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Global solar radiation characteristics at Dumdum (West Bengal)

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The data of the hourly global solar radiation (*G*) on a horizontal surface of Dumdum/ Gangetic West Bengal for the period 1980 to 2010 has been obtained. The diurnal extra terrestrial solar radiation for the station (22.39° N, 88.27° E) has been computed and then the clearness index has been calculated. The diurnal variations of the results have been studied. Also the daily total values and its monthly and seasonal averages as well as their frequency distribution in percentage have been computed and examined. The seasonal and climatic effects of the fluctuation of the results have been discussed. These effects have been particularly large during pre monsoon season (i.e. March to May); the period which experiences the thunderstorm activity the most in this area and this fact may be attributed as one of the cause for generation of the thunderstorm. The clearness index (G/G_o) shows that the incoming solar radiation is almost halved on reaching the earth. Also the comparative statistical as well as graphical study of average total global solar radiation with the average maximum temperature confirms once again the fact that the total global solar radiation is fairly related to average maximum temperature in correlation (0.77) as well as in wave form.

Keywords: Solar radiation, Global solar radiation, Clearness index, Radiation

1 Introduction

Over the past years, the solar radiation data has gained importance due to increased use of solar energy systems. The analysis of this data is of fundamental importance for successful development of projects for the practical utilization of solar energy by agriculturists, hydrologists, architects and engineers, particularly where sunshine plays a major role[1-9]. India has about 300 clear, sunny days in a year, it's theoretically calculated that global solar radiation incidence on its land area alone is about 50 lakh trillion Wh per year, so to use this huge renewable source in all fields, it is doing an extensive study by setting up a large network of 45 radiation observatories to record the different components of solar radiation. One such radiation measurement observatory is at Dumdum in West Bengal. Indian scientists too have done extensive research on solar radiation pertinent to this country, to mention a few, they have found new correlation to estimate Global solar radiation on horizontal surface using sunshine hour and temperature data for Indian sites[10], a general formula for computing the coefficients of the correlation connecting global solar radiation to sunshine duration has been found[11], neural network approach for modeling global solar radiation was done[12], techniques for the precise estimation of hourly values of global, diffuse and direct solar radiation has been devised[13].

Dumdum is a city lying in the tropical belt in Gangetic West Bengal, lying close to Bay of Bengal and its solar radiation data is of great importance for study of development of weather system during the year. Also this knowledge can be utilized in agricultural field, in its adjoining areas. In this paper we have attempted to provide some useful solar radiation information to the agricultural scientists and to the designers of solar energy utilization systems under the climatic conditions of Dumdum, which may also serve as a useful reference for system designers and users in other regions, with similar climatic conditions.

In this work the characteristics of global solar radiation (*G*) and the clearness index have been studied and the correlation of average of total of diurnal global radiation received by this station with average of diurnal maximum temperature has been found. It has already been shown that there exists a high correlation between global solar radiation computed by Angstrom Prescott formula and Hargreaves formula with daily maximum temperature for this region[5] and the study with actual observed global solar radiation corroborates the fact.

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2 General Climates of Dumdum (West Bengal)

Dumdum is located in the south part of West Bengal at latitude (22.39° N, 88.27° E) and elevation 6 m above sea level. Climatically, Dumdum lies within the tropical region and characterized with hot and humid weather. Average temperature is 17.6 °C in January, 21.7 °C in February, 26.7 °C in March, 29.8 °C in April, 30.9 °C in May, 30.5 °C in June, 29.6 °C in July, 29.5 °C in August, 29.5 °C in September, 28.4 °C in October, 24.3 °C in November and 19.5 °C in December. Average relative humidity is 75% in January, 71% February, 67% in March, 72 % in April, 74% in May, 80% in June, 83% in July, 83% in August, 82% in September, 76% in October, 70% in November and 72% in December. The prevailing winds are south easterly to southerly during monsoon with wind speed ranging from 9 to13 km/h, north easterly during winter with wind speed ranging from 5 to7 km/h, north easterly during pre-monsoon with wind speed ranging from 9 to13 km/h and north easterly to southerly with wind speed ranging from 7 to 30 km/h.

