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Distribution of Sunshine and Solar Radiation over the Indian Peninsula

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(*Received 15 July 1959*)

1. Introduction

A study of the solar radiation received on the earth's surface and its global distribution is of great importance for a better understanding of the mechanisms of circulation processes in the atmosphere and of the energy available in ordinary sunshine for utilization as sources of power in the arid and semi-arid regions of the world. Maps depicting the areal distribution of total radiation received at the surface with normally cloudy skies have been prepared by Fritz and MacDonald (1949) for the United States, Mateer (1955) for Canada and Drummond (1957) for South Africa, on the basis of actual observations at a large number of stations in these countries. In the absence of similar observations from a satisfactory network of radiation stations in India, Ramdas and Yegnanarayanan (1954) have recently estimated the total solar radiation for 22 stations in India from duration of sunshine data, using Ångström's wellknown empirical formula correlating hours of sunshine S with total solar radiation Q. Maps showing the distribution of total solar radiation over the country based on their computations have been prepared and the distribution of the solar radiation over the Indian subcontinent is discussed in the present paper. Since a study of the distribution of sunshine over the country and its day-to-day variations are of interest in a study of the spatial distribution of solar energy over India, the distribution of sunshine and its variation in time and space over the subcontinent have also been discussed in the paper.

2. Distribution of sunshine over the Indian subcontinent

The Annual Summary Part A of the *Indian Weather Review* for each year contains tables of sunshine at a number of stations in India giving the mean duration of bright sunshine, the number of days with various hours of duration of sunshine, total hours of sunshine for the month and year and the percentage of possible hours of sunshine for the month. The above data for 15 stations in India for the years 1948 to 1955 (except Ahmedabad for which data form 1951 to 1955 alone were available) and the sunshine data for 22 stations given by Ramdas and Yegnanarayanan (1954) based on observations for 5 to 8 years have been used in the present study.

2·1. *Mean daily duration of bright sunshine* —Table 1 gives the average duration of bright sunshine per day, month by month for the 15 stations in India, while Table 2 gives the percentage of actual to possible hours of bright sunshine at each station in each month. Fig. 1 shows the distribution over the Peninsula of the mean daily hours of bright sunshine for each month.

It will be seen that during the cold season November to February, the duration of sunshine is maximum in the Indian Peninsula to the south of the Gangetic Plains and to the north of 13°N, the duration exceeding 10

hours in certain places. To the north of this region, the duration is less, as a result of the passage of winter disturbances from the west and the decrease in the length of the day with latitude. To the south, cloudiness associated with disturbances in the Bay of Bengal or the Arabian Sea and convectional clouds associated with higher humidity as a result of the flow of currents from the adjacent seas, is responsible for the reduction in the hours of sunshine.

With the advance of the year, the region of clear skies shifts towards the northwest till in April the region with hours of sunshine exceeding 10 lie over Gujarat and the adjoining regions of Sind and Rajasthan. This extends further to the north over West Pakistan in May but the maximum remains over Gujarat.

With the onset of the monsoon in June, the region of maximum sunshine lies over West Pakistan and the adjoining regions of Rajasthan and the Punjab. During July to September the clearest skies are over Quetta and the nearby districts of Pakistan. Skies begin to clear over India by October and the days become shorter over the northern latitudes, till by November the region with clearest skies lies over Gujarat and the adjoining regions.

Considering the whole year, the region with maximum sunshine is Rajasthan and its adjacent areas with an average duration of 8 to 9 hours a day. There is also a small area in Mysore and nearby Andhra Pradesh where the duration of sunshine exceeds 8 hours.

Except in the extreme north, the duration of bright sunshine is least over the whole subcontinent during the monsoon months July to August, the sunshine received being less than half the possible value. In the west coast of the Peninsula and over Bengal and its adjacent districts, the skies remain overcast for days together. At Bombay for example, more than 20 days in each monsoon month receive on an average less than 3 hours of sunshine per day. In the extreme north on the other hand the sunshine is less than half its possible value during the months December to April, the maximum occurring during October to November, just after the retreat of the monsoon but before the incidence of the western disturbances. This is a common feature over the rest of India, except in the south of the Peninsula, which is influenced by the northeast monsoon and cyclones and depressions occurring in the adjacent seas. Even here, less sunshine is received during the southwest than during the northeast monsoon period. It is interesting to note that while most places in India receive less than 50 per cent of the possible sunshine in July and August, the West Coast, Bengal and its adjacent areas receive less than 50 per cent for four months from June to September.

2·2. *Mean duration of bright sunshine during each hour*—Isopleths of duration of cloud in each hour for the different months for all the fifteen stations are given in Fig. 2. It will be seen that in the south of the Peninsula, cloudless skies occur from 0800-1500 hours, only at Bangalore in March. Skies are also clear for about 2-3 hours around noon in January and February. Further north, skies are clear continuously for about 6-8 hours at Bombay in December and from February to April. The decrease in sunshine during January is presumably due to the passage of western disturbances at lower latitudes than usual. Similar variations are observed at Poona and Ahmedabad.

The variation of the mean duration of bright sunshine at Ahmedabad and Baroda indicates that Gujarat and adjacent areas have the longest spells of bright sunshine from January to May and from November to December. This feature is less pronounced towards the east of Gujarat as indicated by the values for Nagpur.

At Jodhpur the skies are clear nearly 7-8 hours a day in April, May and October to December, while at Jaipur this is so

only from October to December. Further north at Delhi, October and November are the months with longest duration of bright sunshine. It decreases towards the east of Delhi as indicated by the values at Allahabad and Calcutta. While there is no clear spell of even one hour duration at Calcutta, Allahabad has no cloud for nearly 5 hours in May, November and December. The clear spells are distributed evenly about noon at all stations studied, no particular preference for any period before or after noon being present at any station.

The amount of sunshine received during the cloudy monsoon months of July-August is clearly illustrated in Fig. 2. All stations except Kodaikanal and Calcutta seem to have a symmetrical diurnal variation, with the maximum sunshine about noon. But in Kodaikanal, the maximum sunshine occurs from 0700 to 1100 hours LAT in all the months of the year. At Calcutta the corresponding period is from 0800 to 1100 hours LAT.

The distribution of bright sunshine has similar characteristics at all the stations in India except in Kashmir, *viz.*, a minimum during the monsoon months July-August, with clear skies in the months before and after this monsoon season. But the isopleth chart for Srinagar in Kashmir is entirely different and distinct from those for the other stations in India. June, July and September to November are the months with least amount of clouds in Srinagar. In June and July, the cloud amount is greater in the forenoon than in the afternoon.

It is interesting to note that at Kodaikanal the least cloudy months are February to April and during the day the cloudiness is least from 0700 to 1100 hours LAT.

2·3. *Frequency distribution of occurrence of bright sunshine of different durations*— An important factor in the study of solar energy is the frequency distribution of sunny days during the year, since in addition to large values of hours of bright sunshine a continuity in the supply is necessary for the proper utilisation of solar energy. In Table 3 are given the monthly frequencies of occurrence of days with 0·1 to 3 hours, 3·1 to 6 hours, 6·1 to 9 hours and more than 9 hours of bright sunshine for the 15 stations. These values recast to indicate the number of days in each month with sunshine less than 3, 3 to 6 and greater than 6 hours and their monthly variations for each station are given in Fig. 3. It will be seen that sunshine for more than 6 hours a day can be expected to occur for more than half the number of the days in the month throughout the year only at Jodhpur. During the monsoon sunshine exceeding 3 hours occurs daily for more than half the month throughout the year at all stations except Kodaikanal, Bangalore, Bombay, Poona and Nagpur.

