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DISTRIBUTION OF TOTAL SOLAR RADIATION ON A HORIZONTAL SURFACE OVER THE BRITISH ISLES AND ADJACENT AREAS

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Summary.—Total solar radiation data, available from stations in the British Isles and from British ocean weather ships, are examined and linear regression equations between monthly mean daily totals of total solar radiation on a horizontal surface and monthly mean daily durations of bright sunshine obtained where possible. It is found that the constants of the equations vary somewhat but apparently not systematically. Each set of constants is therefore used to derive total solar radiation data in the general area of a station at which radiation is recorded, duration of bright sunshine data being taken for stations of roughly comparable exposure. A distribution of total solar radiation is obtained, from direct and deduced data, and this is linked with a similar distribution recently obtained by Black[1] for the area 50°–60° N, 05°–30° E. The distribution is extended to the west by consideration of the data from the British ocean weather ships. The data are presented in the form of a series of monthly maps.

Introduction.—Interest exists in the areal distribution of solar radiation both from the aspect of the hemispherical heat balance and from the aspect of applied meteorology in the context of civil engineering and agriculture. In agricultural studies the use of solar radiation by crops and the associated uptake and loss of water is of particular significance.

At the present time solar radiation observing stations are few in number and even now the available records are of relatively short duration, being confined to the present century for the oldest stations, but to the last decade for most. In these circumstances it has been necessary in the past, and it is still, to use the very numerous long records of duration of bright sunshine (obtained with the Campbell–Stokes sunshine recorder and similar instruments) to infer total radiation data when no direct information is available. The intermediate step is usually taken of determining regression equations between total solar radiation and corresponding duration of bright sunshine data for stations where both are available. These regression equations are then used as interpolation formulae and the required data are deduced.

One of the earliest examples of such an approach was that of Angström[2] who obtained an equation of the form

$$Q = Q_A\left(a + b\frac{n}{N}\right),$$

where Q = total solar radiation

Q_A = total solar radiation received through a transparent atmosphere

n = duration of bright sunshine

N = maximum possible duration of sunshine

a, b are constants, taking the values $a=0 \cdot 25$ and $b=0 \cdot 75$ for Stockholm.

In recent years Penman[3] has incorporated this approach in his well known work on evaporation and reports that, for Rothamsted, $a=0 \cdot 18$ and $b=0 \cdot 55$. Also Black[4,5] has investigated total radiation data from 37 stations, principally in the northern hemisphere, with records lasting three years or longer. He has concluded that the constants a and b may be allotted the general values $a=0 \cdot 23$ and $b=0 \cdot 48$, and that there is no evidence for a systematic latitudinal variation of a and b though both may be grouped according to latitude ranges. On the basis of these latter figures Black has derived fairly coarse distributions of total solar radiation for the northern hemisphere.

In recent years the number of stations making solar radiation observations has increased greatly and the further development of international co-ordinating bodies has led to the adoption of a common pyrheliometric scale (the International Pyrheliometric Scale, 1957) and recognized standard techniques. It is worthy of comment that international co-operation in this field dates from early in the present century.

In Great Britain recording of total solar radiation on a horizontal surface started in 1913 at South Kensington where a continuously recording Calendar instrument operated until 1939; a similar record was made at Rothamsted between 1931 and 1940. Spot readings of the normal incidence radiation near noon on substantially clear days were made at the geophysical observatories at Kew and Eskdalemuir, after about 1911, with Angström compensation pyrheliometers.

Continuous recording of normal incidence radiation commenced at Kew Observatory in 1932 and the data has been analysed by Stagg[6]. Continuous recording of total solar radiation on a horizontal surface, however, was not recommenced until 1946, this time at Kew Observatory. In 1950 a small network of solar radiation recording stations was set up, though continuous recording was not general until 1952, but it was not until late in 1955 that arrangements were made for the regular calibration of equipment, the supervision of techniques and the reporting of data to a central organization. At about the same time, that is the middle of the last decade, several research groups outside the Meteorological Office and mainly working in agriculture commenced recording total solar radiation on a horizontal surface following the lead given by Rothamsted many years before.

At the present time there are 17 stations recording total solar radiation on a horizontal surface in the United Kingdom and one in Eire. Of these, six are operated by the Meteorological Office (which also makes radiation observations from ocean weather ships), one by Trinity House, one by the Electrical Research Association, one by the Building Research Station and the remainder by groups concerned in some way in agricultural or horticultural research. These stations are equipped variously with Moll–Gorczynski solarimeters or photocell detectors of a pattern developed by the National Institute for Agricultural Engineering[7] and recording is by thread-recorder, potentiometric recorder, integrating motor or electrolytic integrator.

All these stations report their data on the International Pyrheliometric Scale and derive their standardization from one of three sources:

(i) Kew Observatory,

(ii) National Institute for Agricultural Engineering (N.I.A.E.),

(iii) Physikalische Observatorium, Davos,

all three of which are linked by regular intercomparisons. The majority report their data, on a daily basis, on a common form to the Meteorological Office for registration on standard Hollerith cards and storage as part of the national library of meteorological records. Analysis of these data is undertaken as required.

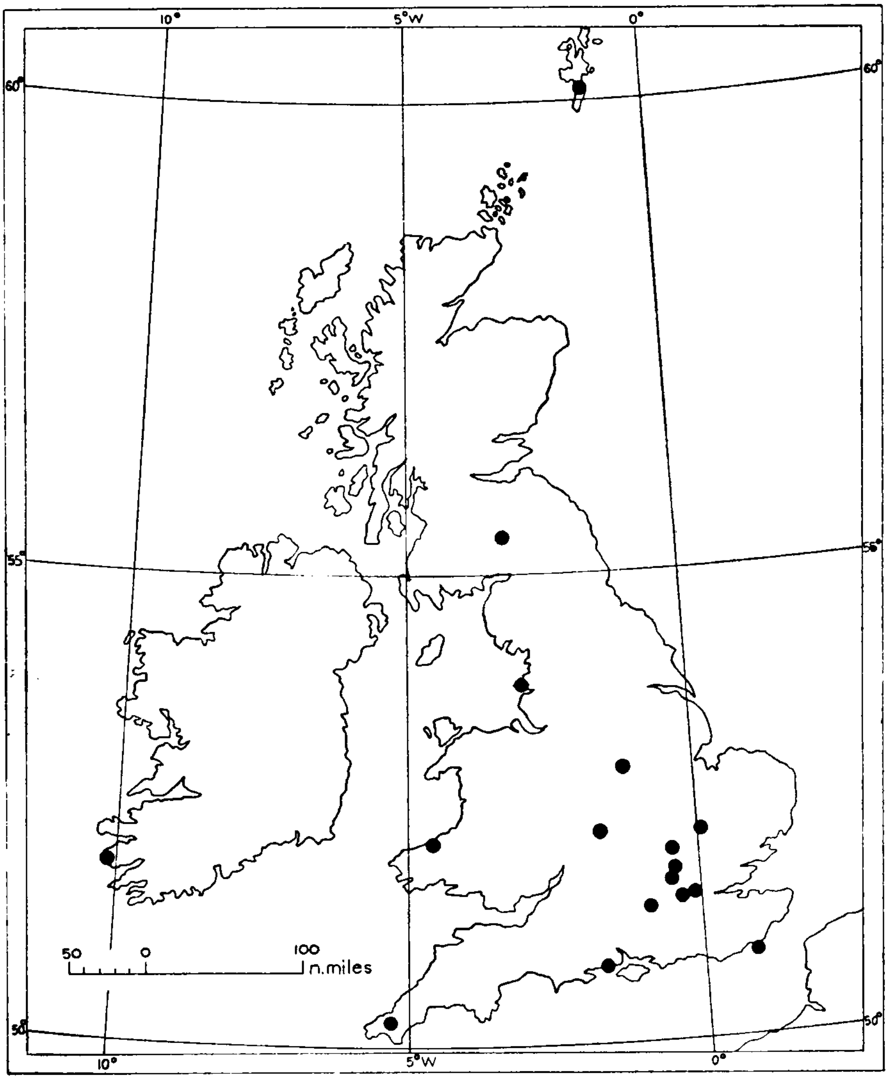

FIGURE 1—DISTRIBUTION OF STATIONS FROM WHICH DATA HAVE BEEN DRAWN

The data.—Data have been drawn from 17 land stations and 3 ocean weather stations having records lasting two years or longer. Table I lists these stations and some relevant information concerning them and Figure 1 shows their distribution.

TABLE I—DETAILS OF STATIONS USED

Station	Position	Responsible body	Period now available	Equipment	Source of standardization	Reports to Met. Office
Lerwick	60°08′N 01°11′W	Met. Office	1958–60	S. + T.R.	Kew	Yes
Eskdalemuir	55°19′N 03°12′W	Met. Office	1950–60	S. + T.R.	Kew	Yes
Fairfield	53°48′N 02°53′W	Min. of Agric. Fish and Food	1958–60	S. + E.I.	N.I.A.E.	Yes
Sutton Bonnington	52°50′N 01°15′W	School of Agric., Univ. of Leicester	1958–60	S. + E.I.	N.I.A.E.	Yes
Wellesbourne	52°12′N 01°36′W	National Vegetable Research Station	1956–60	S. + E.I.	N.I.A.E. and Kew	Yes, not in standard form
Cambridge	52°13′N 00°06′E	Met. Office	1956–59	S. + T.R.	Kew	Yes
Silsoe	52°00′N 00°28′W	N.I.A.E.	1956–60	S. + P.	Kew	Yes
Rothamsted	51°48′N 00°21′W	Lawes Agric. Trust	1955–59	S. + P.M.	Kew	Yes
Garston	51°42′N 00°23′W	D.S.I.R. Building Research Station	1957–60	S. + P.E.	Kew	Yes
Aberporth	52°08′N 04°34′W	Met. Office	1957–60	S. + T.R.	Kew	Yes
Air Ministry, Kingsway	51°30′N 00°07′W	Met. Office	1956–60	S. + T.R.	Kew	Yes
Kew Observatory	51°28′N 00°19′W	Met. Office	1952–59	S. + I.M.	Compares with Davos	Yes
Shinfield Green	51°25′N 00°57′W	Electrical Research Assoc.	1957–60	S.	N.I.A.E.	Yes
Rosewarne	50°13′N 05°18′W	Min. of Agric. Fish and Food	1958–60	Ph. + E.I.	N.I.A.E.	Yes
Efford	50°44′N 01°36′W	Min. of Agric. Fish and Food	1957–60	S. + E.I.	N.I.A.E.	Yes
Dungeness	50°55′N 00°58′E	Trinity House	1957–60	B.	Kew	Yes, not in standard form
Valentia Observatory	51°56′N 10°15′W	Met. Office	1958–60	S.	Davos	No
Ocean weather stations	A 62°60′N 33°00′W; I 59°00′N 19°00′W; J 52°30′N 20°00′W	Met. Office	1958–60	S. + P.	Kew through Eskdalemuir	Yes

S. = Solarimeter
T.R. = Thread recorder
Ph. = Photometer
I.M. = Integrating motor + counter
E.I. = Electrolytic integrator
P. = Potentiometric recorder
P.M. = Potentiometric recorder + mechanical integrator
P.E. = Potentiometric recorder + electrical integrator circuit
B. = Bimetallic actinograph (M.O. Mk. III)

In addition to these data certain other stations record solar radiation but their data are either in an unsuitable form (for example, the School of Cosmic Physics, Dublin, which records radiation received by a spherical collector) or for a short period (for example, the Scottish Horticultural Research Institute, Invergowrie, and the Stockbridge House Experimental Horticulture Station). In the case of Dungeness, which is listed in Table I, a duration of bright sunshine record is not available, but data obtained directly have been used as a guide in drawing the distributions in the area.

In the case of those stations in Table I, the record used is often only a fraction of that available. In these cases a portion of the period has been discarded because of instrumental uncertainties, because the data are not easily accessible, or because a reliable duration of sunshine record has not been available for the whole period. The data remaining are, so far as can be ascertained, entirely reliable.

Following the precedent of Angström, Penman, Black and others a regression equation has been obtained for each of the stations listed, except for the ocean weather stations where a duration of bright sunshine record is not maintained. The regression equation takes the form stated above, that is

$$Q = Q_A\left(a + b\frac{n}{N}\right),$$

and the quantities used are monthly mean daily totals of bright sunshine n and of total solar radiation on a horizontal surface Q. In all cases n is derived from the Campbell–Stokes sunshine recorder. N is the length of day and Q_A that radiation which would be received on a horizontal surface at the station through a transparent atmosphere. The values of Q_A used are those listed by Angot.[8] The results obtained are summarized in Table II.

Previous work has suggested that although the constants may be grouped according to latitude ranges there is no regular latitudinal variation. The present values appear to support this view. Of the values quoted in Table II those for Cambridge, Aberporth, Kingsway and Rosewarne call for comment. The view has been expressed (Penman) that these anomalous values arise from defects of instrumentation, tabulation or exposure and that they should be rejected, particularly as they produce local maxima in the deduced total solar radiation distributions. In the case of Aberporth, Cambridge and Kingsway these matters have been examined and there appears no cause to fault them save that the exposure at Kingsway is not entirely perfect. Rosewarne is regularly inspected by staff of the N.I.A.E. and there appears no reason for the station to be at fault any more than other stations supervised by the same institution. Further, Aberporth and Rosewarne, supervised independently by two different institutions and having differing types of equipment produce consistent data.

