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Diffuse solar (sky) radiation measurements over India

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ABSTRACT. The paper summarises the results of measurements of diffuse solar radiation made at a network of 10 stations in India since 1958. In highly polluted urban areas the ratio of diffuse to global radiation is almost twice that in non-industrial regions. The diffuse radiation has also shown a marked increase in urban areas during the last ten years.

1. Introduction

Diffuse solar radiation represents the shortwave energy of solar origin scattered downwards by gas molecules, aerosols or suspended particulate matter, water vapour and clouds in the atmosphere. The variability in the amount and type of cloud has predominating influence on the value of diffuse radiation.

For a proper understanding of the radiation climatology of a region, apart from information on direct and global solar radiation, a knowledge of the distribution in the region of diffuse or sky radiation is necessary. An assessment of the radiation received from the sky assumes great importance in problems concerning the utilization of solar energy, in illumination studies and in architectural research, especially in the tropics where the diffuse radiation reaches very high levels.

Earlier published data on diffuse solar radiation refer to extensive observations at Blue Hill Observatory (Hand and Wollaston 1952) and Kew (Blackwell 1954) and in South Africa (Drummond 1956) and the Belgium Congo (Schüepp 1952). While measurements of global solar radiation have been made at a large number of stations in the world, particularly during and after the IGY and IQSY, observations of diffuse radiation have not been so extensive. Observations of diffuse radiation were started at two stations in India during the IGY. The results of these measurements made at Poona and Delhi during 1958 and 1959 have been published (Mani and Chacko 1963). Diffuse radiation measurements have now been extended to 10 stations in India and there are plans to extend them to 16 stations representing the various climatic regions of the country. The present paper summarises the results of measurements of diffuse solar (sky) radiation made at a network of 10 stations in India since 1958.

2. Instrumental equipment and method of measurement

The instrumental equipment used for the continuous registration of diffuse solar (sky) radiation is the same as that used (Mani, Chacko and Venkiteshwaran 1962) for recording global solar radiation, *viz.*, a Moll-Gorczynski pyranometer and a Cambridge recording milli-voltmeter with the addition of a Schüepp shading ring to shade thermopile element with its two hemispherical glass domes from the direct sun. The shading ring arrangement, the installation of the instrumental equipment, the correction to be applied for the sky inevitably obstructed by the ring, the standardisation of instruments and the evaluation records etc have already been discussed in detail in earlier papers (Mani *et al.* 1962, Mani and Chacko 1963).

3. Discussion of data

3.1. *Seasonal variations in diffuse solar radiation* — The mean daily values of diffuse solar radiation D in cal/cm^2 for 10 stations, *viz.*, Poona, Delhi, Madras, Dum Dum (Calcutta), Panjim (Goa), Trivandrum, Shillong, Ahmedabad, Nagpur and Visakhapatnam are given in Table 1. The

TABLE 1

Mean daily values of diffuse solar radiation (cal/cm²/day)

	Period to which data refer	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Poona	1958-67	95	96	135	168	192	278	282	288	245	141	111	99	177
Delhi	1958-67	99	118	156	199	229	290	253	227	179	115	89	93	171
Madras	1962-67	167	145	160	173	217	245	262	255	211	189	171	171	197
Dum Dam	1964-67	121	134	182	205	246	259	256	236	209	140	116	109	185
Goa	1964-67	86	100	130	146	211	244	222	271	231	161	121	79	167
Trivandrum	1964-67	157	173	198	217	241	246	261	278	233	210	183	175	214
Shillong	1967	111	112	182	185	238	295	279	275	227	165	115	118	192
Ahmedabad	1967	109	116	132	173	189	256	290	292	212	132	88	100	175
Nagpur	1967	91	101	153	157	192	225	—	—	—	—	—	—	—
Visakhapatnam	1967	135	106	144	158	197	208	222	246	203	131	110	109	164

TABLE 2

Values of mean daily diffuse solar radiation in cal/cm²/day during different seasons and their annual percentages

	Feb–May		Jun–Sep		Oct–Jan	
	D	(%)	*D*	(%)	*D*	(%)
Poona	148	28	273	51	111	21
Delhi	175	34	237	47	99	19
Madras	174	29	243	41	175	30
Dum Dum	192	35	240	43	121	22
Goa	147	30	242	48	112	22
Trivandrum	207	32	255	40	182	28
Shillong	179	31	269	47	127	22
Ahmedabad	153	29	263	50	107	21
Visakhapatnam	151	31	220	45	121	24

daily mean values are based on data available during the period 1958-1967. The period for which data are available for each station is also indicated in the table. The data for Nagpur is only for six months from January to June 1967.

