Prediction of maximum temperature over Bhopal

D. P. Dubey and M. L. Kanojiya*
Meteorological Centre, Bhopal
**Regional Meteorological Centre, Nagpur*

ABSTRACT

Daily Maximum Temperature of Bhopal for four Summer months i.e. March, April, May and June has been studied for the year 1990 to 2000. The temperature changes from the previous day and departure from normal were also calculated. Depending upon their ranges, they are classified as per the standard meteorological convention. The frequency of occurrence of each category has been worked out for these months. Also monthwise percentage departure from normals of those cases where temperature either continuously fell or rose or did not change for more than one day have been documented separately. The result indicates that in case of changes. "Little change" together with "No change" predominates and accounts for 64% of the cases. It is also observed that for all the months, there is a gradual fall in the frequency of these categories as the magnitude of variation of maximum temperature increases. Five regression equations based on data for the period 1990 to 1996, were developed for forecasting daily maximum temperature over Bhopal. The results have been verified for the year 1997 to 1998 for April and May which indicate that estimated values are very close to the actual.

Keywords :

1. Introduction

The daily changes in the maximum temperature and its trend during summer months are of immense importance as the general public is greatly concerned with these changes. The variation of maximum temperature over Bhopal has been studied by Dubey and Balajrishnam[1] based on the data from 1977 to 1987. Raghvan[2] and Bedekar *et al.*[3] studied the climatological aspects of heat waves over India. It is observed that the number of cases of heat waves over Bhopal are very few except in the month of June but for issuing local forecast the variation in maximum temperature are very important to improve the accuracy of local forecast, the best way is to study the behavior of the parameters over the station. In this study the maximum temperatures data of Bhopal for last eleven years for the summer months were collected and the changes classified under different scales of magnitude were also calculated. The attempt also has been made to explain the changes more that 4°C with the prevalent situations on those days. Recent report of the Inter-governmental on climate charge has shown that last 11 years since 1995 rank among the 12 warmest years since 1750. As advance knowing of temperature is of immense importance and useful in agriculture as well human comforts etc. hence attempt has been made to predict the maximum temperature daily on the basis of past meteorological data i.e. the dry bulb and dew points temperatures at 0830 hrs. (IST) of same day.

2. Data and Methodology

(i) The daily maximum temperature data of Bhopal for the period of 1990 to 2000 for summer months of March to June was collected from Daily Weather Report. The changes in maximum temperatures were calculated with respect to the previous days value and were tabulated. These changes were then classified accordingly to their magnitudes based on the standard meteorological convention given by India Met Dept.

The changes of a particular magnitude for a particular month were counted and tabulated. This analysis was repeated for the months from March to June. The total number of percentage of cases "No change" "Little change" fall rise, fall appreciable, rise appreciable, fall markedly and rise markedly were counted and presented in Table 3. In individual cases where temperature changes 4°C or more in magnitude, the synoptic situations were examined for offering the proper explanation.

TABLE 1

The actual computed and difference in daily, maximum temperature of Bhopal for April and May for the year 1997 and 1998

