METEOROLOGICAL SERVICE

ANALYSIS OF SOLAR RADIATION MEASUREMENTS AT VALENTIA OBSERVATORY FOR THE 11-YEAR PERIOD 1964 - 1974

by

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Analysis of Solar Radiation Measurements
at Valentia Observatory
for the 11-year period 1964-1974

Summary

Measurements of Global (G) and Diffuse (D) Solar Radiation on a horizontal surface at Valentia during the 11 year period 1964 - 1974 are analysed. Mean annual, monthly and daily totals, the diurnal variation, frequency distribution of daily totals, frequency of occurrance of daily totals of Global radiation less than 250, 500 and 1000 J/cm^2 for 2, 3, 4 and 5 successive days are computed and discussed.

Direct solar radiation at normal incidence (I) is computed from the standard G, D and I relationship and analysed in a similar manner to that of Global and Diffuse Radiation.

Vertical (V) and Horizontal (H) components of I and the components of H directed N-S and E-W are also computed and estimates made of the direct radiation received by variously inclined and orientated surfaces.

It is considered that this analysis of measurements at Valentia should closely represent the radiation climatology of south-west Ireland.

1. Introduction

Solar Radiation observations were begun at Valentia Observatory in September, 1954. At that time a Moll thermopile pyranometer and a recording millivoltmeter were installed, and have, since then, provided a continuous record of Global Solar Radiation. In 1962, a second Moll thermopile pyranometer, fitted with shading ring, was installed to provide a record of Diffuse Solar Radiation.

Data derived from the Global and Diffuse pyranographs together with full details of the site, instruments used and their calibration can be found in the annual volumes of solar radiation data published by the Meteorological Service.

During 1962 and 1963 a number of breaks occurred in the continuity of the diffuse radiation measurements. This was due to lack of spare equipment so that at times the instruments used for Diffuse measurements had to be diverted to the measurement of Global radiation which was always given priority. Since the beginning of 1964 the measurements of both Global and Diffuse radiation have been continuous so that the analysis which follows confines itself to the eleven year period 1964 to 1974.

Even though the data are available for one station only (Valentia Observatory) the analysis should depict closely the radiation climate of south-west Ireland.

2. Global and Diffuse Solar Radiation on a Horizontal Surface

2.1. Monthly and Annual Totals

The monthly and annual totals of Global (G) and Diffuse (D) solar radiation on a horizontal surface are shown in Tables I and II respectively.

From Table I it can be seen that in an average year the total radiation from sun and sky received on a horizontal surface at Valentia is about 364,000 J/cm^2 and in the past 11 years it has ranged between 345,659 and 407,648 J/cm^2.

The summer period, April to September contributes 77% of the annual total while six summer months contribute only 23%. December contributes least, being responsible for only about 1·6%.

The highest mean monthly total occurs in June (54,819 J/cm^2) but the highest recorded total for a month was in May, 1966, (64,264 J/cm^2). The lowest mean monthly total occurs in December (5,772 J/cm^2) and the lowest recorded monthly total also occurred in December i.e. 4,829 J/cm^2 in December, 1972.

The variability from year to year for the annual totals is quite small, the overall range (maximum - minimum) being only 17% of the mean value. The most variable month is January where the range is 56% of the monthly mean and the steadiest month is June with a range of 22·7% of the monthly mean.

Table II shows that Diffuse Sky (D) radiation contributes 217,541 J/cm^2 in an average year i.e. about 60% of the Global radiation. The annual totals of sky radiation range between 201,756 and 233,846 J/cm^2 so that the overall range (maximum to minimum) is only about 14·8% of the annual mean. As in the case of the Global radiation the highest mean monthly value of Diffuse Sky radiation is found in June (32,788 J/cm^2) and the lowest in December (4,269 J/cm^2).

2.2. Daily Totals of Global (G) and Diffuse Sky (D) Radiation

Average daily totals of G and D were computed for all days for each month of the year and are shown in Table III.

In the average year the mean daily G income is 997 J/cm^2 with a seasonal variation from 186 J/cm^2 in mid winter to 1827 J/cm^2 in mid summer. Over the year the Diffuse Sky contribution is 60% of the Global radiation. This contribution varies between 55% in April to a maximum of 74% in December. Such relatively high values of D/G combined with the very small annual variation are typical of the temperate climate of Western Europe and are mainly due to the general high degree of cloudiness.

2.3. Maximum Values of Daily Totals of G and D

Table IV shows the maximum recorded daily totals of Global and Diffuse radiation on an horizontal surface for each month of the year and the relevant D/G ratios.

The highest daily total of G was in July, 1964, when a total of 3230 J/cm^2 was recorded. Generally maximum daily totals of G were found on days of almost continuous sunshine with only small amounts of broken fair weather cloud. On these days the sky radiation contributed only about a quarter of the total Global radiation on an horizontal surface. The sky contribution may be as low as 15% on such days.

The maximum Diffuse radiation for a day occurred in June, 1966, when a total of 1887 was recorded. On this occasion the sky contributed 92% of the total Global radiation received and on average for the year the Diffuse radiation contributed 86% to the Global total on occasions of maximum D radiation. Generally highest D values are recorded on days when cloud amount is at least 6 eights but not overcast, the broken cloud not completely eliminating the direct sun.

2.4. Diurnal Variation of G and D

Mean hourly values of G and D for each month of the year for all days of the eleven year period are given in Table V. On the basis of these data the isopleths of Global and Diffuse solar radiation on an horizontal surface and expressed in mW/cm^2 are drawn in Fig. 1 and 2.

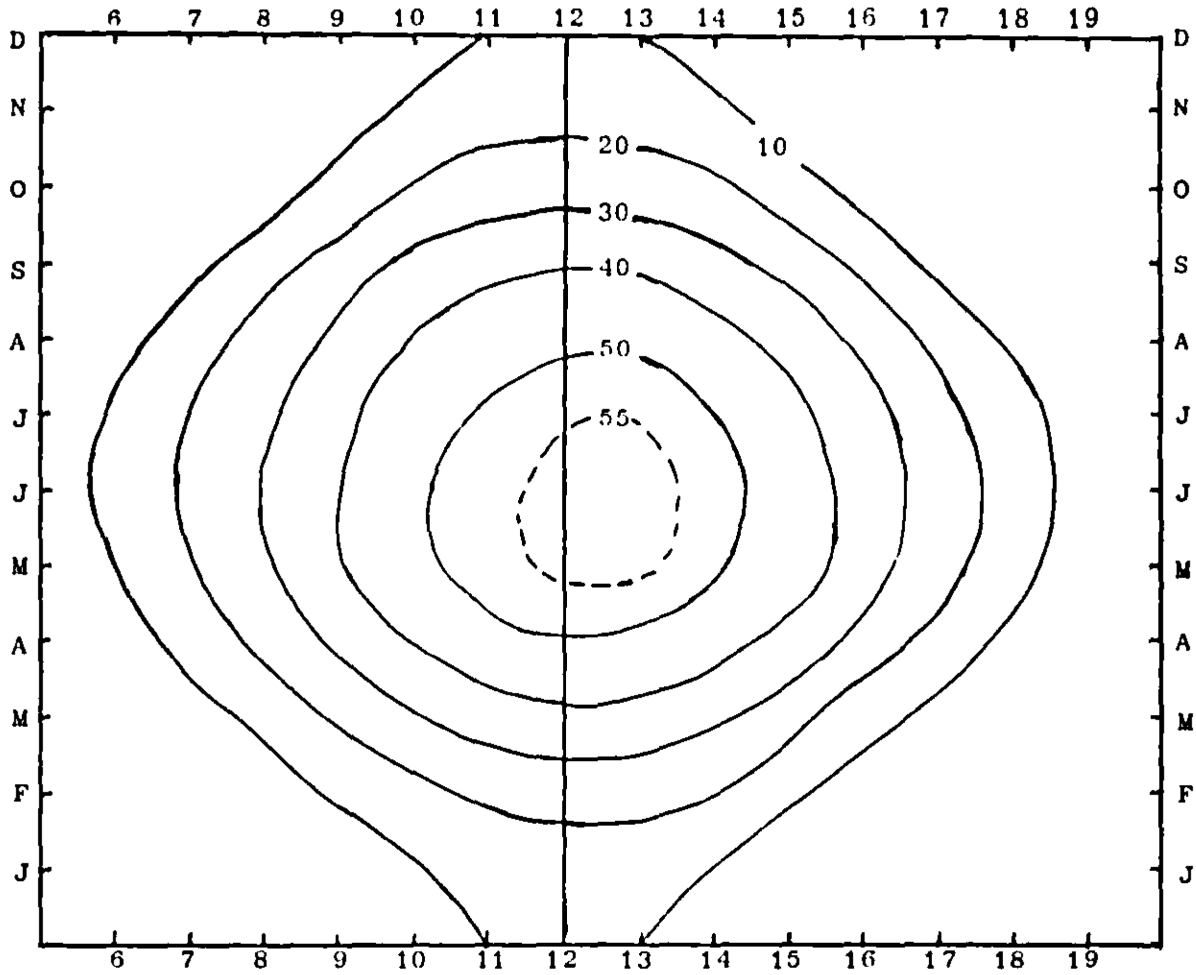

Fig. 1 Isopleths of Global Radiation on a Horizontal Surface
All Days mW/cm^2

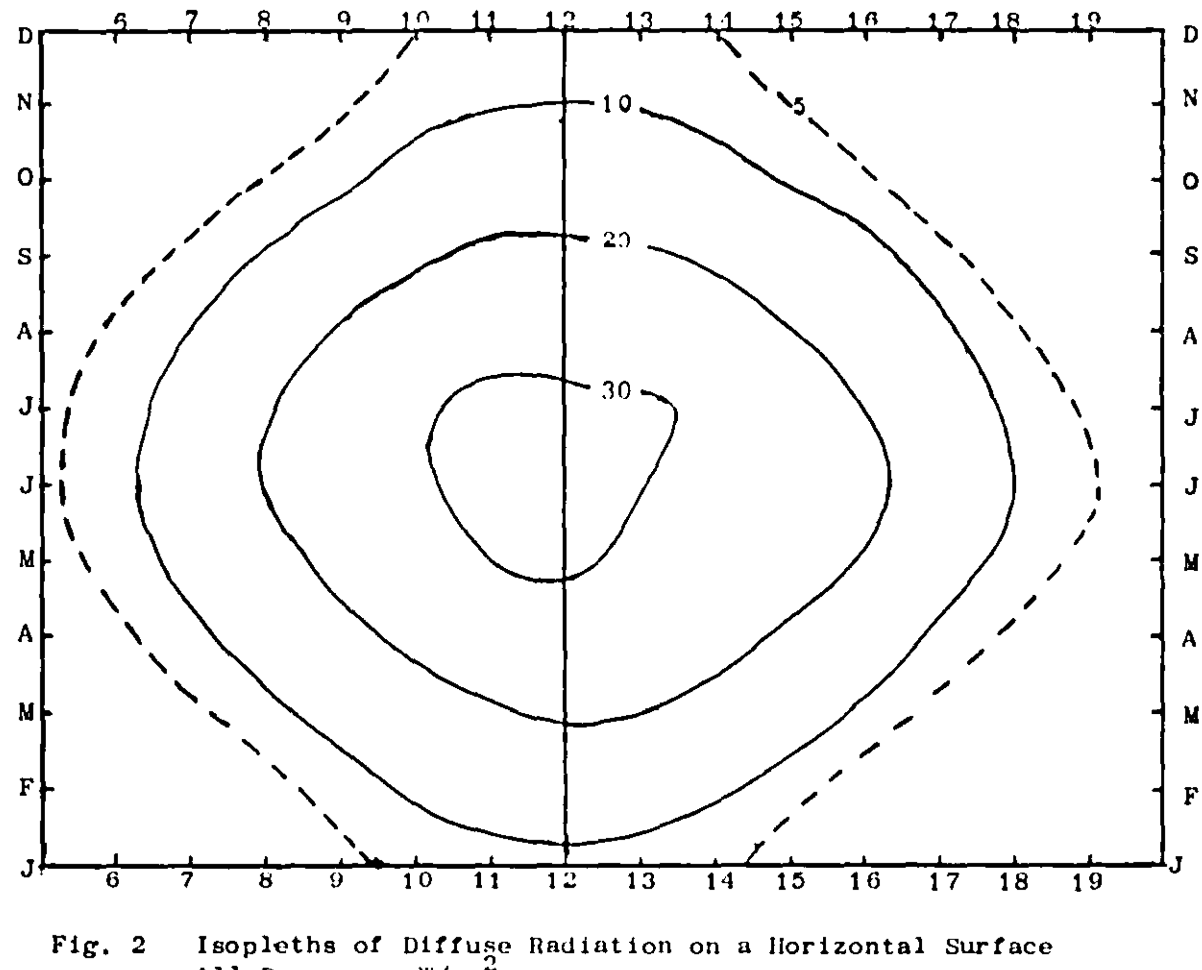

Fig. 2 Isopleths of Diffuse Radiation on a Horizontal Surface
All Days mW/cm^2

A feature of diurnal variation of the Global radiation is the fact that in almost all months the highest values are recorded in the hour immediately afternoon (12h - 13h) and the afternoon values are generally higher than the corresponding forenoon values. As discussed below in para. 3.5. it is found that for the same solar altitude the afternoon values of the Direct solar radiation are higher than the corresponding forenoon values, so this factor could explain the higher afternoon Global values.