Figs. 4(a) and 4(b) show the latitudinal variation of the frequency of occurrence of days with durations of sunshine exceeding 6 hours and less than 3 hours respectively. For this purpose, the values used are for those at Trivandrum, Bombay, Ahmedabad, Jodhpur, Delhi and Srinagar. While the minimum number of days with sunshine exceeding 6 hours occurs at Trivandrum in June, it occurs between July and August in Bombay and in August in higher latitudes. During these months it is a maximum at Srinagar. These features are also brought out in Fig. 4 (b) which shows the frequency of occurrence of days with duration of sunshine less than 3 hours.

3. Distribution of total solar radiation in India

The distribution of total solar radiation over India is shown in Figs. 5 and 6. Fig. 5 shows the distribution of Q_o, the total radiation on clear days, computed by Ramdas and Yegnanarayanan (1954), for the different months of the year, from sunshine data. The values of radiation q from the sun and sunlit sky, per sq. cm of horizontal surface per minute were computed by them for a network of 22 selected stations in India,

from the isopleths of q computed by Fritz (1949) for different values of precipitable water and air masses corresponding to the different hours of the day at the selected stations and for the middle of each of the months of the year. The total mean radiation Q_o for cloudless skies in different months of the year was then estimated by integration from curves showing the computed diurnal variation of q.

A study of Fig. 5 shows that a gradient in radiation intensities received on clear days exists, as a result of the increasing inclination of solar rays and the decreasing length of the day with increasing latitude over India during the winter months, November to February. During these months, the radiation received in the plains of India in the north is less than that received in the extreme south by nearly 200 cal/cm^2/day in March, the radiation received being fairly uniform over the whole country in April (about 775 cal/cm^2/day). The reversal in the gradient occurs from May to July, with a maximum of about 850 in the extreme north in May-June and about 750 cal/cm^2/day in the extreme south. The energy received on a clear day in August is almost the same over the whole country and resembles the distribution in April (about 750 cal/cm^2/day). The setting in of the winter conditions is prominently noticeable in the northern regions by September. The minimum radiation received in the plains of India on a clear day is about 400 cal/cm^2/day in December near Jullundur and the minimum radiation received in the extreme south at Trivandrum is about 625 cal/cm^2/day also in December.

Fig. 6 shows the distribution of the actual total solar radiation Q over India and its variation during the different months, computed by Ramdas and Yegnanarayanan (1954) from the records of duration of sunshine S and theoretical and computed values of S_o and Q_o respectively. The values of Q computed by Ramdas and Yegnanarayanan, and the actual values of total radiation recorded at Poona, Delhi, Calcutta and Madras during the IGY are given in Table 4.

It is seen that there is fair agreement between the actual values of radiation received at Poona, Delhi, Calcutta and Madras and those computed by Ramdas and Yegnanarayanan (1954) for these stations. Till radiation observations from a more extended network of stations are obtained, the computed values of solar radiation may be considered to be fairly representative of the actual values.

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TABLE 1

Average duration of bright sunshine per day (hrs)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Trivandrum (8°29′N, 76°57′E)	8·2	8·7	8·5	6·3	6·6	3·7	3·9	5·5	6·3	5·4	6·1	7·9	6·5
Kodaikanal (10°14′N, 77°28′E)	7·4	8·5	8·2	7·3	6·8	4·5	3·0	4·0	4·7	4·2	5·3	7·0	5·9
Bangalore (12°58′N, 77°35′E)	8·5	9·0	9·7	8·7	7·3	5·0	3·3	4·2	5·3	5·8	7·1	8·2	6·9
Madras (13°04′N, 80°15′E)	8·8	9·8	9·9	9·3	8·3	6·1	5·0	5·3	6·1	6·6	7·2	7·8	7·6
Bombay (18°54′N, 72°49′E)	9·0	9·3	9·0	9·3	9·3	5·3	2·2	2·8	4·6	8·0	9·6	9·5	7·3
Poona (18°32′N, 73°51′E)	9·1	9·8	9·7	9·5	9·6	6·4	3·1	3·4	5·3	7·8	9·0	9·3	7·7
Baroda (22°18′N, 73°15′E)	9·7	10·3	9·6	10·5	11·3	7·7	4·6	4·4	6·5	9·6	10·3	9·9	8·7
Nagpur (21°09′N, 79°07′E)	9·3	10·0	9·5	9·4	9·8	5·9	3·3	3·5	5·1	8·6	9·6	9·6	7·8
Ahmedabad (23°04′N, 72°38′E)	9·6	10·2	9·4	10·4	10·9	8·3	5·4	4·2	6·8	9·6	10·1	9·8	8·6
Jodhpur (26°18′N, 73°01′E)	8·9	9·3	9·0	10·2	10·5	9·4	6·8	6·6	8·6	10·1	9·8	9·4	9·1
Jaipur (26°55′N, 75°50′E)	8·6	9·1	8·8	9·7	8·9	6·3	4·5	4·8	7·9	10·0	9·8	9·3	8·3
Allahabad (25°27′N, 81°44′E)	8·4	9·1	8·8	9·8	10·0	7·1	5·4	4·9	6·9	9·3	9·4	9·0	8·1
Calcutta (22°32′N, 88°20′E)	8·7	9·0	8·5	9·1	8·8	4·8	4·1	3·9	5·1	6·5	8·0	8·6	7·1
New Delhi (28°35′N, 77°12′E)	7·6	8·7	7·6	9·2	8·2	6·2	5·3	6·0	7·5	9·4	9·4	8·2	7·8
Srinagar (34°05′N, 74°50′E)	2·0	3·0	4·3	6·1	7·5	6·9	7·8	7·7	7·5	7·9	7·1	4·4	6·0

TABLE 2

Percentage of possible hours of bright sunshine

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Trivandrum	70	73	71	52	53	30	31	43	52	45	51	68	53
Kodaikanal	63	72	68	59	54	34	25	32	38	35	45	61	49
Bangalore	75	77	79	70	61	39	25	33	43	49	65	71	57
Madras	77	84	82	75	65	52	39	40	53	56	63	69	63
Bombay	81	83	75	74	70	39	17	21	28	68	85	86	61
Poona	83	85	80	75	73	48	23	28	43	65	80	85	64
Baroda	89	89	82	83	86	58	34	34	53	82	91	92	73
Nagpur	78	81	73	73	73	43	25	27	40	70	80	81	63
Ahmedabad	89	88	78	83	82	62	41	33	55	83	93	92	72
Jodhpur	81	83	75	80	78	68	53	45	71	86	90	89	75
Jaipur	79	81	74	76	67	46	36	34	63	88	91	88	68
Allahabad	76	80	74	77	74	52	35	38	56	79	86	85	66
Calcutta	80	79	71	72	67	36	31	30	42	56	73	80	60
New Delhi	70	74	64	71	61	43	39	45	61	81	88	79	64
Srinagar	17	33	34	48	53	51	56	57	63	71	70	43	50