Date	April 1997			May 1997			April 1998			May 1998		
	A	C	D	A	C	D	A	C	D	A	C	D
1	33.7	35.5	1.8	34.3	37.7	–3.4	36.4	37	–1	40.8	39.5	1.3
2	31.2	33.4	–2.2	35.6	37.1	–1.5	38.9	37.6	1.3	41.2	39.5	1.7
3	29.2	34	–4.8	37	38	–1	39.8	37.7	2.1	41.6	40.4	1.2
4	31.2	32.6	–1.4	35.7	36.9	–1.2	37.6	37.9	0	41.2	40.1	1.1
5	33.2	35.2	–2	35.1	37.2	–2.1	38	37.1	0.9	42.4	40.2	2.2
6	33.8	34.1	–0.3	35.8	38.1	–2.3	39.8	38.8	1	41.6	41.1	0.5
7	34.8	38.1	–3.3	38.5	39.2	–0.7	40	38.6	1.4	42.1	40.9	1.2
8	36.6	37.6	–1	38.5	39.2	–0.7	38.4	37.3	1.1	40.9	41.8	–0.9
9	35.7	36.6	–0.9	38.8	38.1	0.7	36.5	36.9	0	40.1	40.6	–0.5
10	36.1	36.2	–0.1	39.4	40	-–0.6	36.1	34.8	1.3	37.6	37.1	0.5
11	36.8	38	–1.2	40.7	39.7	1	38.1	36.8	1.3	38	40.9	–2.9
12	36.1	36.2	–0.1	40.4	39.4	1	37	37.2	0	39.8	39.5	0.3
13	37.2	37.4	–0.2	39.9	39.5	0.4	37.2	37.1	0.1	40.2	40.1	0.1
14	37.3	36.7	0.6	40	39.6	0.4	38.4	37.6	0.8	41.6	42.1	–0.5
15	36	36.9	–0.9	40.8	40.5	0.3	37	36.1	0.9	42.6	41.4	1.2
16	36.1	36.6	–0.5	40.1	39.9	0.2	38.1	36.7	1.4	43.3	41.6	1.7
17	36.8	37.3	–0.5	40.4	41.2	–0.8	38.7	38.1	0.6	42.8	41.6	1.2
18	38.2	37.8	0.4	41	41.5	–0.5	38.6	38.8	0	42.6	41.3	1.3
19	36.4	37.4	–1	41.9	39.7	2.2	39.2	37.1	2.1	43.6	40.1	3.5
20	36.6	37.8	–1.2	39.5	41.8	–2.3	39.1	38.8	0.3	43.2	42.1	1.1
21	37	37	0	38.4	39.6	–1.2	38	38.2	0	44.1	42.7	1.4
22	38.8	37.1	1.7	39.1	38.6	0.5	39.5	38.1	1.4	45	42.7	2.3
23	39.4	39.9	–0.5	40.6	40	0.6	39.7	39.3	0.4	44.6	44.3	0.3
24	40.1	39.8	0.3	40.8	39.8	1	39.8	39.9	0	43.6	42.6	1
25	39.7	39.5	0.2	41.1	39.9	1.2	40.6	40.4	0.2	44.2	42.3	1.9
26	39.7	40.6	–0.9	41.6	41.3	0.3	40	40.7	–1	44.6	42.7	1.9
27	38.4	39.5	–1.1	41.6	41.3	0.3	39	41.1	–2	44	41.7	2.3
28	35.4	36.7	–1.3	40.9	40.8	0.1	36.5	36.9	0	45	42	3
29	35.3	34.7	0.6	39.8	40.2	–0.4	40.2	40.6	0	42.6	41	1.6
30	36.4	36.3	0.1	38.8	39.9	–1.1	40.2	39.6	0.6	41.9	42.1	–0.2
31				38	38.8	–0.8				42.3	44.2	–1.9

A -Actual C - Computed D - Departure

TABLE 2

Actual percentage of accuracy of ranges

Year	April				May			
	(a)	(b)	(c)	(a)+(b)	(a)	(b)	(c)	(a)+(b)
1997	40	40	20	80	32	52	16	84
1998	40	50	10	90	26	35	39	61

a = -0.5 to 0.5 b = +0.6 to 1.5 c = c1.5

(ii) Table 2 indicate departure from normal of different magnitudes classified as per the Meteorological convention given by India Met. Dept. The values of the individual months are tabulated against the ranges in percentage. This include data of all the eleven years for the months indicated.

