551·521·326+551·524·32(54) "1957-58"

# Measurements of the total Radiation from Sun and Sky in India during the IGY

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(*Received 28 July 1959*)

ABSTRACT. A comparative study of the solar radiation and sunshine data recorded during the IGY at four representative stations in India, *viz.*, Delhi, Calcutta, Poona and Madras, using Moll-Gorczynski solarimeters, Bellani Spherical Pyranometers and Campbell-Stokes sunshine recorders has been made. The seasonal and diurnal variation of total radiation from sun and sky on a horizontal surface $T$ at all the four stations is discussed; also the variation month by month of the total radiation from sun, sky and ground on a spherical surface $T'$, and the hours of bright sunshine $S$. The percentage of annual radiation received in any of the seasons October—January, February—May and June —September is roughly the same despite the large variations during the monsoon and winter. Poona receives more radiation than the other stations throughout the year except during the monsoon when it receives the lowest. While the ratio $T/T'$ varies with the sun's elevation, the seasons and with the nature of the surroundings and is a maximum during the summer and least during the winter, it is nearly constant at all the four stations and has an average value of 2.

The constants of Angstrom's formula giving the empirical relationship between both radiation from sun and sky and the duration of sunshine have been determined for all the four stations for both cloudy and all days using the IGY data.

## 1. Introduction

Measurements of solar radiation have been made at Poona since 1931 and the results of the measurements of the total radiation from the sun and sky made at Poona during 1935 have been published by Raman (1938). Radiation observations were started at Delhi in 1955 and at two more stations, *viz.*, Calcutta and Madras, in connection with the implementation of a scheme of radiation measurements in India in September 1957. Radiation observations taken during the IGY at these four stations consisted of (1) continuous records of the total incoming radiation on a horizontal surface with solarimeters at all four stations, (2) measurements of the total radiation from sun, sky and ground with spherical pyranometers at all four stations, (3) daily measurements of the direct solar radiation with and without filters at two stations, (4) daily measurements of the longwave effective outgoing radiation at two stations, (5) continuous records of the diffuse radiation from the sky at two stations and (6) records of the duration of sunshine at all four stations. The present paper makes a comparative study and discusses the results of the measurements of the total solar radiation and of the duration of sunshine at the four stations. Though the mean data for the 18 months of the IGY are given in the paper, only the data for January to December 1958 are discussed.

The radiation data obtained for these four stations may be considered to be roughly representative of the climatic conditions existing in the north, northeast, centre and south of the Indian Peninsula. Delhi (Lat. 28°35′ N and Long. 77° 13′ E) is typical of the north/northwest part of the country with the extreme summer and winter conditions, while Calcutta (Lat. 22° 39′ N and Long. 88° 27′ E) is typical of the northeast region with its more humid summer followed by the monsoon and a mild winter. Poona (Lat. 18° 32′ N and Long. 73° 51′ E) data may be considered to be characteristic of conditions in the centre of the country and to some extent of the west coast of India. Madras (Lat. 13° 00′ N and Long. 80° 11′ E) further south, on the east coast of the Peninsula has climatic conditions quite different from that of the rest of the country, the northeast monsoon occurring during October and November, being a special feature of this area. The data for all the four stations for one year, cannot be considered to be 'normal'. They may however, be considered to be generally representative of the conditions prevailing over the country during the main seasons, *viz.*, summer (March to June), monsoon (July to September), post-monsoon (October to November) and winter (December to February).

## 2. Description of instruments and exposure

The instrumental equipment at the four stations consisted of Moll-Gorczynski solarimeters with Cambridge thread recorders for the continuous record of the total incoming radiation of sun and sky received on a horizontal surface, Bellani spherical pyranometers for the integration of the total radiation from the sun, sky, surroundings and from the ground on a spherical surface and Campbell-Stokes sunshine recorders for the record of the duration of the hours of bright sunshine.

2.1. *Moll-Gorczynski Solarimeter*— The theory and principle of working of the instrument has been discussed in detail by Bener (1950). The solarimeters used were model G18 (at Delhi model G2 was in use) by Kipp and Zonen, based on an improved model developed in the South African Union Radiation Service (Drummond 1956). The thermopile mounting in the improved model is on a separate inner sliding tube, which reduces the risk of damage to the thermopile, should reblackening or repairs be required; the thermopile surface can also be easily set to the correct exposure height, as the mounting can be screwed up or down this inner tube and it can be properly levelled in the laboratory. Both glass hemispheres are mounted on rings which unscrew, facilitating the removal of condensed moisture between the two glass hemispheres, which is often a great source of trouble in the tropics. The space between the hemispheres is kept dry by means of a dehydrating agent like silicagel. The sensitivity of the solarimeter is about 7-8 mv. per cal/cm$^2$/min and the resistance approximately 10 ohms.

The thread recorders used were model B recording millivoltmetres by Cambridge Instrument Co. with a range of 15 millivolts. The clock works were electrically driven and made one complete revolution in a day. The hourly values of total radiation in cal/cm$^2$/hr were measured by estimating the mean intensity for the hour on the record by means of a transparent scale and multiplying this value by 60. The daily totals in calories/cm$^2$/day were obtained by summing the hourly values for the day.

The solarimeters were installed at the highest point available on the roofs of the observatory buildings at all stations and in such a position that there were no obstacles to obstruct the sun's rays in all seasons between sunrise and sunset, and between the instrument and sky down to the horizon in all directions. In order to reduce to a minimum the variation of sensitivity of the instrument with azimuth and to make observations at the different stations strictly comparable, the solarimeters were mounted so that the longer line of thermocouples of the sensitive element always lay along the N-S direction. The recorder was installed indoors and time marks were given every three hours by shorting the galvanometer.

2.2. *Bellani Spherical Pyranometer*—The instrument used was the improved model, recently developed at the Davos Physical Meteorological Observatory and described by Courvoiser and Wierzejewski (1954). It consists of a glass sphere filled with very pure alcohol, which when warmed by the solar radiation falling on the sphere, distils into a graduated tube below. The glass sphere has a metallic coating which acts as a partial non-selective (grey) absorber. The speed of distillation is dependent on the intensity of radiation that falls on the sphere and the integrated radiation for any given time is proportional to the amount of liquid which condenses in the tube. The difference between the readings of the liquid in the graduated tube at the beginning and end of a given period multiplied by a calibration factor expressed in cal/cm$^2$/cm, gives the total shortwave radiation received during the period on a sphere of unit surface, in cal/cm$^2$ (as a mean of their radiated and shaded faces). The indications of the spherical pyranometer are not comparable with those for horizontal surface pyranometer; the ratio between them varies with the sun's elevation, with the season and with the nature of the surroundings.

The pyranometers were standardised at Davos and were provided with calibration factors, the calibration constants being given for every ten degrees Celsius, since the amount of alcohol that evaporates is dependent on the air temperature. The instruments have a range of 37 cm and with a calibration constant of the order of 8 cal/cm$^2$ per cm division of the tube, they can record a total radiation of about 300 cal/cm$^2$ at one setting.

The spherical pyranometers were installed in the observatory enclosures at each station and were mounted on wooden posts so that the upper scale end was slightly above the level of the eye. The instruments were set every evening after sunset and read both at noon and evening when it was reset again. A second resetting at noon was found necessary at most stations during the summer months.

### 3. Standardisation of the instruments

3.1. *Solarimeter*—The solarimeters were standardised initially at the Central Radiation Unit at Poona before installation and later at the stations themselves during the annual inspection, (1) by direct standardization against a primary or working sub-standard pyrheliometer using the sun as source and (2) by comparison over a suitable period with a standardized solarimeter under natural conditions of exposure.

In the direct method (1) the output of the solarimeter is measured first when it is exposed to radiation from both sun and sky and when temporarily screened from the sun's rays by a small disc. The intensity of the direct radiation is measured with an Angstrom pyrheliometer while the solarimeter is screened and three or four such standardisations around solar noon are made at a time. If $T$ is the toal solar radiation from sun and sky and $D$ the diffuse radiation from sky alone when the solarimeter is shaded the direct solar radiation on a horizontal surface is given by $T$-$D$, and is equal to $I \sin h$ obtained with the Angstrom pyrheliometer, *i.e.*, $I=(T\text{-}D)/\sin h$, where $I$ is the direct intensity and $h$ the mean solar height over the interval of shading. Normally the comparison is carried out several times each day for several days over a range of air temperatures and solar elevations exceeding 20—25°.

In method (2) usually 100-150 occasions are selected over a period of days with cloudless skies, when the traces provided by the standard and station solarimeters are steady. The electrical output in millivolts of the two solarimeters are derived either from the recorder to which they are both connected or by means of an independent potentiometer.

The primary standard instrument maintained at Poona is Angstrom pyrheliometer No. 145, standardised at Stockholm, while pyrheliometer No. 72 repaired and standardised at Poona is used as a travelling substandard. The reference standard solarimeter at Poona is No. 1039 received in 1957. It has also been used as a travelling standard when additional instruments to serve as touring standards were not available. The standards at Poona were intercompared frequently among themselves, whenever the skies were clear. All readings were based on the International Pyrheliometric Scale 1956.

The resistance of the thermopile and thread recorder, the output of the solarimeter in mv. per cal/cm/min, the current sensitivity of the recorder in microamperes for full scale deflection of the recorder and the radiation intensity to which the full scale deflection corresponds, were determined during the standardization at Poona. Normally the full scale deflection of the recorder was made to correspond to a radiation intensity of about 2·0 cal/cm²/min by connecting a fixed resistance in series with the solarimeter. One chart division then corresponds to 0·013 cal/cm²/min. The solarimeter record was calibrated as a whole during intercomparison at the outstation, *i.e.*, the solarimeter with leads, resistances and thread recorder combined. Calibration constants are not changed unless a persistent change of more than 1 per cent has been noticed during a number of comparisons.

3.2. *Spherical Pyranometer*—The checking of the calibration of the spherical pyranometer was carried out by comparing the readings of the test instrument with a reference standard exposed simultaneously. This was done at Poona before the instruments were issued and later annually at the outstations. Pyranometer No. 56016 received from Davos in 1957 is used as the reference standard. During comparison, both instruments are exposed simultaneously for some days and the ratio $Q$ between the amounts of distillation, measured in cm established. To obtain the calibration factor, the station pyranometer is shielded from the sun temporarily to receive sky and reflected radiation from the ground only and the solar intensity $I$ at the time of shading is measured simultaneously with a pyrheliometer. The difference between the distillation amount $\triangle Y_1$ of the first instrument and the amount $Q \triangle Y_2$ of the second represents the effect of direct solar radiation on the first instrument.

$$\triangle Y_1 - Q\triangle Y_2 = kS$$

where $k$ is constant and $S$ is the energy received per sq. cm during the period of shading. *i.e.*, $S = \int I\, dt$.

The calibration factor is :

$$E = \frac{S}{4(\triangle Y_1 - Q\triangle Y_2)}$$

The factor 4 makes allowance for the fact that the surface of a sphere is 4 times its cross-section. The calibration factor in cal/cm²/cm is then given by $QE$. Changes of calibration constants within 3 per cent are neglected, since this is the order of accuracy of observations possible with the instrument.

#### 4. Analysis of the results and discussion of data

4.1. *Actual and possible duration of sunshine at Poona, Delhi, Madras and Calcutta*—Before discussing the actual measurements of solar radiation it is worthwhile considering the actual and possible hours of bright sunshine at these four stations and the importance of sunshine data in the estimation of solar radiation at other stations. Table 1 gives the average number of hours in each month during which the sun is above the horizon and the mean number of actual hours of bright sunshine per day as recorded by the Campbell-Stokes sunshine recorders, at the 4 stations during the IGY, from July 1957 to December 1958. In the last column the actual hours of bright sunshine are expressed as percentages of the possible hours of sunshine.

Table 1 and Figs. 1(a) and 1(b) give an idea of the variation of the amount of bright sunshine and cloudiness in different months at the four stations, which may be considered as roughly representative of the different climatic regions of India.

