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Climatological studies of thunderstorms to the west and east of the Western Ghats in the State of Maharashtra and Goa : Part I

S. K. PRASAD and B. C. PAWAR
Regional Meteorological Centre, Colaba, Bombay

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सार — महाराष्ट्र राज्य और गोआ में पश्चिमी घाट के पूर्व और पश्चिम मे स्थित दस स्टेशनों के पिछले 10- 11 साल के आंकड़ों के आधार पर तड़ित झंझाओं की बारम्बारता, उनकी कार्यविधि, उनके वार्षिक तथा दैनिक परिवर्तन के संबंध में जलवायु विज्ञानी सूचना पर निर्धारित की गई है और उन्हें प्रस्तुत किया गया है।

ABSTRACT. Based on the data of ten stations located to the west and east of the Western Ghats in the State of Maharashtra and Goa for period of about 10-11 years, climatological information on the frequency of thunderstorms, their durations, annual and diurnal variation of thunderstorms to the west and east of the Ghats have been determined and presented.

1. Introduction

Rao *et al.* (1971) have discussed the diurnal frequency and duration of thunderstorms at the four aerodromes of Bombay, Calcutta, Madras and Delhi. Raman and Raghavan (1961) have studied the diurnal variations of thunderstorms in India during different seasons using data for 5 years. Of the 47 stations studied by them, only 4 stations — Bombay, Pune, Jalgaon and Nagpur are in the State of Maharashtra. The Western Ghats play an important role in the development of cumulonimbus clouds which give thunderstorms in association with favourable synoptic situations. A detailed study of the thunderstorms in the State of Maharashtra and Goa on the two sides of the Western Ghats has not been carried out so far. The present paper presents the resutts of such a study regarding distribution of thunderstorms monthwise and seasonwise, their durations and the diurnal variation of the thunderstorm incidence.

2. Data

From the available monthly meteorological registers, the data have been extracted. Data for the 11 years period (1968-1978) have been used for the stations, Santacruz, Colaba, Ratnagiri, Goa, Mormugao, Chikalthana, Pune, Sholapur and Kolhapur while the data for the 10 years period (1969-1978) have been used for Dahanu. The distribution of stations under study is shown in Fig. 1.

3. Analysis and discussion

3.1. *Average monthly incidence of thunderstorms*

The monthly meteorological register gives the times of commencement and cessation of a thunderstorm. From this information, the average monthly incidence of thunderstorms has been determined. If a thunderstorm commences at 10 P.M. at a station and ceases by 2 A.M. of the next day, it is considered as one occurrence. If a thunderstorm commences by 4 A.M. and ceases by 5.30 A.M. on a day and another begins at 6.15 P.M. and ends at 8 P.M. on the same day, the occurrences are taken as two. The statistics of occurrences determined in this way for different stations for the various months are given in Table 1.

It is seen from Table 1 that the annual frequency of thunderstorms is much more to the east of the Ghats than to the west. Sholapur and Pune, in central Maharashtra get the highest number of thunderstorms, 32 and 29 respectively with the frequency decreasing both to the north and south.

Of the stations on the west coast, Santacruz and Ratnagiri get the maximum annual frequency of 21, which is slightly smaller than that of Kolhapur which has the lowest frequency in Madhya Maharashtra. To the north of Bombay the frequency decreases considerably and Dahanu has an annual frequency of only 10.

All the stations show double maxima in their annual variation. Sholapur and Kolhapur have their first maximum in the month of April, Chikalthana gets its

TABLE 1

Average monthly incidence of thunderstorms
(No. of occasions)