TABLE 3

Mean monthly frequency of occurrence of bright sunshine of different duration

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
						0.1 to 3 hrs							
Trivandrum	2	2	1	4	4	11	11	7	4	7	5	3	61
Kodaikanal	3	2	1	2	3	10	13	10	8	11	7	5	75
Bangalore	1	1	0	1	2	9	13	11	7	6	2	2	55
Madras	1	0	0	1	3	4	8	8	5	4	4	4	41
Bombay	1	0	0	1	1	5	9	13	7	2	1	0	39
Poona	1	0	0	1	1	5	14	13	5	2	1	0	43
Baroda	0	0	0	0	0	4	8	8	4	0	0	0	24
Nagpur	1	0	1	0	0	5	11	11	10	2	1	0	42
Ahmedabad	0	0	0	0	0	3	6	10	4	0	0	0	23
Jodhpur	1	1	1	0	0	1	5	5	1	0	0	1	16
Jaipur	2	1	2	1	1	4	9	10	3	1	0	0	34
Allahabad	2	1	1	0	0	4	7	7	4	1	1	0	28
Calcutta	1	1	1	1	2	8	9	9	6	4	3	1	46
New Delhi	3	2	3	1	4	8	8	5	3	1	1	3	44
Srinagar	5	5	7	7	5	6	4	5	2	3	4	6	59
						3·1 to 6 hrs							
Trivandrum	3	2	3	5	6	7	7	8	7	7	5	4	64
Kodaikanal	5	3	5	6	8	9	9	11	12	11	7	4	90
Bangalore	2	2	2	2	3	8	8	9	9	9	4	3	61
Madras	3	1	1	2	3	5	7	6	5	6	4	3	46
Bombay	1	1	0	0	1	6	5	6	6	4	1	0	31
Poona	1	0	1	1	2	5	9	9	9	5	1	0	43
Baroda	0	1	0	1	0	5	8	9	6	1	0	0	31
Nagpur	1	0	1	2	1	8	7	6	7	3	1	0	37
Ahmedabad	0	1	0	0	0	4	9	9	5	1	0	0	29
Jodhpur	1	2	2	1	1	2	4	7	3	0	1	1	25
Jaipur	2	1	2	2	2	6	8	8	4	0	1	1	37
Allahabad	3	2	2	1	1	4	8	7	5	2	0	1	36
Calcutta	2	2	2	2	2	7	9	10	9	5	2	1	53
New Delhi	8	7	13	8	8	7	10	8	10	5	3	11	98
Srinagar	3	5	6	7	8	10	9	9	9	9	12	12	99
						6·1 to 9 hrs							
Trivandrum	8	6	9	9	9	7	7	10	10	10	8	7	100
Kodaikanal	8	5	10	12	12	7	5	6	8	6	7	7	93
Bangalore	12	6	6	10	12	7	5	7	9	10	10	10	104
Madras	6	4	3	4	6	9	7	9	10	9	8	9	84
Bombay	4	3	13	8	6	7	4	4	11	11	3	4	78
Poona	4	2	5	6	5	9	4	4	10	9	6	4	68
Baroda	3	2	3	1	1	7	7	7	9	4	1	2	47
Nagpur	3	3	5	6	7	7	6	6	8	5	2	3	61
Ahmedabad	3	2	6	2	1	6	8	6	10	5	1	3	53
Jodhpur	6	4	6	4	3	7	8	9	7	2	2	3	62
Jaipur	8	6	7	5	9	7	6	6	7	3	1	4	69
Allahabad	8	3	7	5	5	9	7	7	8	4	2	8	73
Calcutta	9	7	11	7	8	7	7	7	10	8	6	11	98
New Delhi	8	7	13	8	8	7	10	8	10	5	3	11	98
Srinagar	3	5	6	7	8	10	9	9	9	9	12	12	99

TABLE 3 (*contd*)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
						Above 9 hrs							
Trivandrum	17	18	18	10	10	1	3	5	7	5	10	16	120
Kodaikanal	13	17	15	9	8	2	0	2	1	2	6	13	88
Bangalore	16	19	23	17	13	5	1	2	4	5	13	15	133
Madras	21	23	27	22	18	10	6	6	8	10	13	15	179
Bombay	25	24	18	22	23	7	1	1	2	14	25	27	189
Poona	25	26	25	22	23	9	1	2	4	15	22	27	201
Baroda	28	25	28	28	30	14	4	3	10	26	29	29	254
Nagpur	26	25	24	22	23	8	2	2	3	20	26	28	209
Ahmedabad	28	25	25	28	30	17	6	3	10	25	29	28	254
Jodhpur	23	20	22	25	27	20	13	9	19	29	27	26	260
Jaipur	19	20	20	22	19	11	6	5	15	27	28	26	218
Allahabad	17	22	21	24	25	12	6	7	12	24	27	22	219
Calcutta	19	18	17	20	19	5	3	2	3	11	17	18	152
New Delhi	14	17	13	20	17	8	4	9	13	24	26	16	181
Srinagar	0	3	3	9	14	10	15	13	16	17	10	0	110

TABLE 4

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
						DELHI						
Computed	361	441	509	599	610	571	491	486	478	524	442	353
Observed during IGY	349	445	557	606	630	612	—	461	489	501	414	346
						POONA						
Computed	488	561	631	620	632	489	378	375	435	474	489	464
Observed during IGY	459	561	598	617	663	589	395	401	498	518	474	447
						CALCUTTA						
Computed	442	506	568	617	682	482	416	441	387	431	445	415
Observed during IGY	335	396	483	503	543	474	453	481	433	396	386	363
						MADRAS						
Computed	526	610	643	626	581	495	442	467	510	489	489	473
Observed during IGY	472	559	590	595	546	523	424	422	503	369	372	397