The largest variation in the possible hours of bright sunshine per day occurs naturally at Delhi, the minimum value being 10·3 hrs in December and maximum 14·1 hrs in June. The smallest variation is at Madras, the lowest and highest possible values being

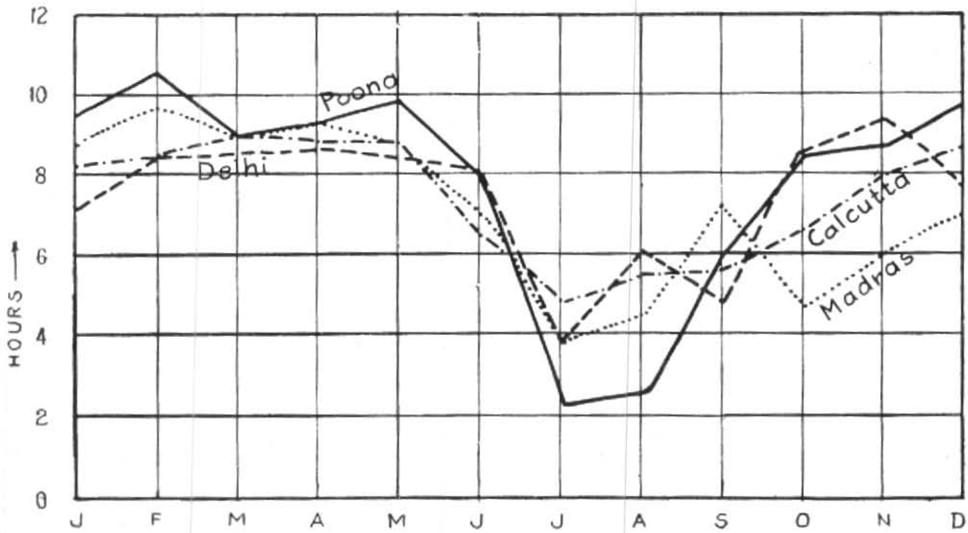


**Fig. 1(a). Mean hours of bright sunshine ($S$) per day in each month (1958)**

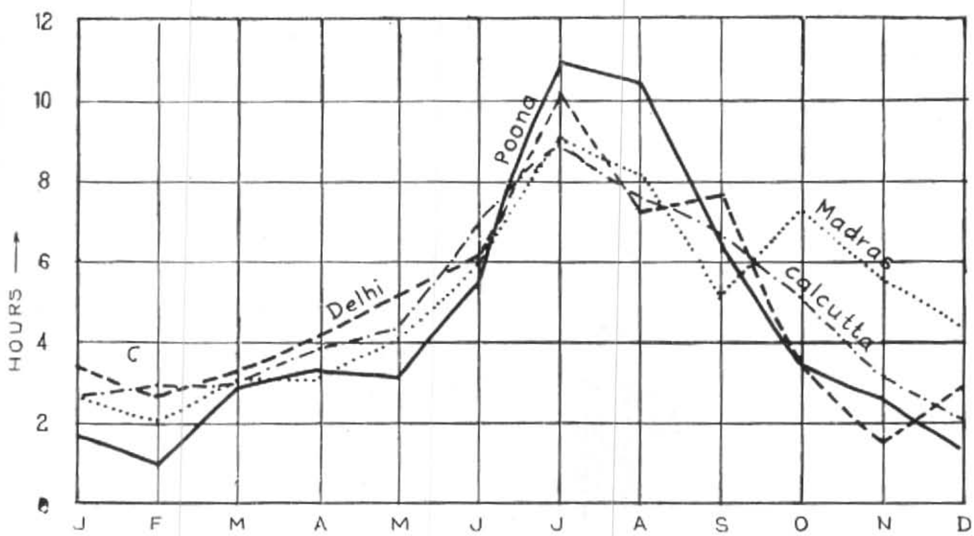


**Fig. 1(b). Mean hours of cloudiness per day in each month (possible hours of bright sunshine minus actual hours of bright sunshine) (1958)**

11.4 hrs in December and January and 12·9 hrs in June. The values for Poona and Calcutta lie between these. The actual mean daily hours of sunshine during the IGY was highest at Poona (7·9 hrs). and lowest in Madras (7·2 hrs); Delhi and Calcutta had nearly similar values (7·5 and 7·4 hrs).

The lowest amount of sunshine actually received is naturally lowest during the monsoon months July—August at all the stations. During this season. it was only about 18 per cent of the possible value at Poona, 33 per cent at Madras, and about 38 per cent at both Calcutta and Delhi. During the northeast monsoon months of October-November, the amount of sunshine received was lowest at Madras as compared to other stations, being only about 5 hrs per day, as compared to about 9 hrs at Poona and Delhi during this period. The effects of cyclones and disturbed weather in the Bay of Bengal affecting northeast India during October-December are reflected in the values of the duration of sunshine at Calcutta. Sunshine exceeded on an average, 8 hrs per day at Poona and 7 hrs per day at Delhi throughout the year except during the monsoon months June—September. The corresponding value for Calcutta was 8 hrs per day except during the four months June to October and for Madras 7 hrs except during the months July to August and October to November. The largest percentage of the possible hours of duration of sunshine was recorded in November in Delhi (87 per cent), in December at Calcutta (81 per cent). and February in Poona (92 per cent), and at Madras (83 per cent).

4.2. *Total solar radiation in each month**— The monthly means of the total solar radiation $T$ in cal/cm$^2$/day received from the sun and sky obtained from solarimeter records, the total solar radiation $T'$ in cal/cm$^2$/day received from the sun, sky and ground obtained from spherical pyranometer measurements, the mean duration of sunshine, the mean actual sunshine expressed as a percentage of the possible duration etc are given in Tables 2(a) to 2(d) for the 4 stations for the different months of the year. The highest and lowest values of the daily totals of $T$ and $T'$ recorded during each month and the ratios of mean daily values of $T$ and $T'$ are also given. The mean values of both $T$ and $T'$ on clear days, cloudy days and on overcast days are given separately with the number of occasion of each type.

In Figs. 2(a) to 2(d) are shown the values of the mean daily radiation income $T$ and $T'$ in cal/cm$^2$/day for the various months of the year for the 4 stations, the hours of bright sunshine $S$ and $Q_o$, the mean daily radiation for cloudless skies in different months computed by Ramdas and Yegnanarayanan (see ref. and Section 6). As the air temperature near the ground depends on the amount of radiation received, the mean of the daily maximum temperature have also been shown in these figures.

4.3. *Mean daily total solar radiation from sun and sky*—The mean daily total radiation $T$ (cal/cm$^2$/day) attains its maximum value at Poona (664), Delhi (630) and Calcutta (542) in May, while at Madras it is maximum in April (591). The mean daily hours of sunshine is maximum in April (9·4) at Madras and in May (9·9) at Poona, while at Delhi it is highest in October (9·6) and only 8·4 hrs in May, and at Calcutta it is highest in November (9·6) and only 8·9 hrs in May. But while the number of hours of bright sunshine in May is less at Delhi than at Calcutta, the amount of radiation received at Delhi is more than that at Calcutta by 88 cal/cm$^2$. It will be seen from Tables 2(b) and 2(c) that while Delhi had 5 clear days in May, Calcutta had none. and therefore presumably though Calcutta received a slightly larger amount of bright sunshine, the total radiation received was slightly less than that at

*Radiation observations are available for only about 10 days at Delhi in July and September 1958 and at Calcutta in July. The available 1957 data for these stations during these months, it is felt, will be more representative of the average conditions than that for 1958.

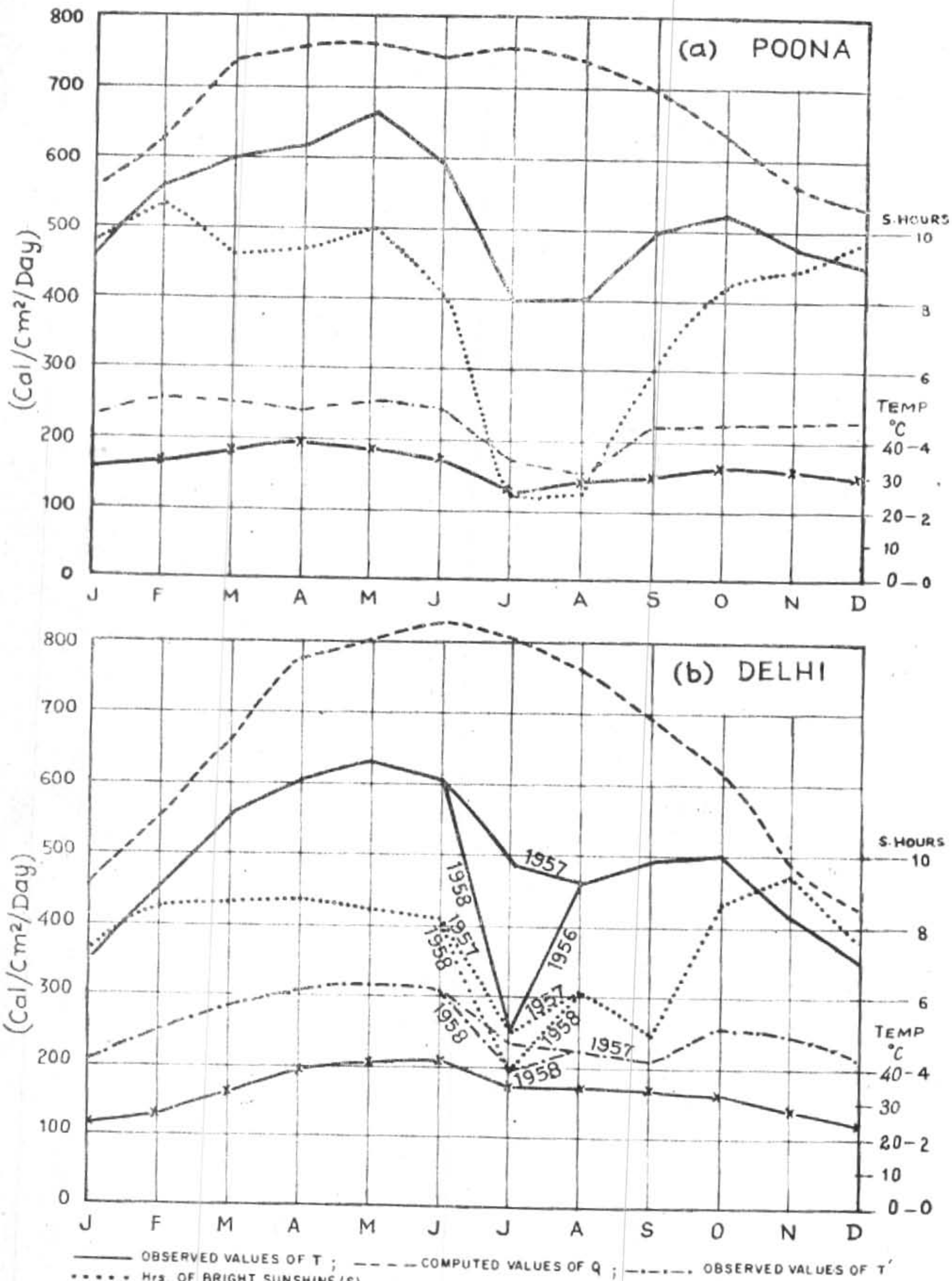


Fig. 2. Annual march of total solar radiation (1958)

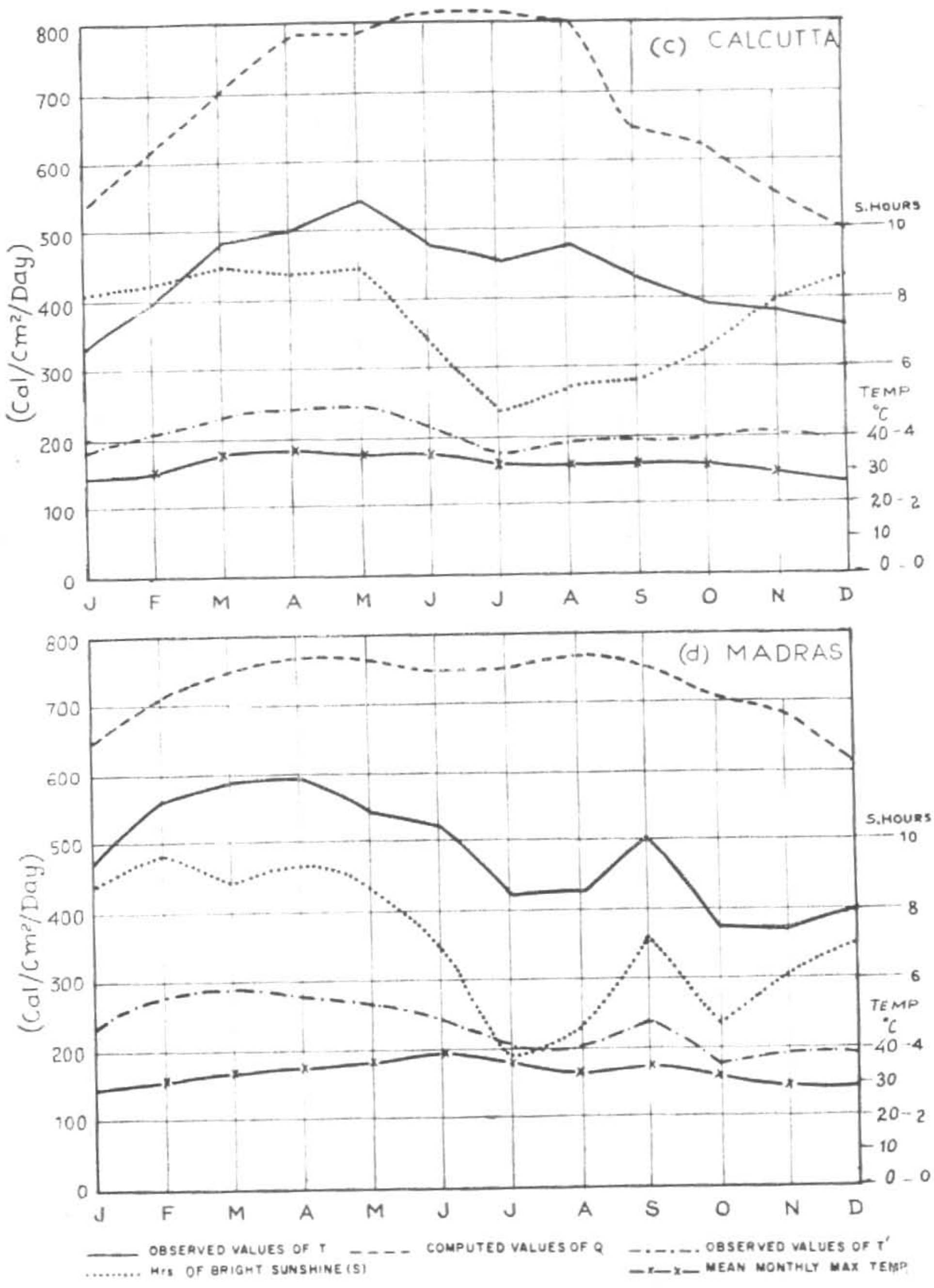


Fig. 2. Annual march of total solar radiation (1958)

Delhi as a result of the greater cloudiness at Calcutta.

The mean daily radiation on only clear days at Poona is 716 in May and 731 cal/cm$^2$/day in June, while the highest sums are 736 and 745 in these two months respectively. So though the mean value of $T$ is higher in May than in June at Poona, the maximum daily radiation was received in June, the difference between May and June being however, small.

At Delhi, the mean radiation received on clear days was 742 and 684 cal/cm$^2$/day in May and June respectively and the maximum radiation received in a day was 756 in May and 728 in June. They are similar to the values at Poona during these months.

At Calcutta, clear days were few during the year, the largest number being in the winter, *viz.*, November and December 1957 and 58 and January 1958. The highest value received on any day was 640 cal/cm$^2$ in May 1958.