It will be seen that at all stations, on the whole, diffuse radiation is highest during the summer and monsoon months April to September and least during the clear winter months November to February. The higher values in summer and monsoon are due to increased turbidity and cloudiness during this period, cloudiness having the greatest influence on diffuse radiation. An exception is Delhi, which receives the maximum diffuse radiation in June, the hot summer month, when the atmosphere is very turbid and there are frequent duststorms.

The highest values are recorded during June at Shillong and Delhi; July and August at Ahmedabad and during August at Poona, when nearly 300 cal/cm²/day of scattered radiation are received at these stations. At the remaining stations, diffuse radiation is of the order of 250-280 cal/ cm²/day during the monsoon months.

The lowest diffuse radiation values received are about 90 cal/cm²/day during January at Nagpur; November at Ahmedabad; December—January at Goa and November—December at Delhi during the clear winter months. At all other stations the minimum is of the order of 100 cal/ cm²/day except Madras and Trivandrum where cloud-free skies are very rare and the minimum is as high as 150 cal/cm²/day.

Madras and Trivandrum receive relatively uniform diffuse radiation throughout the year, as a result of the more or less uniform clouding during the year. The annual values of diffuse radiation are therefore highest at these two stations, with 78 Kcal/cm²/year at Trivandrum and 72 Kcal/cm²/year at Madras. During the year

TABLE 3

Ratios of mean daily values of diffuse (D) to global solar radiation (T) for all days

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Poona	·21	·18	·24	·27	·32	·55	·76	·74	·57	·31	·25	·25	·37
Delhi	·29	·28	·30	·32	·36	·51	·59	·56	·38	·25	·24	·29	·37
Madras	·39	·27	·28	·30	·39	·49	·58	·54	·44	·45	·45	·47	·42
Dum Dum	·34	·31	·39	·38	·45	·63	·65	·64	·57	·35	·32	·33	·45
Gca	·18	·18	·22	·24	·36	·54	·73	·64	·52	·33	·29	·17	·31
Trivandrum	·31	·33	·36	·39	·50	·58	·61	·65	·47	·49	·42	·42	·45
Shillong	·35	·24	·46	·42	·50	·75	·76	·69	·66	·43	·34	·39	·50
Ahmedabad	·27	·24	·22	·27	·29	·50	·73	·77	·48	·26	·20	·28	·37
Nagpur	·21	·20	·29	·27	·32	·40	—	—	—	—	—	—	—
Visakhapatnam	·32	·30	·27	·27	·33	·49	·53	·56	·49	·25	·23	·28	·34

as a whole about 70 Kcal/cm^2 of solar radiation are received indirectly over the whole country.

The mean daily values of D for the three main seasons of the year, October–January, February–May and June–September with the percentage of annual diffuse radiation received at each station during these three seasons are given in Table 2. It will be seen that about 40-50 per cent of the diffuse radiation is received during the cloudy monsoon months and 30–35 per cent during the turbid summer months. At Madras and Trivandrum about 30 per cent of the diffuse radiation is received during the winter season due to clouding during the northeast monsoon.

3·2. *Spatial variation of diffuse solar radiation*—Maps showing the monthly and annual distribution of mean daily values of diffuse radiation are shown in Fig. 1.

Fig. 1(a) shows the annual values of diffuse solar radiation in cal/cm^2/day. Isolines are drawn for every 25 cal/cm^2/day. The highest values of D occur in the south and northeast regions of the country, where the maximum clouding occurs, and the lowest values occur in the drier, semi-arid regions in central and northwest India. Considering the year as a whole the mean D ranges from 150 to 200 cal/cm^2/day or 55–75 Kcal/cm^2/year.