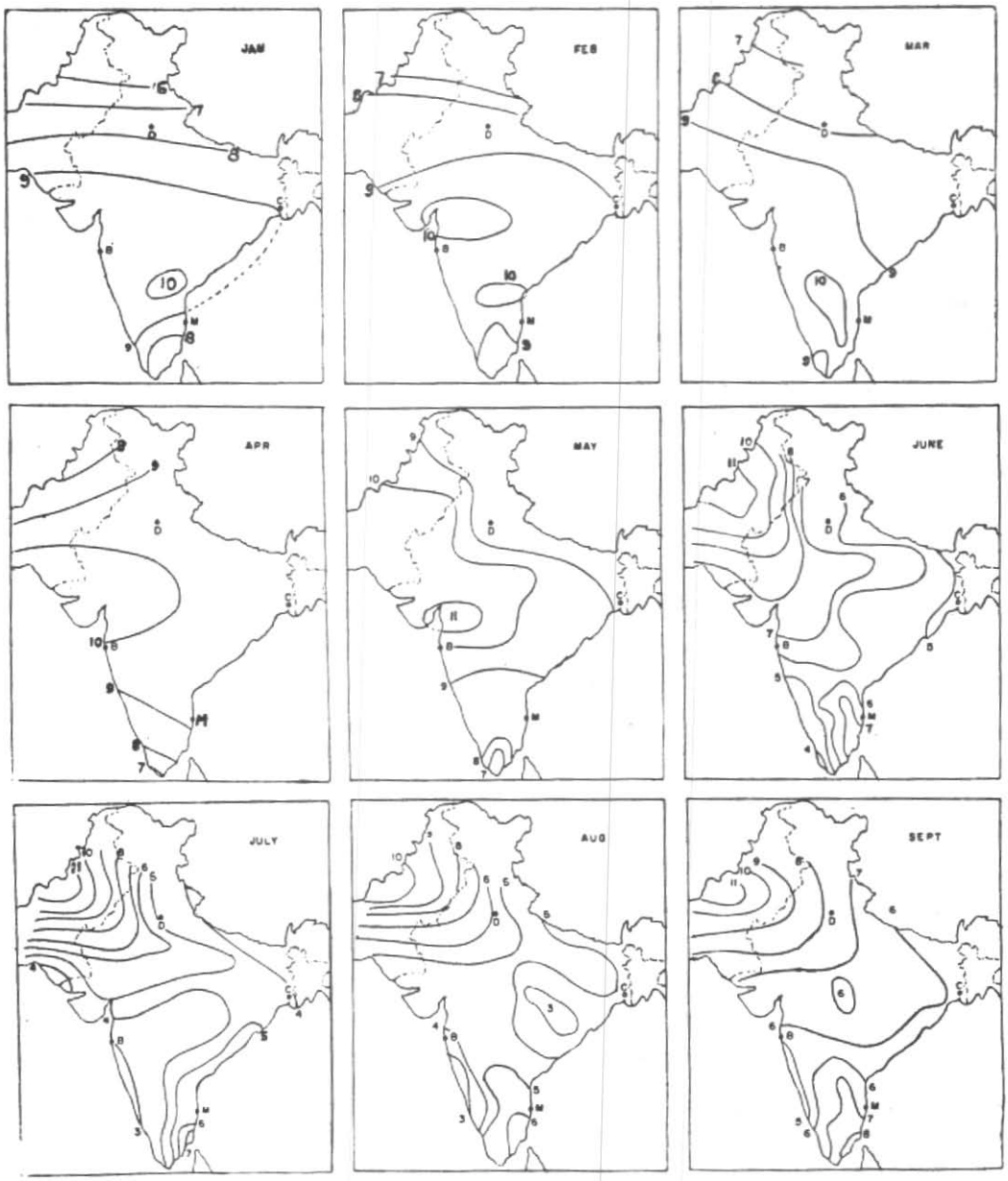
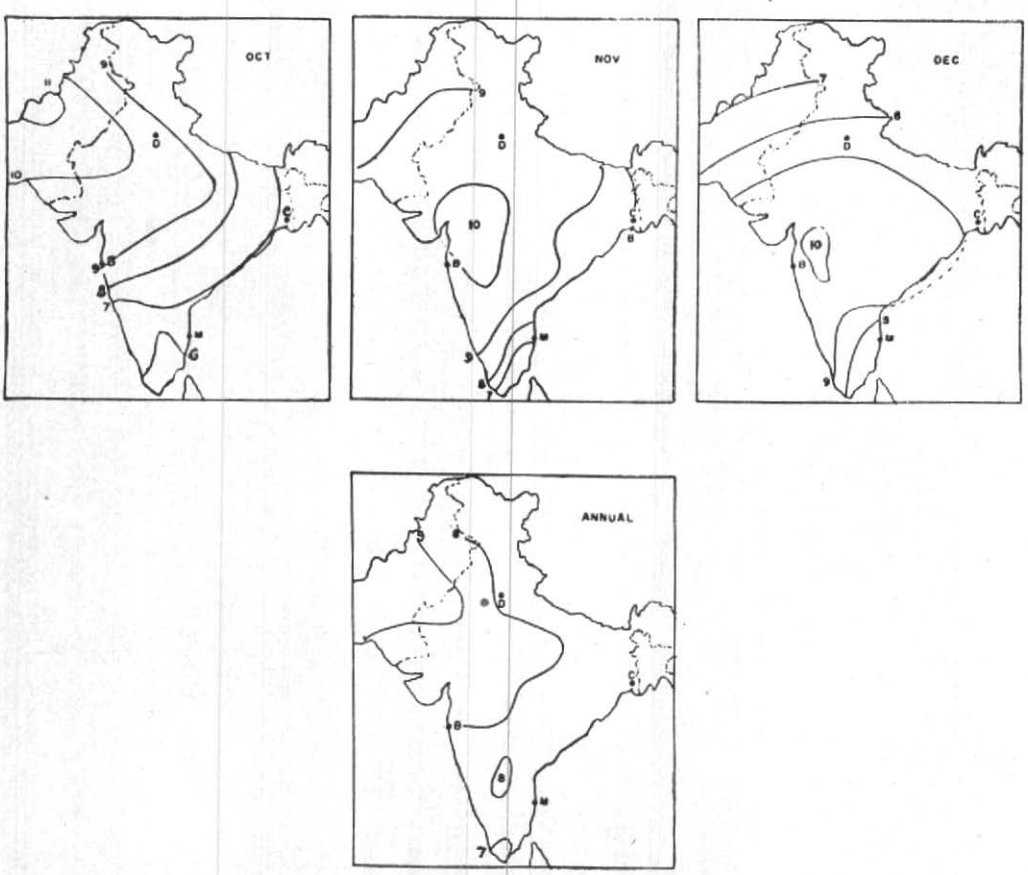