The number of clear days was very small at Madras during the year, the largest number (7) being in February 1958.

The lowest mean daily radiation occurs during July—August at Poona and is of the order of 400 cal/cm$^2$/day and is a consequence of the monsoon clouding, the number of overcast days being 10 and 8 respectively. The minimum radiation in winter is in December when about 450 cal/cm$^2$/day are received and this is slightly higher than that in the monsoon. The lowest minimum on any day occurs in July (99 cal/cm$^2$ /day).

At Delhi the lowest mean daily radiation was received in July (245 cal/cm$^2$/day) during the monsoon in 1958 based on observations on 10 days 6 of which were overcast. However, in July in 1957, the mean radiation was 485 cal/cm$^2$/day with an average of 249 for the 7 overcast days. During winter, the minimum radiation is received in December (350 cal/cm$^2$/day). The lowest minimum radiation was received in July (98 cal/cm$^2$/day).

At Calcutta, the lowest mean daily radiation occurs in January (339 cal/cm$^2$/day) while the lowest value in the monsoon is 454 in July. The lowest minimum radiation was received in October.

At Madras, the minimum mean daily radiation occurs in the most cloudy months during the northeast monsoon (October-November). The lowest minimum occurred in October 1958 (only about 11 cal).

It is observed that during the fairly clear months January—March and October—December at Poona and Delhi, the mean daily radiation received is less than the computed value of the radiation $Q_o$ for cloudless skies by about 100 cal/cm$^2$. The corresponding value for Calcutta is 200 cal/cm$^2$ and for Madras it is about 150 cal/cm$^2$. The larger difference at Calcutta and Madras is presumably due to the cloudiness. Also during the monsoon months, July and August, the decrease of $T$ below $Q_o$ is of the order of 350 cal/cm$^2$ at all the four stations except at Delhi in July. This is observed also during northeast monsoon months of October-November in Madras.

A comparative study of the annual variation of the mean daily radiation $T$ and $T'$ at the different stations has been made and is illustrated in Fig. 3. Poona receives the maximum radiation throughout the year except during the monsoon months June—September. The highest radiation occurs at Poona in May (664 cal/cm$^2$/day). Poona also receives the lowest radiation during the monsoon months July—August except for July 1958 at Delhi. This is due to the larger amount of cloudiness at Poona than at any of the other stations. During the winter months November—February, though Calcutta is warmer than Delhi, Calcutta receives lesser radiation than Delhi, presumably due again to the larger cloudiness. It is also seen that the rate of increase of radiation from month to month is larger at Delhi than at Poona and the rate of decrease for October to December is larger at Delhi than at Poona.

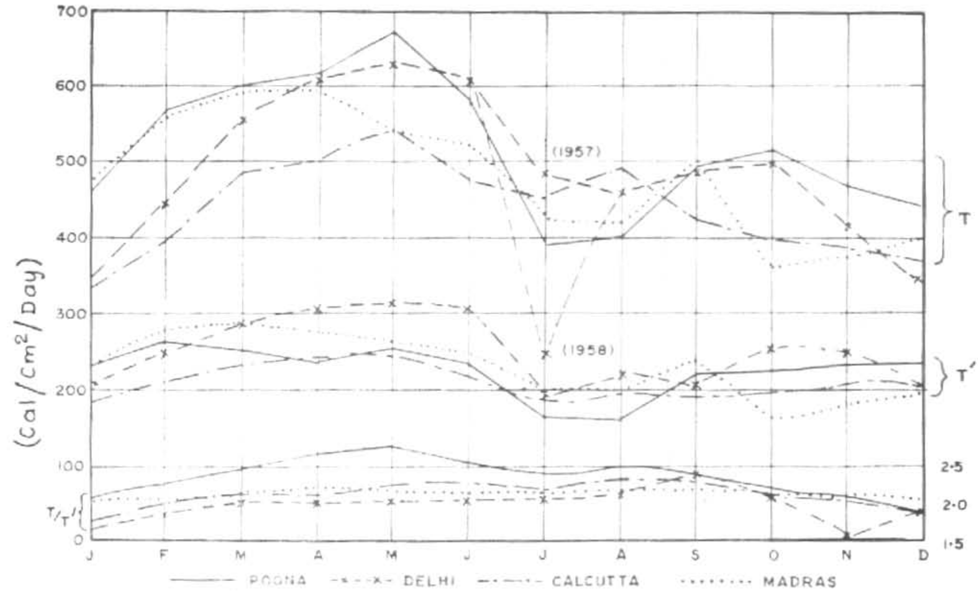


**Fig. 3. Mean daily total radiation (cal/cm² /day) in each month (1958)**

However taking the year as a whole, the mean daily radiation at Poona, Delhi, Calcutta and Madras are 518, 471, 438 and 481 respectively.

The percentage of annual total radiation received in each of the seasons October-January, February-May, and June-September for each station is given below—

| | Oct-Jan | Feb-May | Jun-Sep |
|---|---|---|---|
| Poona | 30 | 39 | 31 |
| New Delhi | 29 | 39 | 32 |
| Calcutta | 29 | 36 | 35 |
| Madras | 28 | 39 | 33 |

It is interesting to note that the percentage of the annual radiation received in any season at all the stations is almost the same. Also nearly the same proportion of energy is received in the different seasons, except for a small increase in the period February-May.

4.4. *Frequency distribution of daily totals*—The percentage frequency distribution of daily values of total radiation for each month is given in Table 3 in steps of 100 cal/cm². The maximum radiation is received in the year in the interval 501-600 cal/cm² at all stations except at Calcutta where it is in the range 401-500 cal/cm².

4.5. *Total solar radiation from sun, sky and ground*—The annual march of the mean values of the daily totals of solar radiation $T'$ measured with the Bellani spherical pyranometer at all the four stations is also illustrated in Fig. 3. $T'$ represents the total radiation (cal/cm²) on a sphere of 1 sq. cm surface and is a mean of the irradiated and shaded surfaces and is naturally smaller than $T$.

At Poona, the values of $T'$ in February and May are nearly the same and reach the largest value for the year. The minimum is reached during the monsoon months July-August. At Delhi and Calcutta, the maximum values are reached in May and the lowest during the monsoon month of July. However at Madras, the highest value occurs in March and the lowest in July-August.

The annual march of $T'$ agrees fairly with that of $T$ from January-August at all the three stations except at Poona from February to May. The highest values of $T'$ occur at Delhi in May, while that of $T$ occurs at Poona in the same month. During the post-monsoon months, there is an appreciable fall in $T$ at Madras during the northeast monsoon from September to October and $T'$ also shows the same trend. At Delhi, there is a steep fall in $T$ from October to December while $T'$ shows such a change only from November to December. Some of the differences in the variation of $T$ and $T'$ arise probably from the difference in exposure at the 4 stations and the amount of radiation reflected from the ground and surroundings which vary at each station.

4.6. *Relation between total solar radiation T and T'*—The ratios of the values of daily totals of solar radiation $T$ from sun and sky with a solarimeter on a horizontal surface to the daily totals of solar radiation $T'$ from sun, sky and ground with a spherical pyranometer were calculated for all days of the IGY and the mean values for the different months at the 4 stations are tabulated in Table 4 and its variation during the year is illustrated in Fig. 3. It will be seen that while the ratio $T/T'$ is roughly 2, it varies from station to station and from month to month. Poona has the highest mean ratio 2·3 and this reaches its maximum values in May and minimum in December. Delhi has the lowest mean with $T/T'$, 1·9 and it reaches its maximum value in September and the lowest in November. In Madras it is more or less constant throughout the year. While the ratio between the indications of the horizontal surface pyranometer and the spherical pyranometer are generally found to vary with the sun's elevation, with the season and with the nature of the surroundings it has been found to be nearly constant (*Radiation Instruments and Measurements—See* Ref.) in the tropical regions. A study of Table 4 shows that while the ratio is practically constant at all four stations, it is maximum during the summer months March-May and least during the winter months. With the onset of the monsoon, there is only a small decrease in the value of the ratio. The clouding appears to have little effect since even in October at Madras the value remains steady at 2·1.

4.7. *Mean hourly variation of radiation T from the sun and sky during different months of the year*—Tables 5(a) to 5(d) and Figs. 4(a) to 4(d) give the mean values of $T$ during each hour of the day during different months of the IGY for the four stations. The values refer to the total radiation received during the hour ending at each hour LAT. The information contained in these curves is also illustrated in the isopleth diagrams in Fig. 5, where lines of equal intensity of radiation in cal/cm$^2$/hr have been drawn for the four stations.

4.7.1. *Poona*—From January to May and October to December the intensity of radiation increases from the time of sunrise upto about 12-13 hrs LAT and decreases later. During the monsoon months June to September, due to the cloudiness, the variation is small from 11-14 hrs.

If we compare the intensity of radiation at equal time intervals before and after 12 hrs LAT, it is found that the values are nearly symmetrical about 12 LAT though the forenoon values are slightly higher than the afternoon values.

The intensity during each hour increases from January to February by nearly 10 cal/cm$^2$. From February to March, the increase is only half of this value, and it occurs only up to the maximum epoch, after which the intensity is nearly the same in both the months. However in April and May, the intensity is nearly the same upto about 12 hrs LAT after which the hourly values in May are greater than the corresponding values in April by nearly 10 cal/cm$^2$. The highest intensity occurs in May at 12-13 hrs LAT (87 cal/cm$^2$/hr).

The effect of the monsoon can be noticed in June , by a fall in the maximum intensity and a flattening of the curve during the maximum epoch. The radiation received during the day in July and August are nearly

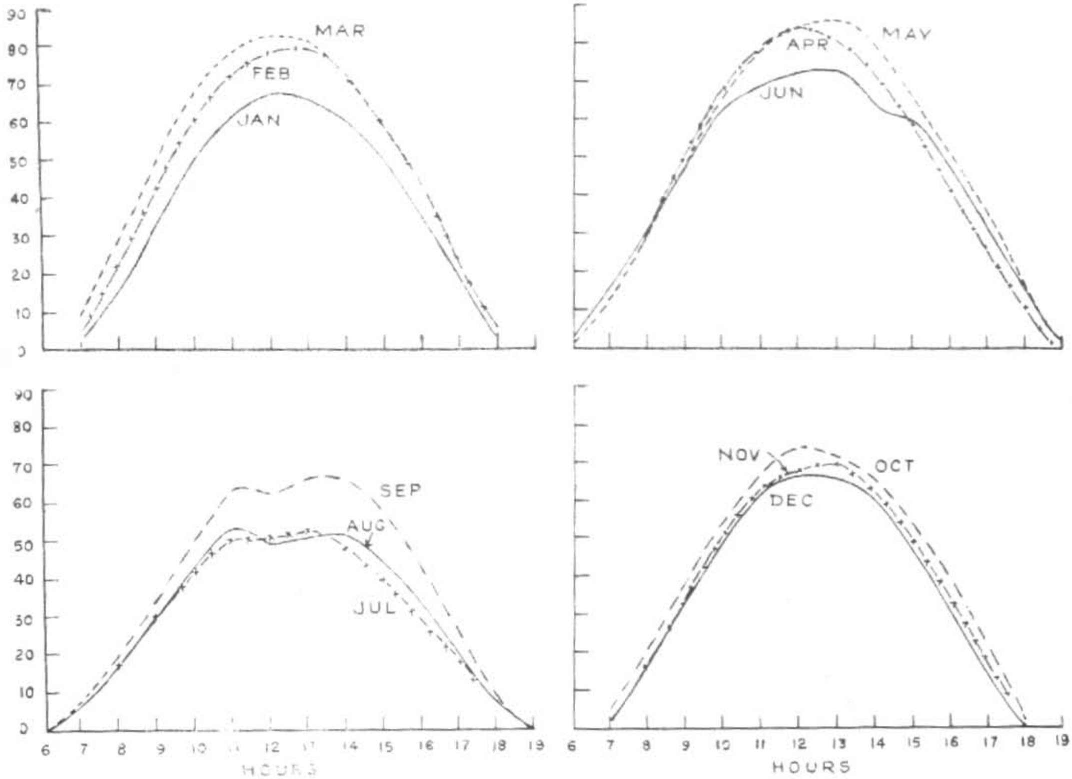


**Fig. 4(a). Hourly variation of solar radiation $T$ (cal/cm²/hr) at Poona**

the same, being the lowest during the year at each hour and there is an increase in September with a secondary maximum in October, after which the intensity decreases gradually till December. The above feature is strikingly illustrated in Fig. 5(a).

4.7.2. *Delhi*—The intensity of radiation in each hour increases month to month from January to March by nearly 10 cal/cm²/hr; this rate of increase is later reduced and conditions are almost similar in April, May and even in June. The change from June to July is characteristic of the monsoon. Later there is an increase with a secondary maximum in October as at Poona, but it is a little more pronounced. After October there is a steady decrease in the radiation in each hour by approximately 5-10 cal from month to month; December and January are nearly the same. Except during the monsoon months of July and August, the maximum intensity of radiation occurs at Delhi between 12 to 13 hrs LAT as at Poona.

The intensity of radiation at equal intervals of time before and after 12 hrs LAT showed that as in the case of Poona the values were symmetrical about 12 hrs LAT with a tendency for the forenoon values to predominate.