A further objection which might be raised is that in some cases (for example, Rosewarne) $a + b$ exceeds or approaches unity whence it would appear possible that $Q \geqslant Q_A$. However, the regressions have been obtained on the basis of monthly means of daily totals of the related data and $Q \geqslant Q_A$ would imply n/N approaching unity on a monthly basis. This is clearly highly improbable in the area to which the investigation is confined and it is not intended that the values obtained for the constants a and b should be regarded as generally applicable outside this area. The use of regression equations on a

TABLE II—REGRESSION EQUATION BETWEEN TOTAL SOLAR RADIATION AND DURATION OF BRIGHT SUNSHINE, $Q = Q_A\left(a + b\frac{n}{N}\right)$

Station	Number of months used	Period	Mean values of $\frac{Q}{Q_A}$	Mean values of $\frac{n}{N}$	Range of values of $\frac{Q}{Q_A}$	Range of values of $\frac{n}{N}$	Regression constants a	Regression constants b	Sum $a+b$	Correlation coefficient
Lerwick	43	1956–60	0·323	0·212	0·217 0·446	0·060 0·420	0·19	0·65	0·84	0·84
Eskdalemuir	100	1950–60	0·316	0·258	0·170 0·478	0·048 0·534	0·17	0·55	0·72	0·74
Fairfield	22	1958–60	0·313	0·317	0·145 0·457	0·127 0·518	0·11	0·63	0·74	0·63
Sutton Bonnington	25	1958–60	0·319	0·289	0·202 0·436	0·068 0·488	0·17	0·52	0·69	0·85
Wellesbourne	31	1951–60	0·276	0·280	0·179 0·425	0·089 0·521	0·12	0·57	0·69	0·87
Cambridge	32	1956–59	0·351	0·316	0·190 0·514	0·064 0·539	0·12	0·75	0·87	0·99
Silsoe	47	1056–60	0·346	0·325	0·203 0·545	0·078 0·591	0·15	0·59	0·74	0·86
Rothamsted	32	1955–59	0·344	0·312	0·203 0·501	0·050 0·579	0·16	0·60	0·76	0·78
Garston	40	1957–60	0·313	0·253	0·176 0·468	0·087 0·524	0·14	0·68	0·82	0·83
Aberporth	33	1957–60	0·400	0·320	0·227 0·563	0·145 0·580	0·15	0·77	0·92	0·81
Air Ministry, Kingsway	35	1956–60	0·304	0·277	0·135 0·551	0·028 0·581	0·10	0·75	0·85	0·87
Kew Observatory	96	1952–59	0·327	0·331	0·150 0·480	0·130 0·600	0·14	0·57	0·71	0·86
Shinfield Green	31	1957–60	0·270	0·315	0·096 0·457	0·116 0·598	0·08	0·61	0·69	0·86
Rosewarne	22	1958–60	0·411	0·349	0·224 0·631	0·127 0·623	0·08	0·96	1·04	0·95
Efford	45	1957–60	0·399	0·378	0·190 0·512	0·143 0·646	0·20	0·54	0·74	0·84
Valentia	60	1954–59	0·404	0·290	0·256 0·616	0·130 0·610	0·22	0·65	0·87	0·90

daily basis, when n/N may approach unity, has been investigated by Blackwell[9] who has shown that (for Kew) it is not possible to obtain a simple linear equation. For this reason the extension of these data to periods significantly less than a month is specifically excluded from the present investigation.

For these reasons it has been decided to accept all the values listed in Table II as valid and they have been used in the deduction of distributions of total solar radiation on a horizontal surface. Further, since the constants *a* and *b* vary widely from place to place a single set of mean values has not been used, but the regression equation for a particular radiation station applied to sunshine stations of approximately similar exposure in the vicinity. In this way solar radiation data have been deduced for 40 stations, reasonably uniformly distributed over the British Isles (though there are some notable areas of sparse coverage). Table III lists the sunshine stations used and the "parent" radiation station in each case.

TABLE III—STATIONS USED IN THE DEDUCTION OF SOLAR RADIATION DISTRIBUTIONS

"Parent" radiation station	Sunshine station	Position
Lerwick	Onich	56°43′N 05°13′W
	Stornoway	58°13′N 06°20′W
	Kirkwall	58°59′N 02°57′W
	Nairn	57°36′N 03°52′W
	Inverness	57°26′N 04°13′W
	Oban	56°25′N 05°30′W
	Craibstone	57°11′N 02°12′W
Eskdalemuir	Keswick	54°36′N 03°09′W
	Newton Rigg	54°40′N 02°47′W
Fairfield	Douglas	54°10′N 04°28′W
	Bidston	53°24′N 03°04′W
	Morecambe	54°04′N 02°52′W
Sutton Bonnington	Leamington Spa	52°18′N 01°30′W
Wellesbourne	Birmingham	52°29′N 01°56′W
	Coventry	52°23′N 01°29′W
	Malvern	52°08′N 02°18′W
Cambridge	Norwich	52°37′N 01°17′E
	Hunstanton	52°57′N 00°29′E
	Yarmouth	52°35′N 01°43′E
Cambridge (cont.)	Cromer	52°56′N 01°17′E
	Felixstowe	51°57′N 01°20′E
Aberporth	Holyhead	53°19′N 04°37′W
Shinfield Green	Oxford	51°46′N 01°16′W
Rosewarne	Bude	50°50′N 04°33′W
	Penzance	50°07′N 05°32′W
	Jersey	49°11′N 02°06′W
	Guernsey	49°27′N 02°23′W
Efford (Lymington)	Brighton	50°49′N 00°50′W
	Bexhill	50°50′N 00°28′E
	Totland Bay	50°41′N 01°33′W
	Ryde	50°44′N 01°10′W
	Eastbourne	50°46′N 00°17′W
	Weymouth	50°36′N 02°27′W
	Sidmouth	50°41′N 03°14′W
	Calshot	50°49′N 01°18′W
	Sandown	50°39′N 01°09′W
	Ventnor	50°36′N 01°13′W
	Worthing	50°49′N 00°22′W
	Bournemouth	50°43′N 01°53′W
	Hastings	50°51′N 00°34′E