Fig. 1. Hours of bright sunshine—Average total per day



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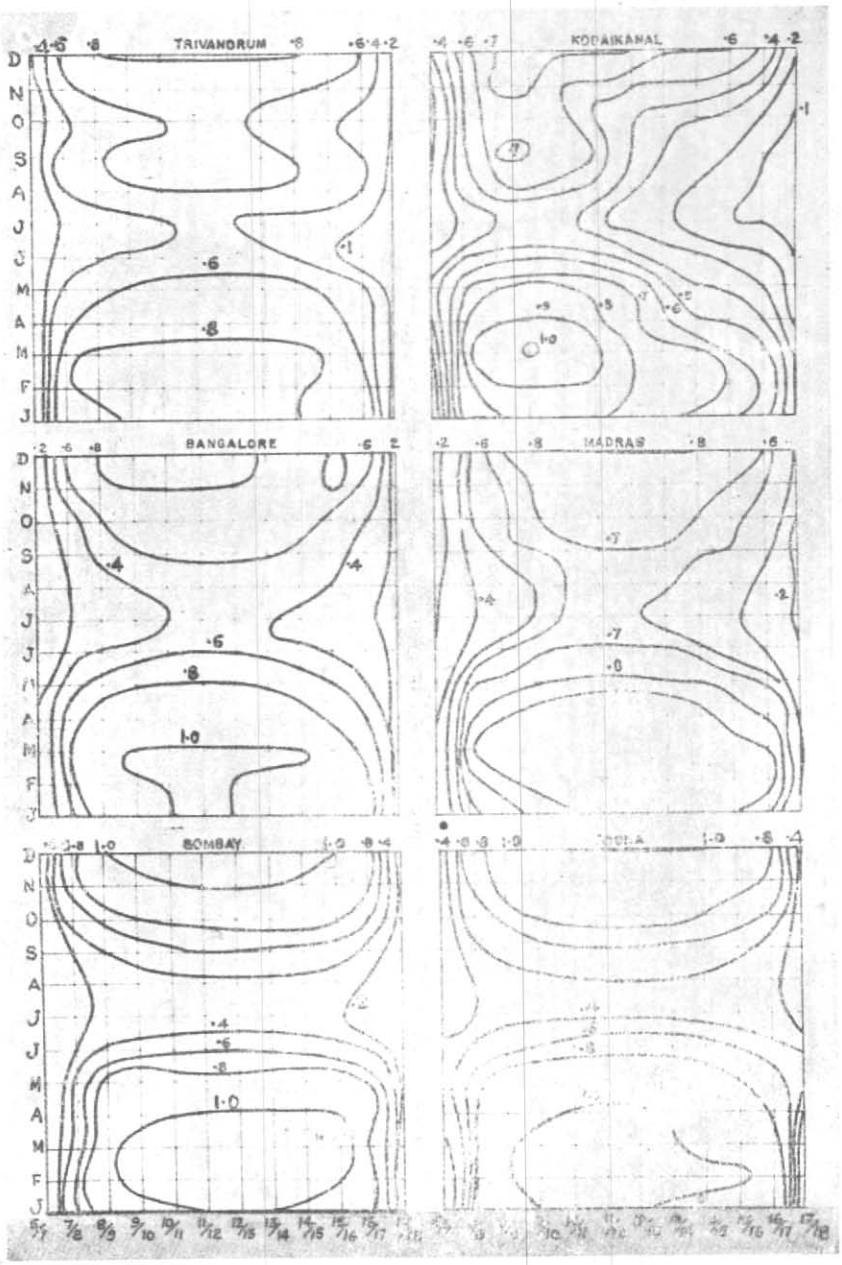
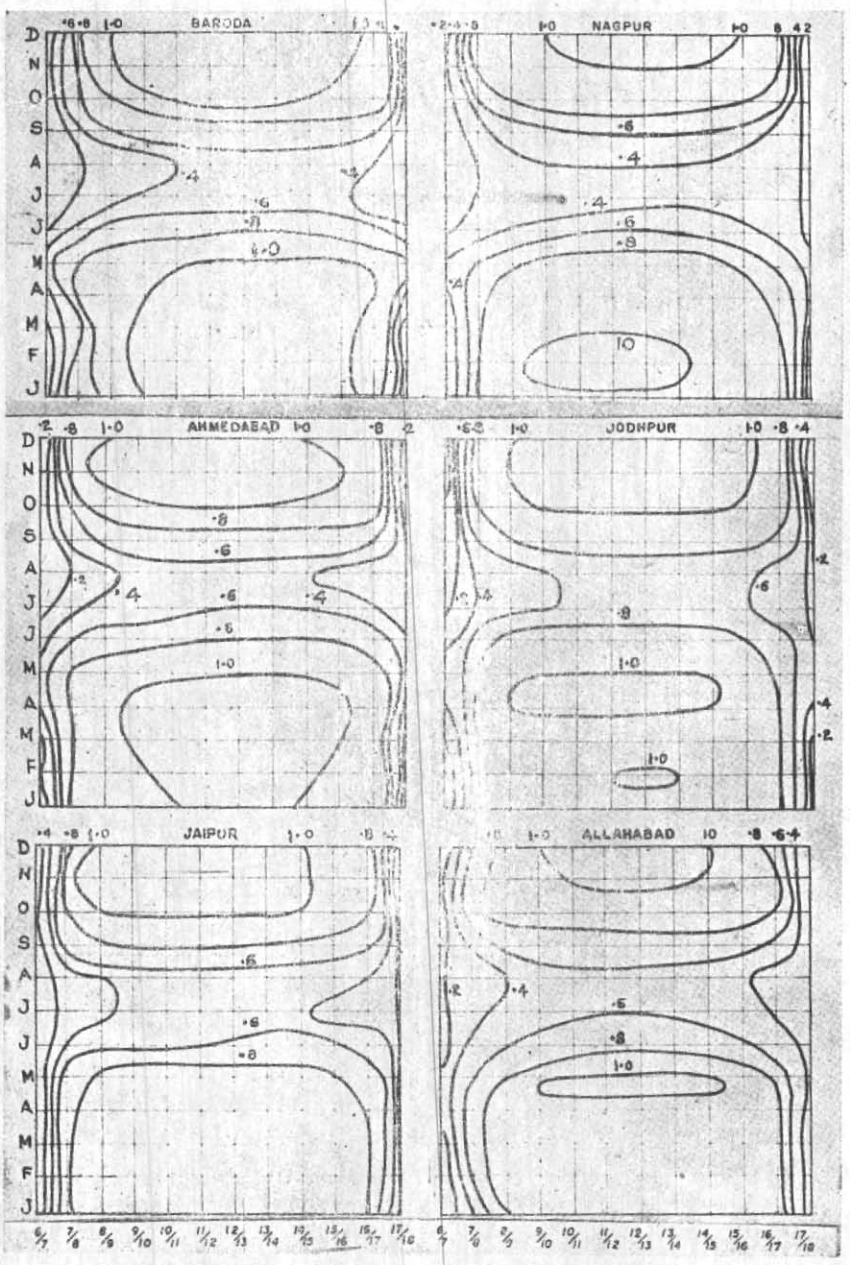


Fig. 2. Isopleths of duration of bright sunshine in each hour (LAT)



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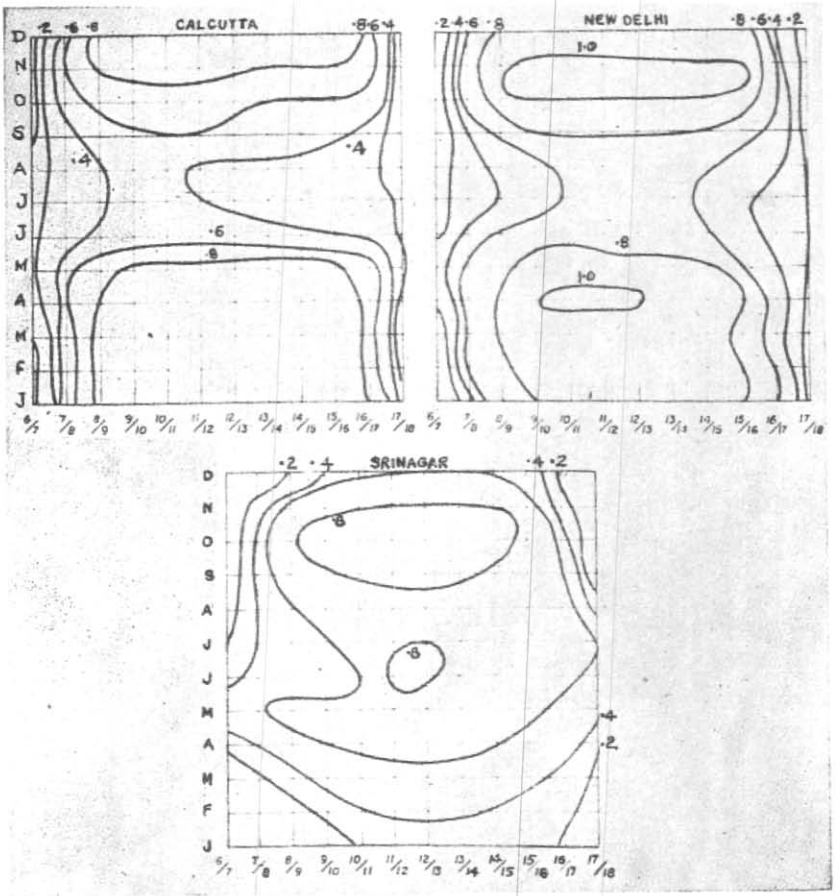