4.7.3. *Calcutta*—The variation from month to month for the two periods from January to March and April to June nearly resemble those at Delhi. The intensity of radiation in each hour increases by about 5 cal/cm² from January to February and by about 10 cal/cm² from February to March. In April and May the values of hourly radiation are nearly the same. A maximum is registered in May. The effect of monsoon on

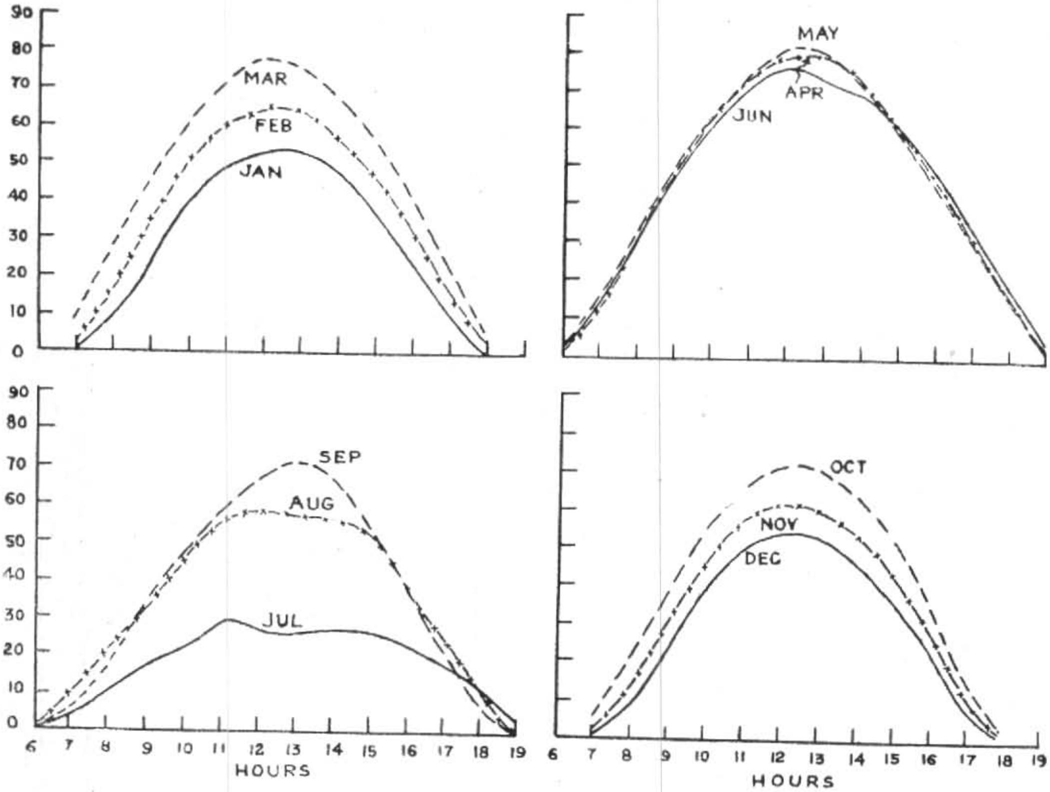


**Fig. 4(b). Hourly variation of solar radiation $T'$ (cal/cm²/hour) at Delhi**

the radiation can be noticed in the months of June and July by a fall in the maximum intensity. The variations from month to month for the period January to June resemble those at Delhi. There is an increase of radiation from July to August with a secondary maximum in August. The hourly radiation decreases thereafter till December. As in the case of Poona and Delhi, the values are symmetrical about noon. The maximum intensity of radiation occurs between 12 and 13 hrs in all months except during July and August.

4.7.4. *Madras*—While at Poona, Delhi and Calcutta there is almost a similar rate of increase in radiation in each hour from month to month from January to March, at Madras there is an increase of nearly 5-10 cal/cm$^2$/hr from January to February after which the change is small till June. In June there is an appreciable reduction in the afternoon presumably due to the increase in clouding of a convectional type. The conditions in July and August are similar, with minimum variation from 11 to 13 hrs LAT. There is an increase from August to September and a decrease in October. The conditions from October to December are similar. While the secondary maximum occurred in October at Poona and Delhi, it is observed in September at Madras.

From an analysis of the records of total radiation at Kew Observatory, Blackwell (1954) has observed that there is a high degree of symmetry about noon LAT with a slight tendency for the forenoon values to be a little higher than those of afternoon. The observations in India also show that the forenoon values are slightly higher than the corresponding values in the afternoon except

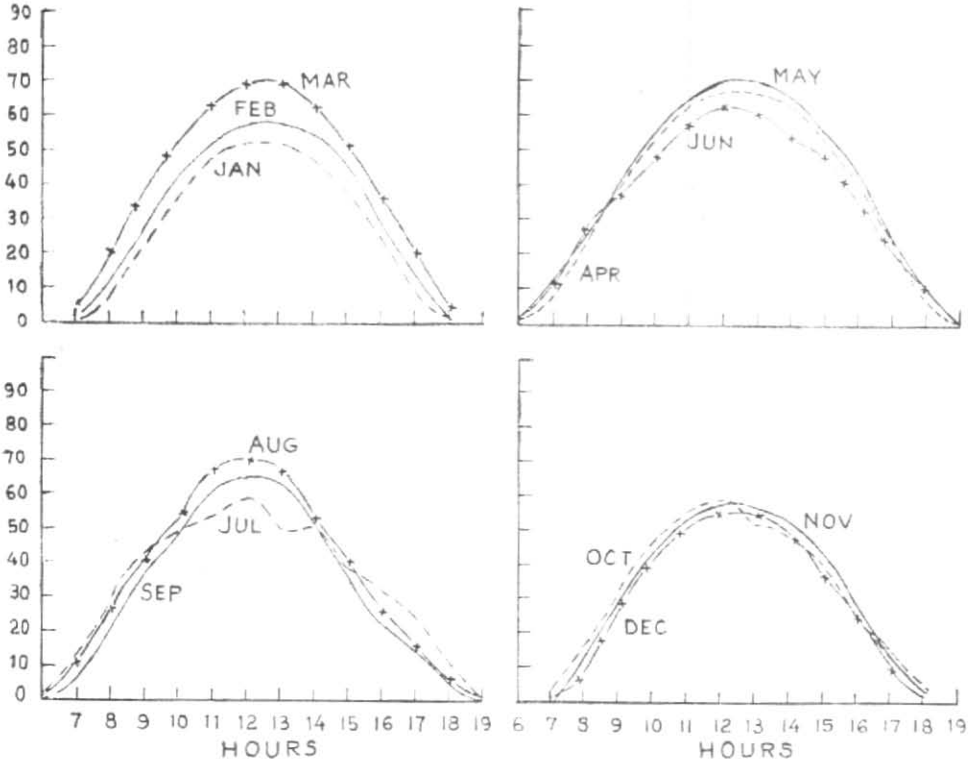


**Fig. 4(c). Hourly variation of solar radiation $T$ (cal cm$^{-2}$/hr) at Calcutta**

in the case of Madras where the afternoon values are predominantly higher.

Fig. 6 gives the mean maximum radiation intensity during the day for each month for the 4 stations. This shows that before the monsoon, Poona gets the maximum intensity and Calcutta receives the least; during the monsoon, the corresponding stations are Madras and Calcutta. After the monsoon till December, Poona gets the maximum intensity and Madras the least.

It has to be remembered that the conclusion made in this and in some of the previous sections are based on the data for one year only. All the same except for certain details, it is felt that many of the general features have been brought out by these observations.

**5. Calculation of total solar radiation $Q$ from values of duration of sunshine $S$**

It was first suggested by Angstrom (1928) in 1924 that an approximate estimate of the solar radiation received at the surface of the earth could be obtained from observations of bright sunshine by a consideration of the relationship between recorded solar radiation at the earth's surface and the duration of sunshine. He expressed it in the form:

$$Q = Q_o \left\{ a_1 + (1 - a_2) \frac{S}{S_o} \right\}$$

where $Q$ is the radiation actually received, $Q_o$ is the total radiation income on a clear day, $S$ is the number of hours of sunshine measured on a sunshine recorder and $S_o$ is the maximum possible hours of sunshine; $a_1$ and $a_2$ are constants. With an overcast sky $Q/Q_o$ equals $a_1$, while with a perfectly clear sky, $Q = Q_o$. As pointed out by Angstrom (1956), $a_1$ is dependent on the latitude and altitude of the station and on the reflectivity of the ground and the frequency with which high or low clouds are present when the sky is overcast.

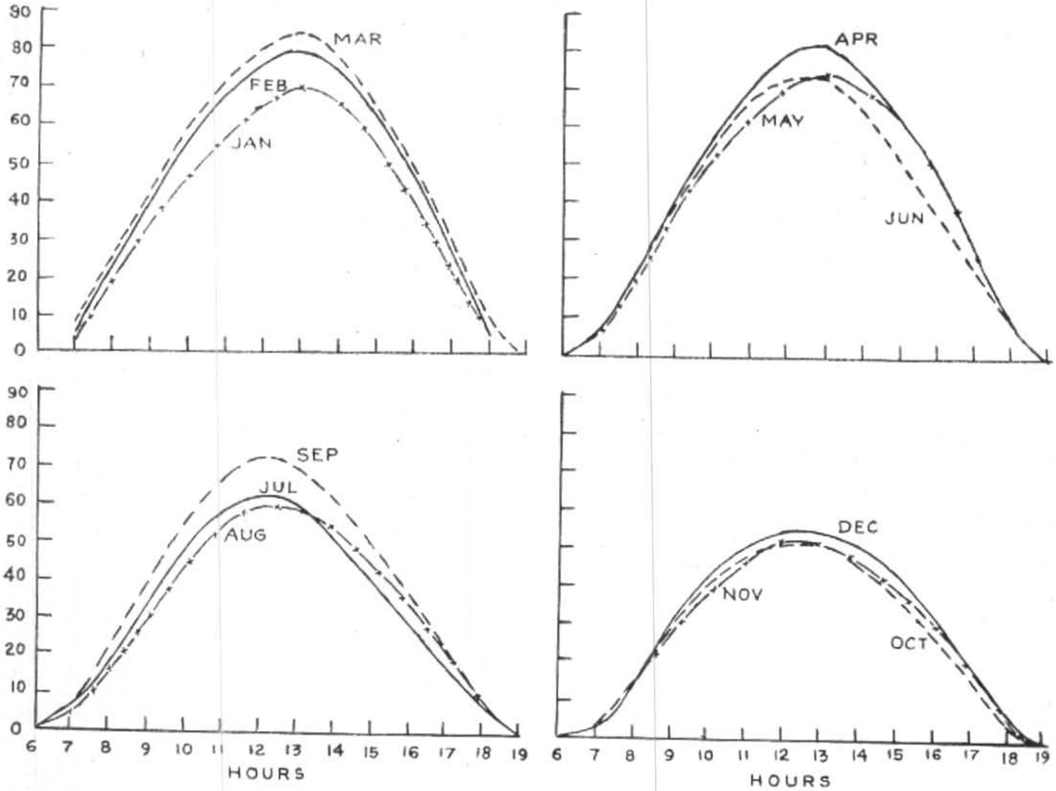


**Fig. 4(d). Hourly variation of solar radiation $T$ (cal/cm²/hr) at Madras**

Angstrom found $a_1$ to have a value of 0·25 for Stockholm and Kimball and Hand (1936) obtained a value of 0·22 for Washington. Fritz and Macdonald (1949) have used the equation, $Q/Q_0=0\cdot35+0\cdot61\ S/S_o$, which allows for the fact that no recording instrument gives a full record of sunshine on cloudless days. Raman (1938) has calculated the value of $a_1$ from a year's data at Poona and obtained the equation $Q/Q_o=0\cdot37+0\cdot68\ S/S_o$. Black, Bonython and Prescott (1954), using a simplified formula $Q/Q_A=a+b.\ S/S_o$, have calculated values of $a$ and $b$ for a number of stations all over the world, including Poona. $Q_A$ corresponds to a perfectly transparent atmosphere; $a$ and $b$ are constants so that $a_1=a/(a+b)$. They found $a$ and $b$ to be 0·27 and 0·613 respectively for Poona and $a_1$ to be 0·306.

Estimates of the values of $a_1$ and $a_2$ have been made using Angstrom's formula, from the daily values of the total radiation $Q$ and the duration of sunshine $S$ for the four stations in India, on the basis of the IGY data for 1958. The values estimated by Ramdas and Yegnanarayanan (1954) for $Q_o$ and the theoretical values of $S_o$ given in Table 1 were used. The values of $a_1$ and $1-a_2$ for the four stations with the correlation coefficient $\gamma$ between $Q/Q_0$ and $S/S_0$ are tabulated below—

| | $a_1$ | $1-a_2$ | $\gamma$ |
|---|---|---|---|
| Poona | 0·44 | 0·51 | 0·93 |
| New Delhi | 0·38 | 0·57 | 0·90 |
| Calcutta | 0·33 | 0·48 | 0·84 |
| Madras | 0·37 | 0·49 | 0·89 |

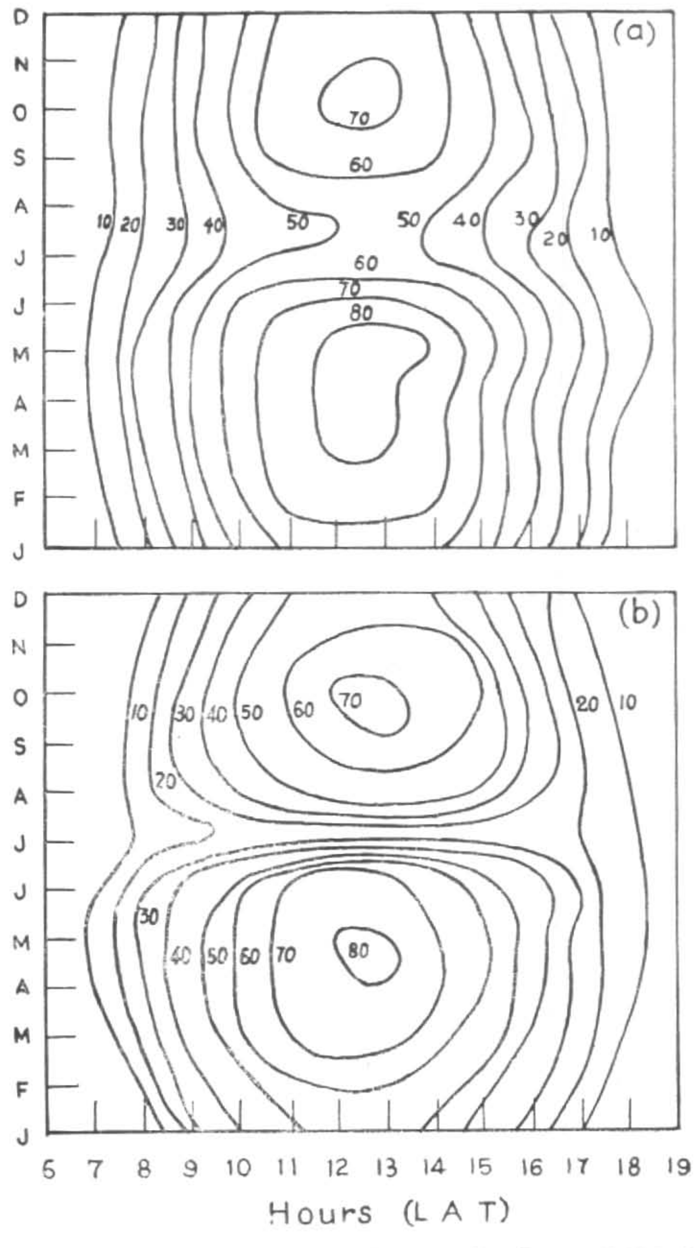


**Fig. 5.** Isopleths of total radiation $T$ (cal/cm$^2$ hr) of (a) Poona and (b) Delhi, showing hourly variation in different months