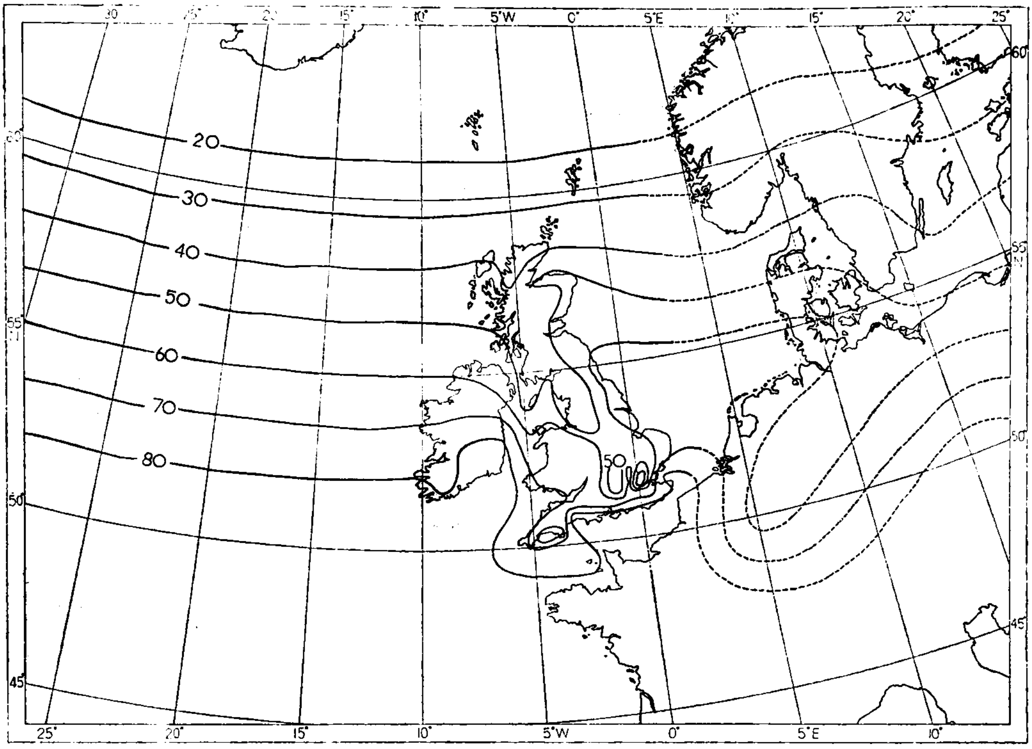

FIGURE 2—ISOPLETHS OF MEAN DAILY TOTAL OF TOTAL SOLAR RADIATION ($MW\ HR\ CM^{-2}\ DAY^{-1}$) FOR JANUARY

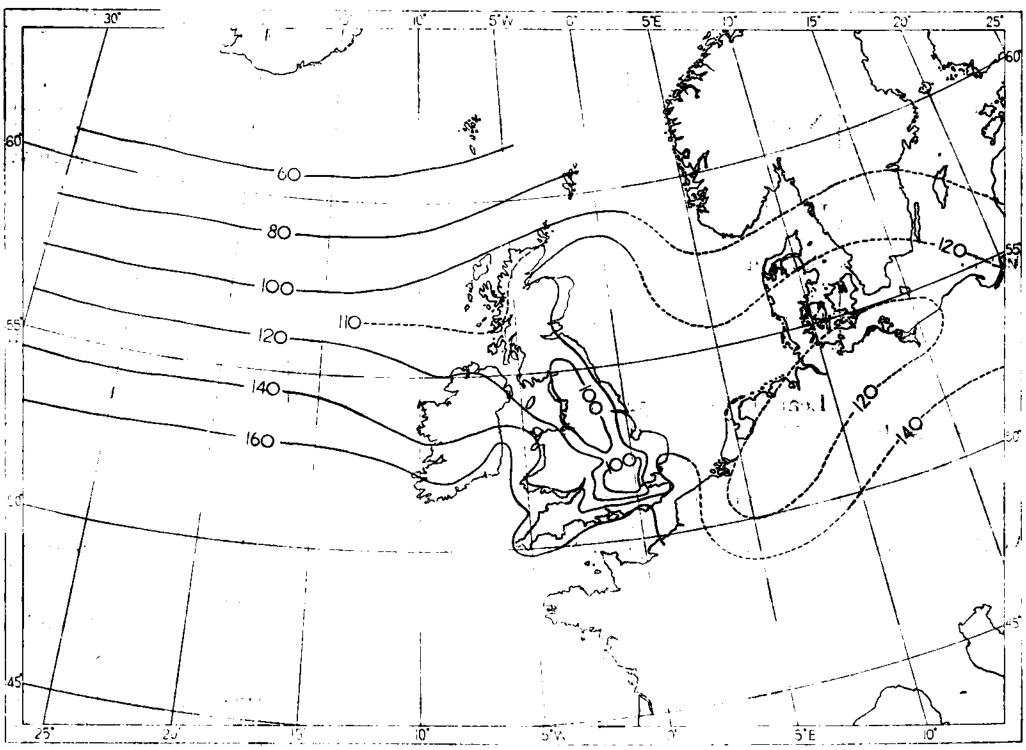

FIGURE 3—ISOPLETHS OF MEAN DAILY TOTAL OF TOTAL SOLAR RADIATION ($MW\ HR\ CM^{-2}\ DAY^{-1}$) FOR FEBRUARY

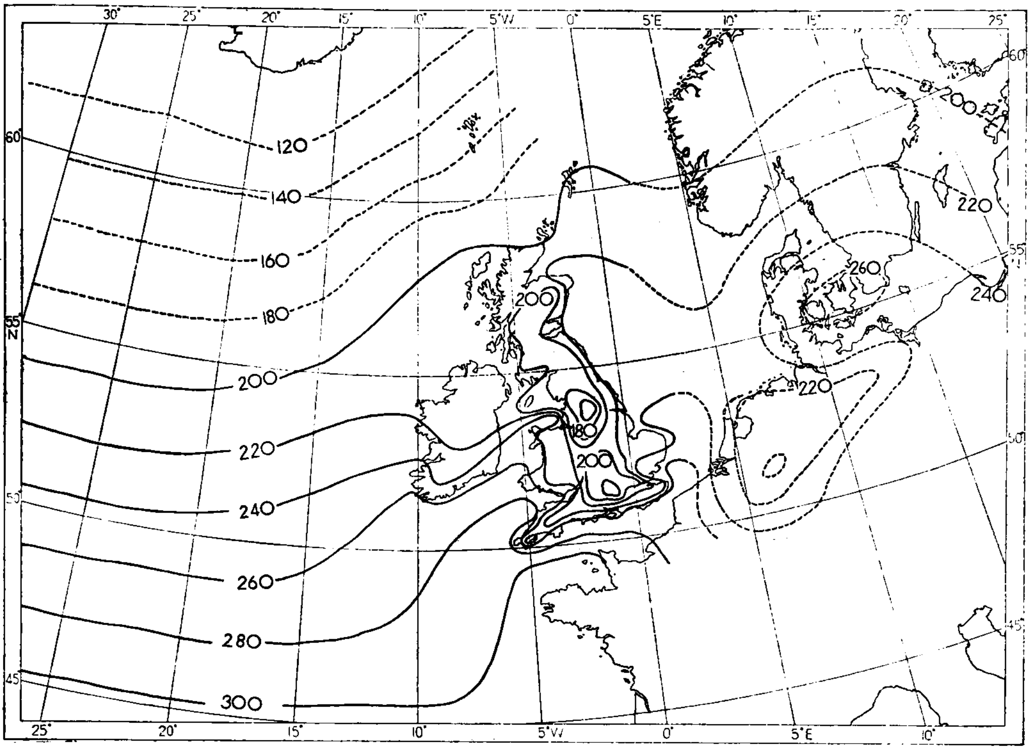

FIGURE 4—ISOPLETHS OF MEAN DAILY TOTAL OF TOTAL SOLAR RADIATION (MW HR CM^{-2} DAY^{-1}) FOR MARCH

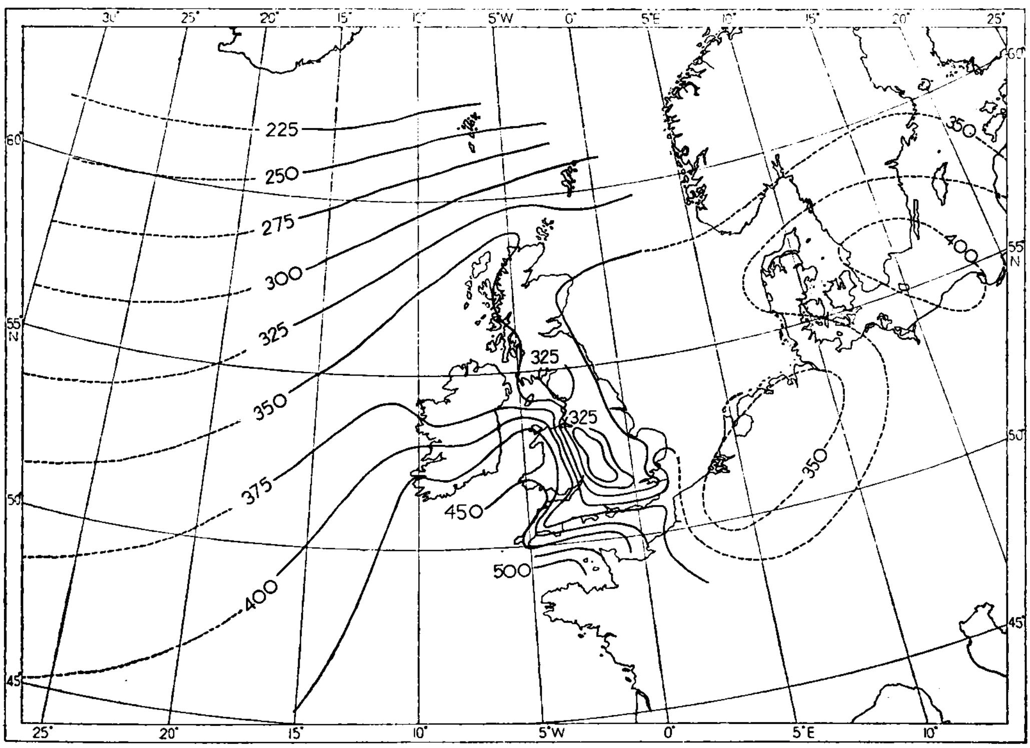

FIGURE 5—ISOPLETHS OF MEAN DAILY TOTAL OF TOTAL SOLAR RADIATION (MW HR CM^{-2} DAY^{-1}) FOR APRIL

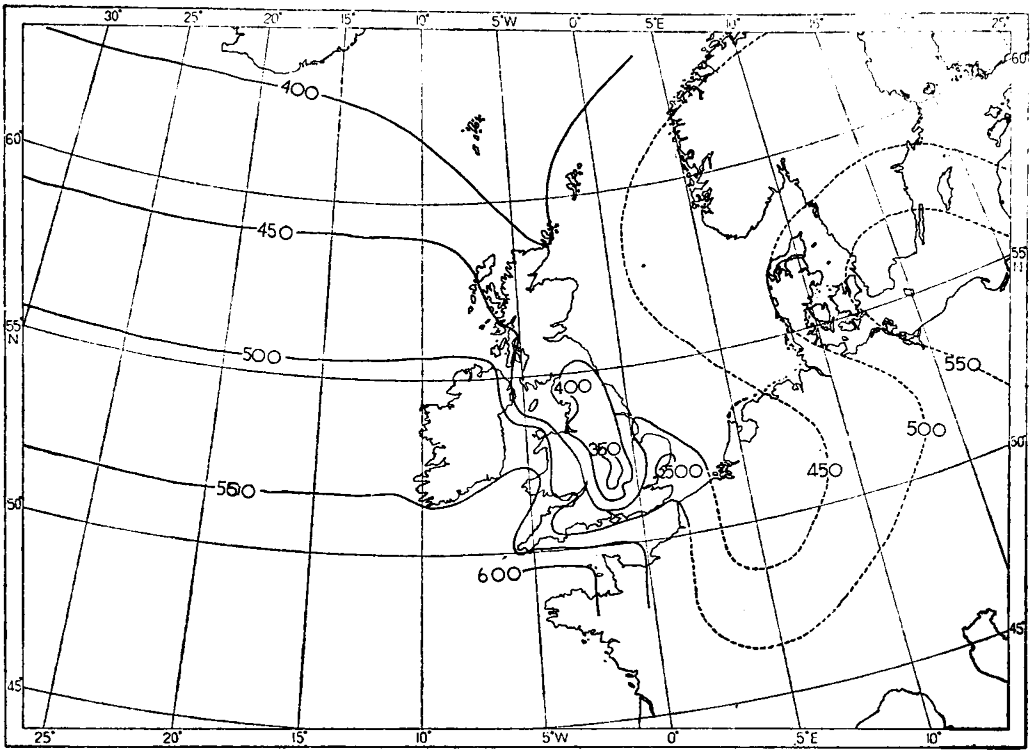

FIGURE 6—ISOPLETHS OF MEAN DAILY TOTAL OF TOTAL SOLAR RADIATION (MW HR CM^{-2} DAY^{-1}) FOR MAY

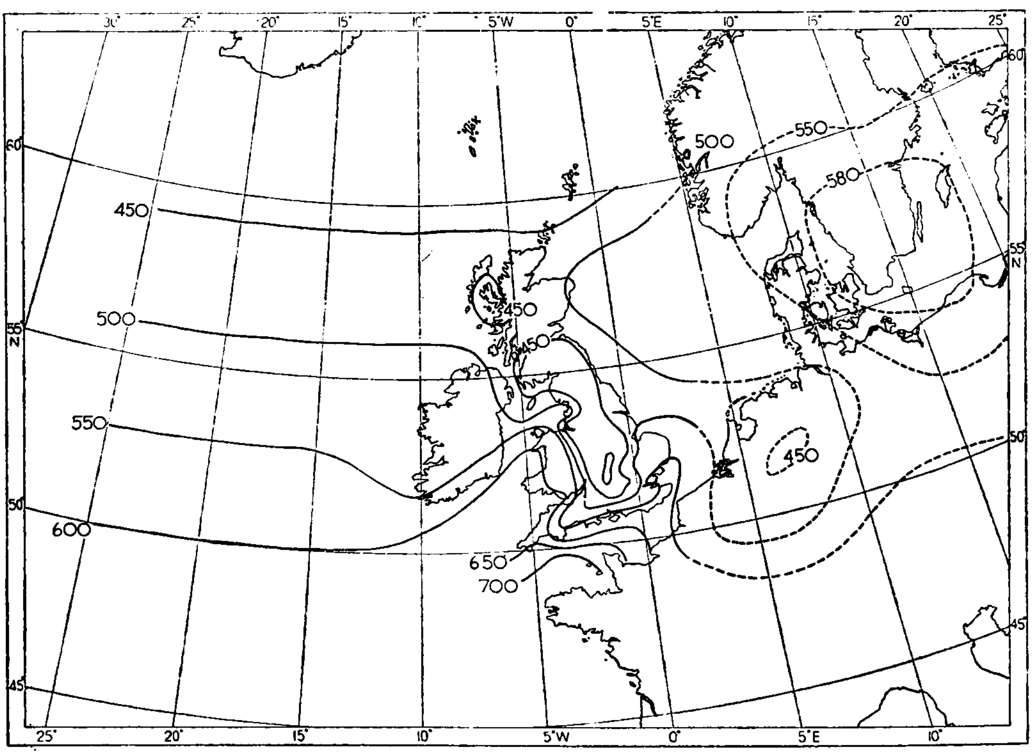

FIGURE 7—ISOPLETHS OF MEAN DAILY TOTAL OF TOTAL SOLAR RADIATION (MW HR CM^{-2} DAY^{-1}) FOR JUNE

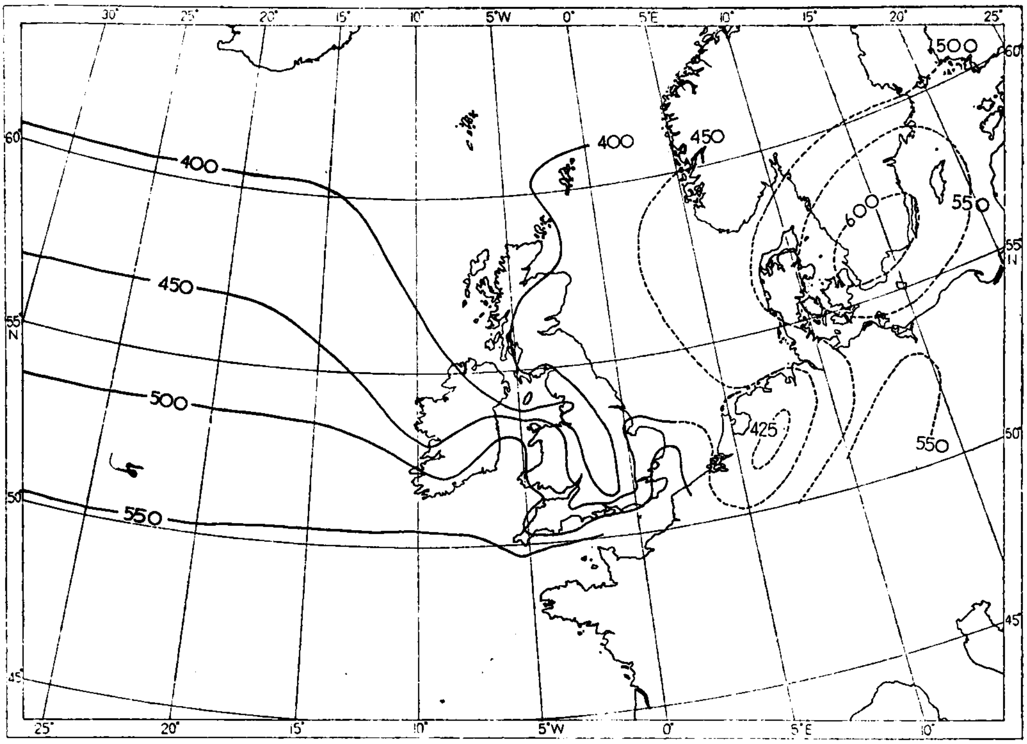

FIGURE 8—ISOPLETHS OF MEAN DAILY TOTAL OF TOTAL SOLAR RADIATION (MW HR CM^{-2} DAY^{-1}) FOR JULY

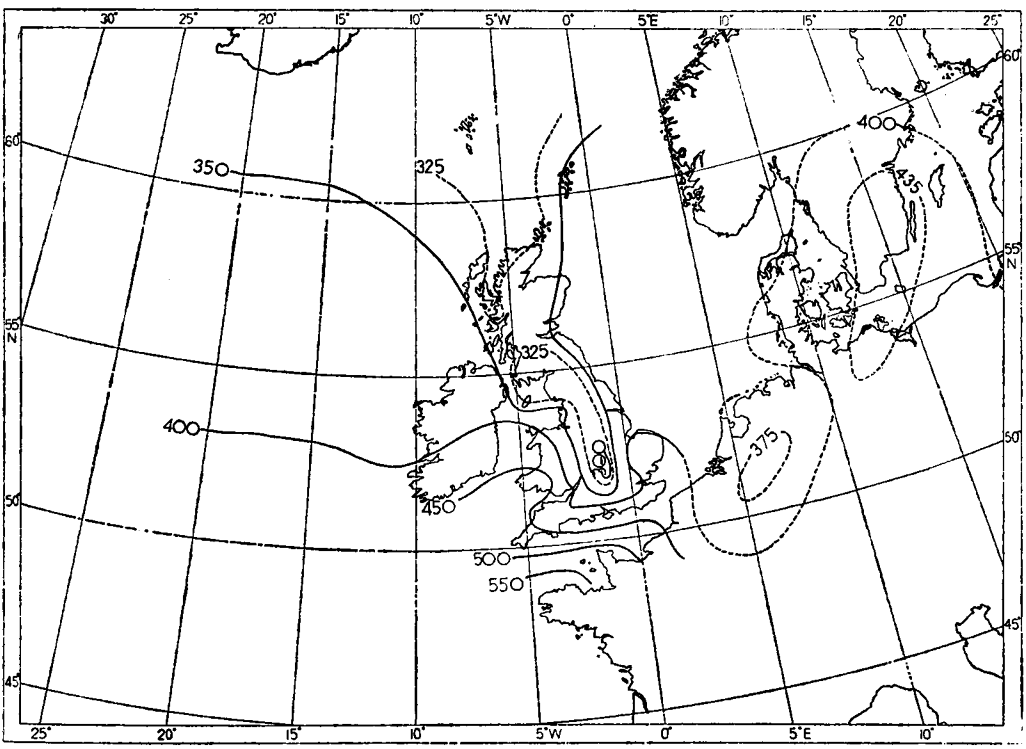

FIGURE 9—ISOPLETHS OF MEAN DAILY TOTAL OF TOTAL SOLAR RADIATION (MW HR CM^{-2} DAY^{-1}) FOR AUGUST

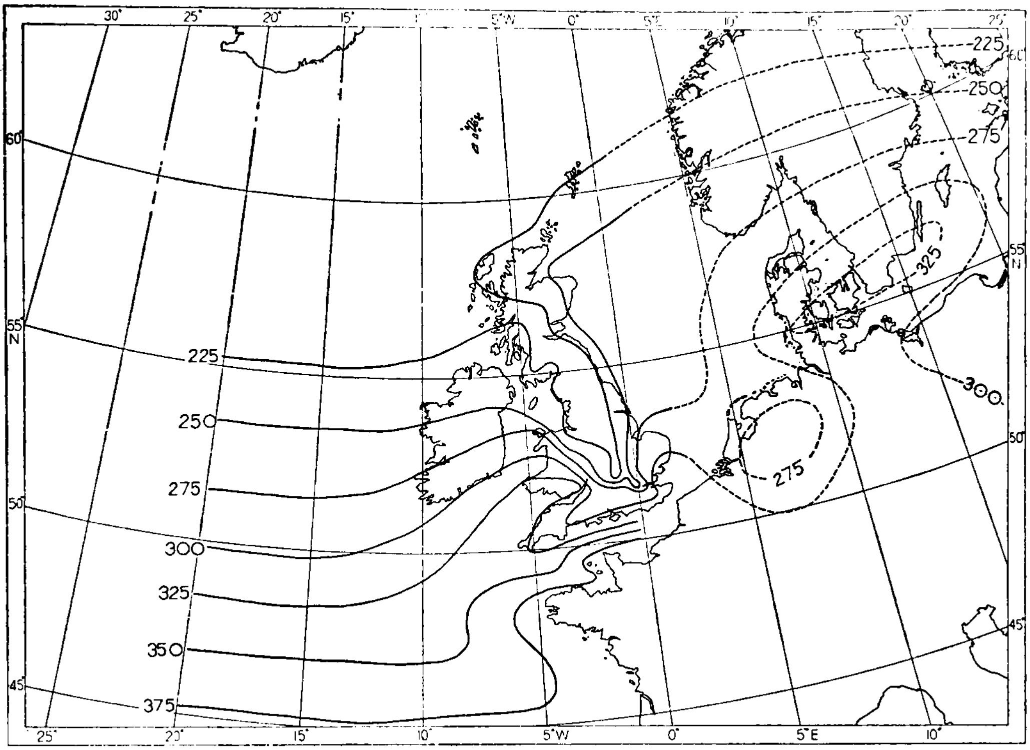

FIGURE 10—ISOPLETHS OF MEAN DAILY TOTAL OF TOTAL SOLAR RADIATION (MW HR CM^{-2} DAY^{-1}) FOR SEPTEMBER

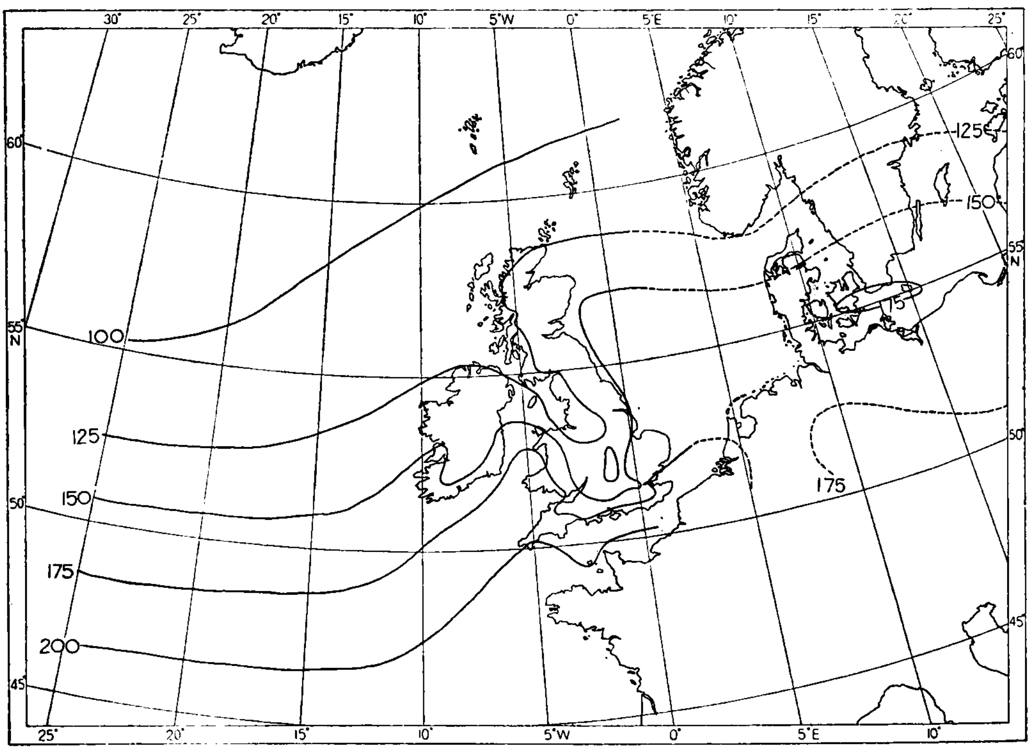

FIGURE 11—ISOPLETHS OF MEAN DAILY TOTAL OF TOTAL SOLAR RADIATION (MW HR CM^{-2} DAY^{-1}) FOR OCTOBER

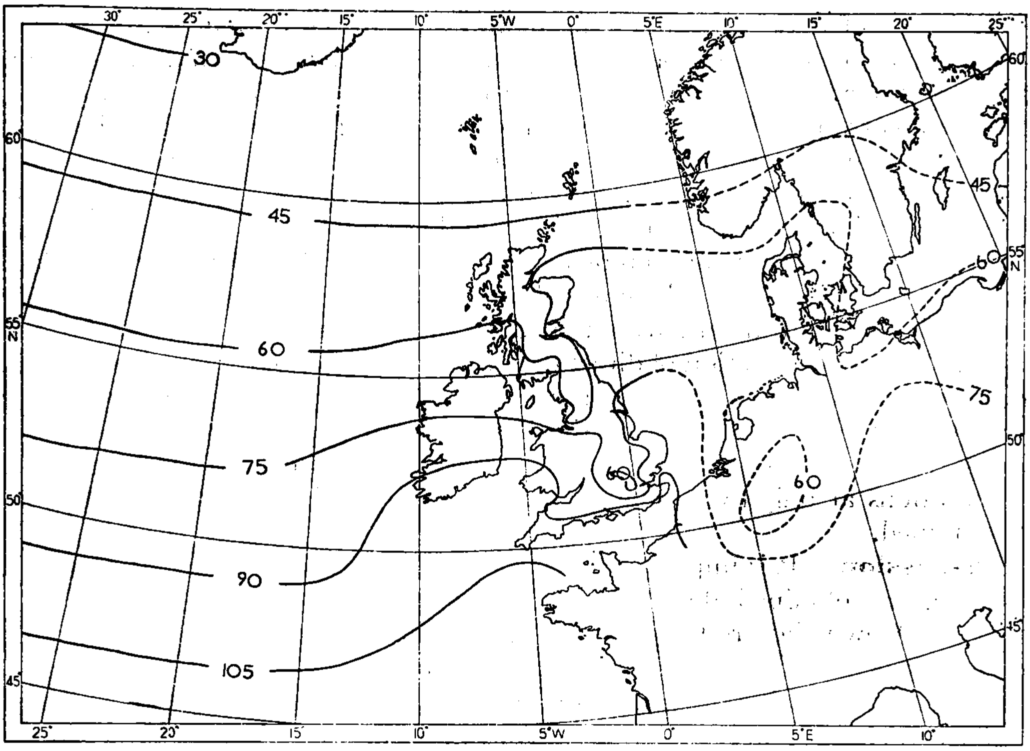

FIGURE 12—ISOPLETHS OF MEAN DAILY TOTAL OF TOTAL SOLAR RADIATION (MW HR CM^{-2} DAY^{-1}) FOR NOVEMBER

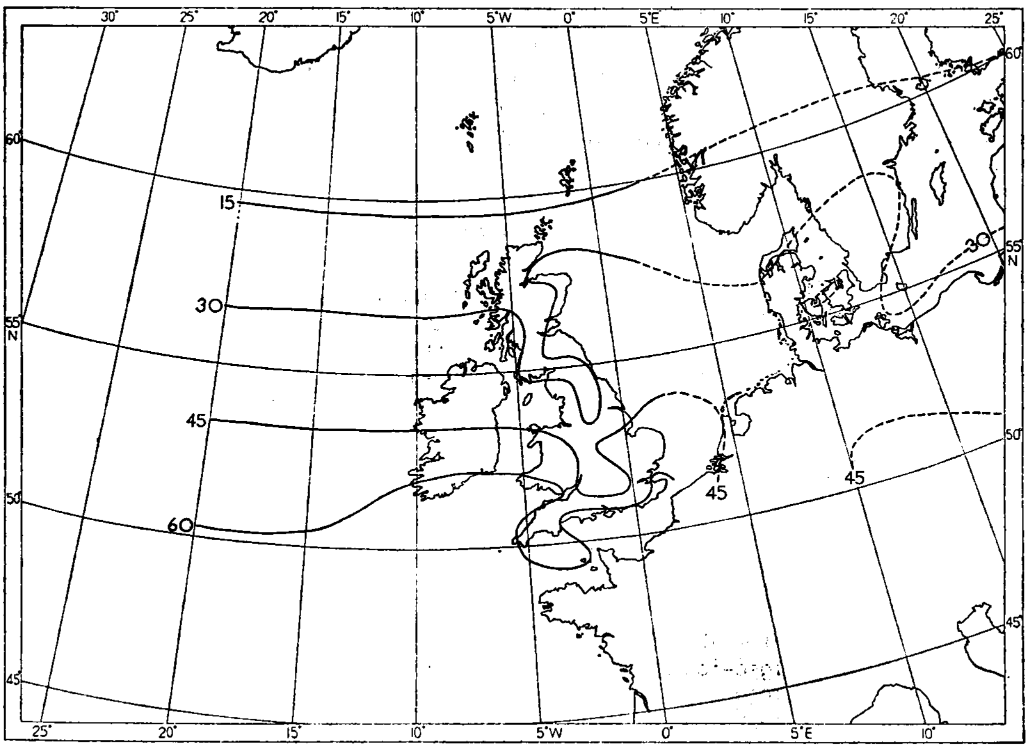

FIGURE 13—ISOPLETHS OF MEAN DAILY TOTAL OF TOTAL SOLAR RADIATION (MW HR CM^{-2} DAY^{-1}) FOR DECEMBER