The Diffuse radiation shows little significant difference between the afternoon and corresponding forenoon values.

The highest Global radiation is generally recorded in the hour after midday averaging about 57 mW/cm^2 in the May/June period and about 11mW/cm^2 in December.

Fig. 3 shows the isopleths of the ratio D/G (Diffuse/Global) derived from the data in Table V. These again show the influence of the relatively higher Direct Sun component of the Global radiation in the afternoon.

The minimum values of D/G are found in the early summer generally between 1300 and 1400 local time. This is the best period for Direct Solar Radiation at Valentia (See para. 3.2. below). There is a distinct "ridge" of higher values of D/G in July. Compared with the early summer months July is generally a more unsettled month when increased cloud cover could result in more diffuse reflection from clouds thereby enhancing the Diffuse component of the Global radiation.

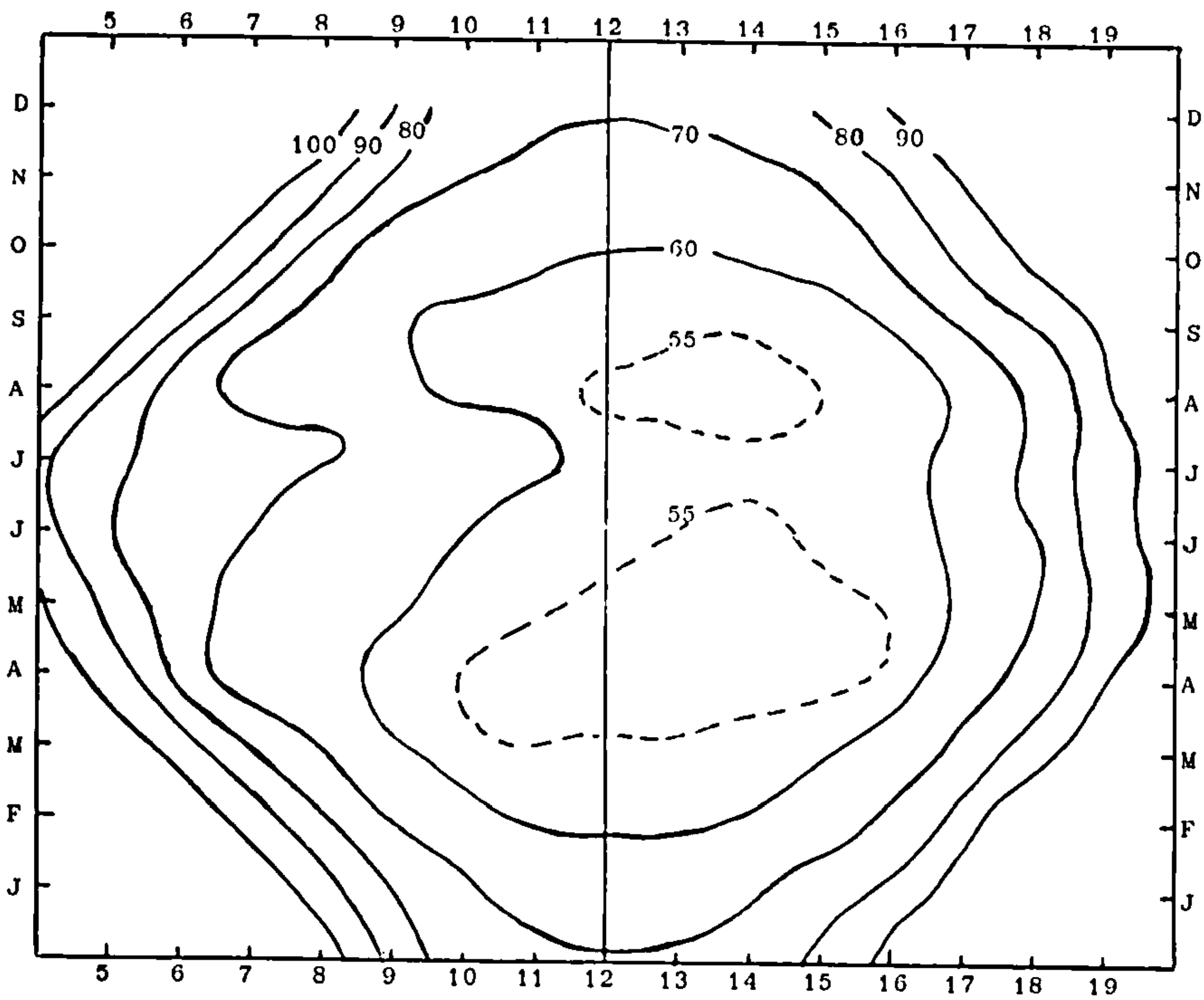

Fig. 3. Isopleths of ratio D/G - All Days

2.5. Global and Diffuse Radiation on Occasions of Little or No Cloud

For some purposes the solar radiation on cloudless days is of interest. Since completely cloudless days are rare at Valentia a different approach was adopted. The five days in each month having the highest daily totals throughout the eleven year period were selected and the means computed. These best radiation days are referred to as the "Top 5" and in the case of Global radiation should coincide very closely with days of cloudless or nearly cloudless skies.

Figs 4 and 5 show for Winter (Dec.) and Summer (June) the following curves:-

(1) Global radiation on an horizontal surface for all days

(2) Global radiation on an horizontal surface for Top 5 days

(3) Diffuse radiation on an horizontal surface for all days

(4) Diffuse radiation on an horizontal surface for Top 5 days of Global radiation.

On the best radiation days the Global radiation around midday in June is about 65% higher than the average recorded for all days. On the other hand the Diffuse radiation in near cloudless conditions is considerably lower than the average Diffuse radiation for all days. In December the curves maintain the same relative positions on the graph but on a much reduced scale compared to the June values.

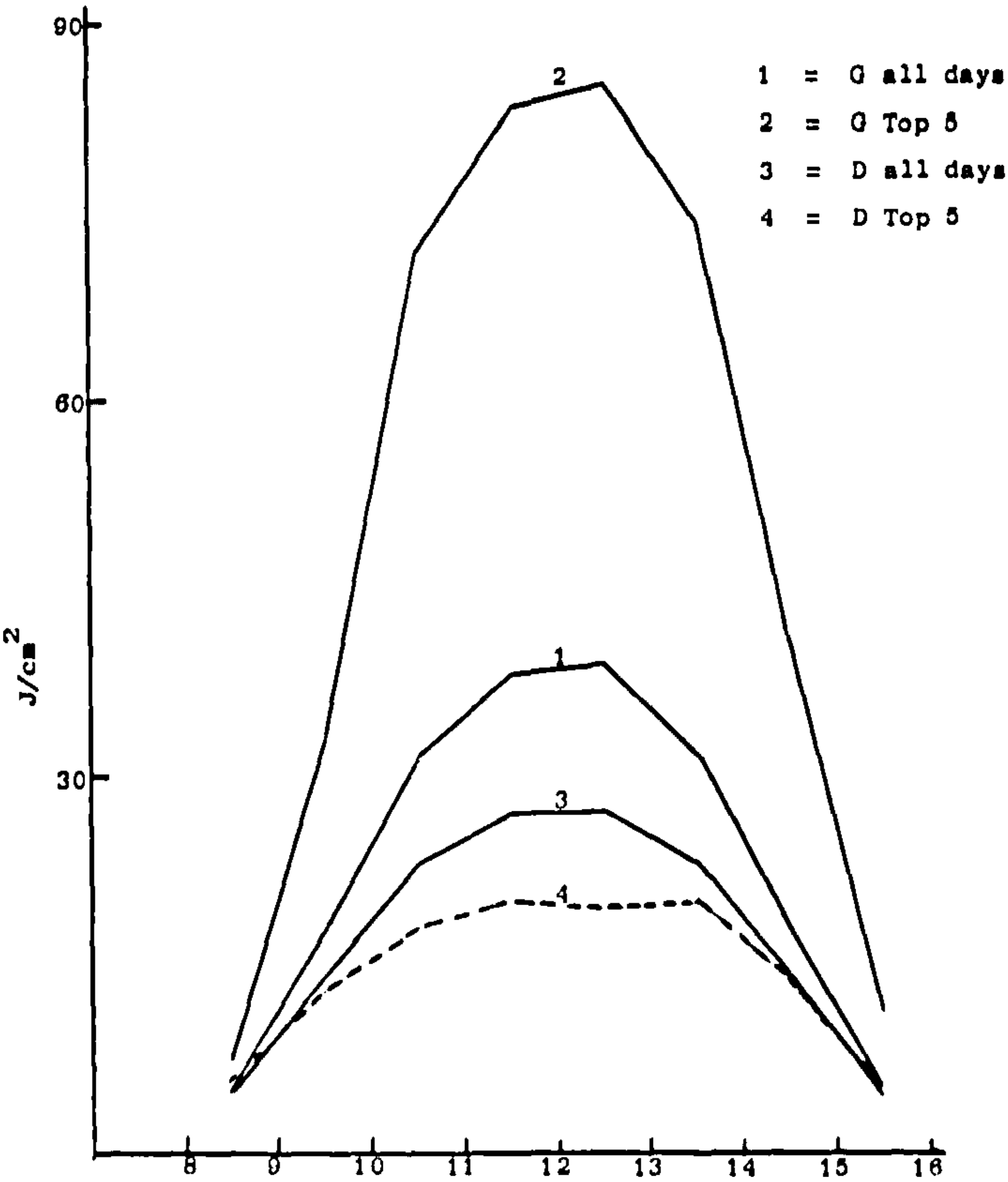

Fig. 4 Diurnal Variation of Global and Diffuse Radiation December.

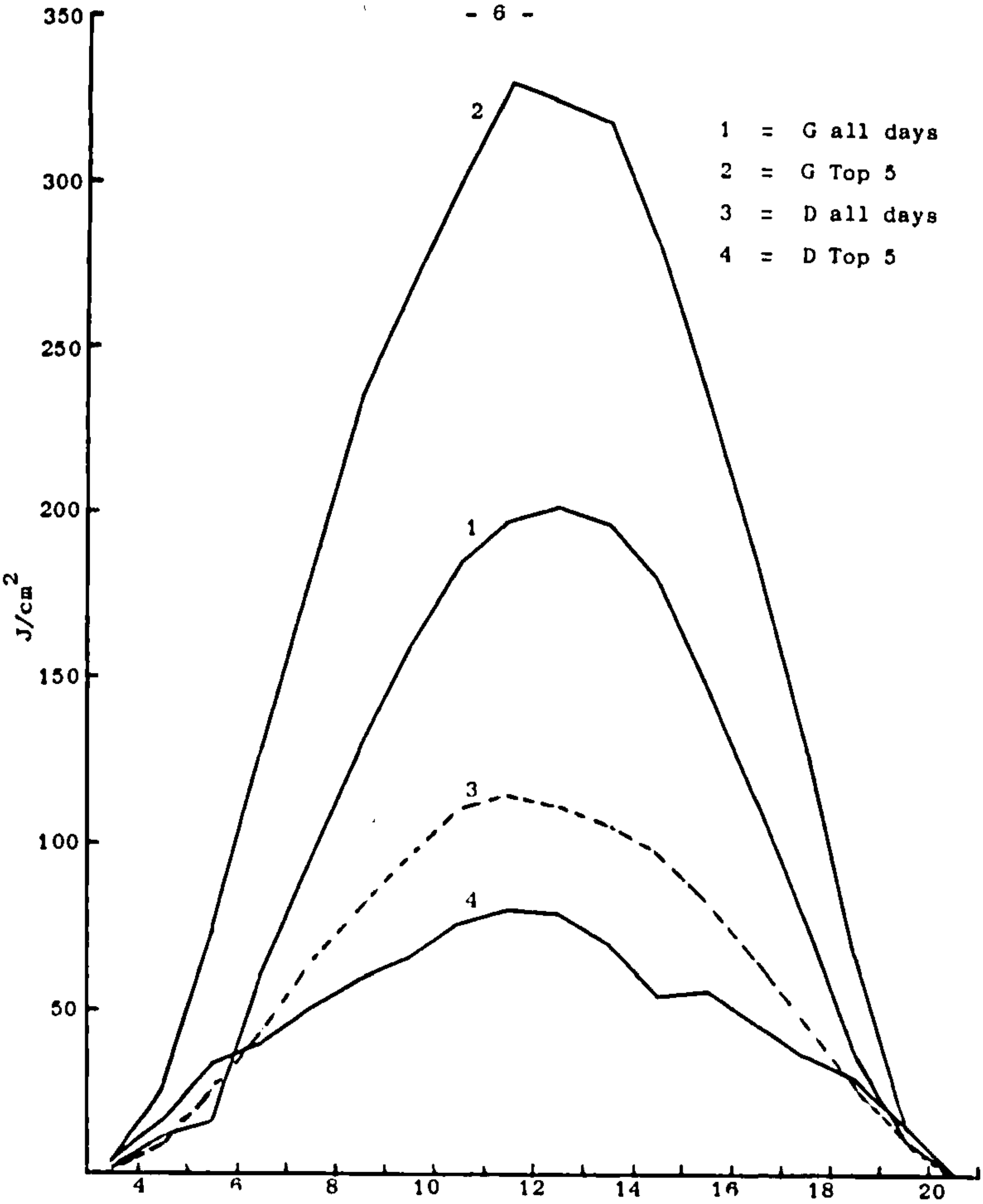

Fig. 5 Diurnal Variation of Global and Diffuse Radiation June.