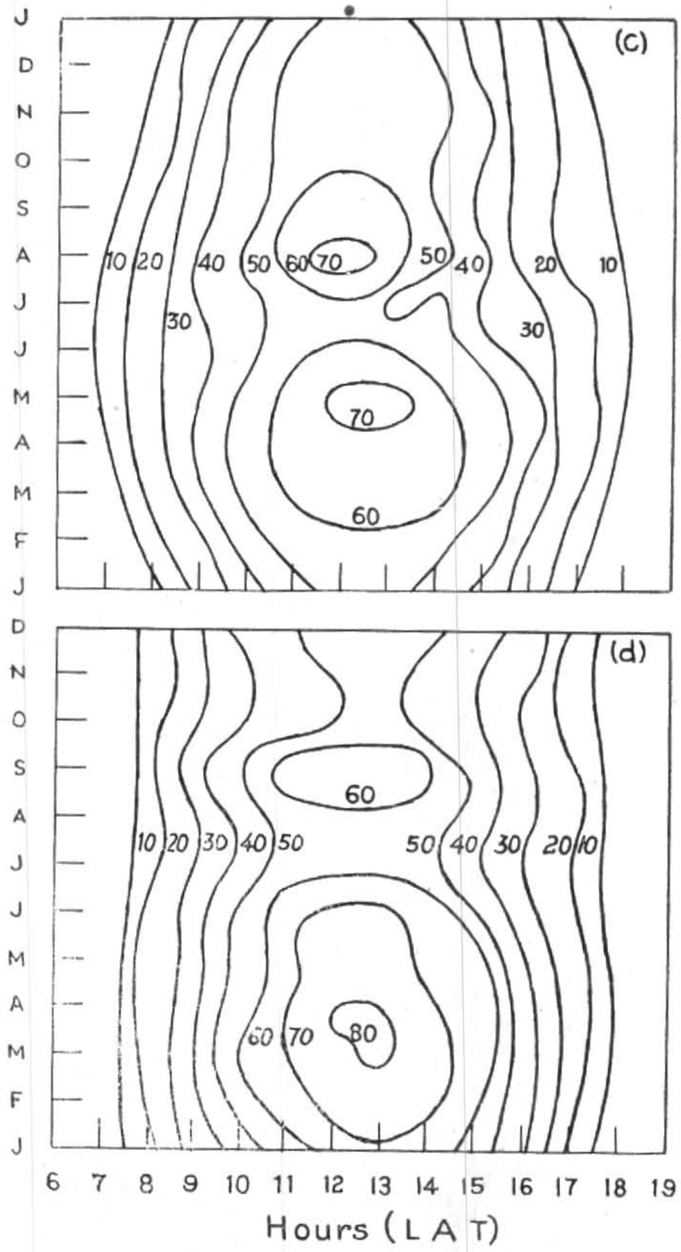


Fig. 5. Isopleths of total radiation $T$ (cal/cm$^2$/hr) of (c) Calcutta and (d) Madras, showing hourly variation in different months

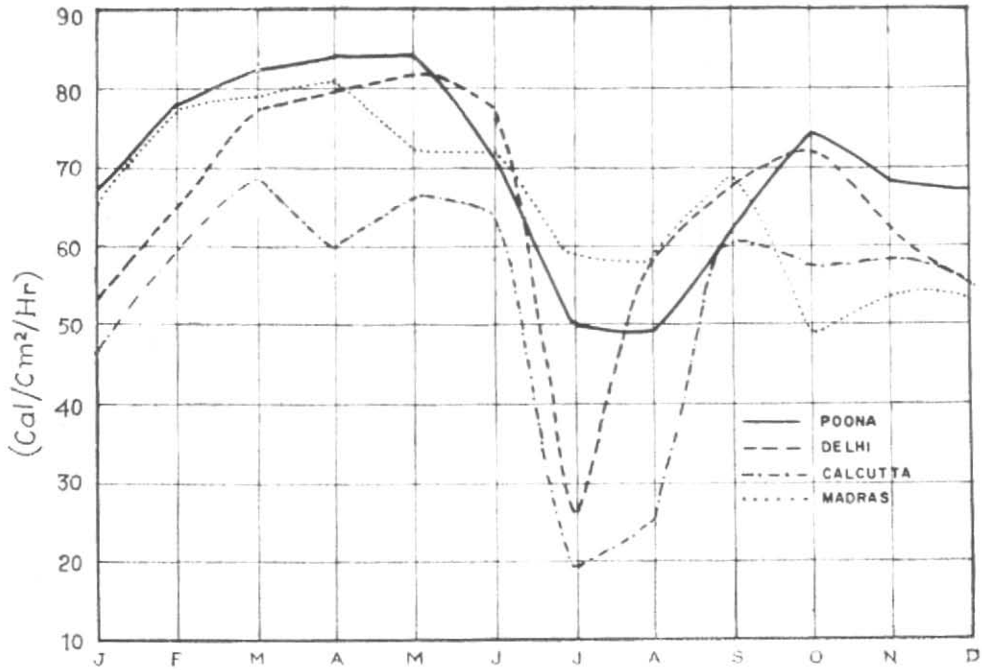


Fig. 6. Mean radiation (cal/cm² hr) at 1200 LAT in each month (1958)

Angstrom's formula gives only approximate values of $Q$, the total radiation actually received, for typical average days when cloud cover is nearly normal. In India, the variations are very large in the different seasons during which long spells with skies either perfectly clear, overcast or partly cloudy generally occur. Thus if using the relation $Q/Q_0 = a_1$ on overcast days one obtains the value of $a_1$ and the values of $a_2$ are estimated, the values of $Q$ may be underestimated on partly clouded days, since the cloud layers on overcast days are much denser than at other times and will give a low figure for the constant $a_1$. However, the formula can give a fair estimate of the radiation values on clear days, if the values of the constants are known for such days. Estimates of the values of $a_1$ and $a_2$ were made for the four stations in India for the monsoon months July to September and for the rest of the year. They are given below—

| | Jul—Sep | | | Rest of the year | | |
|---|---|---|---|---|---|---|
| | $a_1$ | $1-a_2$ | $\gamma$ | $a_1$ | $1-a_2$ | $\gamma$ |
| Poona | 0·42 | 0·61 | 0·91 | 0·42 | 0·52 | 0·90 |
| New Delhi | 0·29 | 0·71 | 0·95 | 0·47 | 0·45 | 0·85 |
| Calcutta | 0·35 | 0·54 | 0·83 | 0·32 | 0·49 | 0·86 |
| Madras | 0·39 | 0·49 | 0·89 | 0·37 | 0·49 | 0·90 |

### 6. Comparison of the values of radiation measured during the IGY with those computed by Ramdas

Ramdas and Yegnanarayanan (1954) as stated earlier have worked out, on the basis of sunshine data at 43 stations in India, the provisional estimates of the total solar radiation received during the day for different months of the year at a network of 22 selected stations in India. Actual observations at only one station, *viz.*, Poona was available at the time these important and valuable results were first published. For computing the values of $q$, the amount of radiation from the sun and the sunlit clear sky per sq. cm on a horizontal surface per minute at the ground surface, they used isopleths of $q$ computed by Fritz (1949) for different values of the precipitable water and air masses corresponding to the different hours of the day at the selected stations for the middle of each of the months of the year. From curves showing the computed diurnal variation of $q$, the total mean daily radiation $Q_0$ for cloudless skies on different months of the year were estimated by integration.

From the data of duration of sunshine available at 43 stations in India, the ratio $S/S_0$ was calculated and using the formula $Q=0 \cdot 35+0 \cdot 61\ S/S_0$ and computed values of $Q_0$, the values of $Q$, the actual insolation on a horizontal surface for the different months of the year were calculated.

Table 6 shows the observed values of $Q$ at Poona, Delhi, Calcutta and Madras and the corresponding values computed by Ramdas and Yegnanarayanan. It is interesting to note how well the computed values for these four stations agree with the actual observed values of the total radiation from the sun and sky during the IGY.

### 7. Conclusion

This paper summarises the radiation data obtained with the Moll-Gorczynski solarimeter, Bellani pyranometer and the Campbell-Stokes sunshine recorder during the IGY at the four stations in India, *viz.*, Poona, Delhi, Calcutta and Madras. It brings out clearly for the first time the seasonal and diurnal variation of radiation from sun and sky in the representative regions of India. It is hoped that this summary for India will be useful to other investigators in this field and to those engaged on radiation problems on a world scale collected during the IGY. Data relating to other aspects of radiation are being summarised and it is hoped to publish them separately in the near future.

*REFERENCES*


Angstrom, A. 1928 *Medd. met.-hydr. Anst., Uppsala*, **4**, 3.

1956 *Arkiv Geofys.*, **2**, 22, p. 471.

Bener, P. 1950 *Arch. Met. Geophys. Bickl.*, Serie B 2. p. 188.

Black, J. N. Bonython, C. W. and Prescott, J. A. 1954 *Quart. J. R. met. Soc.*, **80**, p. 231.

Blackwell, M. J. 1954 Five years continuous recording of total and diffuse solar radiation at Kew Observatory, M.R.P. 895.

Courvoiser and Wierzejewski 1954 *Arch. Met., Wien*, **5**, p. 413.

Drummond, A. J. 1956 *Ibid.*, **7**, p. 413.

Fritz, S. 1949 *Heating and Ventilating*, **46**, p. 69.

Fritz, S. and Macdonald, T. H. 1949 *Ibid.*, **46**, p. 61.

Kimbal, H. H. and Hand, I. V. 1936 *Biological effects of radiation*, McGraw Hill.

Ramdas, L. A. and Yegnanarayanan, S. 1954 Solar Energy in India—Proceedings of Symposium on Wind and Solar Energy, Arid Zone Research Committee of the UNESCO, New Delhi.

Raman, P. K. 1938 *Mem. India met. Dep.*, **26**, pt. VIII, p. 151.

—— 1957 *Radiation Instruments and Measurements, Part IV IGY Instruction Manual*, Pergamon Press, p. 425.

**TABLE 1**

**Actual and possible hours of duration of sunshine during the IGY at Poona, Delhi, Calcutta and Madras**

| | Hours of possible sunshine per day | | | | Hours of actual sunshine per day | | | | Percentage of possible sunshine | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | PNA | DLH | CAL | MDS | PNA | DLH | CAL | MDS | PNA | DLH | CAL | MDS |
| | | | | | | **1957** | | | | | | |
| Jul | 13·2 | 13·9 | 13·5 | 12·8 | 3·7 | 5·0 | — | 4·1 | 28 | 36 | — | 32 |
| Aug | 12·9 | 13·3 | 13·0 | 12·6 | 3·1 | 6·8 | 5·5 | 5·2 | 24 | 51 | 42 | 41 |
| Sep | 12·3 | 12·5 | 12·4 | 12·3 | 7·5 | 7·0 | 6·1 | 6·2 | 61 | 56 | 49 | 50 |
| Oct | 11·8 | 11·6 | 11·7 | 11·9 | 7·1 | 9·6 | 7·2 | 6·0 | 60 | 83 | 61 | 50 |
| Nov | 11·3 | 10·8 | 11·1 | 11·6 | 8·1 | 9·2 | 9·6 | 5·7 | 72 | 85 | 87 | 49 |
| Dec | 11·0 | 10·3 | 10·7 | 11·4 | 9·7 | 7·0 | 8·9 | 6·4 | 88 | 68 | 83 | 56 |
| | | | | | | **1958** | | | | | | |
| Jan | 11·1 | 10·4 | 10·8 | 11·4 | 9·5 | 7·2 | 8·2 | 8·8 | 86 | 69 | 76 | 77 |
| Feb | 11·5 | 11·1 | 11·3 | 11·7 | 10·6 | 8·5 | 8·5 | 9·7 | 92 | 77 | 75 | 83 |
| Mar | 11·9 | 11·8 | 11·9 | 12·0 | 9·1 | 8·6 | 9·0 | 8·9 | 76 | 73 | 76 | 74 |
| Apr | 12·5 | 12·7 | 12·6 | 12·4 | 9·3 | 8·7 | 8·8 | 9·4 | 74 | 69 | 70 | 76 |
| May | 13·0 | 13·5 | 13·2 | 12·7 | 9·9 | 8·4 | 8·9 | 8·7 | 76 | 62 | 67 | 68 |
| Jun | 13·3 | 14·1 | 13·5 | 12·9 | 8·0 | 8·1 | 6·6 | 7·0 | 60 | 57 | 49 | 54 |
| Jul | 13·2 | 13·9 | 13·5 | 12·8 | 2·3 | 3·9 | 4·8 | 3·8 | 17 | 28 | 35 | 30 |
| Aug | 12·9 | 13·3 | 13·0 | 12·6 | 2·5 | 6·1 | 5·5 | 4·5 | 19 | 46 | 42 | 36 |
| Sep | 12·3 | 12·5 | 12·4 | 12·3 | 6·1 | 4·9 | 5·7 | 7·2 | 50 | 39 | 46 | 59 |
| Oct | 11·8 | 11·6 | 11·7 | 11·9 | 8·4 | 8·6 | 6·6 | 4·7 | 71 | 74 | 56 | 59 |
| Nov | 11·3 | 10·8 | 11·1 | 11·6 | 8·8 | 9·4 | 8·0 | 6·1 | 78 | 87 | 72 | 53 |
| Dec | 11·0 | 10·3 | 10·7 | 11·4 | 9·7 | 7·5 | 8·7 | 7·1 | 88 | 72 | 81 | 62 |
| Mean for 1958 | 12·0 | 12·0 | 12·0 | 12·0 | 7·9 | 7·5 | 7·4 | 7·2 | 66 | 63 | 62 | 61 |