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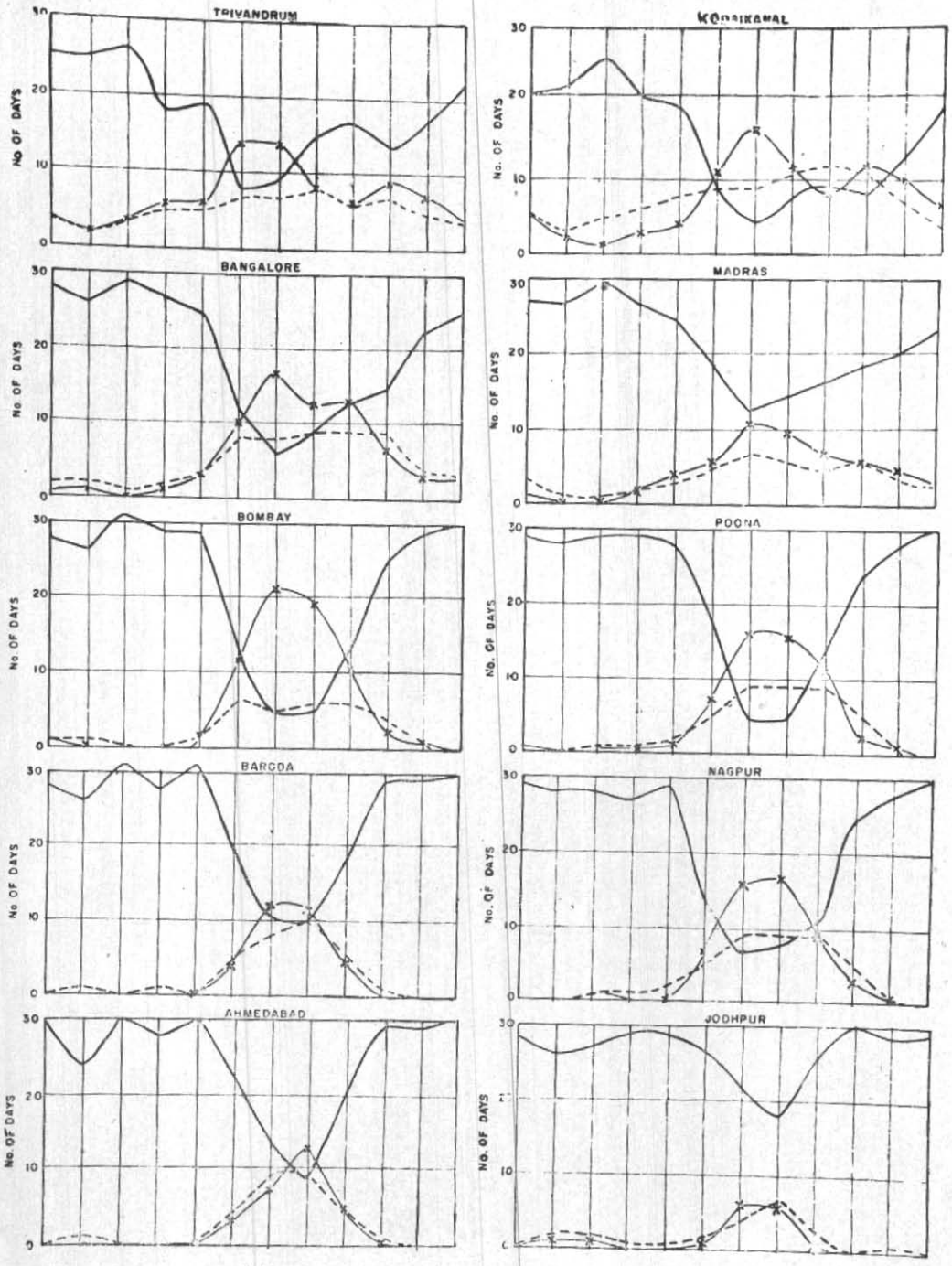

Fig. 3. Mean number of days with different durations of bright sunshine in each month

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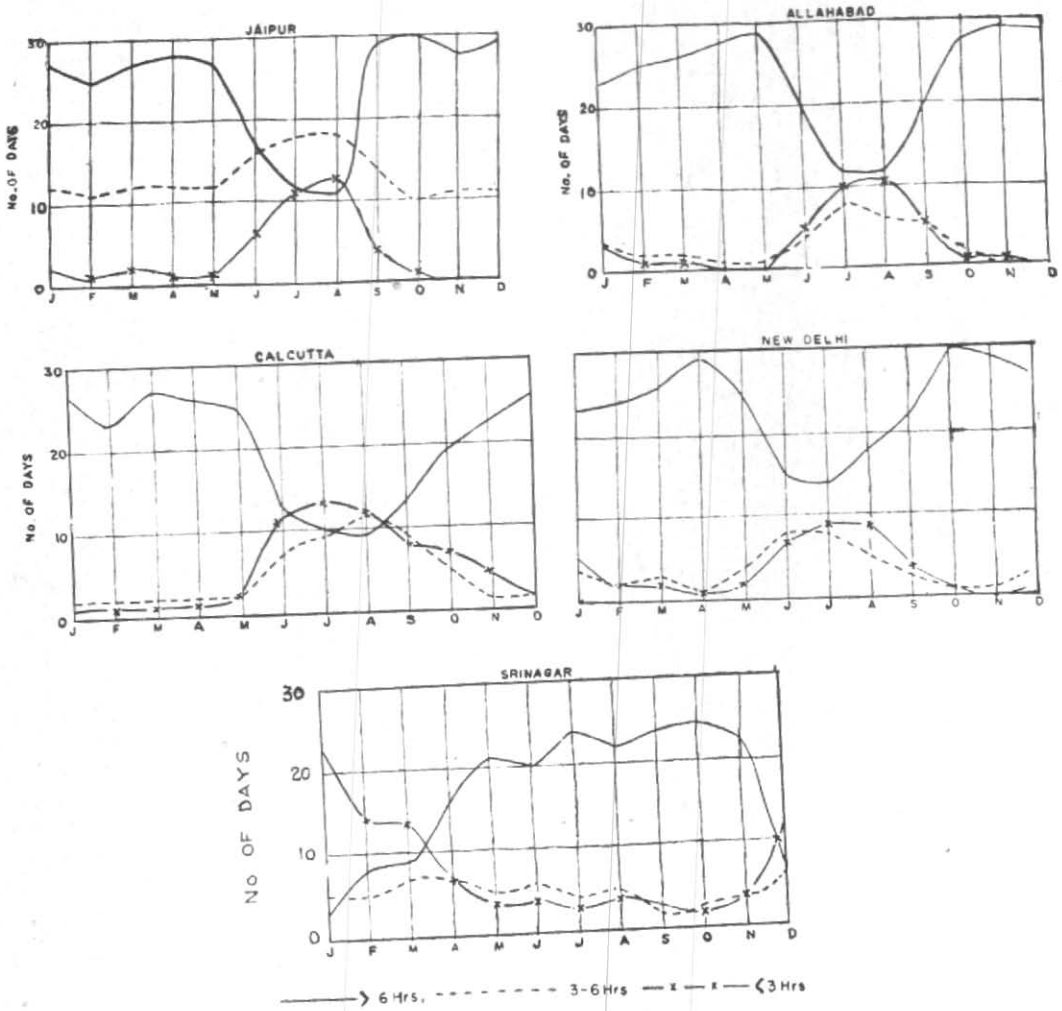

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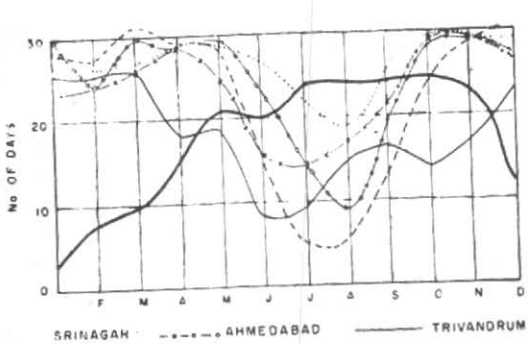