TABLE 3

Percentage variation of changes of maximum temperature over Bhopal under different magnitude for March to June

Month	Types of changes							
	No change	Little change	Rise	Fall	Appr. rise	Markedly rise	Fall appr.	Markedly fall
March	18.7	39	24.7	3.3	0.7	12	3	1.3
April	31.8	44.9	11.5	0.9	—	7.6	1.8	0.3
May	29	51.3	4.7	0.6	—	7.9	1.2	0.3
June	22.4	38.5	16.7	1.2	0.3	13	5.8	2.1

(iii) It is interesting to note that persistency account higher frequency of occurrence of particular phenomena. To study this, the maximum temperature has been divided into three categories viz. ' No change', rise or fall. The term rise indicate the cases where the next day value is higher than previous day value by 2°C or more while "No change" is ±1°C from the previous day. Analysis of data based on this principle is carried out and individual days of such occasions are counted. All the cases for the same month for different years under each category were summed up and percentage is calculated. Results are given in Table 3 which gives percentage number of continuous days on which maximum temperature either does not change, rise or fall continuously.

The five regression equations for prediction of maximum temperature based on data for the period 1990 to 1996 were developed which are estimated below.

(A) when dew point Td Td is >=20°C

Tmax = 1.82 t +.7 Td Td –31

(B) when dew point Td Td >= 15°C but < 20°C

Tmax = .68T + .05 Td Td + 18.95

(C) when dew point Td Td < 15°C but >= 10°C

Tmax = .58 T + .1Td Td + 22.44

(D) when dew point Td Td < 10°C but >= 5°C

Tmax = .5T + .04TdTd +14.4

(E) when dew point Td Td is < 5°C but >= 5°C

Tmax = .34 T = .4 TdTd + 28.5

Where Tmax is the estimated maximum temperature T is the dry bulb temperature at 0830 (IST) and Td is the dew point temperature at 0830 hrs (IST) (all in °C). The above regression equations were verified for 1997 and 1998 for the month of April and May. Table 1 shows the actual and computed values for the months of April and May 1997 and 1998 & Table 2 indicate actual percentage of accuracy of values of ranges

(a) –0.5 to 0.5 (b) 0.6 to +1.5 and (c) >1.5

3. Discussion of results

(i) Percentage of changes of maximum temperature of Bhopal shown in Table 3, indicate that cases of 'little change' predominate increase from 39% in March to 45% in April and 51% in May and rapidly falls to 39% in June "No change" is next to "little change" in the frequency spectrum. It is also seen that 'Little change' and 'No change' together constitutes nearly two third in each month. Rise is next category after 'No change'. It is also observed that from the month March to May there is gradual fall in the frequencies while increase is noticed in June. In the case of appreciable rise, frequencies also follow the same trend. It is noted that in the above table, there are large number of cases in the month of March when the increase in daily temperature more that 2 °C recorded. The rise recorded in two cases, one in March and another in June. This is examined in a general way to the fact that heating at higher rates takes place for more number of days in March comparatively less in April and least in May. Higher rate of heating in the month of June as compared to the previous months can be examined in the following way. The Geographical location of Bhopal is unique. It lies on the tropic of cancer and close to the Northern limit of the sun for large number of days giving extensive heating by direct solar radiation.

It is also found that whenever there is cyclonic circulation over southeast Madhya Pradesh in the lower tropospheric levels there is a maximum temperature of order of 4°C over Bhopal with more northerly locations of the systems. The increase of maximum temperature by as much 6°C observed in these cases (Dubey and Balajrishnam)[1].

(ii) Table 4 represents number of cases of maximum temperature departure from normal over Bhopal from March to June. It is found that in all the four months, nearly normal occupies the highest percentage frequency. The case of above normal takes second place in percentage frequency spectrum. In the case of appreciable above normal a fall trend from March to May and rise in June is seen. The cases of 'Moderate heat waves' are maximum in June with 4.2 and 1.3 in March 3 in April and 3.2 in May. The cases of 'below normal' and appreciably below normal' are less as compared to the corresponding figures for their positive counter part. Number of cases where the departure in temperature are –6°C or less are more as compared to the positive values. The case of markedly below normal are exceptionally high in the month of June. The study of Dubey and Balajrishnam[1] revealed that prior to the onset of monsoon, whenever the station is under the influence of western disturbances, the fall in the temperature of the order of 6°C takes place. The same fall is notices at time of onset of monsoon as well as when the station was under the influence of monsoon depression or other well marked systems.