PNA — Poona DLH — Delhi CAL — Calcutta MDS — Madras

TABLE

**Mean values of $T$ and $T'$ (cal/cm² day) on all days**

$T$—Total radiation of sun and sky on a horizontal surface

| | 1957 | | | | | |
|---|---|---|---|---|---|---|
| | Jul | Aug | Sep | Oct | Nov | Dec |
| Mean $T$ (cal/cm²/day) | 510 | 421 | 518 | 488 | 423 | 428 |
| No. of days | 11 | 30 | 28 | 27 | 24 | 31 |
| Mean hours of sunshine | 3·7 | 3·1 | 7·5 | 7·1 | 8·1 | 9·7 |
| % possible hours of sunshine | 28 | 24 | 61 | 60 | 72 | 88 |
| Max. value of $T$ | 692 | 603 | 676 | 597 | 542 | 490 |
| Min. value of $T$ | 339 | 242 | 262 | 214 | 105 | 183 |
| Ratio Max/Min $T$ | 2·0 | 2·5 | 2·6 | 2·8 | 5·2 | 2·7 |
| Mean $T$ on clear days | — | — | — | 563 | 501 | 445 |
| No. of ,, ,, | 0 | 0 | 0 | 1 | 9 | 15 |
| Mean $T$ on overcast days | — | 274 | 262 | 221 | 160 | |
| No. of ,, ,, | 0 | 4 | 1 | 3 | 4 | 0 |
| Mean $T$ on cloudy days | 510 | 443 | 528 | 519 | 454 | 412 |
| No. of ,, ,, | 11 | 26 | 27 | 23 | 11 | 16 |
| Mean $T'$ (cal/cm²/day) | 185 | 186 | 241 | 221 | 210 | 228 |
| No. of days | 31 | 31 | 30 | 31 | 30 | 31 |
| Max. value of $T'$ | 270 | 273 | 309 | 299 | 289 | 246 |
| Min. value of $T'$ | 43 | 104 | 124 | 54 | 50 | 88 |
| Ratio Max/Min $T'$ | 6·3 | 2·6 | 2·5 | 5·5 | 5·8 | 2·8 |
| Mean $T'$ on clear days | — | — | — | 269 | 252 | 236 |
| No. of ,, ,, | 0 | 0 | 0 | 1 | 9 | 15 |
| Mean $T'$ on overcast days | 103 | 122 | 124 | 93 | 84 | — |
| No. of ,, ,, | 5 | 5 | 1 | 4 | 5 | 0 |
| Mean $T'$ on cloudy days | 201 | 199 | 245 | 239 | 227 | 220 |
| No. of ,, ,, | 26 | 26 | 29 | 26 | 16 | 16 |
| Ratio mean daily sum (***T/T'***) | **2·3** | **2·2** | **2·2** | **2·1** | **2·0** | **1·9** |
| Mean $T$ (cal/cm²/day) | 485 | 540 | 494 | 491 | 428 | 328 |
| No. of days | 25 | 23 | 28 | 23 | 23 | 28 |
| Mean hours of sunshine | 5·0 | 6·8 | 7·0 | 9·6 | 9·2 | 7·0 |
| % possible hours of sunshine | 36 | 51 | 56 | 83 | 85 | 68 |
| Max. value of $T$ | 772 | 725 | 629 | 539 | 481 | 393 |
| Min. value of $T$ | 143 | 119 | 132 | 455 | 346 | 73 |
| Ratio Max/Min $T$ | 5·4 | 6·1 | 4·8 | 1·2 | 1·4 | 5·4 |
| Mean $T$ on clear days | 725 | — | 596 | 495 | 449 | 378 |
| No. of ,, ,, | 1 | 0 | 14 | 12 | 12 | 13 |
| Mean $T$ on overcast days | 249 | 119 | 221 | — | — | 149 |
| No. of ,, ,, | 7 | 1 | 6 | 0 | 0 | 3 |
| Mean $T$ on cloudy days | 568 | 559 | 520 | 484 | 406 | 319 |
| No. of ,, ,, | 17 | 22 | 8 | 11 | 11 | 12 |
| Mean $T'$ (cal/cm²/day) | 231 | 246 | 242 | 277 | 250 | 199 |
| No of days | 31 | 31 | 30 | 31 | 30 | 31 |
| Max. value of $T'$ | 341 | 346 | 332 | 320 | 294 | 253 |
| Min. value of $T'$ | 70 | 102 | 18 | 157 | 174 | 90 |
| Ratio Max/Min $T'$ | 4·9 | 3·4 | 1·8 | 2·0 | 1·7 | 2·8 |
| Mean $T'$ on clear days | 334 | 309 | 303 | 291 | 273 | 233 |
| No. of ,, ,, | 1 | 1 | 14 | 12 | 12 | 14 |

2

**and on clear, cloudy and overcast days**

*T′*—Total radiation from sun, sky and ground on a spherical surface

| | 1958 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| (a) POONA | | | | | | | | | | | | |
| | 460 | 562 | 598 | 617 | 664 | 588 | 395 | 402 | 496 | 518 | 474 | 447 |
| | 31 | 27 | 31 | 26 | 24 | 28 | 30 | 30 | 29 | 31 | 25 | 26 |
| | 9·5 | 10·6 | 9·1 | 9·3 | 9·9 | 8·0 | 2·3 | 2·5 | 6·1 | 8·4 | 8·8 | 9·7 |
| | 86 | 92 | 76 | 74 | 76 | 60 | 17 | 19 | 50 | 71 | 78 | 88 |
| | 542 | 633 | 669 | 710 | 736 | 745 | 616 | 534 | 655 | 611 | 542 | 498 |
| | 200 | 513 | 446 | 412 | 320 | 236 | 99 | 149 | 218 | 272 | 196 | 362 |
| | 2·7 | 1·2 | 1·5 | 1·7 | 2·3 | 3·1 | 6·2 | 3·6 | 3·0 | 2·2 | 2·8 | 1·4 |
| | 489 | 561 | 634 | 669 | 716 | 731 | — | — | — | 559 | 518 | 477 |
| | 23 | 22 | 8 | 10 | 10 | 8 | 0 | 0 | 0 | 11 | 9 | 7 |
| | 205 | — | — | — | 320 | 308 | 240 | 288 | 218 | — | — | — |
| | 2 | 0 | 0 | 0 | 1 | 3 | 10 | 8 | 1 | 0 | 0 | 0 |
| | 431 | 568 | 585 | 584 | 651 | 570 | 473 | 443 | 506 | 495 | 449 | 436 |
| | 6 | 5 | 23 | 16 | 13 | 17 | 20 | 22 | 28 | 20 | 16 | 19 |
| | 228 | 256 | 249 | 234 | 250 | 234 | 166 | 162 | 221 | 223 | 226 | 230 |
| | 31 | 28 | 31 | 30 | 31 | 30 | 31 | 31 | 30 | 31 | 30 | 31 |
| | 261 | 283 | 292 | 271 | 286 | 298 | 240 | 220 | 286 | 275 | 267 | 264 |
| | 94 | 233 | 170 | 154 | 145 | 102 | 45 | 65 | 142 | 119 | 95 | 179 |
| | 2·8 | 1·2 | 1·7 | 1·8 | 2·0 | 2·9 | 5·3 | 3·4 | 2·0 | 2·3 | 2·8 | 1·5 |
| | 245 | 256 | 269 | 258 | 272 | 289 | — | — | — | 260 | 262 | 251 |
| | 23 | 23 | 8 | 11 | 11 | 8 | 0 | 0 | 0 | 11 | 10 | 8 |
| | 95 | — | — | — | 145 | 135 | 104 | 125 | 142 | — | — | — |
| | 2 | 0 | 0 | 0 | 1 | 3 | 10 | 8 | 1 | 0 | 0 | 0 |
| | 210 | 255 | 214 | 220 | 243 | 227 | 196 | 175 | 224 | 218 | 208 | 222 |
| | 6 | 5 | 23 | 19 | 19 | 19 | 21 | 23 | 29 | 20 | 20 | 23 |
| | **2·0** | **2·2** | **2·4** | **2·6** | **2·7** | **2·5** | **2·4** | **2·5** | **2·3** | **2·2** | **2·1** | **1·9** |
| (b) DELHI | | | | | | | | | | | | |
| | 350 | 447 | 556 | 606 | 630 | 614 | 245 | 452 | 491 | 501 | 413 | 345 |
| | 24 | 23 | 29 | 28 | 28 | 26 | 10 | 19 | 2 | 17 | 29 | 24 |
| | 7·2 | 8·5 | 8·6 | 8·7 | 8·4 | 8·1 | 3·9 | 6·1 | 4·9 | 8·6 | 9·4 | 7·5 |
| | 69 | 77 | 73 | 69 | 62 | 57 | 28 | 46 | 39 | 74 | 87 | 72 |
| | 445 | 523 | 644 | 694 | 756 | 728 | 505 | 699 | 580 | 549 | 470 | 407 |
| | 182 | 199 | 316 | 391 | 416 | 508 | 98 | 105 | 401 | 460 | 120 | 147 |
| | 2·4 | 2·6 | 2·0 | 1·8 | 1·8 | 1·5 | 5·1 | 6·6 | 1·4 | 1·2 | 3·9 | 2·7 |
| | 408 | 467 | 560 | 655 | 742 | 684 | — | — | — | 498 | 431 | 380 |
| | 7 | 9 | 16 | 9 | 5 | 6 | 0 | 0 | 0 | 8 | 22 | 9 |
| | — | 199 | — | — | 514 | — | 137 | 192 | — | — | — | 147 |
| | 0 | 1 | 0 | 0 | 1 | 0 | 6 | 4 | 0 | 0 | 0 | 1 |
| | 326 | 453 | 515 | 583 | 610 | 562 | 408 | 521 | 491 | 503 | 356 | 337 |
| | 17 | 13 | 13 | 19 | 22 | 20 | 4 | 15 | 2 | 9 | 7 | 14 |
| | 205 | 247 | 283 | 305 | 313 | 307 | 191 | 220 | 208 | 252 | 246 | 207 |
| | 31 | 28 | 31 | 30 | 30 | 30 | 31 | 31 | 30 | 31 | 30 | 31 |
| | 269 | 302 | 330 | 352 | 382 | 371 | 317 | 324 | 293 | 290 | 284 | 259 |
| | 108 | 86 | 154 | 202 | 189 | 256 | 28 | 81 | 100 | 92 | 68 | 76 |
| | 2·5 | 3·5 | 2·1 | 1·7 | 2·0 | 1·4 | 1·1 | 4·0 | 2·9 | 3·2 | 4·2 | 3·4 |
| | 250 | 261 | 305 | 331 | 368 | 345 | — | — | — | 274 | 258 | 238 |
| | 8 | 10 | 17 | 9 | 5 | 6 | 0 | 0 | 0 | 9 | 23 | 11 |

