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Measurements of Global Radiation at Jodhpur

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ABSTRACT. A study on the variation of global radiation (T) in different months of the year has been made from measurements made at Jodhpur with Moll-Gorczynski Solarimeter, during the period 1960-65. Mean daily global radiation on clear/cloudy/overcast days/all days for the year is 558/506/169/512 cal/cm². Mean daily global radiation is maximum in May (653 cal/cm²) and minimum in December (380 cal/cm²).

The variation in the intensity of global radiation in the forenoon and afternoon in the different seasons of the year indicates that the forenoons of hot weather period received more energy and that in winter the energy received is more or less equal in both parts of the day.

The variation in the corresponding hourly values of global radiation during each season of the year has also been studied and the occurrence of the highest and lowest value of global radiation has been discussed in a general way in relation to the existing synoptic conditions.

Mention has also been made of the practical aspect of utilization of this large solar energy incident over Rajasthan.

1. Introduction

The sun is the ultimate source of all energy on the earth and, therefore, a knowledge of global radiation received at the earth's surface is very important in understanding the different physical and biological processes that take place in the atmosphere and on earth and for proper utilisation of the vast energy from sunshine. This is particularly important in the arid regions of India where sunshine provides a readily accessible source of energy.

Measurements of global radiation are being made at a number of stations in India, since the commencement of International Geophysical Year (July 1957). The network of the radiation stations was steadily increased and regular measurement of global radiation by Moll's Gorczynski Solarimeter was commenced at Jodhpur with effect from 12 March 1960. The radiation observatory was located at Jodhpur Airport (Lat. 26° 18′ N, Long. 73° 01′ E and height 217 m amsl). It was shifted from the airport to civil lines area temporarily from 9 October 1965 to 11 April 1966 and is at present, functioning at Sardarpura area at Jodhpur from 12 April 1966.

2. Material utilised

A study on the diurnal and month to month variation of global radiation, depletion of global radiation by water vapour, dust and clouds, intensity of global radiation during duststorm and thunderstorm and variation between (a) the forenoon and afternoon intensity in different months of the year and (b) corresponding hourly intensities of global radiation during each season of the year, at Jodhpur, has been made, by utilising all available global radiation data for the period March 1960 to December 1965.

3. Discussion of data and results

(*a*) *Global Solar radiation on clear /cloudy / overcast days at Jodhpur* — The number of overcast/ cloudy/clear days at Jodhpur is about 1·4, 68·4, and 30·2 per cent respectively for the year. The mean daily global radiation in cal/cm² (T) during each month of the year on clear/cloudy/overcast days has been computed and are given in Table 1. The salient points are given here.

(*i*) *T on clear days* — Mean (T) for clear days increases from January, reaches a maximum in May (exceeding 680 cal/cm²/day) and decreases till December reaching a minimum (being less than 400 cal/cm²/day). The average round the year is 558 cal/cm²/day.

(*ii*) *T on cloudy days* — Mean (T) for cloudy days increases from January, reaches a maximum in May (exceeding 625 cal/cm²/day) and decreases from June to August, then increases slightly (by about 3 per cent) in September and then decreases till December reaching a minimum (being about 375 cal/cm²/day). The average round the year is 506 cal/cm²/day.

The slight increase in the month of September is on account of withdrawal of monsoon from Rajasthan followed by an increase in the number of days with clear skies and also by a decrease of all cloud amount by about 40 per cent.

TABLE 1

Mean daily global radiation (T) from sun and sky in cal/cm² and related climatological data for Jodhpur

(Based on data for the period 1960-65)