During the months from January to December, there is a gradual change in the spatial distribution of diffuse radiation, the pattern closely resembling that for the distribution of cloudiness over India. In January D is least in north and central India as the skies are cloud free, except in the very north, where western disturbances are active and appreciably higher in the south where there is clouding and rain due to the winter monsoon. From February to April D increases at all the stations due to increased clouding in the south and extreme north and increased turbidity in north and central areas. This increase is more marked in the north. The lowest values of D are found in the north Deccan Plateau. With the establishment of the monsoon over the whole country, high values of D are found over the whole region except in east central India, where it is comparatively low. During April and May diffuse radiation over turbid north India is as high as that over cloudy south India. In June the highest values anywhere in the country occurs in north and northwest and central India, where turbidity is a maximum, although the monsoon has established itself in the south. By November and December the maximum values are again in the south and notheast India.

3·3. *The proportion of diffuse in global solar radiation*—Ratios of mean daily values of diffuse to global solar radiation, D/T, for the 10 stations are given in Table 3. Table 4 gives the same ratios for clear days. Taking all days, clear as well as cloudy, into consideration the values of D/T are seen to vary from 17 to 77 per cent, the maximum values occurring in the months June to August and minimum in November to February. This means that as much as 80 per cent of the shortwave radiation received is scattered sky radiation during monsoon months. The variation of this ratio is maximum at Ahmedabad where it varies from 20 per cent in November to 77 per cent in August and least in Madras where it is only from 27 per cent in February to 58 per cent in July. The lower variation at Madras is due to the general cloudiness throughout the year. Stations which are characterised by clear skies and lower turbidity