TABLE

| | 1957 | | | | | |
|---|---|---|---|---|---|---|
| | Jul | Aug | Sep | Oct | Nov | Dec |
| Mean $T'$ on overcast days | 154 | 102 | 89 | — | — | 79 |
| No. of ,, ,, | 7 | 1 | 7 | 0 | 0 | 3 |
| Mean $T'$ on cloudy days | 250 | 249 | 265 | 267 | 234 | 176 |
| No. of ,, ,, | 23 | 29 | 9 | 19 | 18 | 14 |
| Ratio mean daily sum $(T/T')$ | **2·0** | **2·1** | **2·1** | **1·7** | **1·6** | **1·6** |
| Mean $T$ (cal/cm$^2$/day) | — | — | 402 | 384 | 406 | 364 |
| No. of days | — | — | 20 | 28 | 29 | 31 |
| Mean hours of sunshine | — | — | 6·1 | 7·2 | 9·6 | 8·9 |
| % possible hours of sunshine | — | — | 49 | 61 | 87 | 83 |
| Max. value of $T$ | — | — | 593 | 520 | 464 | 398 |
| Min. value of $T$ | — | — | 110 | 185 | 345 | 293 |
| Ratio Max/Min $T$ | — | — | 5·4 | 2·8 | 1·3 | 1·3 |
| Mean $T$ on clear days | — | — | — | 441 | 416 | 372 |
| No. of ,, ,, | — | — | 0 | 3 | 20 | 17 |
| Mean $T$ on overcast days | — | — | 168 | 235 | — | — |
| No. of ,, ,, | — | — | 3 | 2 | 0 | 0 |
| Mean $T$ on cloudy days | — | — | 443 | 389 | 384 | 354 |
| No. of ,, ,, | — | — | 17 | 23 | 9 | 14 |
| Mean $T'$ (cal/cm$^2$/day) | — | — | 184 | 185 | 224 | 212 |
| No. of days | — | — | 21 | 31 | 30 | 31 |
| Max. value of $T'$ | — | — | 265 | 249 | 267 | 233 |
| Min. value of $T'$ | — | — | 47 | 78 | 192 | 186 |
| Ratio Max/Min $T'$ | — | — | 5·6 | 3·2 | 1·4 | 1·3 |
| Mean $T'$ on clear days | — | — | — | 223 | 227 | 214 |
| No. of ,, ,, | — | — | 0 | 3 | 21 | 17 |
| Mean $T'$ on overcast days | — | — | 69 | 119 | — | — |
| No. of ,, ,, | — | — | 3 | 2 | 0 | 0 |
| Mean $T'$ on cloudy days | — | — | 204 | 186 | 215 | 210 |
| No. of ,, ,, | — | — | 18 | 26 | 9 | 14 |
| Ratio mean daily sum $(T/T')$ | — | — | **2·2** | **2·1** | **1·8** | **1·7** |
| Mean $T$ (cal/cm$^2$/day) | — | — | — | 425 | 338 | 354 |
| No. of days | — | — | — | 25 | 27 | 28 |
| Mean hours of sunshine | — | — | — | 6·0 | 5·7 | 6·4 |
| % possible hours of sunshine | — | — | — | 50 | 49 | 56 |
| Max. value of $T$ | — | — | — | 594 | 527 | 476 |
| Min. value of $T$ | — | — | — | 110 | 97 | 180 |
| Ratio Max/Min $T$ | — | — | — | 5·4 | 5·4 | 2·6 |
| Mean $T$ on clear days | — | — | — | — | 527 | 471 |
| No. of ,, ,, | — | — | — | 0 | 1 | 2 |
| Mean $T$ on overcast days | — | — | — | 141 | 165 | 194 |
| No. of ,, ,, | — | — | — | 3 | 7 | 3 |
| Mean $T$ on cloudy days | — | — | — | 464 | 391 | 364 |
| No. of ,, ,, | — | — | — | 22 | 19 | 23 |
| Mean $T'$ (cal/cm$^2$/day) | — | — | — | 206 | 174 | 183 |
| No. of days | — | — | — | 30 | 30 | 31 |
| Max. value of $T'$ | — | — | — | 296 | 258 | 250 |
| Min. value of $T'$ | — | — | — | 51 | 43 | 83 |
| Ratio Max/Min $T'$ | — | — | — | 5·8 | 6·0 | 3·0 |
| Mean $T'$ on clear days | — | — | — | — | 258 | 248 |
| No. of ,, ,, | — | — | — | 0 | 1 | 2 |
| Mean $T'$ on overcast days | — | — | — | 68 | 78 | 91 |
| No. of ,, ,, | — | — | — | 3 | 7 | 3 |
| Mean $T'$ on cloudy days | — | — | — | 221 | 200 | 188 |
| No. of ,, ,, | — | — | — | 27 | 22 | 26 |
| Ratio mean daily sum $(T/T')$ | — | — | — | **2·1** | **1·9** | **1·9** |

2(*contd*)

| 1958 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| (b) DELHI—*contd* | | | | | | | | | | | |
| 0 | 86 | — | — | 259 | — | 85 | 100 | 106 | 92 | — | 76 |
| — | 1 | 0 | 0 | 1 | 0 | 8 | 5 | 2 | 1 | 0 | 1 |
| 189 | 248 | 257 | 294 | 305 | 298 | 228 | 243 | 216 | 250 | 204 | 195 |
| 23 | 17 | 14 | 21 | 24 | 24 | 23 | 26 | 28 | 21 | 7 | 19 |
| **1·7** | **1·8** | **2·0** | **2·0** | **2·0** | **2·0** | **2·0** | **2·1** | **2·3** | **2·0** | **1·5** | **1·7** |
| (c) CALCUTTA | | | | | | | | | | | |
| 339 | 394 | 489 | 506 | 542 | 472 | 454 | 481 | 430 | 396 | 393 | 363 |
| 26 | 23 | 31 | 27 | 28 | 27 | 10 | 11 | 26 | 27 | 30 | 30 |
| 3·2 | 3·5 | 9·0 | 8·8 | 8·9 | 5·6 | 4·8 | 5·5 | 5·7 | 6·6 | 8·0 | 8·7 |
| 76 | 75 | 76 | 70 | 67 | 49 | 35 | 42 | 46 | 56 | 72 | 81 |
| 429 | 486 | 555 | 582 | 640 | 607 | 622 | 624 | 567 | 533 | 485 | 410 |
| 221 | 220 | 318 | 208 | 171 | 188 | 240 | 344 | 204 | 131 | 179 | 303 |
| 1·9 | 2·2 | 1·7 | 2·8 | 3·7 | 3·2 | 2·6 | 1·8 | 2·8 | 4·1 | 2·7 | 1·3 |
| 364 | 451 | 551 | — | — | — | — | 624 | — | 472 | 446 | 394 |
| 14 | 7 | 2 | 0 | 0 | 0 | 0 | 1 | 0 | 4 | 14 | 9 |
| — | — | — | — | 183 | 196 | — | — | — | 131 | 200 | — |
| 0 | 0 | 0 | 0 | 2 | 1 | 0 | 0 | 0 | 1 | 1 | 0 |
| 309 | 369 | 485 | 506 | 570 | 482 | 454 | 467 | 430 | 394 | 342 | 349 |
| 12 | 16 | 29 | 27 | 26 | 26 | 10 | 10 | 26 | 22 | 15 | 21 |
| 182 | 206 | 232 | 242 | 244 | 218 | 177 | 190 | 192 | 193 | 211 | 203 |
| 31 | 28 | 31 | 30 | 31 | 30 | 31 | 31 | 30 | 31 | 30 | 31 |
| 239 | 255 | 267 | 291 | 279 | 283 | 271 | 275 | 280 | 266 | 280 | 238 |
| 62 | 110 | 165 | 146 | 82 | 100 | 83 | 65 | 80 | 63 | 94 | 160 |
| 3·9 | 2·3 | 1·6 | 2·0 | 3·4 | 2·8 | 3·3 | 4·2 | 3·5 | 4·2 | 3·0 | 1·5 |
| 203 | 235 | 251 | — | — | — | — | 275 | — | 244 | 247 | 223 |
| 17 | 11 | 2 | 0 | 0 | 0 | 0 | 1 | 0 | 4 | 14 | 9 |
| — | — | — | — | 95 | 100 | 99 | 84 | — | 63 | 97 | — |
| 0 | 0 | 0 | 0 | 2 | 1 | 6 | 3 | 0 | 1 | 1 | 0 |
| 157 | 186 | 230 | 242 | 254 | 222 | 196 | 199 | 192 | 191 | 185 | 195 |
| 14 | 17 | 29 | 30 | 29 | 29 | 25 | 27 | 30 | 26 | 15 | 22 |
| **1·8** | **2·0** | **2·1** | **2·1** | **2·2** | **2·2** | **2·1** | **2·2** | **2·2** | **2·0** | **1·9** | **1·8** |
| (d) MADRAS | | | | | | | | | | | |
| 472 | 559 | 590 | 591 | 546 | 523 | 423 | 422 | 503 | 369 | 373 | 397 |
| 26 | 26 | 25 | 28 | 25 | 27 | 22 | 31 | 30 | 31 | 29 | 31 |
| 8·8 | 9·7 | 8·9 | 9·4 | 8·7 | 7·0 | 3·8 | 4·5 | 7·2 | 4·7 | 6·1 | 7·1 |
| 77 | 83 | 74 | 76 | 68 | 54 | 30 | 36 | 59 | 39 | 53 | 62 |
| 551 | 607 | 654 | 648 | 669 | 667 | 587 | 639 | 635 | 559 | 562 | 491 |
| 295 | 446 | 360 | 453 | 61 | 176 | 191 | 103 | 221 | 11 | 69 | 195 |
| 1·9 | 1·4 | 1·8 | 1·4 | 11·0 | 3·8 | 3·1 | 6·2 | 2·9 | 50·8 | 8·1 | 2·6 |
| 547 | 586 | 632 | 632 | 649 | — | — | — | 627 | — | 562 | — |
| 3 | 7 | 1 | 4 | 2 | 0 | 0 | 0 | 1 | 0 | 1 | 0 |
| — | — | — | — | 134 | 176 | 221 | 234 | 221 | 187 | 166 | 201 |
| 0 | 0 | 0 | 0 | 2 | 1 | 3 | 8 | 1 | 10 | 6 | 2 |
| 462 | 549 | 588 | 584 | 575 | 536 | 455 | 488 | 509 | 457 | 420 | 411 |
| 23 | 19 | 24 | 24 | 21 | 26 | 19 | 23 | 28 | 21 | 22 | 29 |
| 233 | 275 | 284 | 275 | 266 | 245 | 199 | 198 | 239 | 178 | 189 | 197 |
| 31 | 28 | 31 | 30 | 31 | 30 | 31 | 31 | 30 | 31 | 30 | 31 |
| 278 | 303 | 310 | 305 | 372 | 313 | 269 | 294 | 296 | 275 | 274 | 250 |
| 124 | 208 | 192 | 107 | 33 | 90 | 86 | 48 | 105 | 9 | 37 | 97 |
| 2·2 | 1·5 | 1·6 | 2·9 | 11·3 | 3·5 | 3·1 | 6·1 | 2·8 | 30·6 | 7·4 | 2·6 |
| 266 | 291 | 299 | 298 | 305 | — | — | — | 281 | — | 273 | — |
| 5 | 7 | 1 | 4 | 2 | 0 | 0 | 0 | 1 | 0 | 2 | 0 |
| — | — | — | 107 | 65 | 65 | 121 | 109 | 105 | 88 | 77 | 100 |
| 0 | 0 | 0 | 1 | 2 | 2 | 5 | 8 | 1 | 10 | 6 | 2 |
| 227 | 269 | 283 | 278 | 278 | 258 | 213 | 229 | 242 | 220 | 212 | 203 |
| 26 | 21 | 30 | 25 | 27 | 28 | 26 | 23 | 28 | 21 | 22 | 29 |
| **2·0** | **2·0** | **2·1** | **3·3** | **2·1** | **2·1** | **2·1** | **2·1** | **2·1** | **2·1** | **2·0** | **2·0** |

**TABLE 3**

**Percentage frequency distribution of daily values of total radiation (cal/cm$^2$) for each month**

| | 0—100 | 101—200 | 201—300 | 301—400 | 401—500 | 501—600 | 601—700 | 701—800 |
|---|---|---|---|---|---|---|---|---|
| | | | | (a) POONA | | | | |
| Jan | | 1 | 2 | | 61 | 36 | | |
| Feb | | | | | | 80 | 20 | |
| Mar | | | | | 7 | 38 | 35 | |
| Apr | | | | | 8 | 18 | 70 | 4 |
| May | | | | 2 | | 7 | 41 | 50 |
| Jun | | | 1 | 9 | 11 | 13 | 8 | 58 |
| Jul | 1 | 2 | 11 | 12 | 47 | 22 | 5 | |
| Aug | | 1 | 4 | 32 | 33 | 30 | | |
| Sep | | | 2 | 13 | 18 | 50 | 17 | |
| Oct | | | 4 | 4 | 11 | 77 | 4 | |
| Nov | | 2 | | 3 | 47 | 48 | | |
| Dec | | | | 13 | 87 | | | |
| | | | | (b) NEW DELHI | | | | |
| Jan | | 2 | 9 | 64 | 25 | | | |
| Feb | | 2 | | 7 | 71 | 20 | | |
| Mar | | | | 2 | 9 | 66 | 23 | |
| Apr | | | | 2 | 3 | 28 | 67 | |
| May | | | | | 2 | 29 | 40 | 29 |
| Jun | | | | | | 32 | 54 | 14 |
| Jul | 6 | 19 | 9 | 28 | 18 | 20 | | |
| Aug | | 5 | 12 | | 10 | 13 | 60 | |
| Sep | | | | | 41 | 59 | | |
| Oct | | | | | 39 | 61 | | |
| Nov | | 1 | | 13 | 86 | | | |
| Dec | | 2 | 3 | 90 | 5 | | | |
| | | | | (c) CALCUTTA | | | | |
| Jan | | | 17 | 74 | 9 | | | |
| Feb | | | 11 | 20 | 69 | | | |
| Mar | | | | 12 | 25 | 63 | | |
| Apr | | | 3 | | 21 | 76 | | |
| May | | 2 | 2 | | 3 | 60 | 33 | |
| Jun | | 3 | | 5 | 39 | 44 | 9 | |
| Jul | | | 5 | 16 | 41 | 24 | 14 | |
| Aug | | | | 20 | 27 | 41 | 12 | |
| Sep | | | 7 | 15 | 49 | 29 | | |
| Oct | | 1 | 10 | 19 | 55 | 15 | | |
| Nov | | 5 | | 37 | 58 | | | |
| Dec | | | | 92 | 8 | | | |
| | | | | (d) MADRAS | | | | |
| Jan | | | 2 | 9 | 42 | 47 | | |
| Feb | | | | | 7 | 85 | 8 | |
| Mar | | | | 2 | 3 | 48 | 47 | |
| Apr | | | | | 11 | 20 | 69 | |
| May | $<1$ | | 4 | | 4 | 44 | 48 | |
| Jun | | 1 | | 5 | 19 | 48 | 27 | |
| Jul | | 2 | 8 | 19 | 29 | 42 | | |
| Aug | | 2 | 9 | 11 | 30 | 29 | 19 | |
| Sep | | | 1 | 3 | 33 | 43 | 20 | |
| Oct | 1 | 4 | 9 | 24 | 24 | 38 | | |
| Nov | 1 | 3 | 13 | 13 | 46 | 24 | | |
| Dec | | 2 | 5 | 30 | 63 | | | |