TABLE 4

Percentage number of cases of departure of maximum temperature of very in steps over Bhopal for March to June

Month	No change	Nearly normal	Above normal	Appr. above normal	Markedly above normal	Blow normal	Appr. below normal	Markedly below normal	Markedly below normal(>-6C)
March	10	28	27.3	10.3	1.3	15	7.7	2.1	1
April	17	31.8	26.1	8.8	0.3	16	4.3	0.3	--
May	15	32.8	23.7	4.4	3.2	14	6.7	2.1	1
June	10	24.2	19.1	8	4.3	15	11.8	6.4	2.9

(iii) Table 5 shows that for all the four months and for all the three types of changes, there is a gradual fall. The changes for one day account of nearly 75% of the cases. The cases lasting two days account are 21%. The changes lasting for one or two days together account for 96% of the cases.

(iv) Table 1 shows the actual and computed values for the month April and May 1997 and 1998. Table 2 gives the actual percentage of accuracy for the ranges –0.5 °C to 0.5 °C , 0.6 to 1.5 and >+1.5 °C for the April and May 1997 and 1998. It may be noted that there is a very good agreement of 80% in April 1997, and 84% in May during 1997 and 90% in April 1998. However May 1998 shows accuracy 61%.

TABLE 5

Percentage number of cases "No Change", Rise and fall that last for one day or more

Month	1	2	3	4	5	6	7	8
				No Change				
March	13	4	1	0.7	--	--	--	--
April	20.6	7	3.3	0.6	0.3	--	--	--
May	27.9	6.5	2.1	0.3	--	--	--	--
June	16.1	3	0.3	---	--	--	--	--
				Rise				
March	22	13	7.3	4	3.3	1.3	0.3	--
April	24.2	7.6	3.9	1.8	0.6	0.3	--	--
May	20.8	16.7	1.8	--	--	--	--	--
June	18.7	7	3.3	1.2	0.6	--	--	--
				Fall				
March	19	9.3	3	1	0.3	--	--	--
April	19.4	6.1	1.8	0.6	--	--	--	--
May	18.8	7.6	1.8	0.6	--	--	--	--
June	19.7	7	3	--	--	--	--	--

4. Conclusion

The maximum temperature are mostly found in the category of 'No change' or 'little change'. It is noticed that the fall in temperature occurs when the station is affected by Western disturbance or if it is under the influence of monsoon depression or other well marked weather systems from Bay of Bengal. Percentage number of cases heat waves recorded over the station are very few in April (0.3) and few in March (1.3) high in May and June (3.2) and (4.3) respectively. The cases of departure nearly normal and above normal' accounts 40-55%. For prediction of maximum temperatures over Bhopal, five regression modes have been developed and verified. The actual and computed for the months April 1997 and 1998 showed very agreement of 80% in April 1997, 84% in May 1997, 90% in April 1998 and 61% in May 1998.

Acknowledgement

The authors express their gratitude to the Deputy Director General of Meteorology, R.M.C. Nagpur for the constant encouragement. They are also thankful to Wahid Khan and Ku. Surabhi Purohit for neatly typing the manuscript.

References

1. Dubey D.P., and Balajrishnam, T.K., 1989 Mausam, 40, 4, pp 530-534,
2. Raghwan, K. 1966 Indian J.Met., Geophys 17, 4, pp 581-586.
3. Bedekar, V.C., Decade, M.V. and Beneregee, A.K., 1974, Forecasting manual part IV, 6, India Meteorological Department.