2.6. Frequency Distribution of Daily Totals of G

The percentage frequency distribution of daily totals of Global Radiation (G) for each month of the eleven year period is given in Table VI.

These percentage data are expressed in a modified form in Fig. 6 which shows annual curves of the number of days (as percentage of all days when daily Global radiation income was below a specified level.

In December, 71·8% of all days receive less than 250 j/cm^2 and in January the corresponding figure is 54·6%. During the six winter months (October - March) 65·7% of all days receive less than 500 J/cm^2 and only 1·7% exceed 1500 J/cm^2 and none above 2000 J/cm^2.

In the six summer months (April - September) 47·3% of all days get between 1000 and 2000 J/cm^2 but only 1·5% exceed 3000 J/cm^2. However, almost all days in summer get at least 250 J/cm^2.

For the year as a whole the general frequency distribution with the high concentration in the lower ranges is typical of the climate of mid European latitudes.

To those interested in the use of solar energy for heating and cooling etc. the frequency of extended periods of low radiation income are of particular interest. Table VII shows the frequency of periods of successive days with radiation less than 250, 500 and 1000 J/cm^2/day.

In Dec./Jan. periods of 5 consecutive days with less than 500 J/cm^2/day occur almost continuously i.e. 28·1 occasions in January and 30·7 occasions in December (Note that the maximum number of occasions in a month coincides with the number of days in the month). In summer (April - September) periods of 5 consecutive days with less than 500 J/cm^2/day never occur and similar periods with less than 1000 J/cm^2/day are rare (only 0·8). Periods of 2 successive days with less than 1000 J/cm^2/day will occur on 17 occasions during the summer period while less than 500 J/cm^2/day for 2 censecutive days will occur only about once in the 6 months summer period.

For the year as a whole 5 censecutive days with less than 250 J/cm^2/day will be experienced on about 10 occasions. Similar periods with less than 500 J/cm^2/day and 1000 J/cm^2/day will occur on 77 and 142 occasions respectively. Practically all these occasions occur in the winter period. The high frequency of periods of 5 consecutive days with less than 500 J/cm^2/day during the winter 6 months (mainly in Dec./Jan.) illustrates the problems of storage and/or "back up" facing engineers considering the use of solar energy for water or space heating.

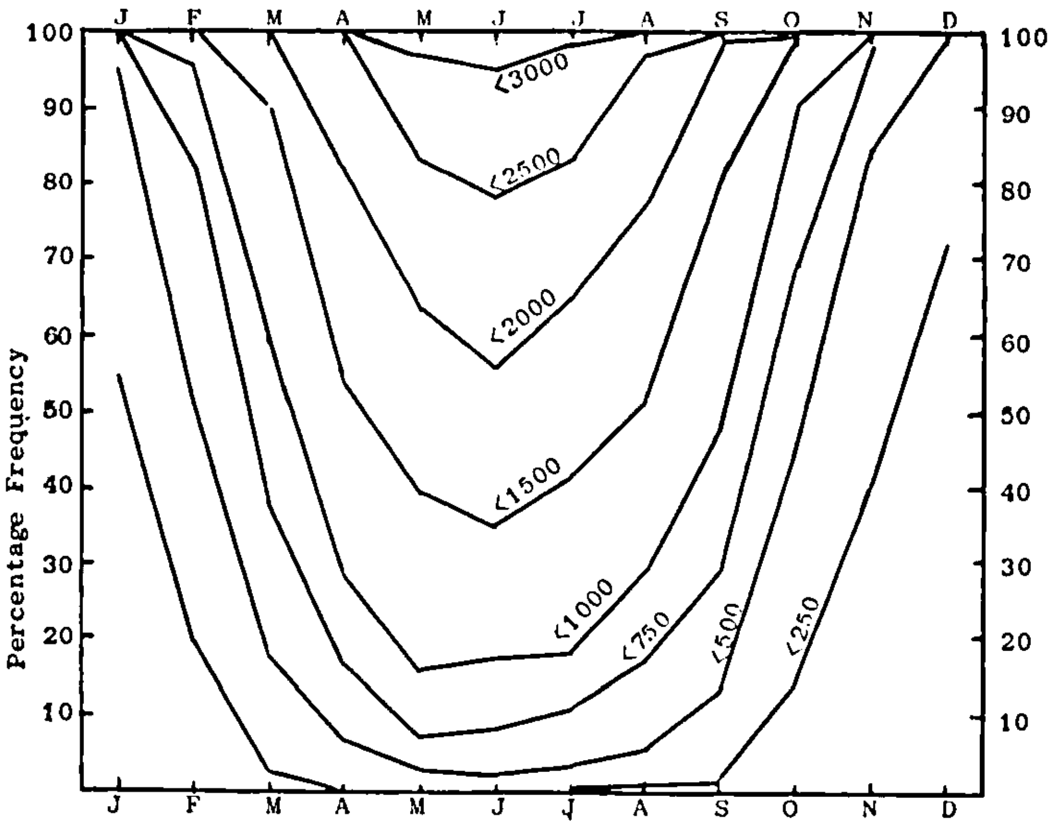

Fig. 6 Percentage Frequency of Daily Totals of G less than Specified Amounts (J/cm^2)

3. Direct Solar Radiation on a Surface Normal to the Solar Beam

The intensity of direct solar radiation (I) on a surface maintained normal to the solar beam is of considerable interest to engineers and others. No direct measurements or recordings are available at Valentia apart from some spot value observations at times when sky conditions permitted. However, it is possible to compute I from the data for Global (G) and Diffuse (D) radiation discussed in previous sections of this paper. The computation of I is based on the relation

$$(G - D) = I \sin h$$

$$\therefore \quad I = (G - D) \operatorname{Cosec} h$$

where h is the sun's altitude. The value of G - D was computed for each hour from the hourly recorded values. Cosec h was also computed for the centre of each hour when the sun was above the horizon. Thus hourly values of I were obtained from which the usual daily, monthly and annual totals and means were derived. The method of computation assumes that all the direct sun radiation received during the hour may be attributed to the sun's altitude as taken from the mid point of the hour. Considerable error may be involved for individual hours at the beginning and end of the day when the sun's altitude is changing rapidly. However, for long term means for the eleven year period considered here the data should be very close to the true values.

3.1. Monthly and Annual Totals - All Days

The monthly and annual totals of direct solar radiation for all days of the eleven year period 1964 - 1974 are given in Table VIII.

The maximum and minimum total for each month are marked by the letters "M" and "m" respectively.

From this table it can be seen that in an average year the total direct solar radiation received at Valentia is about 278,000 Joules/cm^2 and in the past 11 years it has ranged between 316299 (1968) and 233461 (1967) J/cm^2. The summer period April to September contributes 70% of this total while the six winter months contribute only 30%. December contributes least, being responsible for only about 2·5%.

The highest mean monthly total occurs in May (36577 J/cm^2) and the highest recorded monthly total also occurred in this month i.e. 54428 J/cm^2 in 1966.

The lowest monthly total occurs in December (7019 J/cm^2) but the lowest recorded monthly total occurred in January 1968 with 3374 J/cm^2.

The bottom line in Table VIII shows the range (maximum to minimum) expressed as a percentage of the mean for the month. The variability is high for all months of the year, the steadiest month being November, 56%. On this basis the most variable month is January, 144%, closely followed by July, 119 %.

3.2. Daily Totals for Various Catagories of Days

Average daily totals for each month for all days were computed. The formation of average daily totals for completely cloudless days was also considered but the number of such days at Valentia was so few that the same procedure was adopted as in the case of Global radiation (See para. 2.5. above) i.e. for each month the 5 days in the 11 year period with the highest daily totals were selected and the means computed. This class represents approximately the top 1½% of radiation days.

The daily totals for "All Days" and for the "Top 5" days are given in Table IX which also shows the maximum daily total recorded for each month throughout the 11 year period. Table IX data are also shown graphically on Fig. 7.

May is the best month for direct solar radiation with 1180 J/cm^2/day. This is also the month for greatest duration of Bright Sunshine (see Table XVII) indicating that the more favourable sky conditions more than compensate for the higher sun's elevation in June. On clearest days however, the highest daily totals are found in June/July so that on these occasions the higher sun's elevation seems to be the paramount factor.

December is the worst month of the year with only 226 J/cm^2 on the average day and it maintains its low position even when the clearest days are considered. In this month the average day receives only 14·5% of the maximum daily value recorded for the month while the corresponding figure in May is still only 28%. The average for the year is 24·4%.

On clearest days (Top 5) the direct radiation reaches 90% of the maximum in almost all months.

For comparison purposes Table IX and also Fig. 7 show the average daily totals (all days) and the maxima as recorded at Uccle (Belgium) over the period 1951 - 1965 [1]. Although the periods are completely different the daily values are in good agreement, the annual mean for Valentia of 761 J/cm^2 being very close to the 734 J/cm^2 recorded at Uccle. Apart from December the maximum daily value for each month at Valentia is slightly higher than that recorded at Uccle probably due to the very low turbidity which can be experienced at Valentia on such days.

3.3. Frequency Distribution of Daily Totals

The percentage frequency distribution of daily totals of direct radiation (I) during the eleven year period is given in Table X.

In January 29% of all days had no direct sun at all while over 50% of days in Dec./Jan. period had less than 100 J/cm^2. At the other end of the scale only 1% of all days in the May/June period exceeded 4000 J/cm^2. For the year as a whole 10% of all days receive no direct radiation. About 30% receive less than 100 J/cm^2 and about 54% of all days receive less than 500 J/cm^2.

3.4. Diurnal Variation of the Intensity of Direct Radiation (I)

The eleven year means of the hourly values of Direct radiation are given in Table XI. Values are given for all days and for the Top 5 days referred to above.

In the hours just after sunrise and before sunset the effect of the solar elevation is paramount. Considering the hours between 0700 and 1800 L.A.T. the maximum hourly values on the average day occur in the April/May months and the minimum, as expected, in December.

Fig. 8 shows the diurnal curves for April/May/June and December for all days. It is clear that the afternoon values are generally higher than those for the corresponding hour-angle in the forenoon. This facet of the radiation intensities is discussed in section 3.5. below.