**TABLE 4**

**Ratio of daily totals of Solar Radiation $T$ from sun and sky on a horizontal surface to the Solar Radiation $T'$ from sun, sky and ground on a spherical surface**

| | Poona | Delhi | Calcutta | Madras |
|---|---|---|---|---|
| | | **1957** | | |
| Jul | 2·3 | 2·0 | — | — |
| Aug | 2·2 | 2·1 | — | — |
| Sep | 2·2 | 2·1 | 2·2 | — |
| Oct | 2·1 | 1·7 | 2·1 | 2·1 |
| Nov | 2·0 | 1·6 | 1·8 | 1·9 |
| Dec | 1·9 | 1·6 | 1·7 | 1·9 |
| | | **1958** | | |
| Jan | 2·0 | 1·7 | 1·8 | 2·0 |
| Feb | 2·2 | 1·8 | 2·0 | 2·0 |
| Mar | 2·4 | 2·0 | 2·1 | 2·1 |
| Apr | 2·6 | 2·0 | 2·1 | 2·2 |
| May | 2·7 | 2·0 | 2·2 | 2·1 |
| Jun | 2·5 | 2·0 | 2·2 | 2·1 |
| Jul | 2·4 | 2·0 | 2·1 | 2·1 |
| Aug | 2·5 | 2·1 | 2·2 | 2·1 |
| Sep | 2·3 | 2·3 | 2·2 | 2·1 |
| Oct | 2·2 | 2·0 | 2·0 | 2·1 |
| Nov | 2·1 | 1·5 | 1·9 | 2·0 |
| Dec | 1·9 | 1·7 | 1·8 | 2·0 |
| Mean | 2·3 | 1·9 | 2·0 | 2·1 |

**TABLE 5**

**Mean hourly values (cal/cm²/hr) of total radiation from sun and sky (*T*) on a horizontal surface**

| | 06 | 07 | 08 | 09 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 hrs LAT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | (a) POONA | | | | | | | |
| **1957** | | | | | | | | | | | | | | |
| Jul | 1 | 6 | 18 | 32 | 48 | 62 | 68 | 67 | 65 | 60 | 42 | 27 | 13 | 1 |
| Aug | 1 | 8 | 20 | 31 | 44 | 50 | 60 | 58 | 51 | 39 | 31 | 20 | 8 | 1 |
| Sep | 1 | 9 | 24 | 41 | 54 | 63 | 68 | 68 | 63 | 54 | 40 | 24 | 9 | 1 |
| Oct | | 5 | 20 | 39 | 54 | 65 | 71 | 66 | 59 | 50 | 36 | 19 | 4 | |
| Nov | | 2 | 14 | 29 | 43 | 55 | 63 | 63 | 58 | 46 | 32 | 15 | 2 | |
| Dec | | 2 | 14 | 31 | 47 | 57 | 64 | 63 | 58 | 47 | 31 | 13 | 1 | |
| **1958** | | | | | | | | | | | | | | |
| Jan | | 3 | 16 | 34 | 51 | 61 | 67 | 67 | 61 | 50 | 33 | 16 | 2 | |
| Feb | | 5 | 23 | 43 | 59 | 71 | 78 | 79 | 73 | 60 | 44 | 23 | 5 | 0 |
| Mar | 0 | 9 | 28 | 49 | 66 | 77 | 82 | 81 | 72 | 60 | 43 | 23 | 7 | 0 |
| Apr | 1 | 12 | 31 | 52 | 69 | 79 | 84 | 81 | 72 | 57 | 41 | 26 | 10 | 1 |
| May | 1 | 13 | 32 | 50 | 67 | 78 | 85 | 87 | 80 | 66 | 52 | 36 | 16 | 3 |
| Jun | 2 | 13 | 29 | 47 | 62 | 70 | 72 | 73 | 64 | 59 | 47 | 32 | 15 | 3 |
| Jul | 1 | 8 | 19 | 30 | 42 | 50 | 51 | 52 | 47 | 39 | 28 | 19 | 8 | 1 |
| Aug | 1 | 7 | 17 | 29 | 43 | 53 | 49 | 50 | 51 | 44 | 32 | 18 | 7 | 1 |
| Sep | 0 | 6 | 19 | 35 | 49 | 63 | 62 | 66 | 65 | 57 | 43 | 24 | 8 | 0 |
| Oct | | 4 | 20 | 39 | 55 | 67 | 74 | 72 | 66 | 54 | 40 | 21 | 5 | |
| Nov | | 2 | 16 | 35 | 51 | 63 | 68 | 70 | 63 | 51 | 36 | 17 | 3 | |
| Dec | | 2 | 15 | 32 | 49 | 61 | 67 | 66 | 61 | 47 | 31 | 14 | 2 | |
| | | | | | | | (b) DELHI | | | | | | | |
| **1957** | | | | | | | | | | | | | | |
| Jul | 2 | 11 | 22 | 36 | 47 | 56 | 61 | 61 | 53 | 49 | 40 | 29 | 15 | 3 |
| Aug | 1 | 11 | 26 | 40 | 51 | 64 | 68 | 70 | 64 | 56 | 44 | 30 | 14 | 2 |
| Sep | 1 | 9 | 25 | 39 | 51 | 60 | 67 | 68 | 61 | 50 | 36 | 21 | 7 | 0 |
| Oct | | 3 | 18 | 36 | 52 | 62 | 69 | 69 | 64 | 53 | 38 | 20 | 4 | 0 |
| Nov | | 1 | 13 | 29 | 47 | 58 | 63 | 64 | 59 | 47 | 32 | 14 | 2 | |
| Dec | | 0 | 7 | 22 | 35 | 46 | 50 | 52 | 48 | 36 | 23 | 9 | 0 | |
| **1958** | | | | | | | | | | | | | | |
| Jan | | 1 | 9 | 23 | 38 | 49 | 53 | 53 | 49 | 38 | 25 | 10 | 1 | |
| Feb | | 2 | 16 | 34 | 50 | 60 | 64 | 65 | 57 | 47 | 32 | 16 | 3 | |
| Mar | 0 | 8 | 26 | 45 | 60 | 71 | 77 | 75 | 68 | 57 | 41 | 24 | 5 | |
| Apr | 1 | 12 | 30 | 49 | 65 | 74 | 79 | 80 | 73 | 61 | 44 | 28 | 11 | 1 |
| May | 3 | 16 | 34 | 52 | 65 | 76 | 82 | 81 | 72 | 60 | 44 | 30 | 13 | 2 |
| Jun | 3 | 14 | 31 | 49 | 63 | 72 | 77 | 73 | 69 | 59 | 49 | 33 | 17 | 4 |
| Jul | 1 | 5 | 11 | 18 | 22 | 30 | 27 | 26 | 27 | 25 | 23 | 18 | 11 | 3 |
| Aug | 1 | 9 | 21 | 32 | 45 | 53 | 56 | 55 | 55 | 52 | 36 | 24 | 10 | 1 |
| Sep | 0 | 6 | 18 | 34 | 47 | 58 | 67 | 71 | 67 | 55 | 37 | 22 | 7 | 0 |
| Oct | | 3 | 19 | 38 | 54 | 66 | 72 | 72 | 65 | 55 | 36 | 18 | 3 | |
| Nov | | 1 | 12 | 30 | 46 | 57 | 62 | 61 | 55 | 45 | 29 | 12 | 1 | |
| Dec | | 0 | 7 | 23 | 39 | 50 | 54 | 55 | 47 | 38 | 24 | 8 | 0 | |

**TABLE 5** *(contd)*

| | 06 | 07 | 08 | 09 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 hrs LAT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **(c) CALCUTTA** | | | | | | | | | | | | | | |
| **1957** | | | | | | | | | | | | | | |
| Jul | | | | | | | | | | | | | | |
| Aug | | | | | | | | | | | | | | |
| Sep | | 5 | 18 | 32 | 44 | 51 | 55 | 55 | 47 | 44 | 30 | 17 | 5 | |
| Oct | | 3 | 15 | 31 | 45 | 55 | 57 | 53 | 42 | 38 | 28 | 14 | 3 | |
| Nov | | 1 | 13 | 31 | 44 | 55 | 61 | 60 | 55 | 43 | 30 | 13 | 1 | |
| Dec | | 0 | 9 | 25 | 40 | 50 | 56 | 56 | 50 | 40 | 26 | 10 | 0 | |
| **1958** | | | | | | | | | | | | | | |
| Jan | | 0 | 9 | 23 | 37 | 48 | 52 | 52 | 47 | 37 | 23 | 9 | 1 | |
| Feb | | 2 | 13 | 28 | 42 | 52 | 57 | 57 | 55 | 45 | 28 | 13 | 1 | |
| Mar | 0 | 5 | 21 | 39 | 52 | 62 | 68 | 69 | 62 | 51 | 36 | 20 | 5 | |
| Apr | 0 | 8 | 23 | 40 | 53 | 63 | 67 | 66 | 63 | 52 | 40 | 23 | 7 | 0 |
| May | 1 | 12 | 26 | 41 | 56 | 65 | 70 | 70 | 65 | 55 | 44 | 25 | 10 | 1 |
| Jun | 1 | 11 | 28 | 37 | 47 | 57 | 62 | 60 | 53 | 48 | 35 | 22 | 10 | 1 |
| Jul | 2 | 13 | 28 | 43 | 48 | 54 | 59 | 49 | 51 | 38 | 32 | 24 | 11 | 1 |
| Aug | 1 | 11 | 27 | 42 | 53 | 68 | 70 | 68 | 53 | 41 | 26 | 16 | 6 | 0 |
| Sep | 0 | 7 | 21 | 37 | 48 | 61 | 65 | 63 | 50 | 35 | 22 | 14 | 4 | 0 |
| Oct | | 3 | 17 | 33 | 47 | 55 | 59 | 52 | 48 | 40 | 26 | 13 | 2 | |
| Nov | | 1 | 13 | 30 | 43 | 53 | 58 | 56 | 52 | 42 | 27 | 12 | 1 | |
| Dec | | 1 | 10 | 27 | 42 | 51 | 55 | 55 | 50 | 37 | 25 | 10 | 1 | |
| **(d) MADRAS** | | | | | | | | | | | | | | |
| **1957** | | | | | | | | | | | | | | |
| Jul | | | | | | | | | | | | | | |
| Aug | | | | | | | | | | | | | | |
| Sep | | | | | | | | | | | | | | |
| Oct | | 4 | 18 | 35 | 44 | 52 | 59 | 61 | 52 | 45 | 34 | 17 | 4 | |
| Nov | | 2 | 12 | 26 | 36 | 43 | 46 | 45 | 45 | 37 | 28 | 16 | 3 | |
| Dec | | 1 | 13 | 28 | 39 | 46 | 46 | 50 | 45 | 38 | 29 | 15 | 3 | |
| **1958** | | | | | | | | | | | | | | |
| Jan | | 2 | 18 | 34 | 46 | 57 | 65 | 69 | 65 | 53 | 39 | 20 | 4 | |
| Feb | | 4 | 23 | 41 | 57 | 69 | 78 | 79 | 73 | 61 | 45 | 24 | 6 | |
| Mar | | 6 | 24 | 43 | 62 | 71 | 79 | 83 | 76 | 63 | 47 | 27 | 8 | |
| Apr | 0 | 7 | 25 | 44 | 57 | 71 | 81 | 81 | 77 | 66 | 47 | 27 | 9 | 0 |
| May | 0 | 7 | 22 | 39 | 54 | 64 | 72 | 75 | 69 | 62 | 46 | 26 | 9 | 0 |
| Jun | 0 | 7 | 24 | 41 | 58 | 69 | 72 | 74 | 64 | 51 | 34 | 22 | 7 | 0 |
| Jul | 0 | 6 | 19 | 35 | 47 | 58 | 59 | 59 | 50 | 38 | 29 | 16 | 6 | 0 |
| Aug | 0 | 4 | 16 | 29 | 43 | 55 | 57 | 58 | 52 | 43 | 35 | 21 | 8 | 0 |
| Sep | 0 | 6 | 23 | 40 | 54 | 68 | 69 | 69 | 61 | 49 | 36 | 22 | 7 | 0 |
| Oct | 0 | 3 | 16 | 30 | 40 | 48 | 49 | 51 | 45 | 38 | 28 | 16 | 4 | 0 |
| Nov | 0 | 2 | 13 | 29 | 39 | 46 | 53 | 50 | 48 | 40 | 31 | 17 | 4 | 0 |
| Dec | 0 | 2 | 15 | 30 | 44 | 50 | 53 | 56 | 51 | 44 | 32 | 16 | 3 | 0 |

TABLE 6

Sun and sky radiation on a horizontal surface (cal/cm$^2$/day)

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | POONA | | | | | | | |
| Computed by Ramdas | 488 | 561 | 631 | 620 | 632 | 489 | 378 | 375 | 475 | 474 | 489 | 464 |
| Measured during IGY | 460 | 562 | 598 | 617 | 664 | 589 | 395 | 402 | 496 | 518 | 474 | 447 |
| | | | | | DELHI | | | | | | | |
| Computed by Ramdas | 361 | 441 | 509 | 599 | 610 | 571 | 491 | 486 | 478 | 524 | 442 | 353 |
| Measured during IGY | 350 | 447 | 556 | 606 | 630 | 614 | (245)* (485) | 452 | 491 | 501 | 413 | 345 |
| | | | | | CALCUTTA | | | | | | | |
| Computed by Ramdas | 442 | 506 | 568 | 617 | 682 | 482 | 416 | 441 | 387 | 431 | 445 | 415 |
| Measured during IGY | 339 | 394 | 489 | 506 | 542 | 472 | 454 | 481 | 427 | 396 | 393 | 363 |
| | | | | | MADRAS | | | | | | | |
| Computed by Ramdas | 526 | 610 | 643 | 626 | 581 | 495 | 442 | 467 | 510 | 489 | 489 | 473 |
| Measured during IGY | 472 | 559 | 591 | 595 | 546 | 523 | 423 | 422 | 503 | 369 | 373 | 397 |

*245 cal/cm$^2$/day were received in July 1958 while 485 cal/cm$^2$/day were received in July 1957 one may assume that July 1958 was an abnormal month