Element	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
T (clear days)	428	507	585	668	687	672	667	571	570	510	444	392	558
No. of days	66	63	52	29	36	27	3	2	31	112	100	76	597
T (cloudy days)	398	451	543	612	638	616	503	499	516	488	435	375	506
No. of days	85	74	113	134	143	143	138	151	134	64	73	103	1355
T (overcast days)	80	—	122	—	—	151	247	207	208	—	168	—	169
No. of days	1	—	1	—	—	1	8	11	5	—	1	—	28
T (all days)	401	480	555	622	646	624	493	484	518	502	431	382	512
No. of days	152	137	166	163	179	171	149	164	170	176	174	179	1980
T (max.)	451	563	633	694	720	698	643	633	599	553	475	414	590
T (min.)	240	333	364	465	494	402	219	214	332	414	322	272	339
Max. (T)/Min. (T)	188	1·69	1·74	1·49	1·46	1·74	2·89	2·96	1·80	1·33	1·47	1·52	1·74
Related climatological data													
Bright hrs of sunshine	9·1	9·6	8·9	9·9	10·0	9·5	6·1	6·4	8·2	9·8	9·6	9·2	8·9
Possible hrs of bright sunshine (%)	85	86	74	76	74	68	45	49	66	85	89	87	74
Mean hrs of cloudiness (possible—actual)	1·5	1·6	3·0	2·8	3·3	4·2	7·6	6·8	4·2	1·9	1·4	1·3	3·1
Mean cloud amount (oktas)	2·1	2·1	2·1	1·7	1·1	2·4	5·5	5·8	3·5	1·2	1·0	1·8	2·5

TABLE 2

Atmospheric depletions due to dust, clouds and water vapour at Jodhpur

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Global radiation (cal/cm²/day) received at the top of the atmosphere											
560	660	785	885	940	960	945	900	820	710	580	520
Global radiation (cal/cm²/day) received on earth on clear days											
428	507	585	668	687	672	667	571	570	510	444	392
Depletion (per cent) due to water vapour, dust and atmospheric gases											
23	23	25	25	27	30	29	36	30	28	23	25
Global radiation (cal/cm²/day) on all days											
401	480	555	622	646	624	493	484	518	502	431	382
Depletion (per cent) due to water vapour, dust, atmospheric gases and clouds											
28	27	29	30	31	35	48	46	37	29	26	27
Global radiation (cal/cm²/day) on overcast days											
80	—	122	—	—	151	247	207	208	—	168	—
Depletion (per cent) due to overcast conditions											
86	—	84	—	—	84	74	77	75	—	79	—

(iii) T on all days — The variation in mean (T) for all days from month to month is as for cloudy days. The average round the year is 512 cal/cm²/day.

(iv) T on overcast days — Mean (T) on overcast days is maximum in July and minimum in January. The average round the year is 169 cal/cm²/day.

(b) Percentage depletion of global radiation due to water vapour, dust and atmospheric gases and clouds at Jodhpur — The percentage depletion of global radiation at Jodhpur due to absorption and scattering by atmospheric gases, water, dust is given in Table 2. Depletion in global radiation due to atmospheric gases, water vapour and dust is more or less

uniform from January to May with a very slight increase from March to May due to increase in dust suspension in the atmosphere caused by dust raising winds and duststorms. The depletion further increases in the monsoon season, due to increase in water content of the atmosphere. With the withdrawal of monsoon over Rajasthan and the air getting slowly drier, the depletion in global radiation decreases from October onwards.

The depletion in the extra terrestrial energy due to water vapour, dust, atmospheric gases and clouds is also given in Table 2. The depletion is high during the monsoon season, and in the remaining months of the year the depletion is more or less uniform.

The depletion in the extra terrestrial energy due to overcast sky is about 75 to 85 per cent.

In Fig. 1 is shown the percentage depletion of extra terrestrial radiation together with mean cloudiness at Jodhpur. It is interesting to note that there is generally an increase/decrease in the depletion of energy when the all cloud amount increases / decreases. Even though there is a decrease in the clound amount from March to May, there is an increase in the depletion of energy during this period which is mainly due to the dust suspension in the atmosphere over Jodhpur.

(c) *Intensity of global radiation during duststorm and thunderstorm at Jodhpur* — Duststorm activity is mostly confined to hot weather and early part of monsoon season. Thunderstorm occurs both in hot weather and monsoon seasons but being maximum in the latter season at Jodhpur.

To study the effect of duststorm and thunderstorm on the intensity of global radiation, a few occasions of the above special weather phenomena which have occurred at Jodhpur are given in Table 3 and the results are summarised below.