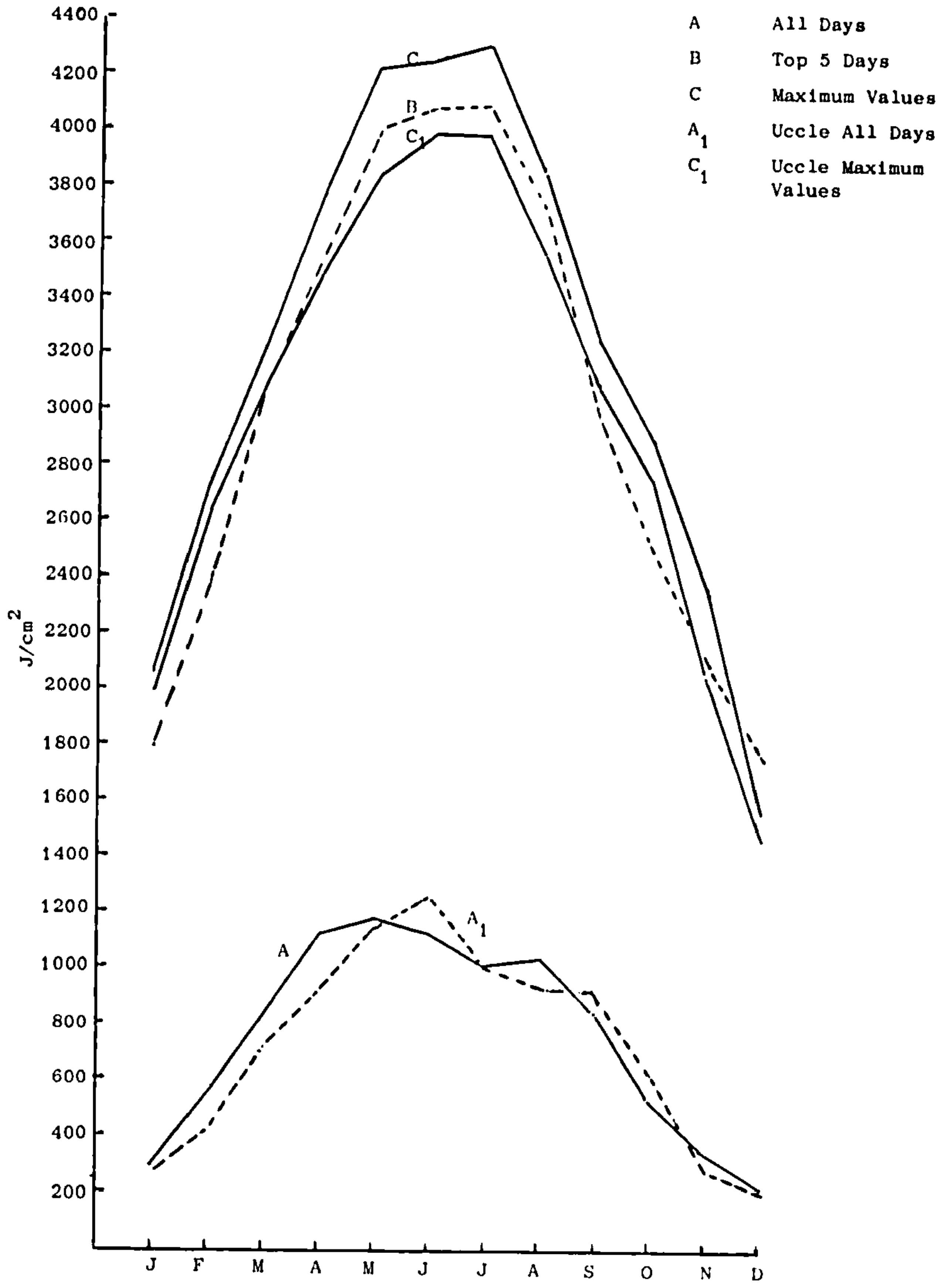

Fig. 7 Mean Daily Totals of I on Various Catagories of Days

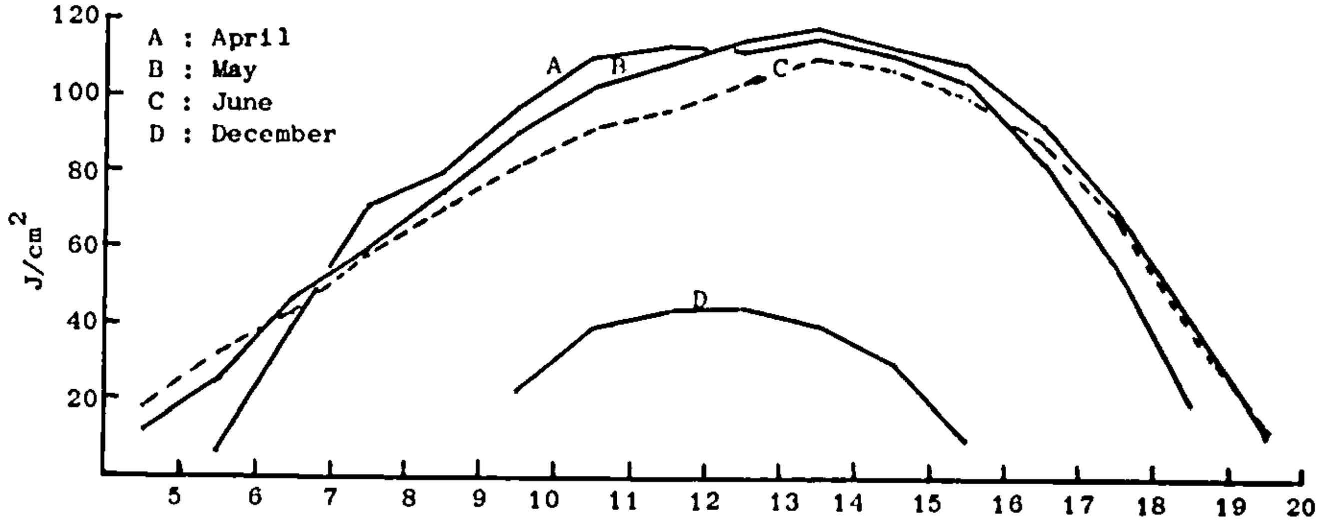

Fig. 8 Diurnal Variation of I for April, May, June and December for All Days

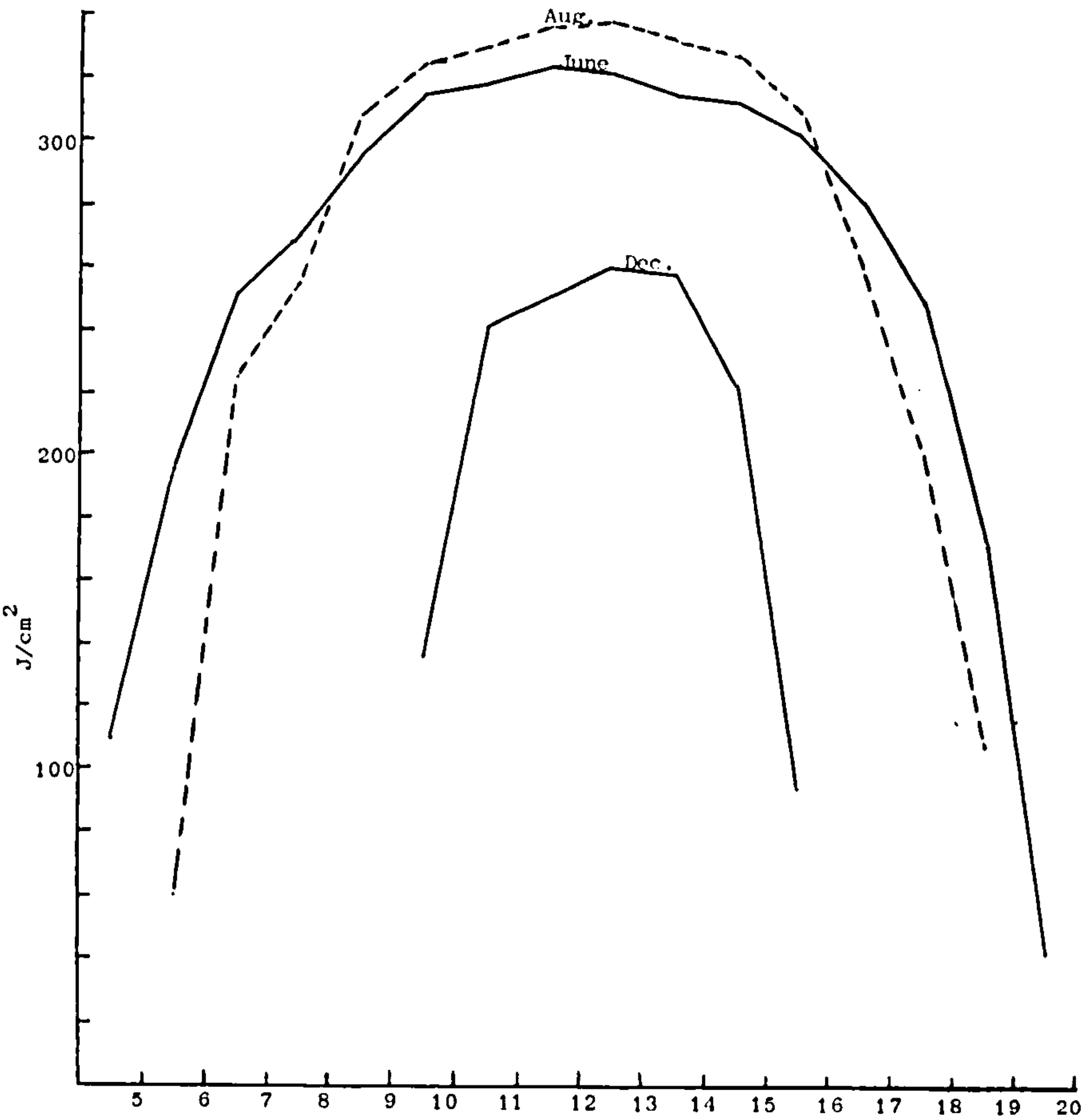

Fig. 9 Diurnal Variation of I for June, August and December on Best Radiation Days - Top 5.

From a consideration of solar elevation alone one would expect the highest hourly values in June. However, for the average day the dominant factor controlling the direct radiation reaching the ground is the cloud cover. June is generally a more unsettled month at Valentia than either April or May so that this factor together with the higher water vapour content of the air in June more than counterbalances the higher sun's elevation.

Fig. 9 shows the diurnal variation on the best radiation days (Top 5) for June, August and December. On these clear, almost cloudless days the June/July values are very similar and provide the highest hourly values apart from the four hours before and after midday. For these eight hours around midday the highest values are recorded an August. On these clear days the turbidity must be a major factor and at Valentia turbidity is found to be steadily decreasing from April onwards [1]. On the other hand, as previously stated, the higher water vapour content of the air in June/July will contribute to the lowering of the values for these months. All the curves show a flattening off before and after midday and a much steeper gradient in the early morning and late evening. This of course is due to the fact that the optical air mass changes much more rapidly with solar elevation when the latter is low.

3.5. Intensity of Direct Radiation as a Function of Sun's Altitude (h)

The true variations in the intensity of direct solar radiation cannot be fully assessed by the hourly values alone due to the fact that the sun's altitude varies greatly during the day and from day to day. To get some idea of the extent of this variation the intensity was computed for each 5° of sun's altitude for each month. The mean monthly values for each hour were attributed to the middle day of the month and plotted against the solar altitude at the middle of each hour of that day. From this graph the value of I corresponding to each 5° of sun's altitude was read off. Values were not extracted below 10° due to the obstructing effect of the hills around the station at lower elevations.

Tables XII and XIII contain the values as computed for all days and the Top 5 days.

One noticeable feature on Table XII (all days) is the fact that for the same solar altitude the afternoon intensity is higher in all the months than the corresponding forenoon value. This is probably a reflection of the fact that the most favourable time for direct radiation at Valentia is in stable weather conditions. In such situations a morning cloud layer tends to break up under the influence of solar heating and by afternoon much of the cloud has dissolved.

On the best radiation days (Top 5 - Table XIII) this feature is very much reduced, the forenoon and afternoon values for the same sun's elevation being very similar except for the low sun elevations. When the sun is low the altitude is changing more rapidly and the method used in the computation is less reliable. Moreover, on these nearly clear days mist and haze are frequent around the horizon so that the adopted value of the air mass is much more critical.

The intensities in Tables XII and XIII have not been corrected for the seasonal changes in solar radiation intensity outside the atmosphere as a result of the variations in the sun - earth distance. This correction varies between +3·4% in early July and -3·3% in early January. Even if this correction were applied solar radiation intensities in winter would still be considerably higher than the corresponding values for the same solar altitude in summer.

Fig. 10 shows the mean values for each solar altitude for the winter (October to March) and summer (April to September) periods for the best radiation days (Top 5). For all solar altitudes the winter intensity is higher than the corresponding summer intensity. The intensity at station level depends mainly on three factors:-

1. the seasonal change in the radiation outside the atmosphere
2. the thickness of the atmosphere traversed
3. the turbidity of the atmosphere

When we compare the intensities at the same solar altitude factor 2 is eliminated. Even of factor 1 is eliminated by applying the appropriate correction the winter values are still higher than the summer values. Thus, the main reason for the winter - summer differences must be due to factor 3 i.e. the turbidity of the atmosphere. Angstroms turbidity coefficient (B) is a measure of the quantity of haze in the atmosphere. McWilliams [1] has shown that at Valentia B is a minimum during the winter months. It rises to a maximum in April and remains relatively high during the summer months. Moreover, the effect of water vapour absorbtion is also highest during the summer months so that the higher winter intensities are in accordance with what would be expected.