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Dahanu	0	0.2	0.2	0	1.0	3.5	0.3	0.5	2.1	1.6	0.8	0	10.2
	(0)	(0)	(0)	(0)	(0)	(0.7)	(0)	(0.2)	(0.3)	(0.1)	(0.1)	(0.2)	(1.6)
Santacruz	0	0.1	0.1	0.3	1.1	6.1	2.5	1.0	4.4	3.5	1.9	0	21.0
	(0)	(0.2)	(0.2)	(0.6)	(2.0)	(6.0)	(1.8)	(0.8)	(4.0)	(3.0)	(0.1)	(0)	(19.0)
Colaba	0	0.2	0.2	0.2	1.2	4.5	1.9	1.5	3.7	3.2	1.5	0	18.1
	(0)	(0.1)	(0.1)	(0.4)	(2.0)	(5.0)	(1.2)	(0.8)	(3.0)	(3.0)	(0.8)	(0.1)	(17.0)
Ratnagiri	0	0	0	1.5	3.3	4.3	1.0	0	3.0	5.2	2.8	0.1	21.2
	(0)	(0)	(0)	(0.4)	(0.9)	(1.4)	(0)	(0)	(1.2)	(2.0)	(0.6)	(0)	(7.0)
Goa	0	0	0.4	1.5	4.1	4.1	0.8	0.4	2.2	3.0	2.1	0	18.6
Mormugao	0	0	0.3	0.6	2.6	2.3	0.8	0.5	1.6	3.3	2.8	0	14.8
	(0.2)	(0)	(0.4)	(3.0)	(4.0)	(4.0)	(0.3)	(0.7)	(2.0)	(9.0)	(3.0)	(0.3)	(27.0)
Chikalthana	0.4	0.6	1.5	1.9	3.6	5.6	2.4	1.7	4.5	1.7	0.6	0.1	24.6
(Aurangabad)	(0.4)	(0.5)	(1.5)	(3.0)	(3.0)	(7.0)	(1.9)	(2.0)	(4.0)	(2.0)	(1.1)	(0.5)	(27.0)
Pune	0	0.3	1.7	3.5	4.8	4.8	0.6	0.2	6.1	4.9	1.5	0.2	28.6
	(0.1)	(0.2)	(1.5)	(4.0)	(5.0)	(3.0)	(0.3)	(0.9)	(4.0)	(5.0)	(1.8)	(0.3)	(26.0)
Sholapur	0.2	0.5	1.9	5.5	4.7	4.9	1.6	2.5	5.5	3.9	0.6	0	31.8
	(0.1)	(0.5)	(1.4)	(3.0)	(3.0)	(4.0)	(1.4)	(1.6)	(4.0	(2.0)	(0.7)	(0.2)	(22.0)
Kolhapur	0	0	1.6	5.6	4.9	1.5	0.1	0.2	3.1	4.3	0.4	0	21.7
	(0.1)	(0.1)	(2.0)	(9.0)	(9.0)	(2.0)	(0.9)	(1.6)	(4.0)	(7.0)	(1.5)	(0.4)	(38.0)

(The figures in bracket indicate climatological thunderstorm days)