Cu and *Cb* clouds accompanied duststorms and thunderstorms and these were further followed by heavy rain. During dust raising winds and duststorms there was vertical motion of dust and the atmosphere was filled with high degree dust suspension. The formation of *Cu, Cb* clouds accompanied by heavy rains caused the depletion in the global radiation and bright hours of shunshine. After the duststorm/thunderstorm passed over the station the sky became clearer resulting in the increase in global radiation and bright hours of sunshine. The reduction in global radiation and bright hours of sunshine during the duststorm/ thunderstorm is well brought out by the occasions shown in Table 3. Reduction in the intensity is highest in the severe types of thunderstorms accompanied by overcast skies.

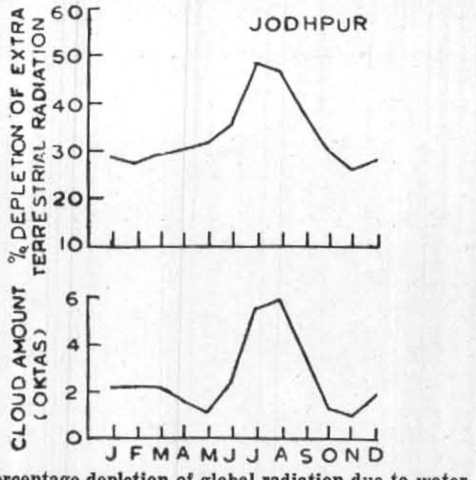

Fig. 1. Percentage depletion of global radiation due to water vapour, dust, atmospheric gases and clouds at Jodhpur

The reduction in global radiation is . bout 10 per cent for duststorms and about 10 to 60 per cent for thunderstorms for those occasions chosen for analysis.

(d) *Mean hourly variation of global radiation during the different seasons of the year* — Fig. 2 gives the mean values of global radiation during each hour of the day between 6 to 19 hr LAT for the different seasons for Jodhpur, based on data for the period March 1960 to December 1965. It will be seen that the intensity of radiation increases steadily from sunrise to about 12-13 hr LAT and then decreases till sunset. At noon the value is (*i*) maximum in May being 82 cal/cm^2/hr, (*ii*) minimum in December being 59 cal/cm^2/hr and (*iii*) averaged to 70 cal/cm^2/hr around the year.

(e) *Variation in the corresponding hourly values of global radiation during each season of the year at Jodhpur* — The highest and lowest intensities of hourly global radiation in hot weather and winter seasons respectively are due to the high/low solar altitudes while the low intensities in monsoon season is mainly due to depletion of energy by clouds.

An estimate of decrease/increase in hourly intensity of global radiation between corresponding hours from season to season can also be had from Fig. 2.

Hot weather season to monsoon season — There is a small increase in intensity at the time of sunrise and sunset, probably suggestive of the formation of haze due to dust and dust suspension which

TABLE 3

Global radiation (T) in cal/cm^2/day and bright hours of sunshine (S.S.) at Jodhpur, during duststorm and thunderstorm

Date	Duststorm						Date	Thunderstorm					
	Preceding day		Day of occurrence		Succeeding day			Preceding day		Day of occurrence		Succeeding day	
	T	S.S.	T	S.S.	T	S.S.		T	S.S.	T	S.S.	T	S.S.
25-9-60	540	9·3	481	8·6	561	9·1	15-5-60	685	10·9	660	9·4	704	11·2
27-5-61	668	10·0	609	8·3	624	8·6	9-4-61	578	7·2	499	6·2	653	8·9
12-6-61	682	9·7	619	7·9	650	9·0	1-7-61	672	12·1	509	7·2	594	10·1
18-3-61	526	8·4	464	6·1	581	8·4	4-7-61	566	8·1	456	3·8	555	8·0
							20-6-62	619	9·4	512	6·1	681	11·1
							14-7-62	561	9·2	370	4·5	546	7·5
							23-4-63	614	10·7	567	9·1	622	10·0
							27-6-63	628	9·3	521	7·3	579	6·9
							30-5-64	549	6·2	437	0·7	638	9·7
							26-7-64	414	2·8	168	0·1	320	0·3*
							12-2-65	474	10·0	303	4·0	478	9·6
							24-4-65	623	10·6	404	2·0	637	11·1