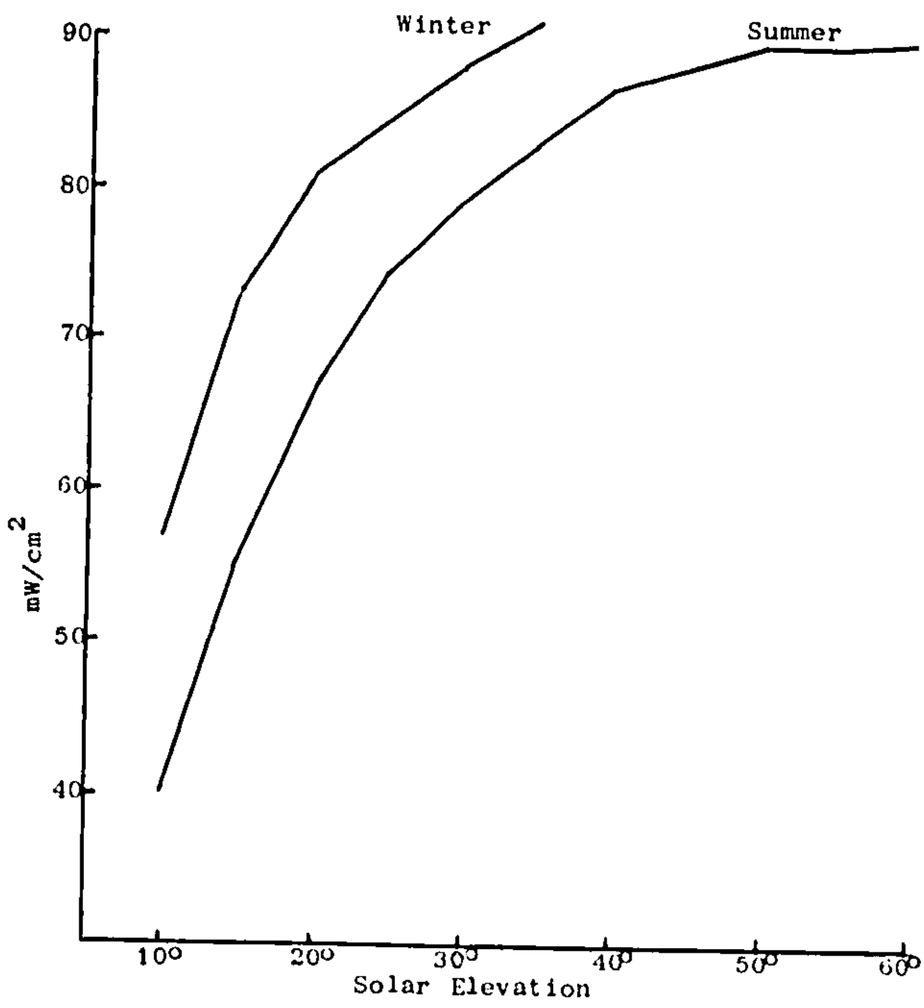

Fig. 10 Variation of Intensity of Direct Solar Radiation (I) with Solar Elevation in Winter and Summer for best Radiation Days - Top 5.

3.6. Components of Direct Solar Radiation of Normal Incidence

So far we have considered only the direct solar radiation incident on a surface maintained normal to the solar beam. For many purposes it is useful to know the radiation falling on differently orientated surfaces. In section 3 above it has been shown how the direct solar radiation incident on a normal surface (I) was computed from the vertical component (V) as derived from the recorded differences between the Global and Diffuse radiation on an horizontal surface and the solar elevation (h). The relation is:

$$V = I \sin h$$

If H denotes the horizontal component of the direct radiation then

$$H = I \cos h$$

The H component may again be resolved into two components S (south to north) and W (west to east) from the relations:

$$S = H \cos A$$

$$W = H \sin A$$

where A is the sun's azimuth (measured positive from south through west. For most purposes the sun's azimuth is measured from north through east but since the sun is mainly in the southern sky it is most convenient in this case from the point of view of the algebraic signs of the components S and W to take the south point as zero azimuth.

The sun's azimuth angle for each hour (centred at the half hour) of the middle day of each month was computed from the formula:

$$\cos A = \tan\varphi \tan h - \sin\delta / \cos\varphi \cos h$$

where φ is the latitude of Valentia (51° 56' N) and δ is the declination of the sun.

These radiation components so computed are given in Tables 14 and 15 for "all days" and for Top 5 days.

The components for the clearest days (Top 5) are also shown graphically in Fig. 11 for the representative months of March, June and December.

The Horizontal Component (H) which determines the energy falling on a vertical surface rotated so as to be always normal to the line of the sun's azimuth shows two maxima in June about 5 hours on either side of midday. In March the maxima are about 2½ hours on either side of noon and in December they merge into one maximum about noon.

Having computed the primary components H, S, W and V one can readily estimate the amount of radiation which falls on other surfaces inclined to the principal directions. Thus, for a vertical surface orientated at an angle "D" west of south the radiation received would be:

$$H \sin (D - A)$$

$$= H \sin D \cos A - H \cos D \sin A$$

$$= S \sin D - W \cos D$$

If the vertical surface is facing SE the radiation received will be

$$S \sin 45 - W \cos 45 = \frac{1}{\sqrt{2}} (S - W)$$

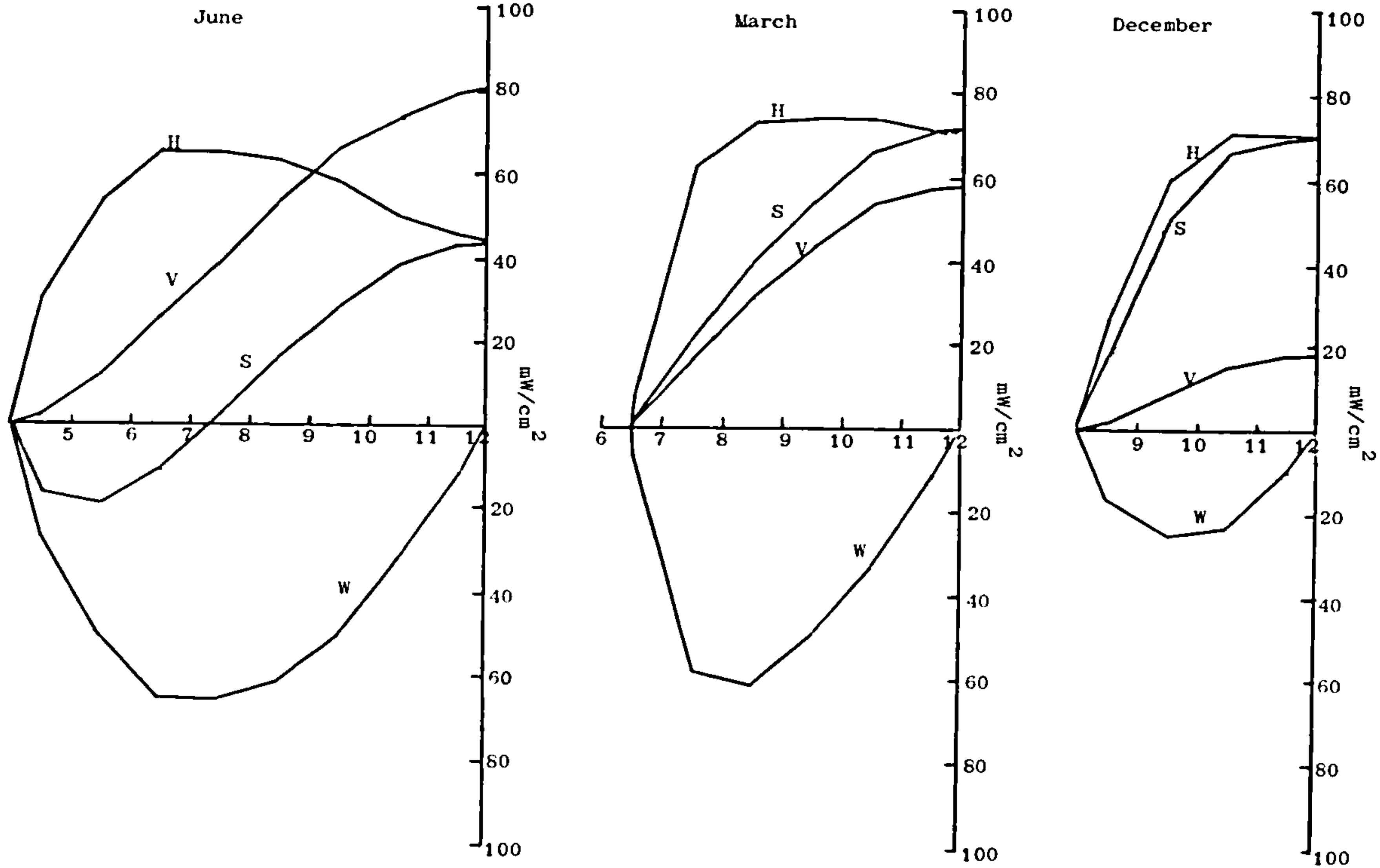

Fig. 11 Components of Direct Solar Radiation for Clearest Days - Top 5 for June, March and December.
V = Vertical Component; H = Horizontal Component; S = South to North component of H;
W = West to East component of H.

If the surface is inclined at an angle "α" to the horizontal the radiation received would be

$$(S \sin D - W \cos D)\sin\alpha + V \cos\alpha$$

For a south facing surface similarly inclined to the horizontal the angle D = 90 so the radiation received becomes

$$S \sin\alpha + V \cos\alpha$$

Table XVI shows the direct radiation falling ona sample selection of surfaces when all days are included and similar data for the Top 5 radiation days.

For those interested in the use of solar energy for domestic water heating the data in Table XVI show how important it is to consider the position of the receiving surface of the solar panels.

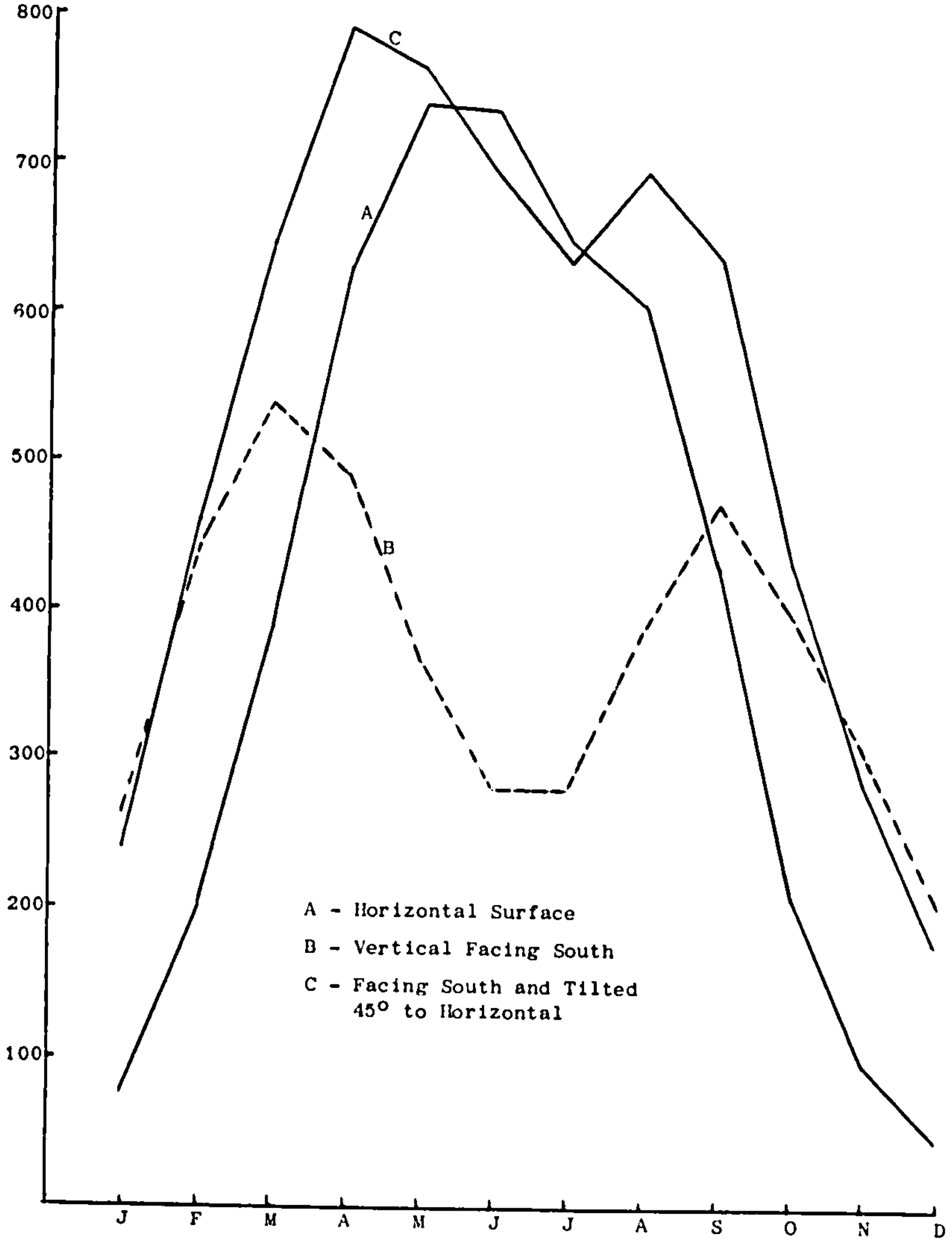

Fig. 12 Annual Variation of Direct Solar Radiation falling on selected surfaces.

Fig. 12 shows the annual variation of the mean daily totals of direct radiation for the surfaces positioned

(a) Horizontal

(b) Vertical facing south

(c) Facing south but tilted 45° to the horizontal.

The surface positioned horizontally receives more radiation over the year than any of the vertical surfaces of which that facing south is best. However, the south facing surface has it's total received radiation more uniformly distributed over the year with lower summer daily totals but much higher daily totals during the critical winter months than for horizontal surface which receives a relatively small proportion of its annual total during winter.

One can get best results by tilting the south facing surface at an angle of about 45° to the horizontal. The results for the three positions referred to may be summarised as follows:-

<u>Average Daily Totals of Direct radiation J/cm²</u>

Surface	Summer	Winter	Year
Horizontal	631	169	400
Vertical facing south	380	357	368
Tilted 45° facing south	702	372	537

It is clear that the surface facing south and tilted at an angle of 45° gets more winter radiation than the vertical south facing surface but also during summer than the seasonally biassed horizontal surface. The overall annual radiation is considerably enhanced in this tilted position.