For each of these 40 stations the monthly mean daily totals of bright sunshine have been taken from *Averages of bright sunshine for Great Britain and Northern Ireland, 1921–1950*[10] and the appropriate regression equation used to deduce a corresponding monthly mean daily total of total solar radiation on a horizontal surface. The direct data available from the 17 radiation stations listed in Table I have been normalized to the same period (1921–50) by use of the relative durations of bright sunshine, and the total of 57 values so obtained plotted as monthly distributions on a conical orthomorphic projection (standard latitudes 60° and 45°N). These distributions have been smoothly linked to the east with similar distributions obtained by Black for the region 50°–60°N and 05°–30°E by consideration of direct data from a number of radiation stations in north-eastern Europe. Similarly the distributions have been extended to the west by use of direct data from the British ocean weather ships, though this latter extension is much more tentative since it is based on a short period of observations at only two positions. Figures 2–13 are the monthly distributions so obtained.

Discussion.—It is important to consider what confidence may be placed in the diagrams obtained above. The questions arise:

(*a*) How valid are the extrapolations of short-period radiation data to the longer periods covered by the sunshine data?

(*b*) How valid is the application of a single regression equation obtained from a run of data to individual months, that is, is there a seasonal variation in the regression constants?

(*c*) How accurate are the estimates represented by the diagrams?