TABLE 2

Average monthly frequency (per cent) of duration of thunderstorm

Station	Dura-tion	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Dahanu	I	0	2.0	2.0	0	7.8	27.6	2.9	4.9	15.7	14.7	6.9	0	84.3
	II	0	0	0	0	2.0	6.8	0	0	4.9	1.0	0	0	14.7
	III	0	0	0	0	0	0	0	0	0	0	1.0	0	1.0
	Total	0	2.0	2.0	0	9.8	34.2	2.9	4.9	20.6	15.7	7.9	0	100 0
Santacruz	I	0	0.5	0.5	1.0	3.3	17.6	7.1	3.8	12.4	8.6	0	0	61.5
	II	0	0	0	0.5	1.9	8.1	2.9	0.9	5.2	6.2	2.4	0	28.1
	III	0	0	0	0	0	3.3	1.9	0	3.3	1.9	0	0	10.4
	Total	0	0.5	0.5	1.5	5.2	28.0	11.9	4.7	20.9	16.7	9.1	0	100.0
Colaba	I	0	1.1	1.1	0.6	3.9	17.7	8.8	7.2	12.1	13.3	6.6	0	72.4
	II	0	0	0	0.6	1.6	5.5	1.1	1.1	8.3	3.8	1.1	0	23.1
	III	0	0	0	0	1.1	1.6	0.6	0	0	0.6	0.6	0	4.5
	Total	0	1.1	1.1	1.2	6.6	24.8	10.5	8.3	20.4	17.7	8.3	0	100.0
Ratnagiri	I	0	0	0	6.6	9.9	14.6	4.7	0	9.9	16.5	9.5	0.5	72.2
	II	0	0	0	0.5	2.8	4.7	0	0	3.3	5.2	3.3	0	19.8
	III	0	0	0	0	2.8	0.9	0.0	0.0	0.9	2.4	0.5	0	7.5
	IV	0	0	0	0	0	0	0	0	0	0.5	0	0	0.5
	Total	0	0	0	7.1	15.5	20.2	4.7	0	14.1	24.6	13.3	0.5	100.0
Goa	I	0	0	1.6	8.1	17.2	19.8	4.3	2.2	9.7	13.4	8.6	0	84.9
	II	0	0	0.5	0	3.2	2.2	0	0	2.2	1.6	2.7	0	12.4
	III	0	0	0	0	1.6	0	0	0	0	1.1	0	0	2.7
	Total	0	0	2.1	8.1	22.0	22.0	4.3	2.2	11.9	16.1	11.3	0	100.0
Mormugao	I	0	0	1.8	3.7	14.1	14.1	5.5	3.7	9.8	20.2	16.0	0	88.9
	II	0	0	0	0.6	3.7	1.2	0	0	0.6	1.9	3.1	0	11.1
	III	0	0	0	0	0	0	0	0	0	0	0	0	0
	Total	0	0	1.8	4.3	17.8	15.3	5.5	3.7	10.4	22.1	19.1	0	100.0
Chikalthana	I	0.8	1.2	2.9	5.7	7.3	12.2	8.1	3.7	8.1	4.5	1.6	0.4	56.5
	II	0.8	1.2	2.9	2.0	4.5	8.5	1.6	2.9	5.3	1.6	0.8	0	32.1
	III	0	0	0.4	0	2.9	2.0	0	0.4	4.9	0.8	0	0	11.4
	Total	1.6	2.4	6.2	7.7	14.7	22.7	9.7	7.0	18.3	6.9	2.4	0.4	100.0
Pune	I	0	1.1	4.5	9.5	10.5	11.5	1.4	0.7	15.7	13.6	4.2	0.7	73.4
	II	0	0	1.1	2.1	5.2	3.8	0.3	0	3.5	3.2	1.1	0	20.3
	III	0	0	0.3	0.7	1.1	1.4	0.3	0	2.1	0.4	0	0	6.3
	Total	0	1.1	5.9	12.3	16.8	16.7	2.0	0.7	21.3	17.2	5.3	0.7	100.0
Sholapur	I	0.6	1.3	4.7	15.1	12.2	12.6	4.7	6.6	11.0	10.4	1.3	0	80.5
	II	0	0.3	0.9	1.9	2.2	2.5	0.3	1.3	5.4	1.0	0.6	0	16.4
	III	0	0	0.3	0.3	0.3	0.3	0	0	0.9	1.0	0	0	3.1
	Total	0.6	1.6	5.9	17.3	14.7	15.4	5.0	7.9	17.3	12.4	1.9	0	100.0
Kolhapur	I	0	0	5.5	22.6	16.1	5.5	0.5	0.5	12.0	17.5	1.8	0	82.0
	II	0	0	1.4	3.2	6.4	1.4	0	0.5	2.3	2.3	0	0	17.5
	III	0	0	0.5	0	0	0	0	0	0	0	0	0	0.5
	Total	0	0	7.4	25.8	22.5	6.9	0.5	1.0	14.3	19.8	1.8	0	100.0

Durations I: < 3 hr; II : ≥ 3 & < 6 hr; III : ≥ 6 & < 12 hr; IV : ≥ 12 hr.