Salient features of pre-monsoon season rainfall over Gangtok

T. P. Singh, Virendra Singh* and R. K. Giri*
India Meteorological Department, Pune
**India Meteorological Department, New Delhi*

ABSTRACT

In this paper, an attempt has been made to analyse statistically pre-monsoon rainfall activity over Gangtok during the period (1983-1992) with the help of hourly collected data of Tadong observatory (Lat. 27^0 20´N, Long. 88^0 38´E and altitude 1322 m. a s l). It has been observed that hourly rainfall sharply increases from afternoon to early night and decreases from night to late morning hours. The almost same type trends are found in rain duration, rain events, rain intensity and average rain amount parameters. The probability of occurrence of rain in chronological hours varies from 3% to 23% with minimum at 1100 IST and maximum at 1800 IST. The convective and cooling phenomenon in afternoon to early night at this hill station can be considered to be more probable for maximum rain.

The seasonal averages for pre-monsoon period are worked out for one decade. The mean hourly rainfall for each month March to May are analysed. The variation in highest and lowest monthly total rainfall from monthly normal is also discussed. By applying Gumbel distribution, the return period of one- day highest record rainfall 176 mm in pre-monsoon season for Gangtok is found to be 31 years.

Key words : *Pre-monsoon, rainfall, diurnal variation, probability and return period.*

1. Introduction

Pre-monsoon (March to May) season is second rain producing season for northeastern region of India as a result of dominant thunderstorm activities associated with moisture over hilly regions. During this season, convective and moisture processes play a very significant role to give accountable amount of rainfall in hilly states. Gangtok is situated at hill, along the valley and near the Kachanjunga Mountain where orographic effects play dominant role in the occurrence of rain in pre-monsoon season. Gangtok is an important tourist and industrial place of hilly state Sikkim. In view of tourism the period of pre-monsoon is very crucial time so that the study of rainfall during this period is very useful in proper planning for drinking water, hydrological projects in power generation, agriculture and industry. A number of studies exist relating to the diurnal variation of rainfall at Indian stations by Iyer and Das[1], Prasad[2], Ananthakrishan and Rajan[3] and Puri *et al*[4]. Statistical analysis of daily maximum and monthly rainfall has been done by Bhadram *and Narayanaswamy*[5] and Unkasevic *and Radinovic*[6].

Gangtok has two class 1 Meteorological observatories viz. Tadong and Rajbhavan. An attempt in this study has been made by using the rainfall data of Tadong (Lat. 27^0 20´ N, Long. 88^0 38´ E and altitude 1322 m.a s l). It has normal annual rainfall 3059 mm of which 807 mm i.e. 26.4 % of annual rain is received in pre monsoon season (1st March to 31st May).

2. Data and methodology

Hourly rainfall values data of each day of one decade (1983-92) during pre-monsoon season were obtained from hyetograms .The day is divided into 24 chronological hourly intervals (00-01, 01-02, ----------------23-24 IST) which are designated as H_1, H_2, -------------------H_{24}. The rain amount r (mm) and rain duration t (min) are estimated for each hour from records corrected to 0.1 mm and 1 minute respectively. Suppose r_1, r_2, --------- r_n be rain amount and t_1, t_2, --------------- t_n the rain durations associated with the rain events n. Rain occurring within any chronological hour is called rain event. The rainfall commences during chronological hour and extends into the subsequent hours or hours without break, it is considered as separate rain events for the chronological hours, which the rain spell extends. For the pre monsoon period of 92 days, the number (n_k) of rain events for any chronological hour H_k is equal or less 92 (for the 10 years period considered in the present study n_k £ 920). Some statistical parameters are to define;

$$\sum_{i=1}^{n_k} r_i = A_k\text{, the total rain amount for the hour } H_k$$

$$\sum_{i=1}^{n_k} t_i = D_k\text{, the total rain duration for the hour } H_k$$

$$\frac{A_k}{D_k} = I_k\text{, the average rain intensity for the hour } H_k$$

$$\frac{A_k}{n_k} = \text{the average rain amount during the hour}$$

$$\frac{D_k}{n_k} = \text{the average rain amount during the hour}$$

$$\frac{n_k \times 100}{92 \times 10} = P_k\text{, the average probability of occurrence of rain during the hour } H_k$$