*Overcast day

TABLE 4

Difference between forenoon (f) and afternoon (a) global radiation T at Jodhpur

	(11–12)—(12–13)hr	(10–11)—(13–14)hr	(9–10)—(14–15)hr	(8–9)—(15–16)hr	(7–8)—(16–17)hr	(6–7)—(17–18)hr	(5–6)—(18–19)hr	$\Sigma f - \Sigma a$
Jan	—0·1	—0·7	+0·6	+0·7	—0·3	0		+0.2
Feb	—0·2	+1·1	+2·0	+1·8	+1·0	0		+5·9
Mar	+0·2	+1·1	+1·9	+3·1	+2·4	+0·4	0	+9·1
Apr	0	+1·9	+3·2	+3·6	+2·9	+1·4	+0·1	+13 ·1
May	+0·3	+1·0	+0·5	+2·0	+2·1	+1·4	+0·1	+7·4
Jun	—0·2	+0·9	0	+0·9	+1·6	+0·8	—0·1	+3·9
Jul	+0·4	—0·3	+0·3	+0·2	+0·6	0	—0·4	+0·8
Aug	—0·7	—0·7	—1·1	—0·5	—0·5	—0·6	—0·2	—4·3
Sep	+0·1	+1·3	+2·2	+1·3	+1·0	0	0	+5·9
Oct	—0·3	—0·3	—0·6	+0·6	+0·5	—0·1		—0·2
Nov	+0·1	—0·3	+0·6	+0·2	—0·8	—0·3		—0·5
Dec	—0·3	+0·2	+0·5	+0·3	0	0		+0·7

depletes the energy at these times in the hot weather period whereas during monsoon season the intensity during these hours is slightly higher than that for the corresponding hours in hot weather period due to the absence of haze. From 0700 hr LAT there is a decrease in intensity which steadily enlarges and reaches a maximum at about noon (12-13 hr LAT) and then becomes smaller till sunset. The steep decrease of about 10 to 12 cal/cm^2/hr between 10-15 hr LAT is suggestive of the development of clouds during this period which depletes the energy.

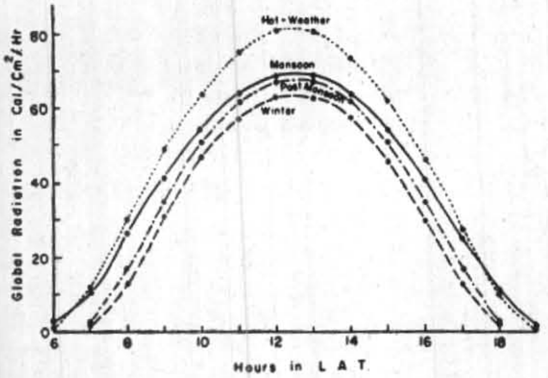

Fig. 2. Hourly variation of global radiation T (cal/cm²/hr) in the different seasons of the year at Jodhpur

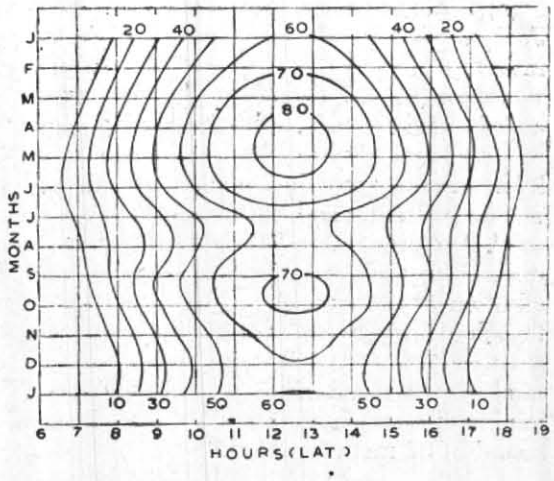

Fig. 3. Isopleths of the global radiation (cal/cm²/hr) at Jodhpur (1960-65)

Monsoon to post-monsoon season — The large decrease in intensity at sunrise and sunset becomes smaller at about noon. The decrease at sunrise and sunset is about 8 to 10 cal/cm²/hr while at noon it is about 1 cal/cm²/hr. The large decrease in intensity at the time of sunrise and sunset is probably suggestive of formation of haze and dust suspension during the post-monsoon season. The decrease in intensity at about noon becomes small probably on account of the lifting of haze by about middle of the day.