3 Measurements

Measurements of global solar radiation (*G*) have been done hourly from sunrise to sunset throughout the year for all these 30 years (1980 to 2010), using pyranometer[6,14]. The pyranometer specifications meet the majority of requirements set for Class-1 radiation sensors by the WMO[15].

3.1 Brief description of pyranometer

Pyranometer[14] is a sensor based instrument, used for measuring global solar irradiance. When the radiant energy falls on the horizontal surface of the pyranometer, the sensing element fixed with the horizontal surface detects the radiant energy and also measures it. To cut off far infrared component of radiation, pyranometers are so designed to allow the radiation between 0.3 to 3.0 μm. For this purpose two concentric hemispherical domes, made of special type of optical glass with requisite transmission properties are used to cover the horizontal surface along with sensor. Figure 1 is the rough sketch of the vertical section of a pyranometer. The sensor is kept at the centre of the circle bounded by glass domes and horizontal surface. In general the sensor of the said instruments is made of thermoelectric sensing elements. In some pyranometers photo electric and bimetallic sensors are also used. Depending upon the circuitry the formula for recording irradiance has to be fixed. The variation of current and voltage are the main input to the above mentioned formula for calculating quantitative value of irradiance. In our work we used Eko pyranometer (diffused dome) made by IMD Pune. Every few days the band position was adjusted according to the actual declination of the sun. Global solar radiation (G) was measured in watt h m^{-2} (Whm^{-2}).

4 Results and Discussion

The different solar radiation components are functions of several variables[1,7] such as the solar elevation angle (solar height), the nature and extent of cloudiness (cloud amount), the atmospheric scattering by air molecules, (Rayleigh scattering) and aerosols (Mie scattering) as well as the absorption by atmospheric gases (H_2O,O_2,CO_2,O_3 in specific wavelength bands) and aerosols. The values and variations of these components are mainly influenced by the mentioned parameters, which are considered in this work to discuss the measurement results in the different periods of the year.

4.1 Characteristics of global solar radiation on a horizontal surface

4.1.1 *All sky conditions measurements*

Table 1 gives the average values of the hourly global solar radiation in Whm^{-2} received on a horizontal surface through a day in different months during the study period. From this table one can see clearly that the rise and fall of the hourly global solar radiation throughout the day is generally symmetrical with respect to the solar noon for all the days the year around. As expected the maximum values were recorded at midday hours with average values 33.5 Whm^{-2} (approx) in April to 23.7 Whm^{-2} (approx) in December in somewhat symmetrical way, while the minimum values were observed at "early morning" and at "late afternoon" with average value being in some measurements in the order of the instrument offset. This behavior is due to longer path traversed by the solar radiation in the early morning and late afternoon ($0.8° \leq h \leq 15.5°$) than in the solar noon time ($39.9° \leq h \leq 81.4°$). This is accompanied with

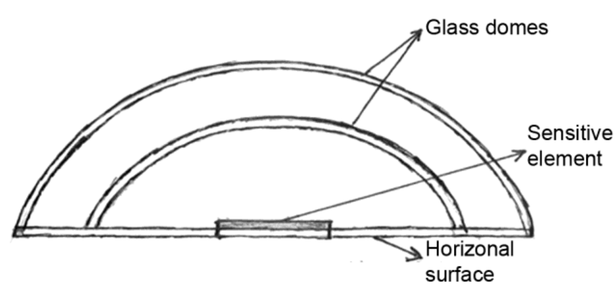

Fig. 1 — Rough sketch of the vertical section of a pyranometer

greater amount of scattering and absorption and leads to marked depletion of the global solar radiation in the early morning and the late afternoon hours compared to the noon time.

4.1.2 *Variation of daily totals of global solar radiation*

Figure 2 illustrates the variation of the daily totals of global solar radiation through the whole measurement period from June to May (average value of 30 years, i.e., 1980 to 2010 was taken) instead of one year[8]. The value of G varies from 139.45 Whm^{-2} (on the day number 12 of Julian day) to 257.97 Whm^{-2} (on the day number 110 of Julian day) with somewhat remarkable variation from day to day. This variation is due to the fluctuation of the atmospheric conditions with respect to water content, dust and amount and type of clouds, which change from hour to hour and day to day in this tropical belt.