Similarly, the following parameters for seasonal total can be defined as below ;

$$\sum_{k=1}^{24} A_k = A\text{, total seasonal rain amount}$$

$$\sum_{k=1}^{24} D_k = D\text{, total seasonal rain duration}$$

$$\sum_{k=1}^{24} n_k = N\text{, total number of rain events in the season}$$

A/D = I, the average seasonal rain intensity

A/N = seasonal rain amount per rain event

D/N = seasonal rain duration per rain event

$$\frac{100\,N}{92 \times 24} = P\text{, seasonal mean probability of rain occurrence per chronological hour.}$$

3. Results and discussions

The statistical parameters classified in above Para from 10 years hourly series for different hours of the day are presented in Table 1. From Table 1 it is seen that the total hourly rainfall (A_k) sharply

TABLE 1

Chronological variation in rainfall parameters

Hour (IST)	Rainfall A_k (mm)	Rain duration D_k(hr)	Rain event n_k	Average Rain Intensity I_k (mm/hr)	Average rain amount during hour, A_k/n_k (mm)	Average rain duration during hour, D_k/n_k (min)	Probability (%)of rain during hour, P_k
01	461.7	37.8	158	12.2	2.9	14.3	17
02	468.9	35.5	152	13.2	3.1	14.3	16
03	303.2	28.1	130	10.7	2.3	13.0	14
04	301.4	25.0	94	12.1	3.2	16.0	10
05	236.7	22.9	92	10.3	2.6	14.9	10
06	198.4	20.1	82	9.9	2.4	14.7	8
07	187.2	19.2	81	9.7	2.3	14.2	8
08	156.0	18.3	70	8.5	2.2	15.7	7
09	71.3	10.2	38	7.0	1.9	16.1	4
10	32.4	6.4	40	5.1	0.8	9.6	4
11	34.9	6.2	35	5.6	1.0	10.6	3
12	46.5	6.0	43	7.7	1.1	8.4	4
13	86.2	11.3	50	7.6	1.7	13.6	5
14	159.3	15.4	85	10.3	1.9	10.9	9
15	255.6	24.0	115	10.7	2.2	12.5	12
16	413.5	32.5	157	12.7	2.6	12.4	17
17	596.9	37.9	184	15.7	3.2	12.4	20
18	619.1	41.2	215	15.0	2.9	11.5	23
19	660.8	44.8	203	14.7	3.3	13.2	22
20	785.3	44.6	189	17.6	4.1	14.1	20
21	603.2	39.7	180	15.2	3.3	13.2	19
22	652.0	39.6	175	16.5	3.7	13.6	19
23	500.9	37.0	171	13.5	2.9	13.0	18
24	497.4	41.9	165	11.9	3.0	15.2	17

increases from afternoon (1500 IST) to early night (2000 IST), whereas it decreases from night to late morning hours. The 75 percent rain of a day occurs between 1500 IST and 0200 IST. The hourly rainfall is maximum i.e. 785.3 mm at H_{20} (1900-2000 IST) and minimum i.e. 32.4 at H_{10} (0900-1000 IST). The almost same type trends are seen in rain duration (D_k), rain events (n_k), average rain intensity (I_k) and average rain amount parameters. The maximum value of rain duration is observed as 44.8 hour at H_{19} and minimum value is 6.0 hour at H_{12}. The rain event is maximum at H_{18}, where it is 215. The minimum value of rain event is 35 at H_{11}. The hourly average rain intensity is maximum 17.6 mm/hr at H_{20} and other maxima of magnitude 16.5 mm/hr at H_{22}. The minimum intensity is of magnitude 5.1 mm/hr at H_{10}. The average rain amount in chronological hour is maximum at H_{20} where it is 4.1 mm, whereas the lowest value is of the order of 0.8 mm at H_{10}. There is no much variation in average rain duration chronological hours. The maximum value of the average rain duration is 16 min at H_4 and H_9, while its lowest value is 8 min at H_{12}. The probability of occurrence of rain in chronological hours varies from 3% to 23%. It is maximum i.e. 23% at H_{18}, whereas the lowest value (3%) is at H_{11}.