Post-monsoon to winter season — The decrease in intensity is uniform between 8 to 17 hr LAT and is about 5 cal/cm²/hr which is due to the decrease in solar altitude.

Winter to hot weather period — The increase in intensity is again uniform between 8 to 17 hr LAT and is about 18 cal/cm²/hr which is due to the increase in solar altitude.

(*f*) *Isopleth diagrams for Jodhpur* — This is shown in Fig. 3 where lines of equal intensity of global radiation in cal/cm²/hr is drawn. The isopleth diagram shows two maxima, in April-May (summer), and September-October (post-monsoon), between 12-13 hr LAT. The maximum intensity for summer is higher (by 10 cal/cm²/hr) than that of post-monsoon season because of the increase in solar altitude. The bulging isopleth lines from March to May indicate the increase in hourly intensities, and the constriction in isopleths during monsoon indicates the depletion of intensities by clouds. With the withdrawal of monsoon the isopleths once again enlarge in post-monsoon (October to November) season and in winter (December to February) the isopleths run more or less parallel indicating no variation in intensity on account of clear skies.

(*g*) *Difference between the forenoon and afternoon values of global radiation* (T) *at Jodhpur* — In Table 4 are grouped the mean difference between the forenoon and afternoon values of global radiation for the same time interval from local noon. '*f*' indicates forenoon and '*a*' afternoon values. In the last row are added the mean differences between the global radiation received in the forenoon and afternoon ($\Sigma f - \Sigma a$). During the winter season the global radiation received in the forenoon and afternoon is more or less equal except in February. During the hot weather season (March—May) the energy received in the forenoon is higher than in the afternoons because of the formation of convective type of clouds, (*Cb* and *Cu*) or dust layers in the afternoon associated with duststorms and thunderstorms.

During the monsoon season the difference between forenoon and afternoon values are primarily due to the difference in quality and quantity of clouds in the two parts of the day. Particularly in June and September the forenoon values are probably higher on account of fact that during the onset and withdrawal of monsoon in June and September respectively, there is development of thunderstorm in the afternoons in these months, associated with *Cu* and *Cb* clouds which cause the depletion of energy received in the afternoons.

In August the energy received in the afternoon is slightly higher than in the forenoon probably because the forenoons generally receive rain in the form of drizzle which depletes the energy. October and November being characterised by clear skies, the energy received in both parts of the day is more or less the same.

(*h*) *Highest and lowest value of global radiation at Jodhpur during the period 1960-65* — The highest intensity of global radiation of 750 cal/cm^2/day was recorded on 7 May 1960. The skies were clear and free from clouds. The weather was dry with relative humidity being less than 10 per cent. The high intensity was due to solar altitude and low moisture content; and maximum temperature was 39°C. The lowest intensity of global radiation of 80 cal/cm^2 /day was recorded on 2 January 1965. In addition to the low solar altitude on this day, a trough of low pressure was over Rajasthan causing scattered rainfall. The sky was overcast with nimbostratus cloud indicative of bad weather. The minimum temperature was 15°C and there was a record of 37 mm of rainfall.

4. Conclusion

As seen from the data presented, global radiation of the order of 500-700 cal/cm^2 /day during the summer months and 400-500 cal/cm^2 /day during the rest of the year is received at Jodhpur. This energy is received on a horizontal surface. At normal incidence to the sun, it will be much higher.

Also during the year for about 8 to 10 months, global radiation exceeding 60 cal/cm^2/hr is received for a period of about 4-5 hr daily. This is significantly important in arid parts of our country because the solar energy available may be utilised in solar plants for water heating, water distillation as well for cooking, air conditioning and refrigeration.

Assuming the global radiation received per day to be 500 cal/cm^2, energy of the order of 6 kwh/m^2/ day will be available and about 2100 kwh/m^2 will be available throughout the year. From each square metre of horizontal surface about 1000 kwh energy can be collected if the order of efficiency of collection is 50 per cent.

5. Acknowledgement

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