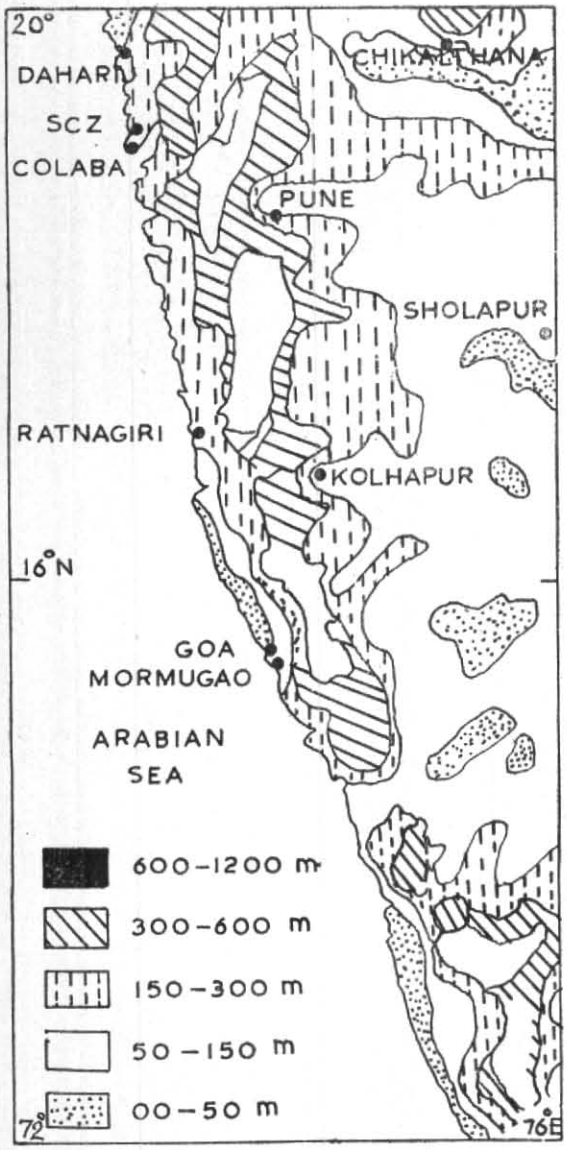

Fig. 1. Altitude contour lines amsl
[*Source* : National Atlas of India]

first maximum in June while Pune has a flat maximum in May-June. The second maximum occurs in the month of October at Kolhapur and in September at the other three stations of Madhya Maharashtra. While Pune has its primary maximum in the month of September, Kolhapur has it in April and Chikalthana in June. The two maxima of Sholapur in April and September are of equal magnitude. As far as the coastal stations are concerned, Ratnagiri and Mormugao are the only stations where primary maximum occur in October. At all other stations, it is at or near about the beginning of the monsoon, May-June in Goa and in June at all other stations.

3.2. *Comparison between average monthly incidence of thunderstorms and the climatological thunderstorm days*

Climatological normals of thunderstorm days for the available stations, namely, Dahanu, Santacruz, Colaba, Ratnagiri, Mormugao, Aurangabad, Pune, Sholapur and Kolhapur are extracted from the *Climatological Tables of Observatories in India* (1931-1960) of India Met. Dep. The climatological values for Goa and Chikalthana are not available in the publication. The climatological thunderstorm days are given station-wise and monthwise in Table 1 in brackets.

A comparison of average monthly incidence of thunderstorms and climatological thunderstorm days from Table 1 indicates a close relationship between these two parameters for the stations, Santacruz, Colaba, Chikalthana/Aurangabad and Pune. Climatological thunderstorm days of Dahanu do not show any incidence of thunderstorm during February to May but they do occur during these months, is clear from Table 1. Though the site of Chikalthana observatory had been shifted to a new site about 2 km away from its old site since 10 December 1973, it has been verified that there was no significant change in the thunderstorm days at new site when compared with climatological values of Aurangabad station in absence of Chikalthana. The station level heights were nearly same at both the sites. The Ratnagiri observatory was also shifted twice, first from site I to site II on 19 July 1971 and thereafter from site II to site III on 22 February 1977 within a distance of 2 to 4 km. The station level heights from mean sea level at site II and site III were more than twice of the site I. When observations were splited over sites I, II and III for the respective periods of functioning of the observatory, it was seen that monthly and annual thunderstorm incidences are very high at sites II and III in comparison to site I for which climatological values are available and are given in Table 1. The high values of annual and monthly incidences of thunderstorms at Ratnagiri irrespective of changes, in site of the observatory, indicate a fresh evaluation of the climatological value with change of site. The effect of conversion of part-time into departmental observatories is not considered here but definitely it would improve quality of the data received.

3.3. *Average monthly frequency (per cent) of duration of thunderstorm*

The average monthwise frequencies of duration of thunderstorms are shown in Table 2 in percentage. The frequencies of duration of thunderstorms are also compared with Table 1 which gives average monthly incidence of thunderstorms. Some of their features are given below :

(a) The sum of the annual thunderstorm frequencies having durations of categories I and II is more than 88 per cent at all the stations under study. The annual thunderstorm frequency having duration of II category is highest at Chikalthana (32 per cent) and the next highest occurs at Santacruz (28 per cent).

(b) The primary and secondary maxima of thunderstorm frequencies of duration of II category of Table 2 is exactly in same months of a year as in Table 1 for the stations except for Colaba, where secondary maximum lies in the month of October rather than in September.