The results for the tited surface above are based on the south facing surface being fixed for the whole year at a tilt of 45° to the horizontal. However, the received radiation can be still further enhanced if one goes to the trouble of adjusting the angle of tilt throughout the year. For maximum radiation reception the best tilts for a south facing surface would be about 75° for December/January and 24° for June/July with an approximate proportional change for the intervening months.

If one is considering the best orientation for solar radiation reception for the four walls of a building, it can also be deduced from the data on Table XVI that it is more advantageous in this area to orientate the walls to face NE - SW - SE - NW than to have them facing the four cardinal compass points.

4. Duration of Bright Sunshine

To complete the picture of solar radiation at Valentia Table XVII gives average daily, monthly and annual totals of the duration of bright sunshine, as measured by Campbell-Stokes recorder. The period considered is the same as discussed above i.e. 1964 - 74.

These figures confirm that May is the best month for solar radiation at Valentia.

For a detailed account of the relation between solar radiation and the duration of bright sunshine at Valentia the reader is referred to a paper by Connaughton "Global Solar Radiation, Potential Evapotranspiration and Potential Water Deficit in Ireland" published by the Irish Meteorological Service.

Acknowledgements

Thanks are due to a number of the staff at Valentia, especially Mr. D. N. Reidy, Meteorological Assistant, who performed much of the laborious computational work involved in the production of the various tables.

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Atmospheric Turbidity at Valentia Observatory
Irish Meteorological Service Technical Note No. 36, 1973.

TABLE 1 — Monthly and Annual Totals of Global Solar Radiation on a Horizontal Surface (G) — J/cm^2

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1974	6751	12919	26149	43262	54966	51779	44137	44724	28306	17787	9868	5011	345659m
1973	5738m	12351	30025	43537	45666m	52317	52271	43173	30980	19065	7510m	5047	347680
1972	7789	13817	30295	38887	51106	51231	47369	45434	36874	17765	8951	4829m	354347
1971	7365	11681m	23999m	43155	52657	50176m	63206M	39573m	32100	16951	8356	5240	354459
1970	8610	15447	35086M	43075	50775	59708	49234	39885	27846	17242	8426	7185M	362519
1969	8358	17031	30477	45829M	56757	59215	52402	45957	31259	16174m	9847	6790	380096
1968	6157	17141M	27208	44357	61708	62634M	62843	56989M	36962M	17628	7770	6251	407648M
1967	8839	13764	29372	46505	53277	54413	43699m	42947	29477	17640	9945	5371	355249
1966	6286	11758	24134	30045m	64624M	54910	56579	48301	32625	22773M	11653M	5713	369401
1965	10005M	16814	31000	40044	49616	56368	58178	42360	27183m	17812	9360	5576	364316
1964	7903	13710	27604	43144	54940	50258	51937	45252	32779	17844	10258	6481	362110
Means	7618	14221	28668	41986	54190	54819	52896	44963	31490	18062	9268	5772	363953
Range Max-min	4267	5460	11087	15784	18958	12458	19507	17416	9779	6599	4143	2356	61989
Range as % of Mean	56·0	33·4	38·7	37·6	35·0	22·7	36·9	38·7	31·1	36·5	44·7	40·8	17·0

TABLE II — Monthly and Annual Totals of Diffuse Solar Radiation on a Horizontal Surface (D) — J/cm^2

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1974	4834	8396	15528	22206	30185	32999	29209m	24844	17804	11587	6414	3909	207915
1973	4007m	8814	16221	22588	27046m	30543	30351	24373	17854	10938	5520	3501	201756m
1972	5011	7998	13811	22695	30614	32825	32084	26322	16734	10433m	5397m	3460m	207384
1971	4573	8509	15546	22313	31272	34290	29653	24188m	16665	10434	6266	3764	207473
1970	5671	8510	19644	24605	32499	31329	33625	27449	18617	12412	6107	4532	225000
1969	5950	8948	19671M	25391	33044	36080M	32986	26953	20416	12095	7416M	4896M	233846M
1968	5236	9539	17482	26364M	33173M	33949	37238M	26983	19904	12869M	5911	4793	233441
1967	6882M	8873	17742	23485	32657	34935	33965	28134M	21907M	11992	6664	4538	231774
1966	4416	7489m	13786m	17736m	31190	33637	36452	26894	21190	11543	6928	4818	216079
1965	5636	9993M	16041	22860	31003	29916m	32255	25826	16545m	10623	6423	4056	211177
1964	5510	9287	17720	25731	31519	30167	32317	25460	16722	11355	6625	4696	217109
Means	5248	8760	16654	23270	31291	32788	32740	26130	18578	11480	6334	4269	217541
Range Max-min	2875	2504	5885	8628	6127	6164	8029	3946	5362	2436	2019	1436	32090
Range as % of Mean	54·8	28·6	35·3	37·1	19·6	18·8	24·5	15·1	28·9	21·2	31·9	33·6	14·8

TABLE III — Average Daily Totals of Global (G) and Diffuse (D) Solar Radiation on a Horizontal Surface — J/cm²

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
G	246	508	925	1400	1748	1827	1706	1450	1050	583	309	186	997
D	169	313	537	776	1009	1094	1057	844	620	371	211	138	595
D/G	0·69	0·62	0·58	0·55	0·58	0·60	0·62	0·58	0·59	0·64	0·68	0·74	0·60

TABLE IV — Maximum Recorded Daily Values of G and D — J/cm²

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
Max G	694	1147	1938	2620	3121	3155	3230	2727	2133	1566	880	415	
Corresponding D	151	285	553	497	949	1001	587	419	861	336	173	102	
D/G	0·22	0·25	0·29	0·19	0·30	0·32	0·18	0·15	0·40	0·21	0·20	0·25	0·25
Max D	398	581	927	1302	1557	1887	1830	1500	1087	789	422	280	
Corresponding G	419	821	1223	1573	1999	2050	2405	1768	1141	929	444	297	
D/G	0·95	0·71	0·76	0·83	0·78	0·92	0·76	0·85	0·95	0·85	0·95	0·94	0·86

TABLE V

Mean Hourly Values of Global and Diffuse Solar Radiation $J/cm^2 x 10^{-1}$

HOUR L.A.T.	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	10 to 11	11 to 12	12 to 13	13 to 14	14 to 15	15 to 16	16 to 17	17 to 18	18 to 19	19 to 20	20 to 21	Total for Day
(a) Global Radiation																			
Jan.					5	80	234	385	477	492	414	269	96	6					2458
Feb.				1	65	274	514	731	845	874	783	588	316	86	4				5081
Mar.			5	74	304	619	942	1191	1317	1363	1270	1014	701	353	91	4			9248
Apr.		2	72	318	663	999	1338	1615	1750	1763	1656	1445	1136	757	380	98	4		13996
May		47	222	518	857	1221	1568	1854	1996	2047	1956	1725	1440	1043	646	283	57		17480
June	5	97	312	595	947	1282	1586	1854	1978	2018	1972	1796	1481	1128	741	365	110	7	18274
July	1	66	253	521	837	1159	1499	1749	1923	1970	1910	1695	1401	1036	659	310	73	2	17064
Aug.		12	125	394	714	1055	1358	1586	1726	1763	1687	1483	1173	823	451	138	12		14500
Sept.			14	142	426	766	1062	1285	1399	1440	1340	1132	829	484	161	17			10497
Oct.				14	126	367	613	779	920	930	867	647	404	144	16				5827
Nov.					17	124	318	482	583	574	492	339	142	17					3088
Dec.						46	174	317	380	389	318	186	52						1862
(b) Diffuse Radiation																			
Jan.					5	68	175	267	313	320	277	190	75	4					1694
Feb.				1	56	197	337	438	494	500	461	367	210	64	4				3129
Mar.			5	64	223	390	538	655	735	744	700	579	429	238	71	3			5374
Apr.		2	61	216	405	599	746	853	923	938	858	758	612	448	258	79	4		7759
May		38	175	365	578	767	927	1051	1099	1095	1033	918	775	599	413	211	49		10093
June	5	82	238	434	638	814	970	1098	1143	1124	1059	979	830	665	480	271	98	7	10935
July	1	55	199	380	600	805	963	1098	1152	1118	1077	943	814	626	135	234	66	2	10568
Aug.		12	102	277	474	670	809	913	957	956	917	805	653	480	290	108	12		8435
Sept.			14	117	298	477	625	753	805	807	740	629	487	309	122	14			6197
Oct.				14	105	252	392	495	552	561	519	419	271	112	14				3706
Nov.					17	106	228	322	377	380	329	231	109	14					2113
Dec.						46	140	233	270	276	230	143	44						1382

TABLE VI   Percentage Frequency Distribution of Daily Totals of Global Solar Radiation

	J/cm^2 ≤250	251 to 500	501 to 750	751 to 1000	1001 to 1500	1501 to 2000	2001 to 2500	2501 to 3000	3001 to 3500
January	54·6	40·4	5·0						
February	19·3	32·4	30·9	12·9	4·5				
March	2·6	15·0	20·8	20·8	30·8	10·0			
April	0·3	6·4	10·0	11·5	25·7	27·6	17·9	0·6	
May	-	2·9	4·1	8·8	24·1	23·8	19·9	13·8	2·6
June	-	2·7	5·5	9·4	17·3	20·6	23·0	16·7	4·8
July	0·3	3·2	7·3	7·3	23·1	22·9	19·4	15·0	1·5
August	-	5·3	12·0	12·0	22·0	26·2	19·9	2·6	
September	1·5	11·5	16·4	19·1	31·8	18·5	1·2		
October	13·8	31·7	24·0	21·1	9·1	0·3			
November	39·9	45·3	13·3	1·5					
December	71·8	28·2							
Summer	0·3	5·3	9·2	11·4	24·0	23·3	16·9	8·1	1·5
Winter	33·6	32·1	15·7	9·4	7·5	1·7			
Year	17·1	18·7	12·4	10·4	15·7	12·5	8·4	4·1	0·7

TABLE VII

Average Number of Occasions when Global Solar Radiation was less than (a) 250 $J/cm^2/day$ (b) 500 $J/cm^2/day$ (c) 1000 $J/cm^2/day$ for 2, 3, 4 or 5 Successive Days

	2 Successive Days $J/cm^2/Day$			3 Successive Days $J/cm^2/Day$			4 Successive Days $J/cm^2/Day$			5 Successive Days $J/cm^2/Day$		
	<250	<500	<1000	<250	<500	<1000	<250	<500	<1000	<250	<500	<1000
Jan.	9·9	29·0	31·0	6·2	28·6	30·8	4·3	28·4	30·7	2·8	28·1	30·6
Feb.	1·4	8·5	26·4	0·4	5·9	26·0	0·1	4·3	25·7	–	3·2	25·6
Mar.	–	1·2	12·2	–	0·5	8·5	–	0·2	4·3	–	0·1	4·4
Apr.	–	0·3	4·7	–	–	1·7	–	–	0·5	–	–	0·5
May	–	–	0·9	–	–	0·2	–	–	–	–	–	–
June	–	–	0·5	–	–	–	–	–	–	–	–	–
July	–	0·1	1·4	–	–	0·4	–	–	–	–	–	–
Aug.	–	0·2	3·0	–	–	0·5	–	–	0·1	–	–	–
Sept.	–	0·5	6·7	–	–	3·1	–	–	1·2	–	–	0·3
Oct.	0·7	7·4	25·8	–	4·2	23·8	–	2·3	22·1	–	1·4	20·2
Nov.	5·5	22·0	30·0	2·3	18·7	30·0	0·6	15·9	30·0	0·1	13·9	29·6
Dec.	15·9	31·0	31·0	12·8	31·0	31·0	9·9	31·0	31·0	7·3	30·7	31·0
Summer	–	1·1	17·2	–	–	5·9	–	–	1·8	–	–	0·8
Winter	33·4	99·1	156·4	21·6	88·9	150·1	14·9	82·1	143·8	10·2	77·4	141·4
Year	33·4	100·2	173·6	21·6	88·9	156·0	14·9	82·1	145·6	10·2	77·4	142·2

TABLE VIII Monthly and Annual Totals of Direct Solar Radiation (I) on Surface Normal to Solar Beam J/cm^2