Table 1 — Results of mean values of month wise and season wise global solar radiation (Whm^{-2}) according to given time range in IST, in all sky condition from June to May for the period 1980 to 2010

Period	5- Sr*-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-Ss*	TOTAL
June	0.67	4.52	10.18	15.98	20.97	24.05	24.85	24.47	21.83	18.46	14.24	9.11	4.10	0.69	194.12
July	0.50	3.85	8.98	14.26	18.84	21.94	22.31	21.82	19.99	16.31	12.51	7.88	3.63	0.54	173.36
August	0.27	3.34	8.87	14.80	19.94	23.24	23.58	22.34	19.85	16.40	12.46	7.40	2.89	0.27	175.65
September	0.05	2.35	8.26	14.66	20.48	24.04	24.49	23.32	20.21	15.87	11.38	6.41	1.93	0.05	173.50
October	0.00	1.23	6.77	14.01	20.31	24.54	25.56	24.61	21.49	17.00	11.86	5.74	1.09	0.00	174.21
November	0.00	0.53	5.09	12.38	19.10	23.71	25.54	25.10	22.22	17.47	11.06	4.27	0.40	0.01	166.88
December	0.00	0.25	3.70	10.30	16.73	21.44	23.68	23.52	20.91	16.04	9.66	3.33	0.19	0.00	149.75
January	0.00	0.26	3.74	10.18	16.75	21.63	23.99	23.87	21.54	17.08	10.72	3.90	0.29	0.00	153.95
February	0.00	0.72	5.56	12.90	19.82	25.14	27.30	27.03	24.83	20.14	13.38	5.82	0.80	0.00	183.44
March	0.01	1.90	8.24	16.27	23.42	28.38	30.53	30.40	27.94	23.09	16.18	8.21	1.86	0.02	216.45
April	0.18	3.49	10.57	18.70	25.96	31.10	33.52	33.14	30.74	25.87	18.77	9.99	3.09	0.19	245.31
May	0.54	4.53	11.39	18.51	24.90	29.39	31.39	30.92	28.93	24.75	18.63	11.27	4.44	0.55	240.14
Monsoon	0.37	3.51	9.07	14.92	20.05	23.31	23.79	22.97	20.46	16.75	12.65	7.70	3.14	0.39	179.08
Post Monsoon	0.00	0.67	5.19	12.23	18.71	23.22	24.92	24.40	21.53	16.83	10.86	4.45	0.56	0.00	163.57
Winter	0.00	0.48	4.60	11.47	18.20	23.29	25.56	25.37	23.10	18.53	11.98	4.81	0.53	0.00	167.92
Pre Monsoon	0.25	3.30	10.06	17.82	24.75	29.61	31.80	31.47	29.19	24.55	17.85	9.82	3.13	0.25	233.85
Year	0.19	2.25	7.62	14.41	20.60	24.87	26.38	25.86	23.36	19.03	13.40	6.95	2.07	0.19	187.18