These questions may be considered in turn as follows:

Question (*a*).—We may take the data from the three stations having the longest run of data known to be reliable—Kew, Rothamsted and Eskdalemuir—and divide the data into minor runs, recalculating the regression equations and comparing the constants so obtained with those originally derived. The results are given in Table IV, whence it would appear that

TABLE IV

(i) *Kew*

Period	Value of constant *a*	*b*
1952–59	0·14	0·57
1952–55	0·15	0·57
1956–59	0·17	0·50

(ii) *Rothamsted*

Period	Value of constant *a*	*b*	
1931–40 ...	0·18	0·55	*Note:* two periods correspond to differing instrumentation, hence earlier period not used in Table II.
1955–59 ...	0·16	0·60	

(iii) *Eskdalemuir*

Period	Value of constant *a*	*b*
1950–60	0·17	0·55
1950–55	0·17	0·59
1956–60	0·16	0·62

in the worst case (that is, of $n/N = 1$) the uncertainty at Kew is about $\pm$ 3·5 per cent, at Rothamsted about $\pm$ 2 per cent and at Eskdalemuir about $\pm$ 2 per cent.

Question (b).—Similarly, the data for Kew, Eskdalemuir and Lerwick may be subdivided into two-month groups and the regression equations recalculated, the constants then being examined for a seasonal variation. Table V lists the data obtained.

TABLE V—BIMONTHLY REGRESSION CONSTANTS

Station	Jan.–Feb. *a*	Jan.–Feb. *b*	Mar.–Apr. *a*	Mar.–Apr. *b*	May–June *a*	May–June *b*	July–Aug. *a*	July–Aug. *b*	Sept.–Oct. *a*	Sept.–Oct. *b*	Nov.–Dec. *a*	Nov.–Dec. *b*
Kew	0·15	0·35	0·16	0·50	0·31	0·02	0·22	0·42	0·18	0·51	0·19	0·27
Eskdalemuir ...	0·13	0·69	0·22	0·42	0·16	0·60	0·20	0·57	0·17	0·59	0·15	0·52
Lerwick	0·17	0·61	0·14	0·75	0·23	0·54	0·20	0·67	0·33	0·04	0·19	0·62

a and *b* are constants in the regression equation $\frac{Q}{Q_A} = a + b\frac{n}{N}$

It will be seen that there is no consistent seasonal trend. This procedure may, however, be criticized in that the number of cases in each group is perhaps too small for a significant result to emerge. It is thought that, though no great use may be made of the values listed, some systematic pattern should have appeared had there been a seasonal variation.

Question (c).—It is instructive to examine records from the three stations Kew, Eskdalemuir and Lerwick once more. Examination of the individual monthly means shows that for a given value of n/N the observed value of Q/Q_A may vary by ± 20 per cent at Kew, ± 15 per cent at Eskdalemuir and ± 25 per cent at Lerwick and this is a measure of the possible error in the estimate for a single month. Obviously, however, for long-term prediction of an average condition the errors are much reduced, but these figures must still be borne in mind as an indication of the basic lack of precision of the method—there is no accurate substitute for actual measurement at a site, though in a particular case this is often impracticable, or not appropriate to the local problem.

The diagrams presented, then, provide an indication of the distribution of total solar radiation on a horizontal surface over the British Isles and adjacent areas, and of the changes in the distribution through the year. Estimates of total radiation based on these diagrams may, however, be in error by up to ± 25 per cent for an individual month and daily totals will differ greatly from these values.

Suggestions for further work.—As will have been noted, the distribution of radiation stations in the network is badly biased and the data at present available very restricted. An investigation similar to this one would appear to be desirable in a further five or ten years' time when more data are available. Consideration of an extension to the radiation network appears to be desirable at the present time.

Acknowledgements.—Acknowledgements are gratefully made to the authorities responsible for the stations named in Table I for permission to use the data gathered at their institutions, and are also due to several of my colleagues and to my wife for their assistance in the analysis of a large volume of data.

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551.501.42 : 551.508.2

RADIATION RECORDING IN THE METEOROLOGICAL OFFICE

By L. JACOBS, M.A., M.Sc.

Introduction.—This paper gives a short account of the types of radiation recording instruments in use in the Meteorological Office. These are solarimeters for measuring short-wave radiation, illumination recorders for measuring daylight, and radiometers responding to the vertical net flux of radiation (long- and short-wave) as well as the normal sunshine recorders. The instruments (and recording systems), described in turn below, are illustrated in Figure 1 and Plates I–IV (between pp. 284–285). Table I lists the home and overseas stations possessing radiation instruments and the dates recording began. The present automatic integration system being used at Kew is described and an outline is given of the digitization system being considered with tapes produced at each station being processed at a computer centre.

Short-wave radiation solarimeters

Normal incidence radiation.—Short-wave radiation in the band $0{\cdot}3\mu$ to 3μ is recorded by pyrheliometers whose outputs are connected to recording galvanometers (Cambridge thread recorders); the direct normal incidence short-wave solar radiation has been recorded since July 1932 at Kew on a Moll-Gorczynski large surface thermopile (80 thermocouple junctions) on an equatorial mounting, driven originally by a pendulum and now by a spring clock. With slight changes of elevation each day to keep pace with changing solar declination, the heliostat ensures that the thermopile surface is kept normal to the direct radiation from the sun. A wire frame attached to a collar which fits on to the thermopile holder carries three metal diaphragms spaced outwards from the thermopile so that the angular aperture allows only radiation from the sun and a narrow annulus of sky to fall on the thermopile (see Plate I). The thermopile is protected by a glass cover.

Also at Kew are twin Moll-Gorczynski pyrheliometers made exactly the same as the direct radiation one just described and in this case driven by an electric clock to keep them pointing into the sun's direct beam. These have filters on their apertures so as to restrict the band of solar radiation received. In the period September 1947 to November 1949 records are available separately for these two instruments and from 19 July 1956 they have been coupled so that the difference between the records of the two instruments is given thus recording short-wave radiation for a narrow band.

PLATE I—SOLAR RADIATION EQUIPMENT AT KEW OBSERVATORY, 1953

(see p. 284)

A. Diffuse (sky) solarimeter
B. Daylight illumination recorder
C. Twin pyrheliometer with filters
D. Total (sun and sky) solarimeters
E. Gorczynski pyrheliometer
F. Sunshine recorder

PLATE II—TOP PLATFORM OF SOLAR RADIATION EQUIPMENT AT KEW OBSERVATORY, 1959

(see p. 285)

A. Daylight illumination recorder
B. Total (sun and sky) solarimeters
C. Diffuse (sky) solarimeter

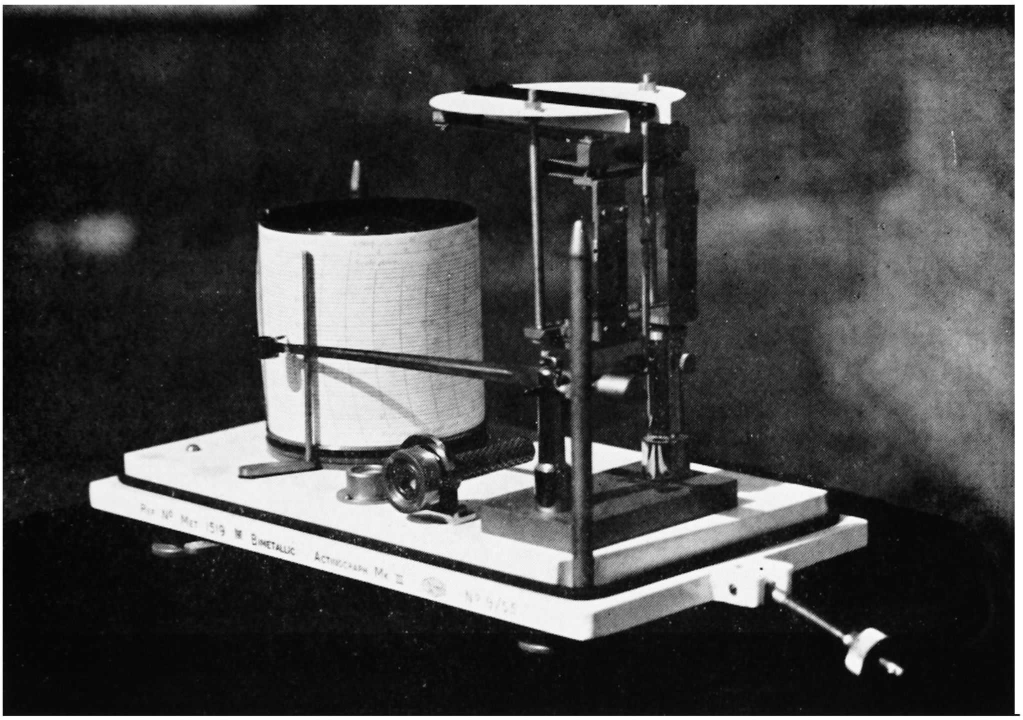

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PLATE III—BIMETALLIC ACTINOGRAPH, MARK III

(see p. 286)

To face p.285]

PLATE IV—VENTILATED NET FLUX RADIOMETER

(see p. 287)

The records of the normal incidence solar radiation instrument were discussed by Stagg[1] for the period up to 1945. A further discussion of these results to 1949, together with the results obtained from the instruments with the filters, was given by Blackwell, Eldridge and Robinson.[2] Figure 2 of their paper shows the transmission properties of the filters used and the narrow band of wavelength (about $0{\cdot}55\mu$ to $0{\cdot}65\mu$) covered by the difference of the filters. Kew is the only Meteorological Office station to have these normal incidence recorders.

TABLE I—METEOROLOGICAL OFFICE STATIONS POSSESSING RADIATION RECORDING INSTRUMENTS (EXCLUDING NORMAL SUNSHINE RECORDER), TOGETHER WITH DATE OF BEGINNING OF RECORDING

	Moll-Gorczynski pyrheliometer for normal incidence solar radiation	Moll-Gorczynski solarimeter for total radiation	Moll-Gorczynski solarimeter for diffuse radiation	Daylight illumination	Net flux of radiation
Kew	July 1932	July 1946	July 1946	Jan. 1947	May 1953
Eskdalemuir		Jan. 1952	Jan. 1952	April 1958	
Lerwick		Jan. 1952	Jan. 1952	April 1958	
Cambridge		Aug. 1956	Sept. 1956		
Aberporth		Jan. 1953	Jan. 1953		
Victory House, London ...		Nov. 1956	Mar. 1957	Feb. 1956	
Four ocean weather ships ...		Jan.–Aug. 1958			Aug.-Sept. 1958
Malta		Oct. 1957	Oct. 1957		Oct. 1957
Aden		July 1957	Julv 1957		July 1957
Stanley		June 1957	June 1957		June 1957
Argentine Islands*		Jan. 1956	Jan. 1956		Mar. 1957
Halley Bay Antarctica* ...		Aug. 1956	Aug. 1956		Mar. 1957

* The meteorological offices are controlled by the Falkland Islands Dependencies Survey but there is close liaison with the British Meteorological Office.

Notes: 1. A blank in the above table indicates that no instrument is held at the station
2. Stations with total radiation solarimeters have bimetallic actinographs as standby instruments (with the exception of the ocean weather ships).

Total and diffuse radiation on a horizontal surface.—The intensity of short-wave solar radiation ($0{\cdot}3\mu$ to 3μ) on a horizontal surface is determined by Moll-Gorczynski solarimeters (obtained from Messrs. Kipp and Zonen). It is usual also to measure the diffuse radiation which is obtained by fitting a shade ring to the solarimeter in such a manner that the direct radiation from the sun is cut off. (The instruments used at Kew are shown in Plates I and II*.) The thermopiles have fourteen thermo-junctions covered by two hemispherical glass domes. The output from the two solarimeters is recorded by a multi-channel recording galvanometer (at land stations) or self-balancing potentiometer (on ocean weather ships). From the calibration factors of each instrument suitable resistances are included in the thermopile circuits so that under overcast skies the two traces will fall together. Recording with these instruments was started at Kew in January 1947 and the first five years of records have been discussed by Blackwell.[3] These instruments are widely distributed—a list of radiation instruments maintained at the various Meteorological Office stations together with the dates of commencement of recording is given in Table I. It will be seen therein that much of the recording began with the International Geophysical Year but it is intended to continue the recording at the observatories as part of the normal routine and to do this also as far as possible at the other stations.

* Before the end of 1954 all the radiation instruments at Kew were on the balcony as shown in Plate I and corrections had to be made to the total and diffuse radiation results for obstruction by the observatory dome to the north and reflection by the dome. After this date instruments likely to be affected were removed to a new platform on top of the dome as shown in Plate II.

Short-wave radiation—bimetallic actinograph.—As a standby instrument for the total radiation solarimeter the bimetallic actinograph was developed at Kew from the Robitzsch-type actinograph.[4] The detecting assembly consists of a central black strip and two outer strips shaded by white screens as shown in Plate III. The Mark III instrument as designed at Kew has been made commercially. The pen records on a chart are not normally analysed but are checked against the station solarimeters from time to time so that if the latter went wrong the bimetallic instrument could be used until a replacement solarimeter was obtained.

Daylight illumination recorder.—The daylight illumination recorder gives nearly the same response to the light as a standard eye, as specified by the International Commission on Illumination from the results of experiments of numerous observers. This specification states the relative sensitivity of the eye throughout the spectrum to a given quantity of monochromatic radiation. Although the sensitivity function varies with intensity at lower levels of illumination it is constant in the range adapted to conditions of high luminance (photopic vision).