3.4. *Diurnal variation of thunderstorm frequency*

To study diurnal variations of thunderstorm frequency, the day has been divided into 8 parts, *i.e.*, 00-03, 03-06, 06-09, 09-12, 12-15, 15-18, 18-21 and

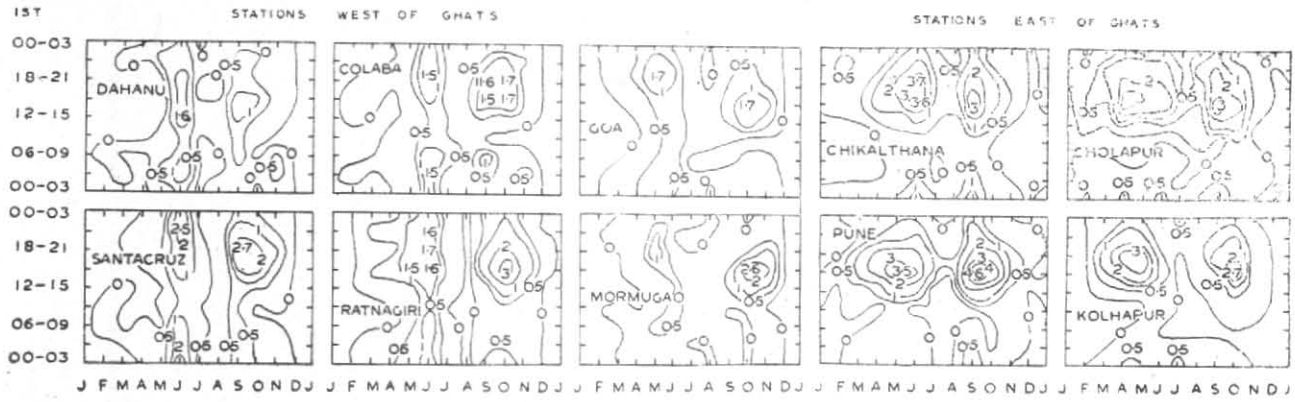

Fig. 2. Diurnal variation of thunderstorms (Time in IST)

21-24 IST. The average frequency of incidence of thunderstorms of each three hourly interval is presented for each month of the year and for all the 10 stations. The isoceraunics lines, *i.e.,* lines of equal frequency of thunderstorms have been drawn and the same is shown in Fig. 2, which represents the diurnal variations of thunderstorm frequency. The essential features of the diagram are given below :

(a) There are two maxima of thunderstorm frequencies in a day during June (12-21 and 03-09 IST) at Dahanu and in September (15-21 and 06-09 IST) at Colaba. The frequencies lie between 1 and 2. The two maxima in a day are not seen at any other stations.

(b) Amongst all the stations under study, the highest frequency occurs to the east of Ghats at Pune in September during 15-18 IST of the day and is between 4 and 5. To the west of the Ghats, Ratnagiri has the highest frequency of 3 occurring during the same period of day in October. The other noticeable frequencies of 2.7 and 2.6 are found at Santacruz (September) during 18-21 IST and at Mormugao (October) during 15-18 IST, of the day respectively.

(c) The thunderstorm frequency is between 0-0.5 at all hours of a day during July and August, at all the stations, to the west of the Ghats. To the east of Ghats, it is between 0.5 & 1.0 at some hours of a day during afternoon and midnight of the same months at the stations, Chikalthana, Pune and Sholapur. The thunderstorm frequency at Kolhapur is between 0 & 0.5 during July and August.

(d) The frequency of occurrence in winter months are nearly zero during all hours of a day at the stations except at Chikalthana and Sholapur where frequency is 0.5 in February and thunderstorms occur during 21-00 and 15-18 IST of the day in February at Chikalthana and Sholapur respectively.

4. Conclusions

(1) Annual frequency of thunderstorms is greater to the east of the Ghats than to the west.

(2) To the east of the Ghats, central parts of Maharashtra get maximum number of thunderstorms, the frequency decreasing both to the north and to the south.

(3) Along the west coast, Santacruz and Ratnagiri have maximum annual frequency which is smaller than that of all the stations to the east of the Ghats. The frequency decreases rapidly to the north of Bombay.

(4) All stations show a double maxima in their annual variation, one at or before the onset of monsoon and the other towards the end or after the monsoon. The maxima are steep along the west coast while to the east of the Ghats, they are flat.

(5) Along the coast, thunderstorms of longer duration are mostly confined to the central parts. In the interior, the duration of thunderstorm increases progressively from south to north.

(6) To the east of the Ghats the frequency of thunderstorm is maximum during the period 15 to 21 IST both during pre-monsoon and post-monsoon seasons.

(7) To the west of the Ghats at or prior to the onset of monsoon, almost all the 24 hours of a day are prone to thunderstorm activity. However, a double maxima from 1200 to 2100 IST and 0300 to 0900 IST are observed at Dahanu while at all other stations there is a single maximum towards late evening and night, *i.e.*, between 18 & 24 IST. During post-monsoon season, the maximum is generally in the afternoon hours.

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