*****Sr−Denotes time of sunrise and Ss −Denotes time of sunset

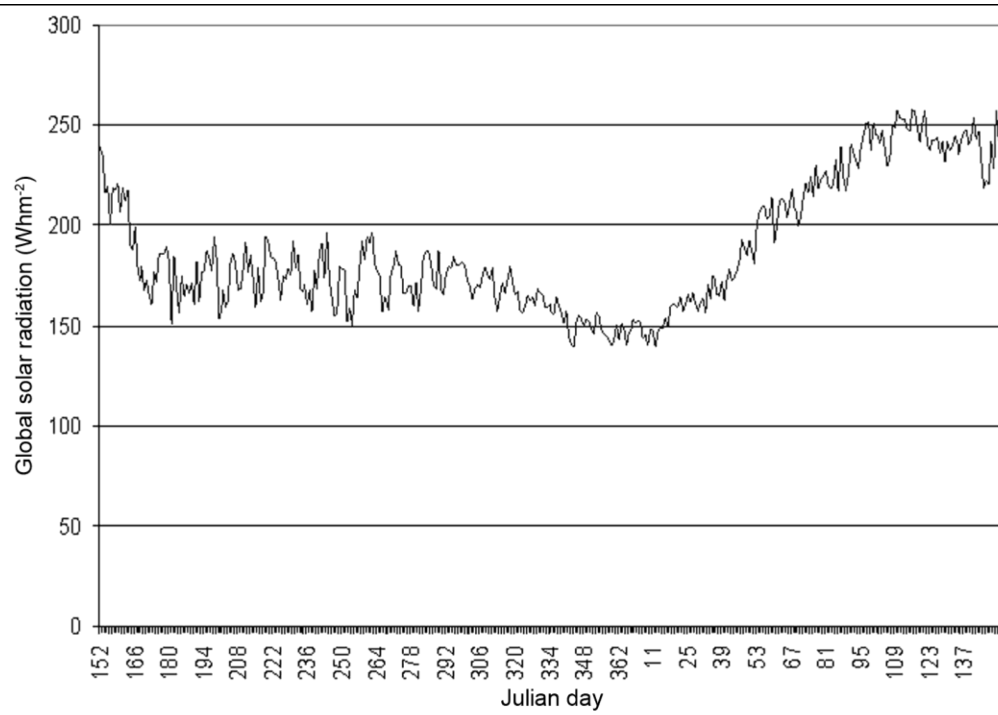

Fig. 2 — Graph of mean of daily hourly total of global solar radiation against Julian days from June to May

4.1.3 *Variation of monthly average of daily totals of global solar radiation*

The variations of the monthly average of *G* are also included in Table 1. The average value of the daily totals of *G* ranges from 149.75 Whm^{-2} in December to 245.30 Whm^{-2} in April. The minimum value of extraterrestrial radiation at the places within the tropics in Northern Hemisphere G_o, occurs in June (G_o = 474.28 Whm^{-2}) and the minimum[9] in December (G_o =287.31 Whm^{-2}). The results of the monthly average of *G* show that the standard deviation has relatively high value in June (23.22 Whm^{-2}), compared with the small value in December (6.44 Whm^{-2}). This may be attributed to presence of clouds during monsoon period.

4.1.4 *Variation of seasonal averages of* G

Table 1 gives the seasonal averages of *G* as well as its average over the whole study period. From this table, one can see that the average *G* over the year is 187.17 Whm^{-2} with seasonal variation from 163.58 Whm^{-2} in post monsoon to 233.84 Whm^{-2} in pre monsoon. This relatively tropical variation is typical of the climate of Gangetic West Bengal and also reflects one of the causes for high frequency of thunderstorm activity in pre monsoon of this study region. The standard deviation of the results, has high values in winter (19.42 Whm^{-2}) and a small value in post monsoon (12.59 Whm^{-2}) indicating the higher stability of the atmosphere in the post monsoon season in this area.

4.1.5 *Percentage frequency distribution of*

The percentage frequency distributions of *G* are given in Table 2 for each month, season and the whole period, respectively. From this table it can be seen that about 96% of the days in the year have values of G within the range from 0 -30 Whm^{-2}. In monsoon period 95.5% of the days in this period, in

Table 2 — Percentage of frequency distribution of mean daily totals of global solar radiation from June to May for the period 1980 to 2010

Range in Whm^{-2}	(0-5)	(5-10)	(10-15)	(15-20)	(20-25)	(25-30)	(30-35)	(35-40)
June	36.67	8.33	12.08	16.88	16.67	8.54	0.83	0.00
July	37.50	12.10	13.10	14.72	22.18	0.40	0.00	0.00
August	37.50	12.50	11.49	14.52	21.37	2.62	0.00	0.00
September	37.50	13.33	10.83	12.92	19.58	5.83	0.00	0.00
October	38.10	12.30	11.69	10.69	16.73	10.48	0.00	0.00
November	46.25	3.75	12.50	11.46	17.92	8.13	0.00	0.00
December	50.00	6.85	6.65	13.10	22.78	0.60	0.00	0.00
January	50.00	4.44	8.06	13.31	22.18	2.02	0.00	0.00
February	40.85	9.15	10.04	10.04	14.29	14.51	1.12	0.00
March	37.50	12.50	1.41	11.09	11.69	16.94	8.87	0.00
April	37.50	5.21	7.29	11.67	3.75	11.88	21.88	0.83
May	36.09	2.02	11.90	11.09	8.06	16.94	13.91	0.00
Monsoon	37.30	11.58	11.89	14.75	19.98	4.30	0.20	0.00
Post Monsoon	44.77	7.68	10.26	11.75	19.16	6.39	0.00	0.00
Winter	45.66	6.67	9.00	11.76	18.43	7.94	0.53	0.00
Prev Monsoon	37.02	6.59	6.86	11.28	7.88	15.29	14.81	0.27
Year	40.46	8.54	9.74	12.64	16.47	8.18	3.89	0.07