The development of the illumination recorder at Kew has been discussed by Blackwell[5] and Blackwell and Powell.[6] Figure 2 of the first of these papers[5] shows how close the "eye" and the selenium photocell combined with a specially constructed correcting filter, exposed below a diffusing surface of opal

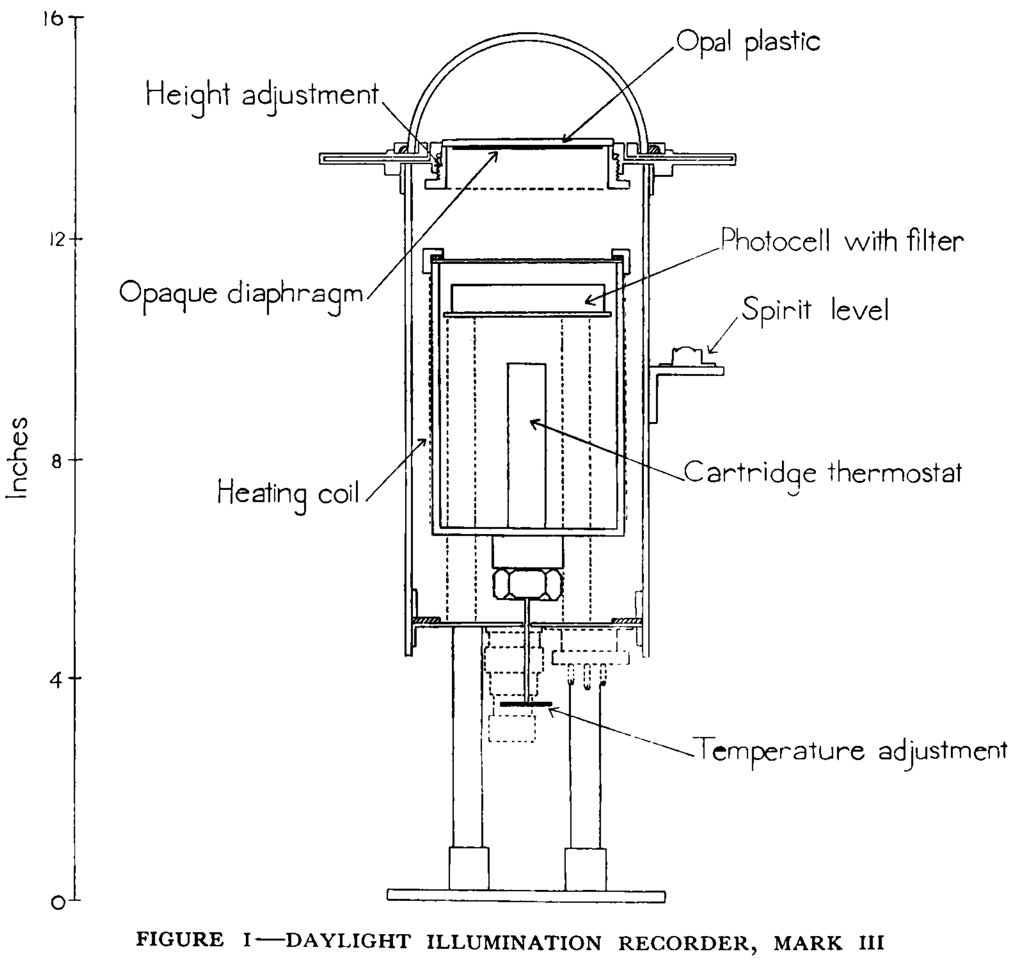

FIGURE I—DAYLIGHT ILLUMINATION RECORDER, MARK III plastic (see Figure 1), match in the given range $0 \cdot 4\mu$ to $0 \cdot 7\mu$. The instrument is thermostatically controlled at 85°F to remove outside temperature effects. The current output against intensity of illumination curve for the type of photocell used depends on the load resistance. To obtain a nearly linear relation this resistance is best fixed at about 200 ohms. The output from the cell is led away to a recording galvanometer which is combined with a network of shunt and series resistors arranged in such a way as to allow three sensitivities (for different times of the year) while keeping the load resistance constant at 200 ohms.

Further development of the daylight illumination recorder is being considered at Kew including the study of photocells and filters with a longer life and the development of a recording photometer for the diffuse component of daylight.

Net flux of radiation (radiation balance).—To study the net flux of radiation, radiometers based on the design described by MacDowall[7] (see Plate IV) are used. The sensitive element is a thermopile arranged to measure the temperature difference between the upper and lower surfaces of a flat plate about three inches square and an eighth of an inch thick. The plate, which is placed horizontally about three to four feet above a surface representative of the surrounding area, is painted black and is ventilated artificially by an electric blower to minimize the effect of wind changes. The black paint is an almost perfect absorber over a wide range of wavelength (at least $0 \cdot 3\mu$ to 40μ) and is reasonably weatherproof (though evaporative cooling causes the instrument to give false readings while the plate is actually wet from rain or snow). Land stations are generally supplied with two instruments, one for routine use and the other as a standard to judge whether the first has gone wrong. The element is robust enough to be washed to eliminate surface contamination by dust, salt or sand particles and can be repainted at the station. The output from these flux plates is recorded by a self-balancing potentiometer (on ocean weather ships) or, after amplification by a magnetic amplifier, on a pen recording milliammeter (at land stations).

On board ocean weather ships two radiometers are used one on each side of the ship surveying a half hemisphere, the two outputs being added before recording. Special mountings are necessary to ensure stability of position. Winds greater than Beaufort force 7 cause trouble through waves and spray and the instruments are then taken under cover.

Sunshine recorders.—Sunshine recorders used at stations are the normal Campbell-Stokes type and are merely mentioned here for completeness. The use of these records in considering the general radiation balance has been discussed by Blackwell, Eldridge and Robinson[2].

Recalibration of instruments.—Kew Observatory issues recalibrated radiation instruments about every year to all stations. Certain routine checks are made at the stations. The bimetallic actinograph is constantly checked against the total radiation solarimeter. For daylight illumination, stations can make a monthly test on a simple optical bench. The mutual check of the two net flux radiometers held at land stations has been mentioned above.

The standard of radiation at Kew is based on readings of Angström compensating pyrheliometers which have unshielded black strips. The Moll-Gorczynski solarimeters used at Kew are calibrated against these Angström instruments (No. 24, 100A and 100B) by direct comparison on clear days. The instruments used at outstations are calibrated by comparison with the Kew instruments, using natural radiation when possible and radiation from a 2000-watt lamp in bad weather. One of the Kew Angström instruments is calibrated against the primary standard at the Meteorological and Geophysical Institute, Stockholm, Sweden about every five years. The last calibration was made in 1959. The Office joins in international comparisons which are held at Davos in Switzerland—the last one was in August 1959. The results of these comparisons show that the Angström instrument keeps its calibration to within one per cent over a period of years.

The illumination recorders are calibrated at Kew by using filament lamps whose light output in standardized conditions has been measured at the National Physical Laboratory.

The response of the net flux radiometers to short- and long-wave radiation was carefully investigated by MacDowall[7] and found to be identical. They are now calibrated (for short-wave radiation only) by comparison with the Angström pyrheliometers at Kew.

Accuracy of radiation measurements.—The general accuracy of radiation measurements including estimation of hourly totals from the recordings, as discussed in the various papers mentioned above, is within about ± 5 per cent, but may be worse in some normal incidence solarimeter records, under broken cloud conditions. It is hoped to eliminate the chart-measuring error by the automatic integration processes which are discussed below.

Publication of data.—The only routine publication of radiation data is in the *Monthly Weather Report* where mean, maximum and minimum daily totals are given for total radiation, diffuse radiation and illumination on a horizontal surface for Eskdalemuir, Kew, Kingsway, Lerwick, Aberporth and Cambridge. The unit for radiation is the standard mw hr cm^{-2} and illumination is given in kilolux-hours, but during and after the International Geophysical Year special World Meteorological Organization radiation forms were completed at all stations in cal cm^{-2}.

The Kew monthly totals of hourly values of normal incidence radiation (and sunshine) have been published in the relevant *Observatories' Year Books* up to 1956, following which all radiation (and meteorological) data no longer appear in the Year Books but are recorded on Hollerith punched cards. Special radiation forms to facilitate the use of Hollerith cards were introduced for routine use by stations from 1 January 1958 with the proviso that stations with records before that date are, as time permits, to complete the forms for earlier years. These forms list mean hourly values and daily totals.

Automatic integration—present system and future plans.—Blackwell[8] described the system in use at Kew for automatic integration of solar radiation to eliminate the tedious procedure of obtaining hourly means by eye readings of the chart records. The method of integration adopted was to use a magnetic amplifier to drive a low inertia, permanent magnet d.c. integrating motor and a suitable counter. The original dials of the counter were read once daily but later (from March 1958) a time-marking system was utilized to operate an automatic camera to photograph all the dials (by then total, diffuse and normal incidence radiation, illumination and net flux of radiation were all recorded on separate dials) in order to give hourly totals of radiation. The negative is projected on a screen in a dark room for convenient reading. However, the photographic method of recording is not very convenient and a system has been developed in which the recorded information is stored automatically on punch paper tape. The method adopted is to measure the output of each instrument by the self-balancing potentiometer once a minute; the reading of the potentiometer is then converted into a number (between 0 and 999) and the digits of this number punched on to the paper tape in the correct order by means of a standard tape punch. This tape will be sent to the Meteorological Office computer (Meteor) for processing. Complete chart records are also to be maintained. The first such automatic data processing equipment will shortly be installed at Kew Observatory and it is expected that such equipment will be used later at all other radiation stations.

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551.521.12 (41–4) : 551.521.16

ESTIMATION OF AVERAGES OF RADIATION AND ILLUMINATION

By S. M. TAYLOR, B.Sc. and L. P. SMITH, B.A.

Data.—Records of daily values of radiation and illumination on a horizontal surface have been taken at Kew since 1947 in units of gram-calories* per square centimetre (R) and kilolux (I). Although they are not all of an equal standard of accuracy, 12 years of data are now available.

Initial analysis.—The data were divided into three 10-day periods per month. A simple regression against sunshine hours was computed for each of these 36 periods, that is 1–10, 11–20, 21–31 January and so on. Considering the possibility of unknown errors in the data and the other unconsidered meteorological factors involved the results were reasonably consistent, but slight irregularities in the terms were apparent. To obviate these, the coefficients were plotted on a time scale. A smooth curve was drawn and the monthly values read off at the appropriate points giving the results shown in Table I.

* [For purposes of comparison with other articles in this number 1 gram-calorie is equivalent to 1·16 milliwatt hours.—*Ed.*]

TABLE I

Month	Radiation	Illumination
January	$10 \cdot 0\,S + 37$	$11 \cdot 6\,S + 48$
February	$15 \cdot 6\,S + 61$	$18 \cdot 4\,S + 77$
March	$23 \cdot 0\,S + 101$	$25 \cdot 6\,S + 128$
April	$28 \cdot 0\,S + 140$	$24 \cdot 0\,S + 185$
May	$31 \cdot 2\,S + 178$	$30 \cdot 2\,S + 240$
June	$32 \cdot 0\,S + 212$	$40 \cdot 8\,S + 300$
July	$30 \cdot 6\,S + 200$	$40 \cdot 2\,S + 288$
August	$28 \cdot 0\,S + 164$	$37 \cdot 2\,S + 236$
September	$22 \cdot 8\,S + 126$	$30 \cdot 4\,S + 180$
October	$16 \cdot 6\,S + 83$	$20 \cdot 0\,S + 113$
November	$11 \cdot 8\,S + 46$	$13 \cdot 2\,S + 62$
December	$9 \cdot 2\,S + 30$	$9 \cdot 6\,S + 40$

S = mean sun hours

The effect of haze.—It is reasonable to assume that a considerable factor is the presence or absence of haze. Figures are available, from an earlier investigation, of the average number of days per month at about 60 stations when the afternoon visibility was (i) below 4400 yards and (ii) below 6¼ miles. It is tempting to use the sum of these two parameters as a "visibility factor" (V). If S is eliminated between the two sets of expressions in Table I, we obtain Table II for Kew:

TABLE II

Month	Value of R in terms of I	Mean visibility factor (V)
January	$0 \cdot 86\,I - 0 \cdot 4$	43
February	$0 \cdot 85\,I - 0 \cdot 3$	33
March	$0 \cdot 90\,I - 0 \cdot 6$	30
April	$0 \cdot 82\,I - 0 \cdot 4$	15
May	$0 \cdot 80\,I - 0 \cdot 4$	11
June	$0 \cdot 78\,I - 0 \cdot 7$	7
July	$0 \cdot 76\,I - 0 \cdot 6$	6
August	$0 \cdot 75\,I - 0 \cdot 4$	6
September	$0 \cdot 75\,I - 0 \cdot 4$	9
October	$0 \cdot 83\,I - 0 \cdot 6$	24
November	$0 \cdot 90\,I - 0 \cdot 8$	39
December	$0 \cdot 96\,I - 0 \cdot 9$	44

The correlation between the coefficient of I and the visibility factor is 0·9, which suggests that although the relationship between R and I is approximately constant, it does vary closely with the visibility in the afternoons. The mean value of the relationship is

$$R = 0 \cdot 83\,I - 0 \cdot 5,$$

when R and I are in the units previously mentioned.