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1974	7840	13016	23188	37659	38642	27714	23001	34798	20406	15033	12575	4821	258693
1973	6614	9522	29081	37928	29371	31903	33730	32237	26553	20970	7159	7134	272202
1972	10919	16352	36519M	28727	30969	27844	23391	32393	39773M	18249	12917	6124	284177
1971	10864	8678m	17845m	36887	33567	24356m	52309M	25715	29698	16817	8108	6915	271759
1970	12639	20091	34393	33163	29157m	44873M	24760	21498m	18562	12101	8645	12898M	272780
1969	9984	23869	23428	36906	38801	36392	30588	31286	21617	10693m	9293	8919	281776
1968	3374m	21671	21960	32954	46346	42577	38373	49396M	33581	12569	6871m	6627	316299M
1967	7786	14042	23693	40620M	32348	29928	15258m	24606	15005m	14344	11889	3942	233461m
1966	6341	11164	21572	21250m	54428M	32977	32178	35690	22377	30298M	17607	3892m	289774
1965	16697M	19869M	32533	30726	30869	39966	40078	27975	20888	18156	10765	7386	295908
1964	8555	12658	22444	32511	37848	31096	30294	35498	32592	15744	12977M	8550	280767
Means	9238	15539	26060	33576	36577	33602	31269	31917	25550	16816	10801	7019	277964
Range Max-min	13323	11191	18674	19370	25271	20517	37051	27898	24768	19605	6106	9006	82838
Range as % of Mean	144·2	72·0	71·7	57·7	69·1	61·1	118·5	87·4	96·9	116·6	56·5	128·3	29·8

TABLE IX — Average Daily Totals of Direct Solar Radiation (I) on a Normal Surface — J/cm^2

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
All Days	298	555	840	1119	1180	1120	1009	1030	851	542	360	226	761
Top 5 Days	1787	2391	3105	3567	4007	4082	4090	3721	2992	2505	2049	1465	2980
Maximum	2055	2722	3220	3764	4212	4246	4304	3850	3256	2897	2355	1561	4304
Uccle All Days	276	433	719	931	1146	1255	1018	936	934	651	300	213	734
Uccle Maximum	1994	2637	3094	3491	3843	3993	3994	3474	3096	2748	2084	1749	3994

TABLE X — Percentage Frequency Distribution of Daily Totals of I (All Days)

J/cm^2	Nil	<100	101-250	251-500	501-750	751-1000	1001-1500	1501-2000	2001-2500	2501-3000	3001-3500	3501-4000	4001-4500
Jan.	29·3	51·3	10·6	16·7	7·3	4·7	7·0	2·1	0·3				
Feb.	15·9	35·1	8·4	13·6	12·0	9·1	13·0	6·2	2·3	0·3			
Mar.	4·7	24·3	8·8	11·1	11·4	9·7	13·8	9·7	5·9	3·8	1·5		
Apr.	1·8	17·3	10·3	7·0	9·4	8·2	13·0	14·8	9·1	7·0	3·0	0·9	
May	0·9	11·4	12·9	13·5	8·8	6·2	12·9	11·7	9·7	5·9	4·1	2·1	0·8
June	5·8	18·8	11·5	10·6	8·5	5·2	12·1	12·4	7·0	5·8	4·5	2·4	1·2
July	5·3	20·6	15·2	9·4	8·8	9·1	11·4	7·6	5·0	4·4	4·1	3·2	1·2
Aug.	3·5	19·5	12·6	10·6	7·6	6·5	14·1	10·6	7·3	5·6	3·8	1·8	
Sept.	4·8	24·3	12·7	10·6	8·5	6·4	13·6	9·7	9·7	3·6	0·9		
Oct.	11·1	34·8	10·6	14·4	8·8	10·9	11·1	6·2	2·6	0·6			
Nov.	14·8	43·2	15·2	15·8	9·7	7·0	5·2	3·3	0·6				
Dec.	19·1	54·6	13·5	15·2	9·1	4·1	2·6	0·9					
Summer	3·7	18·7	12·6	10·3	8·6	6·9	12·9	11·1	7·9	5·4	3·4	1·7	0·5
Winter	15·8	40·8	11·2	14·5	9·7	7·5	8·7	4·7	1·9	0·8	0·2	0·0	0·0
Year	9·8	29·4	11·9	12·4	9·2	7·3	10·8	7·9	5·0	3·1	1·8	0·9	0·3

TABLE XI — Mean Hourly Values of Direct Solar Radiation (I) — $J/cm^2 x10^{-1}$

HOUR L.A.T.	3 to 4	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	10 to 11	11 to 12	12 to 13	13 to 14	14 to 15	15 to 16	16 to 17	17 to 18	18 to 19	19 to 20	20 to 21	Total for Day
(a) All Days																			
Jan.						41	290	444	546	574	520	411	151	5					2962
Feb.					15	333	564	759	819	875	834	706	509	138					5552
Mar.				50	345	645	871	986	991	1051	1043	930	766	517	196	11			8402
Apr.			63	422	704	799	968	1098	1129	1120	1147	1112	1037	835	558	196			11188
May		114	253	462	585	744	898	1015	1081	1142	1166	1128	1086	927	698	388	110		11797
June		164	318	422	591	718	813	909	961	1029	1100	1079	996	884	688	394	130		11196
July		128	286	389	469	559	724	799	901	997	1020	1016	924	810	620	354	91		10087
Aug.			133	436	575	705	833	912	987	1036	1045	1028	940	824	603	241			10298
Sept.				112	433	685	821	875	909	974	989	952	823	628	287	25			8513
Oct.					94	436	595	634	750	752	777	618	515	224	25				5420
Nov.						121	411	542	613	575	548	485	282	24					3601
Dec.							219	384	429	441	397	295	97						2262
(b) Top 5 Radiation Days																			
Jan.						678	2160	2466	2680	2764	2708	2526	1662	226					17870
Feb.					76	1848	2774	3088	3276	3214	3148	2946	2476	1066					23912
Mar.				238	2268	2842	3048	3246	3260	3284	3170	3168	2960	2400	1162				31046
Apr.			402	1590	2596	2842	3058	3200	3200	3238	3196	3050	3116	2832	2220	1134			35674
May		484	1948	2524	2832	3058	3118	3078	3314	3284	3298	3180	3054	2756	2352	1588	198		40066
June		1100	1954	2518	2698	2964	3154	3182	3242	3222	3146	3132	3034	2822	2486	1728	434		40816
July		960	2050	2572	2846	3058	3208	3244	3276	3220	3192	3164	2986	2776	2226	1716	410		40904
Aug.			602	2254	2546	3090	3252	3304	3372	3380	3336	3276	3098	2606	2010	1084			37210
Sept.				290	1588	2646	2942	3192	3264	3202	3142	3034	2904	2300	1264	148			29916
Oct.					714	2466	2930	2966	2894	3174	3082	2846	2618	1242	120				25052
Nov.						1326	2364	2888	2966	2902	2968	2832	1932	310					20488
Dec.							1360	2414	2514	2602	2584	2224	952						14650

TABLE XII Variation of Intensity of Direct Solar Radiation (I) with Sun's Altitude (h) All Days $mW/cm^2 x 10^{-1}$

Month		10°	15°	20°	25°	30°	35°	40°	45°	50°	55°	60°
	a.m.	83	133									
Jan.	p.m.	115	150									
	Mean	99	142									
	a.m.	83	133	184	228							
Feb.	p.m.	129	175	214	243							
	Mean	106	154	199	235							
	a.m.	78	128	179	222	231	275					
Mar.	p.m.	125	170	213	244	247	292					
	Mean	102	149	196	233	239	284					
	a.m.	92	139	183	206	222	253	282	308			
Apr.	p.m.	129	177	220	256	288	302	313	315			
	Mean	110	158	202	231	255	277	297	312			
	a.m.	69	100	131	149	169	194	220	247	271	295	
May	p.m.	104	153	197	233	265	290	305	312	292	319	
	Mean	87	126	164	191	217	242	263	279	281	307	
	a.m.	69	92	109	131	156	178	196	213	229	247	265
June	p.m.	78	122	168	206	236	258	274	288	300	305	288
	Mean	73	107	139	168	196	218	235	251	265	276	277
	a.m.	67	88	103	117	129	142	157	184	207	222	250
July	p.m.	79	119	161	193	222	241	258	273	283	283	277
	Mean	73	104	132	155	175	191	207	228	245	253	264
	a.m.	69	115	139	160	181	201	224	242	264		
Aug.	p.m.	107	162	197	230	248	265	280	288	289		
	Mean	88	139	168	195	214	233	252	265	276		
	a.m.	58	106	150	193	217	236	250				
Sept.	p.m.	108	161	198	230	254	270	271				
	Mean	83	134	174	211	236	253	261				
	a.m.	35	122	155	173	208						
Oct.	p.m.	93	144	165	201	209						
	Mean	64	133	160	187	209						
	a.m.	84	136	170								
Nov.	p.m.	113	145	160								
	Mean	98	140	165								
	a.m.	82	119									
Dec.	p.m.	95	123									
	Mean	89	121									

TABLE XIII Variation of Intensity of Direct Solar Radiation (I) with Sun's Altitude (h) Top 5 Days $mW/cm^2 x10^{-1}$

Month		10^o	15^o	20^o	25^o	30^o	35^o	40^o	45^o	50^o	55^o	60^o
	a.m.	603	706									
Jan.	p.m.	706	758									
	Mean	655	732									
	a.m.	461	672	814	911							
Feb.	p.m.	647	770	847	892							
	Mean	554	721	831	902							
	a.m.	519	692	789	831	878	906					
Mar.	p.m.	594	728	822	864	881	908					
	Mean	557	710	806	848	880	907					
	a.m.	358	522	678	750	789	828	864	889			
Apr.	p.m.	539	667	761	820	867	853	861	892			
	Mean	449	595	720	785	828	842	863	891			
	a.m.	519	622	706	753	797	833	856	864	858	897	
May	p.m.	419	547	661	722	778	825	858	878	903	914	
	Mean	469	585	684	738	788	829	857	871	881	906	
	a.m.	442	567	656	714	742	778	817	850	876	883	897
June	p.m.	306	486	622	717	767	806	836	856	870	875	889
	Mean	374	527	639	716	755	792	827	853	873	879	893
	a.m.	478	608	689	745	789	822	853	875	895	900	911
July	p.m.	347	497	592	678	758	772	833	861	881	886	895
	Mean	413	553	641	712	774	797	843	868	888	893	903
	a.m.	333	592	667	711	797	867	892	908	925		
Aug.	p.m.	397	542	636	731	806	870	900	917	933		
	Mean	365	567	652	721	802	869	896	913	929		
	a.m.	186	383	572	739	792	853	903				
Sept.	p.m.	436	592	714	808	831	858	886				
	Mean	311	488	643	774	812	856	895				
	a.m.	389	689	783	822	803						
Oct.	p.m.	500	731	775	833	881						
	Mean	445	710	779	828	842						
	a.m.	544	739	825								
Nov.	p.m.	692	806	806								
	Mean	618	773	816								
	a.m.	517	697									
Dec.	p.m.	667	722									
	Mean	592	710									

TABLE XIV — Direct Solar Radiation and Components - Mean Hourly Values - All Days - $J/cm^2 x10^{-1}$

Month	Component	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	10 to 11	11 to 12	12 to 13	13 to 14	14 to 15	15 to 16	16 to 17	17 to 18	18 to 19	19 to 20
		W Component Negative								W Component Positive							
Jan.	I					41	290	444	546	574	520	411	151	5			
	V					12	59	118	164	172	137	79	21	2			
	H					41	285	428	522	548	503	404	150	5			
	S					28	230	399	518	544	468	327	103	3			
	W					30	168	156	67	70	183	238	109	4			
Feb.	I				15	333	564	759	819	875	834	706	509	138			
	V				9	77	177	293	351	374	322	221	106	22			
	H				15	325	536	701	741	792	770	671	499	137			
	S				7	203	423	648	737	788	712	530	312	61			
	W				13	254	329	267	74	79	293	412	390	122			
Mar.	I			50	345	645	871	986	991	1051	1043	930	766	517	196	11	
	V			10	81	229	404	536	582	619	570	435	272	115	20	1	
	H			43	335	604	771	828	799	812	841	853	716	504	195	11	
	S			6	113	325	567	740	788	801	752	627	385	170	28	1	
	W			42	315	509	522	372	130	132	377	578	604	475	193	11	
Apr.	I		63	422	704	799	968	1098	1129	1120	1147	1112	1037	835	558	196	
	V		11	102	258	400	592	762	827	825	798	687	524	309	122	19	
	H		63	410	655	692	765	791	771	759	825	874	894	776	545	195	
	S		-12	1	138	296	497	677	757	745	706	568	382	164	1	-37	
	W		62	410	640	626	581	410	145	143	427	664	808	759	545	191	
May	I	114	253	462	585	744	898	1015	1081	1142	1166	1128	1086	927	698	388	110
	V	9	47	153	279	454	641	803	897	952	923	807	665	444	233	72	8
	H	114	249	436	514	590	629	618	599	634	676	789	860	814	658	381	110
	S	-53	-74	-46	52	189	351	497	585	619	544	440	275	82	-70	-113	-51
	W	101	238	434	511	559	522	367	128	136	402	655	815	810	654	364	97
June	I	164	318	422	591	718	813	909	961	1029	1100	1079	996	884	688	394	130
	V	15	74	161	309	468	616	756	835	894	913	817	651	463	261	94	12
	H	163	309	390	503	543	530	505	472	504	612	704	753	752	635	383	130
	S	-84	-107	-63	18	141	266	389	457	488	471	354	195	27	-103	-133	-67
	W	139	290	385	502	524	458	322	120	128	390	609	727	751	627	359	111