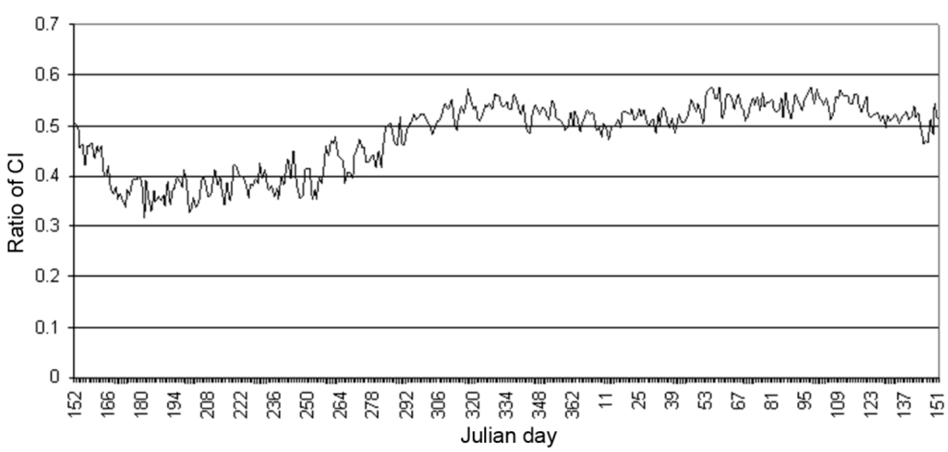

Fig. 3 — Graph of Clearness Index (*CI*) against Julian days (June to May)

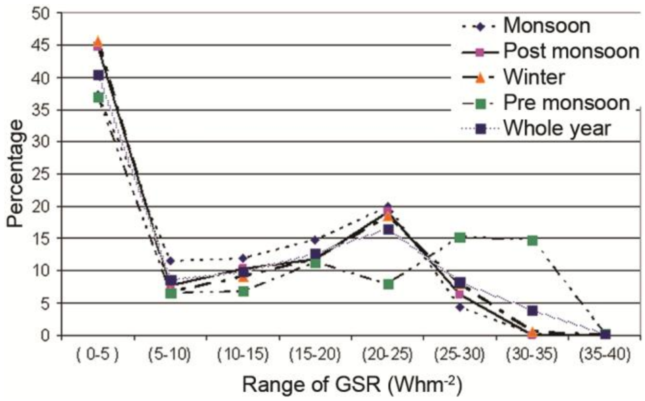

Fig. 4 — Graph of percentage of global solar radiation (GSR) received against different ranges of global solar radiation

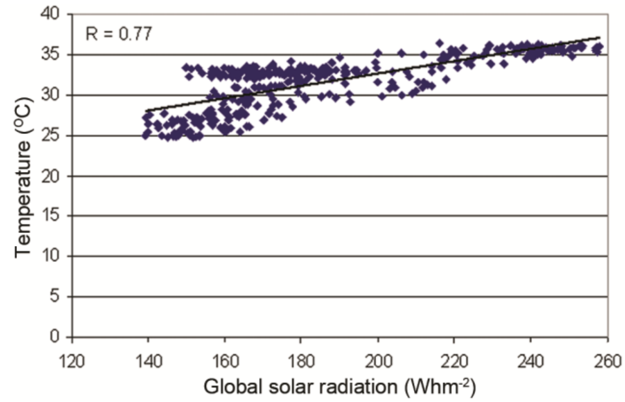

Fig. 6 — Graph of global solar radiation versus maximum temperature with correlation coefficient