Fig. 4(a). Frequency of days with sunshine > 6 hrs

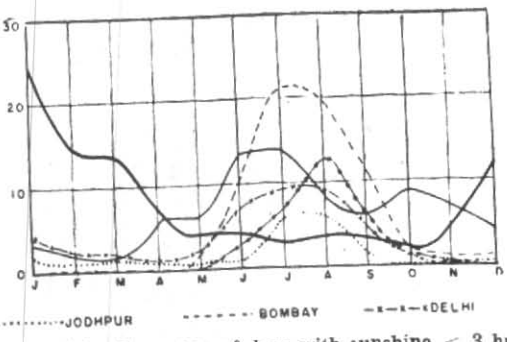

Fig. 4(b). Frequency of days with sunshine < 3 hr

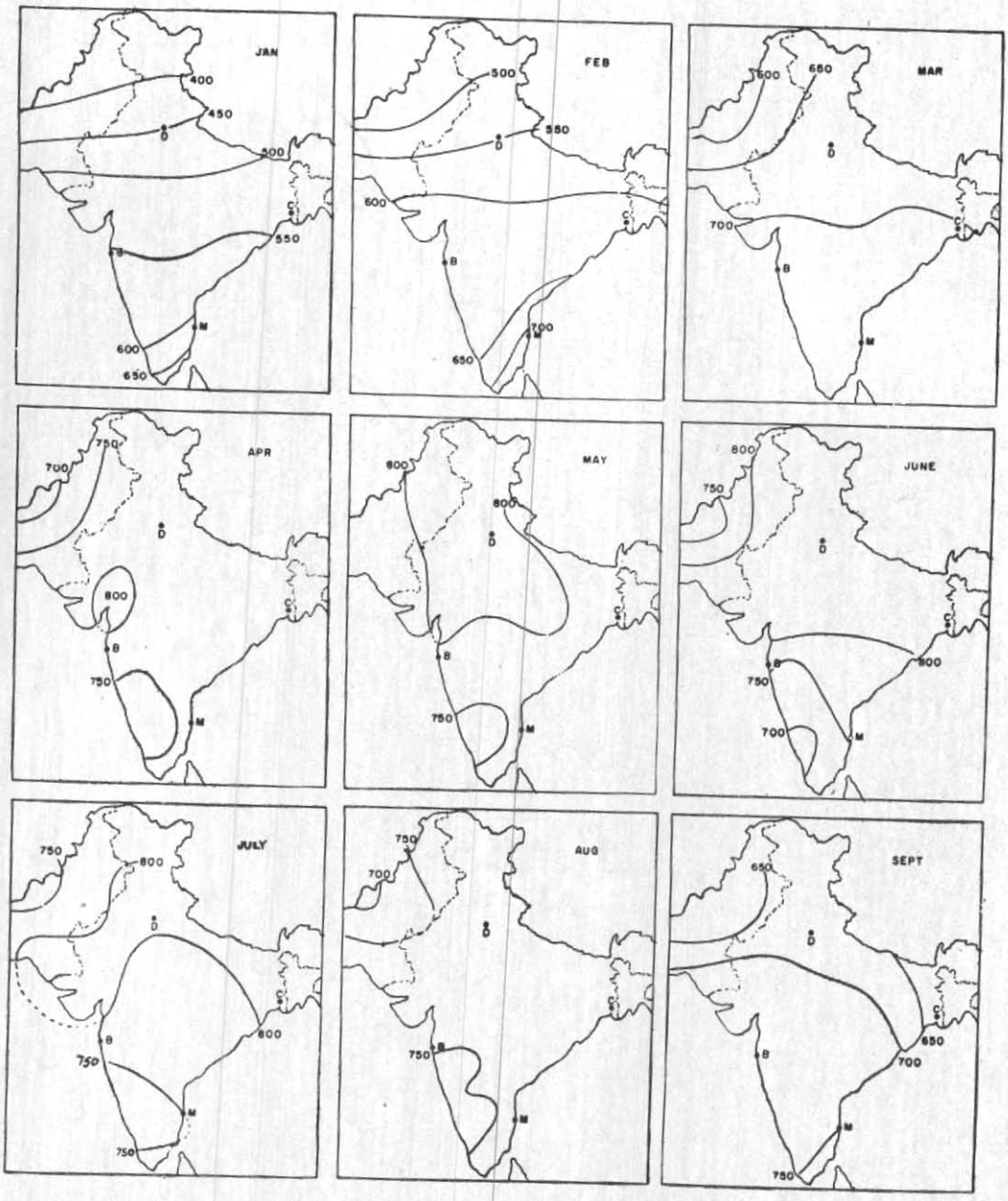

Fig. 5. Distribution of total solar radiation Q_0 received on horizontal surface cal/cm²/day on clear days (Ramdas and Yegnanarayanan)

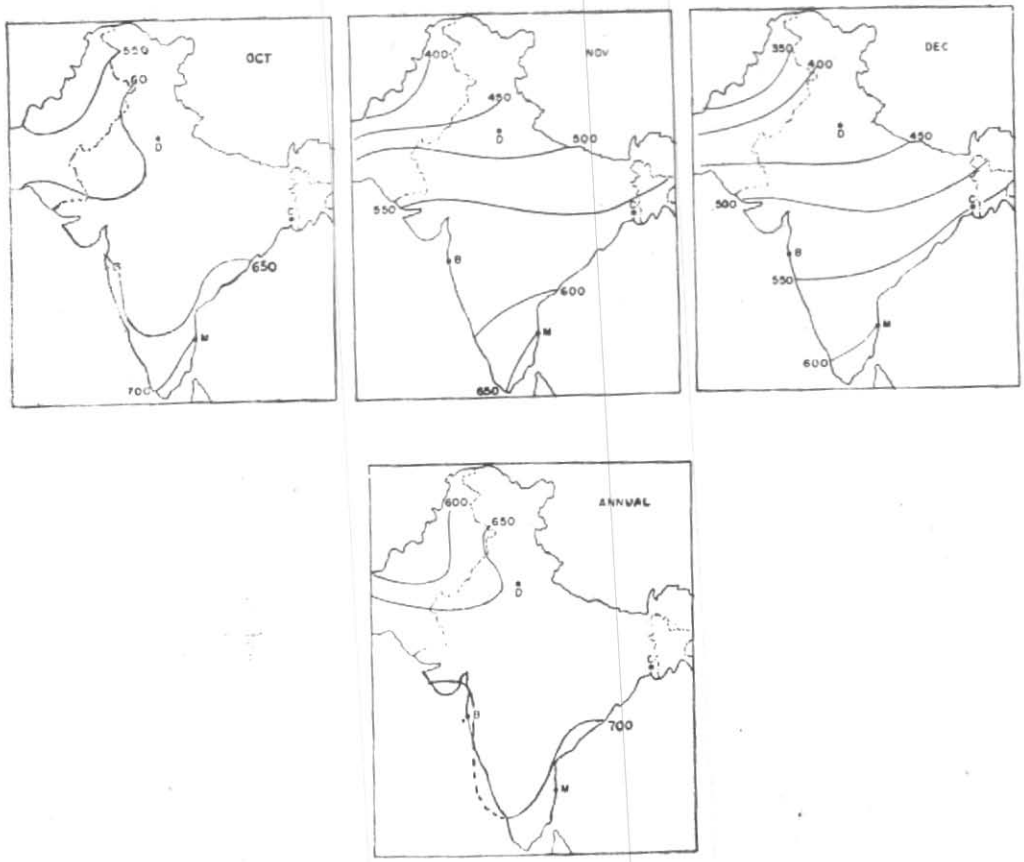

Fig. 5. Distribution of total solar radiation Q_0 received on a horizontal surface cal/cm²/day on clear days (Ramdas and Yegnanarayanan)