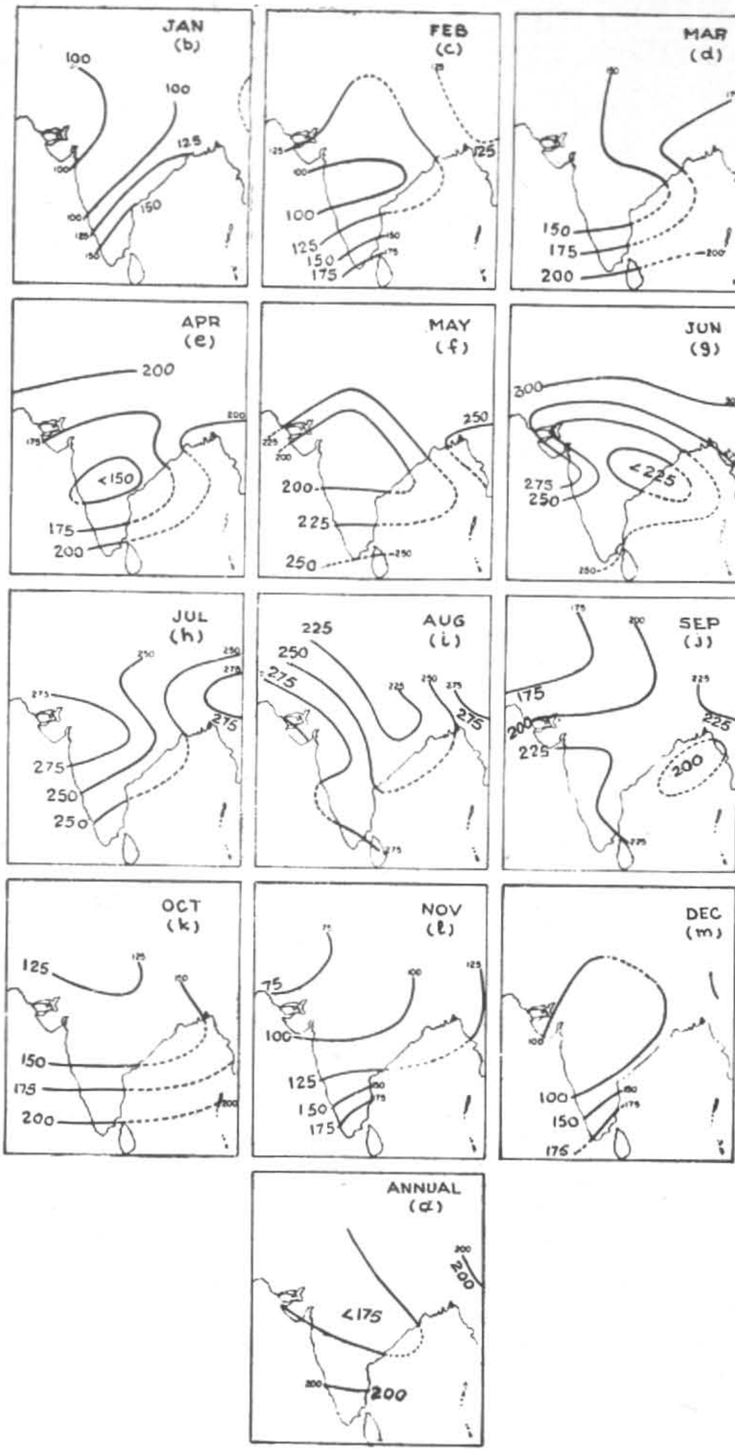

Fig. 1. Diffuse radiation (cal/cm²/day)

TABLE 4

Ratios of mean daily values of diffuse (D) to global solar radiation (T) for clear days only

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Poona	·17	·15	·18	·20	·22	·27	—	—	—	·16	·15	·15	·18
Delhi	·20	·20	·22	·26	·25	·36	·32	·25	·25	·22	·19	·20	·23
Madras	·20	·18	·20	·17	·29	·21	—	—	—	·17	·17	·19	·20
Dum Dum	·24	·25	·37	·32	·36	—	—	—	—	·17	·19	·25	·28
Goa	·16	·17	·19	·19	—	—	—	—	—	·12	·17	·13	·18
Trivandrum	·21	·19	·21	—	·35	—	—	—	—	—	·16	·19	·21
Shillong	—	·17	·26	·21	·28	—	—	—	—	·09	—	·19	·20
Ahmedabad	·21	·17	·20	·21	·24	·21	—	—	·20	·24	·19	·19	·21
Nagpur	·18	·19	·21	·20	·25	—	—	—	—	—	—	—	—
Visakhapatnam	·21	·17	·20	·17	·25	—	—	—	—	·21	·19	·18	·20

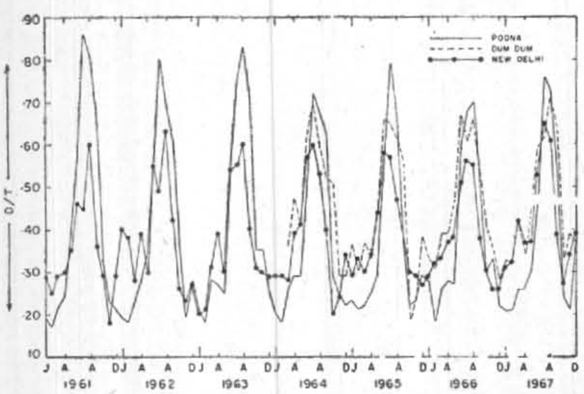

Fig. 2 (a). March of D/T from 1961 to 1967 for Poona, Dum Dum and New Delhi

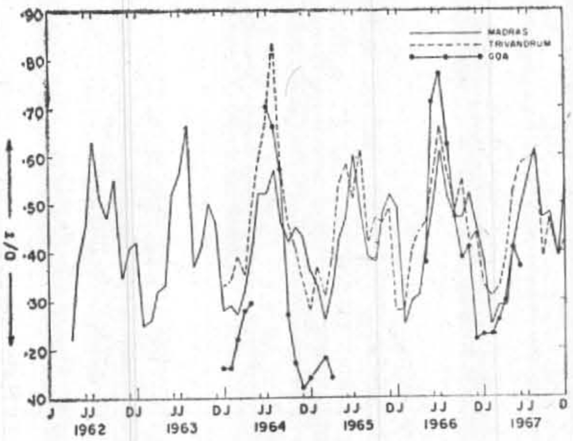

Fig. 2(b). March of D/T from 1962 to 1967 for Madras, Trivandrum and Goa

in winter and higher turbidity and severe clouding in summer and monsoon, as for example, Poona shows a very sharp increase in D/T during the summer and monsoon seasons. Dum Dum, with the industrial smoke and turbid and foggy atmosphere presents comparatively higher D/T values during winter.