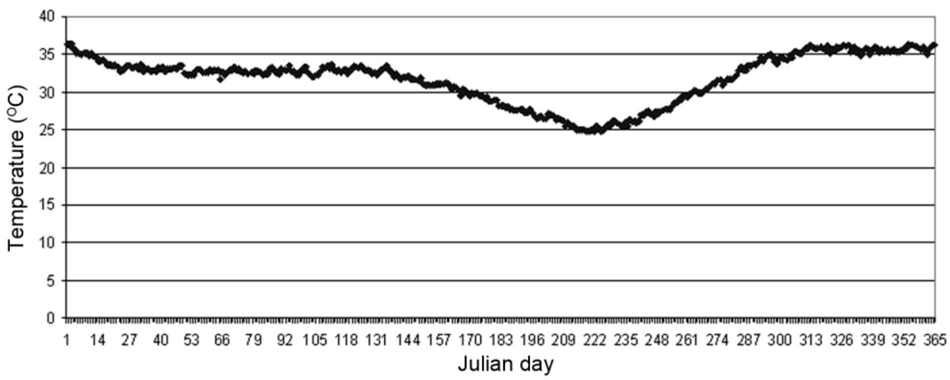

Fig. 5 — Graph of maximum temperature of Dumdum against Julian days (January to December)

post monsoon period 93.6% of the days in this period, in winter period 91.5% of the days in this period and in pre monsoon period 69.6% of the days in this period have occurrence of global solar radiation in the range of 0-25 Whm^{-2}. The above distribution of the global solar radiation is characteristic for the tropical regions and indicates to the richness of the study region with solar energy.

4.1.6 Clearness index

The clearness index (*CI*) is defined as the ratio of global solar radiation at the earth's surface (G) to extraterrestrial solar radiation (G_o) received on a horizontal surface. It refers to the availability of the solar radiation at the ground and indicates the influence of the atmospheric constituents such as water vapor, dust and clouds on it.

5 Conclusions

Based on the measurements and some statistical calculation of global solar radiation, calculation of clearness index, Fig. 2 relating to graph of mean daily global solar radiation against Julian days, Fig. 3 relating to graph of clearness index (*CI*) against Julian days, Fig. 4 relating to graph percentage of global solar radiation (GSR) received against different ranges of global solar radiation, Fig. 5 relating to graph of maximum temperature of the station against Julian days and Fig. 6 relating to correlation coefficient graph of global solar radiation versus maximum temperature, the following conclusions can be deduced:

(i) The North 24 Pargana region in West Bengal receives a fair amount of solar energy. 55.6% of the days through the year have values of global solar radiation in the range from 5-30 Whm^{-2}.

(ii) In Fig. 3, the not so high values of clearness index during monsoon season shows the presence of clouds in this region. The reduction of extra terrestrial radiation shows huge absorption of solar radiation by the atmospheric elements.

(iii) It is observed that the values of clearness index during post monsoon, pre monsoon and winter are high in comparison to monsoon period. Also post monsoon and pre monsoon have higher values in comparison to winter season, indicating the affect of fog which is prevalent in this area during winter season.

(iv) A peculiar aspect was observed while studying the graph of Fig. 4, the trend for percentage of reception of global solar radiation for all seasons namely monsoon, post monsoon, winter and pre monsoon was nearly same from the range 0-20 Whm^2, but while others followed the same trend the pre monsoon season trend become rather opposite. It showed a decreasing trend in the range 20-25 Whm^{-2} while others namely monsoon, post monsoon and winter showed increasing trend in the range 20-25 Whm^{-2}. Again the pre monsoon trend showed increasing trend in the range 25-30 Whm^{-2} and non-increasing and decreasing trend in the range 30-35 Whm^{-2} where as monsoon, post monsoon and winter showed a decreasing trend from the range 25-35 Whm^{-2} Probably this aspect of global solar radiation can throw a light in the explanation of occurrence of frequent thunderstorms in this area[16].

(v) Figures 2 and 5 graphs show close resemblance of the wave form between global solar radiation and maximum temperature, which highlights the fact that this two parameters are closely related which is further statistically proved by the Fig. 6, which is a correlation coefficient graph between this two parameters. It was also observed that some data (i.e. 32.2 °C to 33.5 °C) is not in conformity with the graph trend of global solar radiation versus maximum temperature of the station because those days were cloudy during the monsoon period.

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