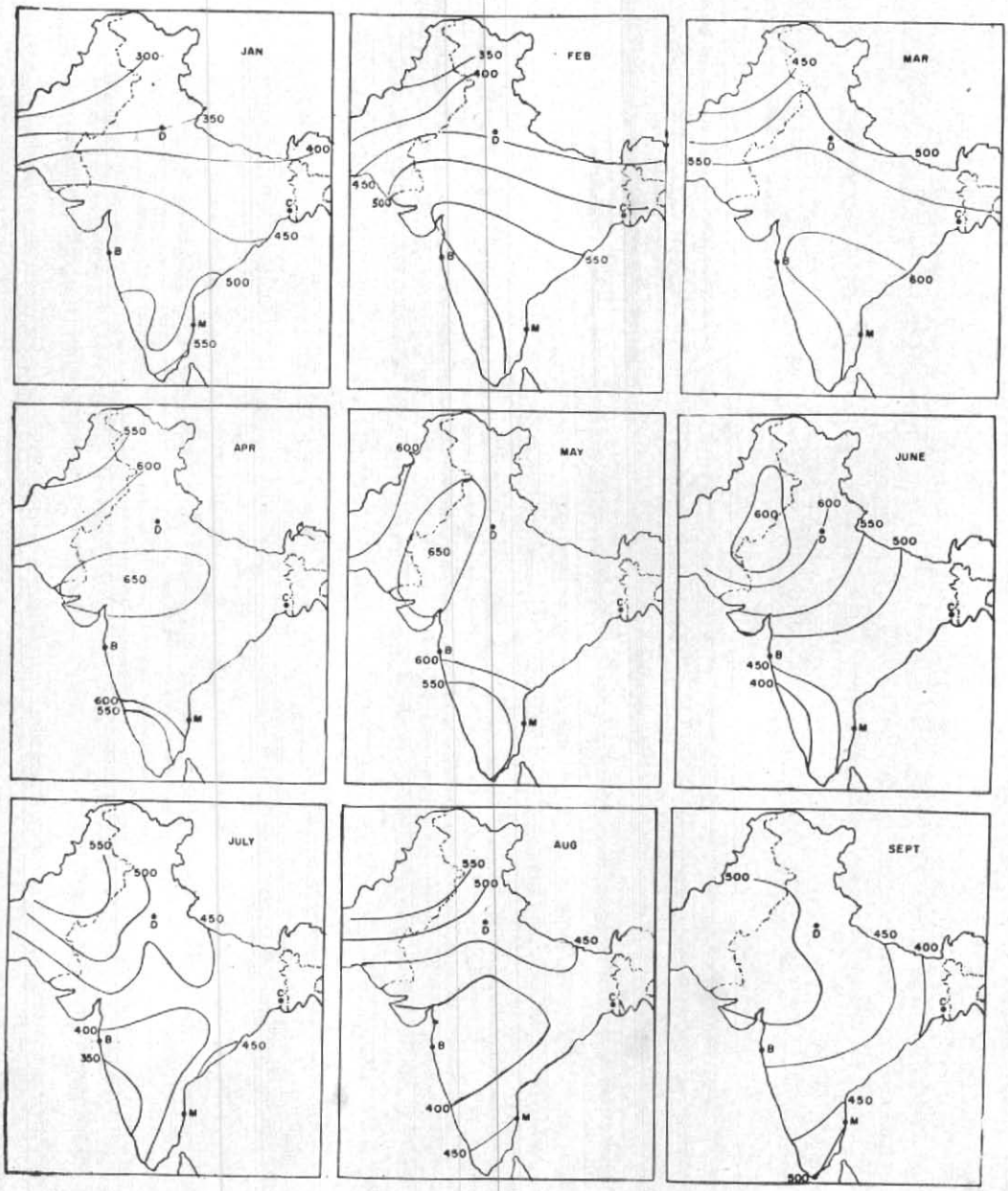

Fig. 6. Distribution of solar radiation Q received on a horizontal surface cal/cm²/day computed for actual hours of sunshine (Ramdas and Yegnanarayanan)

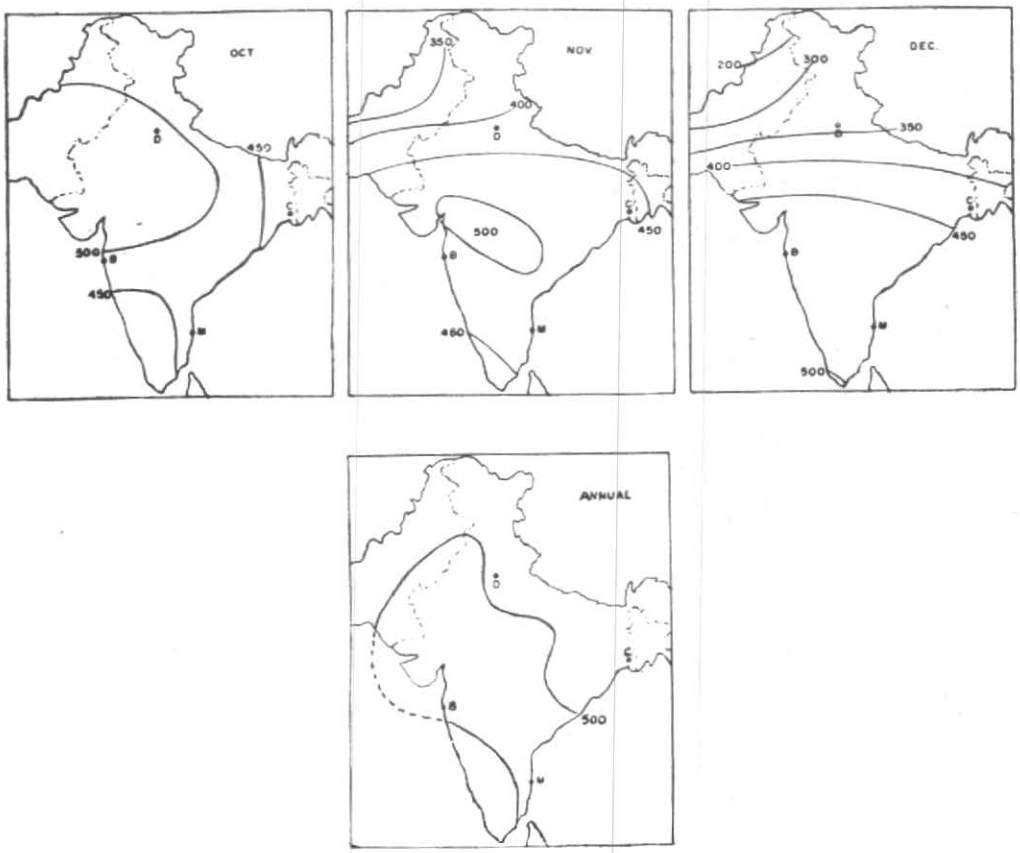

Fig. 6. Distribution of solar radiation Q received on a horizontal surface cal/cm^2/day computed for actual hours of sunshine (Ramdas and Yegnanarayanan)