Further analysis.—The availability of a computer to perform multiple regression analysis enabled further analysis to be made to try to establish a relationship between R (and I) and sunshine, temperature, rainfall and visibility (V). Some close relationships were found but they were not consistent in form from month to month. In other words, the computer found a nearest straight line, but it did not find the nearest sensible straight line. For example, there were occasions when the coefficient of V was positive, implying that in a completely foggy month, illumination would be at a maximum. However closely such equations fitted the Kew data, they were manifestly useless for extrapolation elsewhere.

Final analysis.—Some subterfuge was inevitable. It was therefore decided to apply the expressions in Table I to each monthly mean and to find a relationship between the errors so obtained and the visibility factor (V). During some summer months when V was small, no improvement in fit was possible. To attempt to eliminate possible errors in R and V, the two years with the worst fit were discarded. In most cases these were the 1947 or 1948 readings. The results so obtained are given in Table III.

TABLE III

Month	Radiation	Mean percentage error in 10 "best" years
January	$10{\cdot}0S - 0{\cdot}3\ V + 50$	5·6
February	$15{\cdot}6S - 0{\cdot}9\ V + 92$	6·0
March	$23{\cdot}0S - 1{\cdot}25\ V + 136$	5·1
April	$28{\cdot}0S - 3{\cdot}0\ V + 196$	6·3
May	$31{\cdot}2S - 5{\cdot}0\ V + 240$	4·9
June	$32{\cdot}0S - 3{\cdot}7\ V + 234$	6·9
July	$30{\cdot}6S + 200$	5·1
August	$28{\cdot}0S + 164$	5·9
September	$22{\cdot}8S - 0{\cdot}6\ V + 136$	5·0
October	$16{\cdot}6S - 0{\cdot}35\ V + 92$	7·2
November	$11{\cdot}8S - 0{\cdot}25\ V + 55$	4·6
December	$9{\cdot}2S - 0{\cdot}35\ V + 45$	5·7
		Mean 5·7

TABLE IV

Month	Illumination	Mean percentage error in 10 "best" years
January	$11{\cdot}6S - 0{\cdot}75\ V + 75$	6·5
February	$18{\cdot}4S - 0{\cdot}45\ V + 86$	6·3
March	$25{\cdot}6S - 1{\cdot}2\ V + 152$	3·6
April	$34{\cdot}0S - 4{\cdot}3\ V + 258$	5·8
May	$39{\cdot}2S + 240$	4·6
June	$40{\cdot}8S - 5{\cdot}0\ V + 320$	6·4
July	$40{\cdot}2S - 2{\cdot}35\ V + 270$	4·1
August	$37{\cdot}2S - 3{\cdot}15\ V + 257$	6·4
September	$30{\cdot}4S - 0{\cdot}3\ V + 183$	5·7
October	$20{\cdot}0S - 0{\cdot}2\ V + 110$	5·0
November	$13{\cdot}2S - 0{\cdot}8\ V + 93$	5·4
December	$9{\cdot}6S - 0{\cdot}35\ V + 54$	2·8
		Mean 5·2

Extrapolation.—The expressions in Tables III and IV can be used to estimate average values of radiation and illumination using standard normal data and the visibility data mentioned above, provided that the figures so obtained were corrected by a factor depending on the strength of the sun at various latitudes. The results are given in Tables V and VI (nearest five units). For areas other than in England and Wales, no visibility data were available, so for Scotland, Northern Ireland and the Channel Isles, the expressions of Table I were used in the same way. The results are given in Tables VII and VIII (nearest five units).

Degree of inaccuracy.—As the expressions of Table I were established for a hazy area, the estimates in Tables VII and VIII are probably too low, but if maps are plotted using data obtained by both types of formula, there is no very obvious discontinuity at the Scottish border, so that such inaccuracy may be small, especially in summer.

For year-to-year values these expressions can lead to errors at Kew up to 10 per cent, and on extrapolation this error must increase. For average values,

TABLE V—ESTIMATED AVERAGE DAILY RADIATION IN GRAM-CALORIES PER SQUARE CENTIMETRE

England and Wales	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Acklington	45	100	185	295	370	405	360	295	220	125	60	35
Tynemouth	40	90	175	285	340	390	365	295	220	120	60	30
Catterick	45	95	170	280	330	385	365	290	220	120	60	35
Leeming	45	100	175	280	340	390	365	295	210	120	60	35
Harrogate	45	95	175	280	335	395	365	300	210	125	60	35
Driffield	45	95	180	290	365	385	365	305	225	130	60	35
Squires Gate	45	95	180	315	410	430	380	315	225	125	60	35
Southport	45	95	175	295	365	425	380	315	220	125	60	35
Liverpool (Speke) ...	50	95	180	295	355	410	390	310	215	125	60	40
Manchester	40	80	155	245	325	365	335	285	195	110	50	30
Church Fenton ...	45	90	160	255	345	370	365	300	215	120	60	35
Finningley	45	95	175	280	370	380	370	310	220	125	60	35
Spurn Head ...	50	100	185	290	355	400	390	315	210	130	65	40
Holyhead	55	115	200	325	410	440	380	320	230	135	70	45
Hawarden	50	100	180	290	350	415	370	305	220	125	60	40
Shawbury	55	105	185	300	370	420	370	305	225	130	65	45
Watnall	45	90	175	280	350	380	365	310	220	125	60	35
Cranwell	50	100	185	300	385	420	390	325	230	135	65	40
Wittering	55	100	190	305	380	405	380	320	235	140	70	40
Mildenhall	55	110	200	315	425	440	405	335	245	140	75	45
West Raynham ...	55	110	195	315	415	430	395	335	245	140	70	45
Yarmouth	50	105	195	285	350	410	405	335	240	140	70	45
Aberporth	60	120	205	335	415	430	385	310	235	140	75	55
St. Ann's Head ...	60	120	210	320	390	430	385	320	235	140	75	55
St. Athan	60	120	195	310	395	435	400	320	235	140	75	50
Ross-on-Wye ...	60	115	205	315	385	430	375	315	230	135	70	50
Defford	55	110	195	310	370	420	385	315	235	135	75	50
Birmingham ...	45	90	165	255	310	395	365	305	215	125	60	40
Honiley	50	100	175	295	355	405	375	310	225	135	65	40
Little Rissington ...	55	110	190	315	405	425	380	315	240	135	70	50
Cranfield	55	110	195	300	415	430	380	320	230	140	70	45
Dunstable	55	105	195	295	380	410	380	325	245	140	70	45
Felixstowe	60	115	210	320	415	455	415	345	250	145	75	50
Bristol...	60	115	205	330	400	445	400	320	245	140	75	50
Lyneham	60	115	200	325	400	430	390	320	245	135	75	50
Larkhill	65	120	210	340	415	445	395	335	250	145	80	50
Boscombe Down ...	60	115	200	325	400	440	395	330	245	140	75	50
Worthy Down ...	60	120	210	345	425	445	400	335	250	145	80	50
Abingdon	60	115	200	315	410	430	385	320	240	140	75	50
South Farnborough ...	60	115	205	315	395	450	405	340	245	145	75	50
Kew	50	95	180	280	375	435	395	330	235	135	65	40
Croydon	50	95	185	280	370	440	405	335	240	140	65	40
Greenwich	45	80	160	230	340	415	390	325	230	130	60	35
Biggin Hill	60	105	195	300	390	430	400	335	245	145	70	45
West Malling ...	60	110	200	310	410	445	410	340	255	150	75	45
Shoeburyness... ...	60	115	210	315	415	455	415	345	250	145	75	50
Scillies	70	135	230	360	415	445	400	350	255	160	90	65
St. Eval	65	130	225	355	410	450	400	340	250	155	85	60
Lizard	75	130	230	350	410	445	420	345	255	160	90	65
Falmouth	75	130	225	345	415	465	400	345	255	155	95	65
Hartland Point ...	65	130	225	345	420	455	400	330	245	150	85	60
Plymouth	70	125	225	340	415	450	395	355	255	155	85	60
Exeter	70	130	220	355	430	470	410	340	255	150	85	60
Portland Bill ...	70	130	220	335	420	455	425	355	260	155	90	60
Holton Heath ...	65	125	215	330	410	450	415	345	255	145	90	55
Calshot	65	125	220	335	415	460	420	355	255	155	90	55
Thorney Island ...	65	120	220	340	425	460	420	350	260	155	85	55
Tangmere	65	125	220	325	420	450	420	350	260	155	85	55
Dungeness	65	125	210	325	410	435	430	360	260	155	85	55
Lympne	60	120	220	325	420	460	425	355	255	150	80	55
Manston	60	115	210	330	420	435	425	365	255	150	80	50

England and Wales	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Acklington	50	105	205	375	455	535	460	405	295	150	85	45
Tynemouth	50	100	200	355	455	510	460	390	295	150	80	40
Catterick	55	105	195	355	445	510	465	395	280	145	85	40
Leeming	60	105	200	355	450	515	470	400	285	145	85	45
Harrogate	55	105	200	350	455	520	460	395	280	150	80	45
Driffield	60	105	200	365	460	505	470	415	300	160	85	45
Squires Gate	55	105	205	395	495	565	500	425	300	155	80	40
Southport	55	105	200	365	500	570	485	420	295	155	75	40
Liverpool (Speke) ...	65	110	200	370	475	545	475	415	290	155	85	50
Manchester	50	90	175	305	440	485	425	380	265	135	65	35
Church Fenton ...	55	100	185	315	450	490	450	400	290	150	80	40
Finningley	55	105	200	350	460	505	470	410	295	155	80	45
Spurn Head	60	110	210	360	475	530	485	410	285	160	90	50
Holyhead	75	120	225	410	515	575	490	435	310	165	105	55
Hawarden	65	110	205	360	475	545	475	415	290	155	85	50
Shawbury	70	110	215	375	475	555	480	415	300	155	95	50
Watnall	55	105	200	350	460	505	470	425	295	155	80	40
Cranwell	60	110	215	375	485	560	500	440	305	165	85	50
Wittering	65	110	215	385	490	535	490	440	315	170	90	50
Mildenhall	70	120	225	400	500	580	530	475	325	175	100	50
West Raynham ...	65	120	225	400	505	570	515	465	325	175	95	50
Yarmouth	65	115	220	350	500	555	510	435	320	170	90	55
Aberporth	85	125	230	425	480	565	505	435	315	170	110	60
St. Ann's Head ...	80	130	240	400	500	570	490	435	310	170	110	60
St. Athan	75	130	225	385	495	570	515	440	320	170	105	60
Ross-on-Wye	80	125	225	400	470	570	490	445	310	165	100	60
Defford	75	120	220	395	480	555	500	440	315	165	105	55
Birmingham ...	55	105	190	315	450	520	465	425	290	155	80	45
Honiley	65	110	200	370	475	535	480	425	300	165	90	50
Little Rissington ...	70	120	215	395	485	565	500	445	320	165	100	55
Cranfield	75	120	220	375	490	565	490	450	320	175	100	55
Dunstable	70	115	220	370	490	540	490	450	325	170	95	55
Felixstowe	75	125	240	405	520	600	540	480	335	180	100	60
Bristol...	75	125	230	415	490	585	520	450	325	170	100	60
Lyneham	80	125	225	415	485	570	510	450	330	165	105	60
Larkhill	80	130	235	420	490	590	515	470	335	175	110	60
Boscombe Down ...	80	125	225	410	490	580	515	465	330	170	105	60
Worthy Down ...	80	130	240	430	500	590	535	470	335	180	100	60
Abingdon	80	120	225	400	485	565	505	450	320	170	105	60
South Farnborough ...	75	125	235	400	495	590	525	470	330	180	105	60
Kew	60	110	205	350	485	575	510	460	315	165	85	50
Croydon	60	110	210	350	490	580	515	465	320	170	85	50
Greenwich	45	100	190	280	470	545	500	450	305	165	70	45
Biggin Hill	70	120	220	375	505	565	515	455	330	175	95	55
West Malling ...	75	125	225	390	510	585	530	465	340	180	100	55
Shoeburyness... ...	75	125	240	400	515	600	540	480	335	180	100	60
Scillies	100	140	255	435	525	585	515	480	340	195	130	75
St. Eval	90	135	255	430	505	595	520	465	340	185	125	70
Lizard	100	140	255	440	510	585	540	465	345	190	135	75
Falmouth	100	140	255	435	510	610	515	480	340	190	130	75
Hartland Point ...	90	135	250	435	500	600	520	460	335	180	125	70
Plymouth	90	135	255	430	505	595	510	490	340	190	120	70
Exeter	95	135	250	445	510	615	540	480	340	185	125	70
Portland Bill	95	135	250	425	520	600	550	495	350	190	130	70
Holton Heath ...	85	135	240	415	515	595	535	470	345	175	115	65
Calshot	85	135	250	420	525	605	545	490	340	190	115	65
Thorney Island ...	85	135	245	425	535	605	545	480	350	185	115	65
Tangmere	80	135	245	405	535	595	540	480	350	190	115	65
Dungeness	85	135	240	405	540	575	545	475	345	190	120	65
Lympne	75	130	250	410	525	620	550	490	340	185	105	60
Manston	75	130	240	415	540	590	550	500	345	185	110	60

