends when it rises above 9°C; this compares with official figures for this purpose of 16°C in the U.K. and 18°C in the U.S.A. Of six maps included the first two are unusual. They show the distributions for January and July of the correlation coefficients between the mean monthly air temperatures at Sula Fyr (63°51′N, 8°28′E) and at other places in Scandinavia, 1931–60. The other four maps show the mean annual potential evapotranspiration, the normal dates of beginning and end and the length of the vegetation period (daily mean temperature 6°C or above). Unfortunately there are many misprints and some errors, while statements such as 'the warm Gulf Stream passes north-eastwards close by the west coast of Norway' page 23) and 'this especially applies to autumn which is at present the warmest season of the year' (page 59) do not inspire confidence.

Chapter 3 on the climate of the British Isles is the work of Professor G. Manley formerly of the Department of Enviromental Sciences, University of Lancaster. As was to be expected perhaps from his well-known writings on the subject, a good part of his fifty-odd pages is devoted to snowfall and snow cover and to temperature variations in these islands since 1670. Only two maps are included, both for the period 1931–60, showing the distributions of days with thunder heard and mornings with snow cover. In the section on wind, and elsewhere, references are made to 'Weather in Home Fleet Waters, Vol. 2' which has not yet, in fact, been published, while no mention is made of 'Tables of Surface Wind Speed and Direction over the United Kingdom' published in 1968 and probably the most complete and recent source of information on surface winds. There are many errors and misprints which should not have escaped proof-reading.

In Chapter 4, R. Arléry of the French Meteorological Service has contributed a relatively short but well-written account of the climates of France, Belgium, the Netherlands and Luxembourg. It is illustrated by 10 maps, all 1931–60, showing the distributions of all the main climatic elements. There is a little confusion at the end arising from an apparent last-minute addition of some information on surface winds.

The final chapter dealing with the Iberian peninsula, is also relatively short and is contributed by A. Linés Escardó of the National Meteorological Institute in Madrid. It is very well illustrated by many climatic maps, those of the main elements being for the period 1931–60. Many references to conditions in the Canary Isles and Madeira seem a little out of place. The section on 'Evaporation and evapotranspiration' is puzzling. It opens with a statement that 'in practically the whole territory annual mean values of potential evaporation vary between 1000 and 2000 mm', but a map of potential annual evapotranspiration by Thornthwaite's method shows only two very small areas with over 1000 mm, while Penman's method is stated to give values which may be up to 20 per cent higher than those calculated by Thornthwaite's.

Two main criticisms may be made of the volume as a whole. The first is that although the authors are well-known climatologists who clearly know their subjects, there are many signs of hasty writing and numerous misprints and mistakes in some chapters almost suggest that proof-reading was dispensed with. The second, probably more important, is that the various chapters do not follow any common plan. To a British reader this lack of balance is particularly noticeable, as the chapter on the British Isles is the one that differs most markedly from the others. For example, the other three main chapters all give climatic tables, following a standard format, at the end. Chapter 3 does not, and it is the only one which contains no upper air data whatever. All chapters would have been easier to follow had they included a map showing the districts and places referred to in the text. Frequent reference to an atlas was necessary and even then some places could not be found.

While this volume, and indeed the whole series, must be a valuable addition to every important meteorological library, its variable standard and its price will not induce many individual climatologists to acquire it.

H. C. SHELLARD

Monsoon meteorology, by C. S. Ramage. 233 mm × 160 mm, pp. xi + 296, *illus.*, Academic Press Inc. Publishers, 111 Fifth Avenue, New York, N.Y. 10003, 1971. Price: $15.

This book is Volume 15 of the International Geophysics Series edited by J. Van Mieghem.

It is a mine of information on all aspects of the monsoon. The first two chapters are short and concerned mainly with definitions and discussion on the general causes of the monsoon, heat balance over the ocean, general distribution of rainfall, etc. The longest and most valuable chapter is Chapter 3 in which are described in considerable detail with some theory, all the major synoptic components which occur in monsoon regions; these include tropical and subtropical cyclones, monsoon depressions, heat lows, monsoon troughs, non-circulating disturbances, transequatorial flow, etc.