The D/T values of clear days alone are given in Table 4. The variations are less marked since the influence of clouds has been eliminated. A continuous picture of the variations of D/T during the year is not available for most of the stations due to the absence of clear days for the months June—September. But the effect of turbidity during summer is marked, during April–June, at all stations.

Diffuse radiation is highest at Dum Dum on clear days alone, an obvious result of industrial pollution. Values of D/T at Dum Dum are almost twice those at non-industrial regions like Vizag and Nagpur. The high values at Delhi during June to August during clear days alone are to be ascribed to high turbidity caused by increased dust content in the atmosphere.

3·4. *Annual march of* D/T — The year to year variations of D/T for six representative stations, *viz.*, Poona, Delhi, Dum Dum, Madras, Trivandrum and Goa for the period 1961 or 1962 to 1967 are given in Figs. 2 (a) and 2(b). There are marked variations from year to year with a fall during 1966 at all the northern stations and a rise again in 1967. 1966 was comparatively dry, when

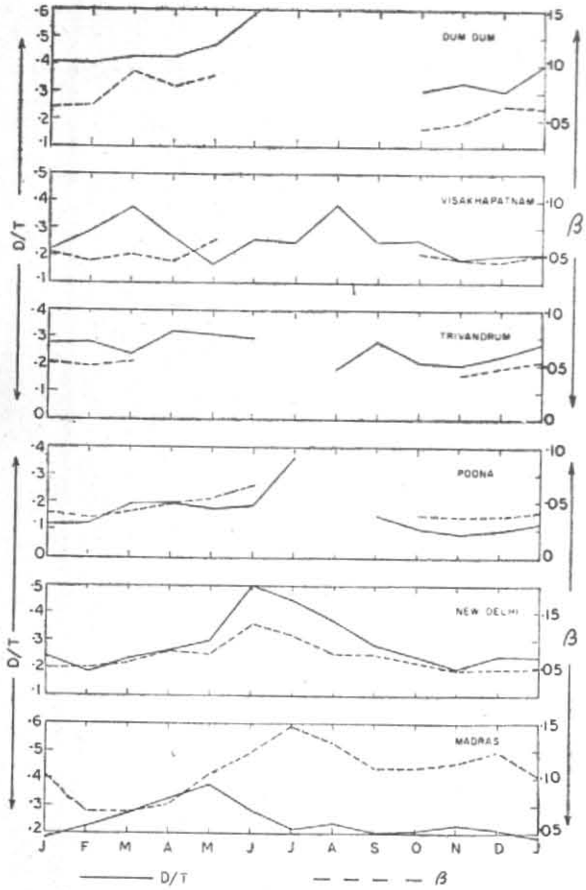

Fig. 3

the monsoon failed over most of the country. The general pattern of the curves is the same for all the stations, a sharp increase during the monsoon months and an appreciable fall during the winter. On the whole, a marked increase in D/T is apparent in urban areas during the last decade.

3.5. *Relation between turbidity and diffuse radiation* — The mean daily values of the ratios D/T for clear days and the mean daily values of β, the Ångstrom turbidity coefficient for six stations, Poona, Delhi, Madras, Dum Dum, Visakhaptnam and Trivandrum are represented in Fig. 3. The mean values refer to the years 1958-1967 for Delhi and Poona; 1965-67 for Madras; 1966-1967 for Dum Dum and Visakhapatnam; and 1967 for Trivandrum. The coefficient β is a factor which defines the extinction due to scattering and absorption of aerosols and on a clear day one should expect D/T to depend mainly on atmospheric turbidity. The general trend in the curves of β and D/T are similar though for Madras, the trends are different during the period June to August. This might be due to the fact that at Madras there are many occasions when pyrheliometer measurements were taken when the sun's disc and the sky immediately around it are free from clouds while the rest of the sky was cloudy. β values thus do not correspond exactly to the conditions under which the value of D/T is determined. There is a close correlation between turbidity and the ratio of diffuse to global solar radiation on cloudless days. Aerosols, contributing as high as 30 per cent of diffuse radiation over the country play a very important role in the radiation climatology of the region.

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