TABLE XIV (Contd.) Direct Solar Radiation and Components - Mean Hourly Values - All Days - $J/cm^2 x10^{-1}$

Month	Component	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	10 to 11	11 to 12	12 to 13	13 to 14	14 to 15	15 to 16	16 to 17	17 to 18	18 to 19	19 to 20
		W Component Negative								W Component Positive							
July	I	128	286	389	469	559	724	799	901	997	1020	1016	924	810	620	354	91
	V	11	54	141	237	354	536	651	771	852	833	752	587	410	224	76	7
	H	128	279	363	405	433	487	461	464	519	589	680	717	699	577	346	91
	S	-64	-92	-51	25	123	257	358	451	505	457	359	203	43	-81	-114	-45
	W	111	263	359	404	415	413	290	108	121	371	577	688	698	571	327	79
Aug.	I		133	436	575	705	833	912	987	1036	1045	1028	940	824	603	241	
	V		23	117	240	385	549	673	769	807	770	678	520	343	161	30	
	H		131	420	522	588	626	615	617	649	706	772	783	749	581	239	
	S		-32	-23	81	222	380	511	603	634	586	469	296	116	-32	-59	
	W		127	419	516	544	497	343	130	136	394	613	725	740	580	232	
Sept.	I			112	433	685	821	875	909	974	989	952	823	628	287	25	
	V			25	128	289	437	532	594	633	600	503	342	175	39	3	
	H			110	414	622	694	694	688	740	786	808	749	603	284	25	
	S			8	115	304	486	605	678	729	685	566	365	168	-21		
	W			110	398	543	496	340	116	124	385	577	654	579	283	25	
Oct.	I				94	436	595	634	750	752	777	618	515	224	25		
	V				21	115	221	284	368	369	348	228	133	32	2		
	H				92	420	552	566	652	656	694	575	497	222	25		
	S				37	246	422	513	645	649	630	439	291	88	9		
	W				84	341	356	238	98	98	292	371	403	204	23		
Nov.	I					121	411	542	613	575	548	485	282	24			
	V					18	90	160	206	194	163	108	33	3			
	H					120	401	518	578	542	522	473	280	24			
	S					79	324	480	573	538	484	382	185	15			
	W					90	236	194	72	68	195	278	210	19			
Dec.	I						219	384	429	441	397	295	97				
	V						34	84	110	113	88	43	8				
	H						216	375	415	426	387	292	97				
	S						179	352	412	423	363	243	68				
	W						120	129	50	51	134	162	69				

TABLE XV Direct Solar Radiation and Components - Mean Hourly Values - Top 5 Days - $J/cm^2 x10^{-1}$

Month	Component	W Component Negative								W Component Positive							
		4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	10 to 11	11 to 12	12 to 13	13 to 14	14 to 15	15 to 16	16 to 17	17 to 18	18 to 19	19 to 20
Jan.	I					678	2160	2466	2680	2764	2708	2526	1662	226			
	V					100	448	686	850	878	756	516	180	16			
	H					670	2115	2370	2542	2622	2600	2475	1653	160			
	S					458	1709	2207	2521	2601	2421	2000	1130	98			
	W					489	1246	863	324	335	947	1458	1206	126			
Feb.	I				76	1848	2774	3088	3276	3214	3148	2946	2476	1066			
	V				12	398	862	1188	1396	1372	1210	920	490	114			
	H				75	1804	2637	2850	2963	2904	2903	2798	2428	1060			
	S				34	1127	2082	2635	2948	2890	2684	2209	1517	475			
	W				67	1409	1618	1085	296	290	1105	1717	1896	948			
Mar.	I			238	2268	2842	3048	3246	3260	3284	3170	3168	2960	2400	1162		
	V			42	590	1122	1546	1906	2048	2062	1882	1608	1168	612	136		
	H			234	2189	2612	2627	2628	2534	2554	2551	2730	2719	2319	1154		
	S			33	738	1405	1932	2349	2500	2520	2280	2008	1462	782	165		
	W			232	2061	2202	1780	1179	412	415	1145	1850	2292	2183	1142		
Apr.	I		402	1590	2596	2842	3058	3200	3200	3238	3196	3050	3116	2832	2220	1134	
	V		50	408	1050	1536	1988	2330	2462	2490	2324	1986	1686	1150	566	122	
	H		399	1537	2373	2392	2323	2193	2044	2069	2194	2316	2622	2588	2147	1128	
	S		-76	4	500	1022	1511	1876	2007	2032	1877	1506	1120	545	5	-214	
	W		392	1537	2320	2163	1765	1135	385	389	1136	1759	2371	2530	2147	1108	
May	I	484	1948	2524	2832	3058	3118	3078	3314	3284	3298	3180	3054	2756	2352	1588	198
	V	38	398	896	1414	1920	2290	2490	2816	2792	2664	2334	1918	1376	834	328	16
	H	483	1906	2360	2454	2381	2117	1809	1747	1729	1944	2160	2375	2389	2199	1554	197
	S	-225	-563	-249	248	762	1181	1455	1705	1688	1564	1205	760	241	-232	-459	-92
	W	427	1821	2347	2442	2256	1757	1075	375	371	1155	1792	2250	2377	2187	1485	174
June	I	1100	1954	2518	2698	2964	3154	3182	3242	3222	3146	3132	3034	2822	2486	1728	434
	V	98	410	940	1398	1916	2372	2634	2798	2782	2604	2354	1962	1462	928	388	38
	H	1097	1904	2337	2307	2262	2079	1786	1638	1626	1768	2066	2314	2413	2307	1683	432
	S	-567	-660	-380	84	587	1044	1376	1584	1573	1362	1037	600	88	-375	-584	-223
	W	939	1786	2306	2305	2185	1798	1139	416	413	1128	1786	2235	2411	2276	1578	370

TABLE XV (Contd.) Direct Solar Radiation and Components - Mean Hourly Values - Top 5 Days - $J/cm^2 x10^{-1}$

Month	Component	W Component Negative 4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	10 to 11	11 to 12	W Component Positive 12 to 13	13 to 14	14 to 15	15 to 16	16 to 17	17 to 18	18 to 19	19 to 20
	I	960	2050	2572	2846	3058	3208	3244	3276	3220	3092	3164	2986	2776	2226	1716	410
	V	82	444	942	1452	1954	2384	2660	2808	2760	2616	2350	1908	1414	818	368	32
July	H	956	2002	2392	2648	2352	2147	1857	1688	1658	1647	2117	2297	2389	2069	1676	409
	S	-476	-660	-335	162	666	1134	1442	1642	1613	1279	1119	650	146	-290	-553	-203
	W	829	1890	2368	2643	2257	1822	1170	393	386	1038	1797	2203	2385	2049	1582	355
	I		602	2254	2546	3090	3252	3304	3372	3380	3336	3276	3098	2606	2010	1084	
	V		82	578	1038	1678	2122	2422	2606	2614	2446	2138	1684	1062	520	126	
Aug.	H		596	2177	2326	2593	2463	2247	2139	2142	2267	2482	2600	2381	1941	1077	
	S		-148	-119	359	980	1496	1865	2091	2094	1882	1508	983	368	-106	-267	
	W		577	2174	2298	2401	1957	1253	450	450	1264	1972	2407	2352	1938	1043	
	I			290	1588	2646	2942	3192	3264	3202	3142	3034	2904	2300	1264	148	
	V			54	460	1066	1510	1900	2080	2040	1870	1570	1168	610	160	12	
Sept.	H			285	1520	2422	2525	2553	2516	2469	2525	2598	2660	2220	1254	147	
	S			21	423	1182	1767	2225	2480	2434	2201	1819	1298	618	93		
	W			284	1460	2114	1804	1251	423	415	1238	1856	2322	2132	1251	147	
	I				714	2466	2930	2966	2894	3174	3082	2846	2618	1242	120		
	V				142	658	1116	1370	1450	1588	1424	1094	706	186	8		
Oct.	H				699	2377	2710	2630	2505	2750	2733	2628	2520	1227	120		
	S				278	1390	2071	2386	2477	2719	2479	2008	1473	488	41		
	W				641	1928	1748	1107	375	412	1150	1695	2044	1126	113		
	I					1326	2364	2888	2966	2902	2968	2832	1932	310			
	V					224	608	956	1098	1072	980	714	288	22			
Nov.	H					1306	2284	2724	2754	2698	2800	2740	1912	309			
	S					864	1846	2527	2732	2677	2597	2215	1266	190			
	W					979	1345	1018	344	337	1047	1613	1433	243			
	I						1360	2414	2514	2602	2584	2224	952				
	V						208	524	638	660	560	322	78				
Dec.	H						1345	2356	2431	2516	2523	2200	948				
	S						1118	2211	2413	2498	2368	1828	667				
	W						748	813	291	302	871	1224	674				

TABLE XVI Direct Solar Radiation Falling on Selected Surfaces - Mean Hourly Values - J/cm^2

Position of Surface	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
(a) All Days													
Normal to Solar Beam	298	555	840	1119	1180	1120	1009	1030	851	542	360	226	277964
Horizontal	76	195	387	624	739	734	650	607	430	212	98	48	146329
Vertical Facing Sun	289	519	731	902	867	789	724	800	722	495	346	221	225239
Vertical Facing North	-	-	-	5	41	56	45	15	-	-	-	-	4961
Vertical Facing South	262	442	530	493	363	281	278	390	473	397	306	204	134110
Vertical Facing East	42	94	189	287	286	274	236	258	200	112	59	30	62975
Vertical Facing West	60	130	237	354	393	370	343	342	263	139	77	42	83796
Vertical Facing NE	0	4	30	99	138	150	125	104	45	10	1	0	21579
Vertical Facing NW	1	10	49	134	200	206	182	149	71	17	2	0	31208
Vertical Facing SE	173	297	391	432	353	304	272	354	361	278	206	136	108073
Vertical Facing SW	198	342	439	491	442	377	366	429	423	310	230	153	127653
Tilted 45° Facing S	239	451	649	788	762	692	636	697	639	431	285	178	196100
(b) Clearest Days - Top 5													
Normal to Solar Beam	1787	2391	3105	3567	4007	4082	4090	3721	2992	2505	2049	1465	
Horizontal	443	796	1472	2015	2452	2511	2499	2112	1450	974	596	299	
Vertical Facing Sun	1721	2242	2685	2833	2980	3002	3030	2943	2569	2290	1953	1432	
Vertical Facing North	-	-	-	29	182	279	252	64	-	-	-	-	
Vertical Facing South	1515	1860	1817	1400	1081	934	985	1363	1656	1781	1691	1310	
Vertical Facing East	292	448	787	970	1250	1287	1337	1111	734	580	369	185	
Vertical Facing West	407	596	903	1144	1179	1220	1180	1143	936	654	467	307	
Vertical Facing NE	2	22	164	369	700	793	800	484	160	64	8	0	
Vertical Facing NW	7	60	227	492	625	715	672	511	274	91	16	1	
Vertical Facing SE	997	1271	1430	1338	1311	1226	1302	1407	1302	1298	1142	841	
Vertical Facing SW	1154	1442	1531	1462	1292	1208	1208	1424	1475	1376	1274	1013	
Tilted 45° Facing S	1384	1878	2326	2403	2409	2314	2354	2426	2267	1949	1618	1138	

TABLE XVII **Daily, Monthly and Annual Mean Values of Bright Sunshine (in Hours)**

	4 to 5	5 to 6	6 to 7	7 to 8	8 to 9	9 to 10	10 to 11	11 to 12	12 to 13	13 to 14	14 to 15	15 to 16	16 to 17	17 to 18	18 to 19	19 to 20	Total for Day	Total for Month
January					·02	·16	·23	·27	·27	·25	·19	·06					1·45	44·95
February				·01	·19	·28	·35	·36	·37	·38	·35	·24	·05				2·58	72·24
March			·02	·17	·31	·38	·41	·41	·43	·44	·41	·35	·21	·03			3·57	110·67
April		·05	·24	·35	·39	·43	·47	·48	·47	·48	·46	·45	·40	·28	·07		5·02	150·60
May	·02	·13	·26	·31	·37	·42	·45	·46	·47	·47	·46	·48	·44	·37	·24	·02	5·37	166·47
June	·06	·20	·25	·30	·33	·36	·40	·41	·42	·46	·45	·43	·41	·37	·25	·08	5·18	155·40
July	·05	·18	·21	·25	·27	·32	·35	·38	·41	·43	·43	·40	·38	·33	·24	·06	4·69	145·39
August		·09	·25	·30	·34	·38	·41	·43	·43	·44	·44	·42	·40	·33	·13		4·79	148·49
September			·06	·24	·34	·38	·42	·40	·42	·41	·42	·38	·30	·10			3·87	116·10
October				·04	·22	·30	·32	·34	·33	·35	·30	·25	·08				2·53	78·43
November					·05	·22	·26	·30	·27	·27	·25	·11					1·73	51·90
December						·13	·22	·22	·22	·21	·15	·03					1·18	36·58
Year	·01	·05	·11	·16	·24	·31	·36	·37	·38	·38	·36	·30	·22	·15	·08	·01		