Chapter 4 is a short but interesting chapter on precipitation, much of it concerned with the differences between monsoon rains and thunderstorms and drawing attention to the importance of the local orography. More could have been made of the value of satellites (especially geostationary ones) in this section and a reference to the proposed GARP tropical experiment would have been appropriate since this has as one of its objectives the study of mesoscale systems on the scale between single cumulonimbus and synoptic systems which are not adequately observed by existing radiosonde networks — just the type of systems important in producing monsoon rains.

Chapter 5 on the march of the seasons considers major monsoon areas and subdivides the weather of each into seasons. It is the most coherent reading of the whole book and is a most valuable descriptive account of monsoon weather in all parts of the world in which it is observed.

The next chapter brings home the unsatisfactory state of analysis and points to the value of statistics and climatology to the forecaster in monsoon areas.

The book closes with about 20 pages on short-period forecasting with some discussion on long-range forecasting and possible relationships between the general atmospheric circulation and the monsoon. Much more could have been said on these topics, long-range forecasting in particular being inadequately discussed.

When the reputation of the author is considered, the style throughout is rather disappointing; much of the book is divided into short paragraphs which are often disconnected in their content thus making continuous reading difficult. The number of cross references is also excessive, creating a disjointed effect which is enhanced by references to diagrams, for example on page 8 one short paragraph refers to 7 diagrams scattered about the book from page 12 to page 250 and this is by no means an isolated example — almost every paragraph refers to diagrams and text in other parts of the book.

As is usual in this series, there is both a subject and an author index; I was perhaps unlucky in looking up two authors, for in each case, the page number of the reference was wrong. The bibliography runs to 11 pages and is useful and up to date; there are a few significant omissions however, notably Findlater's paper in the Quarterly Journal of the Royal Meteorological Society in April 1969 on 'Interhemispheric transport of air in the lower troposphere over the western Indian Ocean'. The author in fact in his discussions on cross-equatorial flow in the region of East Africa seems unaware of Findlater's work although there are later references in the bibliography.

Satellite pictures are a welcome feature of the book but these are rather small and the geography not always clear. Some of the diagrams, too, contain too much detail for clarity and their captions are often wordy and unclear.

Although a difficult book to review, it contains a wealth of sound information but there are some gaps in the presentation and the whole is difficult to read, though easier to use as a work of reference for students and meteorologists concerned with monsoon problems.

R. A. S. RATCLIFFE

Atmosphere, weather and climate (second edition), by R. G. Barry and R. J. Chorley. 214 mm × 140 mm, pp. 379, *illus.*, Methuen and Co. Ltd, 11 New Fetter Lane, London, EC4, 1971. Price: £2·75. (Paperback edition £1·50.)

The first edition of this book appeared in 1968 and was reviewed by Virgo.* It was clearly well received by the readers for whom it was intended, mainly geography students in the sixth form and first year at University, and the demand has apparently been sufficient to justify the publication of a second edition only three years later. The reasons for the book's popularity are not difficult to see. By attempting to describe and explain climate in terms of the properties and behaviour of the atmosphere the authors have treated the subject in a logical and up-to-date manner. Moreover, they have done so in a way which demands very little knowledge of mathematics. The style

* *Met Mag, London*, **97**, 1968, p. 156.

is lively and readable, and a high level of interest is maintained throughout. Illustrations are used liberally and many numerical examples are quoted which give the reader a good idea of the order of magnitude of the quantities involved.

Unfortunately, although in the second edition the book has been improved by revisions and additions to the text, there are some defects. As must be in a book of reasonable length (and cost) covering such a wide field, much of the treatment is sketchy and, particularly in the chapters dealing with the structure and behaviour of the atmosphere, not adequate to meet the needs of the serious student of meteorology. Some sections show signs of hasty or careless preparation of the material, and too many errors are present which should have been weeded out before the first edition was published. Some of the errors are fairly obvious, while others become apparent after a little thought — the use of the formulae on pages 36 and 41, for example, will lead to ridiculous answers if c (cloudiness) and α (albedo) are expressed in 'tenths' and 'hundredths' respectively. There are just a few places where the student may be misled or confused: examples occur in the discussion of conditional instability (pages 99–100), and in the section on mesoscale phenomena (page 181), in which it is implied that the only mesoscale features of the atmosphere are severe thunderstorms.

In spite of its faults, the book is a valuable addition to the literature at a reasonable price. Its main virtues lie in the authors' sound approach to the subject and their ability to stimulate the reader's interest and encourage further study.

J. CRABTREE

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