TABLE VII—ESTIMATED AVERAGE DAILY RADIATION IN GRAM-CALORIES PER SQUARE CENTIMETRE

Scotland	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Stornoway	25	65	150	255	360	385	325	265	180	95	35	15
Fortrose	30	75	155	250	340	395	335	275	185	105	40	20
Inverness	30	75	155	245	335	390	330	275	185	100	40	20
Gordon Castle ...	30	75	155	245	345	390	335	280	190	105	40	20
Banff	30	75	155	250	345	395	340	280	190	105	40	20
Aberdeen	30	75	155	250	345	405	340	280	195	105	34	20
Arbroath	35	85	165	270	365	430	365	295	210	115	50	25
Oban	30	70	155	255	360	395	330	270	185	100	45	23
Perth	35	80	155	260	345	415	355	280	200	110	45	25
Dundee	35	80	160	255	340	405	345	280	200	110	50	25
Leuchars	35	85	165	270	360	425	360	290	210	115	50	25
Rothesay	35	75	155	260	360	410	345	280	195	105	50	25
Helensburgh	35	75	155	250	350	400	335	270	190	105	45	25
Renfrew	35	75	155	255	345	400	345	275	195	105	45	25
Stirling	35	75	155	250	330	395	330	270	195	105	45	25
Boghall	35	80	160	250	335	405	345	275	200	110	50	25
North Berwick ...	35	80	160	260	350	420	360	285	200	110	45	25
Kilmarnock	35	80	160	260	365	405	340	280	200	110	50	25
Turnberry	35	85	165	270	380	415	350	290	200	110	50	30
Dumfries	40	80	165	255	360	415	345	285	195	115	55	30
Eskdalemuir ...	35	80	155	245	340	390	335	270	190	110	50	30
Marchmont	35	75	160	250	345	405	345	280	195	105	50	25
Other areas												
Aldergrove	40	85	165	265	375	400	330	280	200	115	55	30
Douglas I. o. M. ...	45	90	180	290	395	440	375	315	220	125	60	35
Guernsey	65	115	220	330	415	490	445	380	270	155	80	50

TABLE VIII—ESTIMATED AVERAGE DAILY ILLUMINATION IN KILOLUX

Scotland	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Stornoway	30	80	180	325	470	520	455	370	250	125	50	20
Fortrose	40	90	185	320	445	535	465	380	260	135	55	25
Inverness	40	90	185	310	435	525	460	380	260	135	55	25
Gordon Castle ...	40	90	185	315	445	530	465	385	260	135	55	25
Banff	40	90	185	320	450	535	470	390	265	135	50	25
Aberdeen	40	90	185	315	445	545	475	390	275	140	55	30
Arbroath	45	100	200	345	475	585	505	405	290	150	65	30
Oban	40	90	185	325	470	535	460	375	255	130	55	30
Perth	40	95	190	330	450	560	490	390,	275	140	60	30
Dundee	45	100	190	325	440	545	480	390	275	145	60	30
Leuchars	45	100	200	340	465	575	500	400	290	150	65	30
Rothesay	45	95	190	330	470	550	475	390	275	135	60	30
Helensburgh	40	90	185	320	455	540	465	380	260	135	60	30
Renfrew	40	90	185	320	450	545	475	380	270	135	60	30
Stirling	40	95	190	320	430	535	460	375	270	140	60	30
Boghall	45	100	190	320	435	550	475	385	275	145	65	35
North Berwick ...	45	100	195	330	455	565	500	395	280	140	60	30
Kilmarnock	45	95	190	330	475	550	470	390	275	140	60	35
Turnberry	45	100	200	345	490	560	485	405	280	145	65	35
Dumfries	50	100	195	325	465	555	480	395	275	150	65	35
Eskdalemuir ...	45	100	190	315	445	530	460	375	260	145	65	35
Marchmont	45	95	190	320	445	550	480	390	275	140	60	35
Other areas												
Aldergrove	50	100	200	335	490	540	460	390	275	150	70	40
Douglas I. o. M. ...	55	105	215	370	510	595	520	435	305	165	75	45
Guernsey	80	140	265	415	535	655	615	520	370	200	100	65

the position is eased, owing to cancellation of yearly errors, and it is suggested that the absolute errors at any one station should be within the 10 per cent range. The relative errors are probably much less, and it is for this reason that these figures are now made available as they may be found to be useful in problems such as horticulture planning, siting of glasshouses etc. They should only be regarded as an interim guide until better information becomes available, in other words, as a first approximation.

551·557·33·

FLUCTUATIONS IN STRATOSPHERIC WINDS OVER AUSTRALIA

By R. G. VERYARD, B.Sc.

In a recent article by Veryard and Ebdon[1] attention was drawn to a 23–29-month fluctuation which had been discovered in the zonal component of stratospheric winds over tropical regions. With the data then available it was possible to show that the fluctuation existed in the northern hemisphere to about 25°–30°N, but lack of data precluded any firm conclusion regarding the distance to which the fluctuation existed south of the equator. Since the article was written some stratospheric wind data for Australian upper air stations have been received from the Commonwealth Bureau of Meteorology.

Examination of these data confirms that the fluctuation has occurred at Darwin (12°26′S, 130°52′E) at least up to the end of 1958 and probably as far back as 1952. This is demonstrated in Figure 1 which gives a curve of the twelve-monthly running means of the zonal wind component at 60,000 feet (about 70 mb). From 1955 onwards observations were only occasionally missing for ten days or more in any month but for earlier years the data were less plentiful, particularly in the period September–December 1954, and the dashed part of the curve indicates that the values used are unreliable. For comparison, the curve for Aden (12°49′N, 45°02′E) based on winds at the 50 mb level (about 68,000 feet) has been superimposed in Figure 1. It will be noted that the amplitude of the fluctuation at Aden is nearly twice that at Darwin but allowance must be made for the difference in the heights to which the curves refer in view of the finding, mentioned in the earlier article, that there is an increase of amplitude with height (at least up to 25 mb). It will also be seen that, up to about 1959, the curves are in phase except for a lag of a

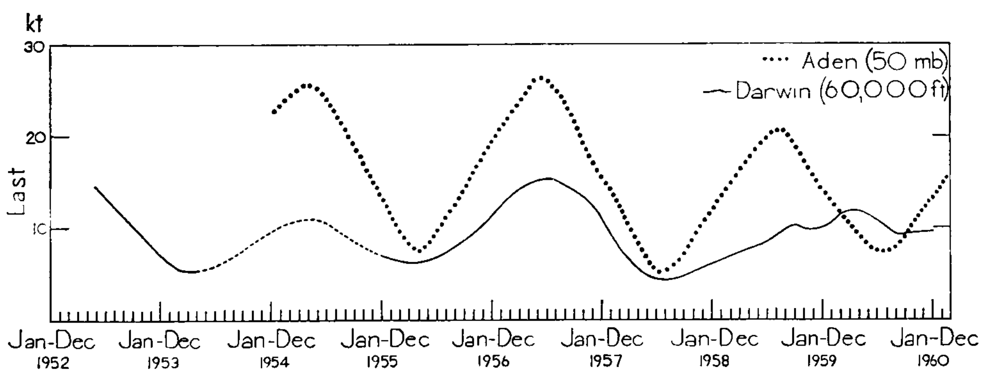

FIGURE 1—TWELVE-MONTHLY RUNNING MEANS OF ZONAL WIND COMPONENT AT DARWIN AND ADEN

month or so at Darwin which is again attributable to the height difference (as the fluctuation was found to have a phase lag from higher to lower levels). But from 1959 onwards, the correspondence disappears and it may be that the fluctuation has now "petered out" at Darwin—but perhaps only temporarily. As was pointed out in the earlier paper, the amplitude of the fluctuation appeared to be decreasing in recent years: in fact, it could not be detected at Bahrain (26°16′N, 50°37′E) from 1958 onwards.

Data from other tropical stations in Australia were found to be inadequate for the drawing of long-period curves as for Darwin and Aden, but the data available for Alice Springs (23°48′S, 133°53′E) suggested that the fluctuation was present at that station from the end of 1956 to mid-1957 but absent from 1958 onwards. However, recent data indicate that the fluctuation after waxing and waning, is still being maintained at equatorial stations; but, in view of the finding that the fluctuation decreases in amplitude with distance from the equator (and perhaps the "meteorological equator"), it could be expected that a waning of the fluctuation would lead to its disappearing in higher latitudes.

A preliminary examination of data for Ascension Island (07°58′S, 14°24′W) indicates the existence of the fluctuation at that station from September 1957 to March 1961; a full report will be given in a later article.

REFERENCE

1. VERYARD, R. G. and EBDON, R. A., Fluctuations in tropical stratospheric winds. *Met. Mag., London*, **90**, 1961, p. 125.

REVIEW

Meteorology and climatology for sixth forms, by Ernest S. Gates. $9\frac{3}{4} \times 7\frac{1}{4}$ in., pp. 203, *illus.*, George G. Harrap & Co. Ltd., 182 High Holborn, London W.C.1, 1961. Price: 13*s* 6*d*.

This book is intended "to convey the physics of meteorology to geographical students in a non-technical and non-scientific language and to stimulate their interest to go beyond the classroom and to carry out some practical studies in the subject". In these aims, except perhaps the last, it is highly successful. It is divided into two distinct sections. The first section, which forms the major part of the book and deals with general meteorology, seemed to the reviewer and to some sixth form pupils the more original and the more stimulating. The second section gives an outline treatment of world climatology in a more conventional manner.

The outstanding feature of the book is the number of excellent diagrams; at first sight many of these seem very large, but they gain thereby in clarity. Occasionally there is some over-simplification, for example, in Fig. 97 of the south-west monsoon; it also seems curious that for Fig. 105 Vancouver should have had to be chosen as an example of a west European climate. In only one case—Fig. 53 to explain the formation of rainbows—does a diagram seem definitely unhelpful. The tabulation employed is very good: the tables of cloud, fog, air mass and frontal characteristics given as appendixes to Part One are particularly commendable. An attractive selection of cloud photographs is also included.

The chapters on meteorology deal very fully with the phenomena described and they include clear explanations of a number of aspects, such as katabatic and anabatic winds and jet streams, which are not usually touched upon in a book of this standard. Some of the large amount of mathematics might seem unnecessary to many sixth form geographers: however it is probably a good thing that they should appreciate early that a good knowledge of mathematics is essential if they are to pursue a serious study of the subject. The treatment of air masses and of the upper atmosphere is very thorough; but it is a pity that only one type of condensation trail is considered. Also the conventional warm-front section in Fig. 66 might well have been modified to take into account the break in the tropopause at the jet-stream centre which is clearly shown in Fig. 72.

The first chapter in the book is perhaps the least successful. More might have been included to encourage the student to use and even construct his own instruments, such as anemometer and rain-gauge. Also on p. 20 the "C." scale of temperature should be described as Celsius rather than Centigrade and mention of the Réamur scale is unnecessary.

In future editions, which it is to be hoped the demand will be sufficient to justify, mention might well be made in Chaper 12 of the possibility of the student's sketching his own weather maps from data such as that given in the shipping forecasts broadcast on 1500 metres.

At the publication price of 13/6 this book offers very good value for money. It should find a place in the school science library as well as in the geography library. Now that meteorology has been eliminated from the "A" level physics syllabus, it is unlikely to be bought as a textbook for sixth form scientists, although they would derive considerable benefit from its study. Many senior geography masters will want to purchase individual copies for their sixth form specialists: to meet "A" level geography requirements there is a wide selection of examination questions at the end of the book. Finally the book can also be recommended as a useful work of reference—and perhaps a welcome Christmas present—for the adult amateur of meteorology.

D. C. LLOYD

METEOROLOGICAL OFFICE NEWS

Retirement.—The Director-General records his appreciation of the services of:

Mr. D. Moriarty, Foreman of Stores, who retired on 22 August 1961. He started his career in the Meteorological Office in 1941 as a storekeeper at Kew Observatory, and on moving to the Instruments Branch at Harrow in 1946 he was promoted Leading Storeman. In 1952 he became Foreman of Stores and remained in the Instruments Branch until his retirement. Mr. Moriarty has accepted a temporary appointment as a Paperkeeper in the Air Ministry.

Sports activities.—The first Annual Sports Meeting organized by the Bracknell Social and Sports Committee was held on the evening of 17 August, in fine weather, at the Palmer Park Running Track, Reading. The various events, open to all members of the staff of the Meteorological Office, were well supported. Three new Meteorological Office records were established. They were:

Long Jump, Ladies. Distance 14 feet 8½ inches, Miss V. Lewis, M.O.3.
100 yards, Ladies. Time 12·2 seconds, Miss V. Lewis, M.O.3.
220 yards, Men. Time 24·2 seconds, Mr. J. Miller, M.O.13.

Four cups, donated by the Dunstable Social and Sports Club, were won by the following:

Tug of War	M.O.13/19
4 × 110 yards Men's Relay	M.O.3
4 × 110 yards Ladies' Relay	M.O.13/9
Division with most points	M.O.3

Four events (100 yards, 440 yards, one mile and Ladies' 100 yards) were Meteorological Office Championships for which medals were awarded.

The meeting was attended by Sir Graham and Lady Sutton, Dr. and Mrs. R. C. Sutcliffe, Dr. and Mrs. A. C. Best, and many of the Staff and their families now located in the Bracknell area, as well as visitors from London Airport, Harrow and other nearby offices. At the conclusion of a successful evening the prizes were presented to the winning competitors and teams by Lady Sutton.