The above features of diurnal variation in this seasonal rainfall are usually associated with thundershowers which mostly develop in the afternoon are often continued into early night at the station. Katabatic winds generally produce a low level convergence and increase the convective activity. Radiation cooling at the top of the cloud further accentuates the convective activity to increase a tendency of rainfall. In a general convective and cooling phenomenon in afternoon to night can be considered to be more probable for maximum rainfall.

The seasonal averages for pre monsoon period for one decade (1983-92) are as follows;

Average pre-monsoon rain duration	65 hours
Average seasonal rain events	290
Average seasonal rain intensity for chronological hour	11.4 mm/hr
Average seasonal rain for chronological hour	2.5 mm
Average seasonal rain duration	13 min
Average seasonal probability of occurrence per chronological hour	13%

Mean hourly rainfall have been worked out for each month March to May and are graphically shown in Figs. 1(a-c). From these hourly rainfall variation patterns in month, it is seen that the maximum rainfall during 24 hours generally occurs in evening or early night. In the month of March the maximum rainfall is found between 1600 IST and 2100 IST. While in April and May there are two maxima. In April maximum rain occurs from 1500 to 2000 IST and 2100 - 2200 IST. In the month of May one maxima of magnitude of 51 mm is found in 1900 - 2000 IST, While another is of less magnitude, i.e. 42 mm in 2100 - 2200 IST. It is also seen that the magnitude of mean hourly rainfall is higher in the month of May.

Mean monthly, highest and lowest monthly totals rainfall, percentage departure from normal and year of occurrence during pre monsoon season in two decade period (1979-1998) are given in Table 2. The lowest monthly total rainfall in March was recorded 2.5 mm i.e. 98% less of its normal value, in the year 1979, whereas the highest total rainfall was received 228.1 mm i.e. 103% more of its normal value, in 1994. In the month of April, the percentage departure of highest total and lowest total rainfall from normal value are +62 in 1984 and -74 in 1989 respectively. In May, the highest total rainfall was recorded 890.6 mm in the year 1996, which is 103% more of its normal value 438.3 mm. However, the lowest the total rainfall was received 237.4 mm i.e. 46% less of its normal, in 1986. The variation in monthly total rainfall is order of high magnitude in the month of May.

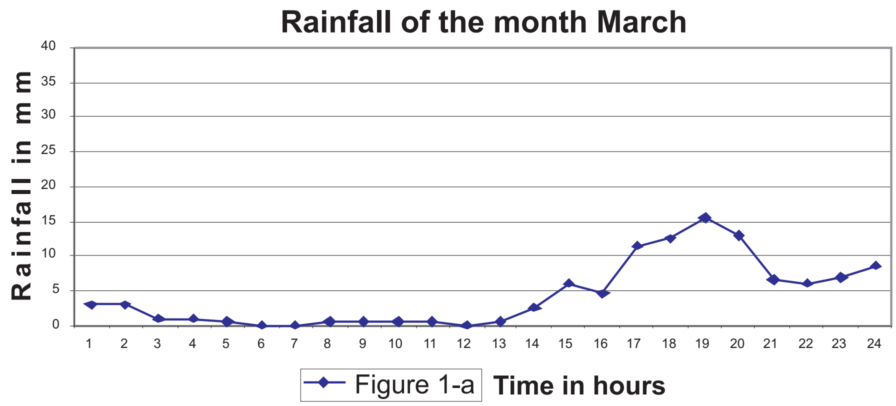
Further more, the highest pre monsoon seasonal rainfall was recorded 1303.7 mm in the year 1996 whereas the lowest seasonal rainfall was received 520.3 mm in 1989. These values are 61% more and 35% less of normal value (807mm) respectively.

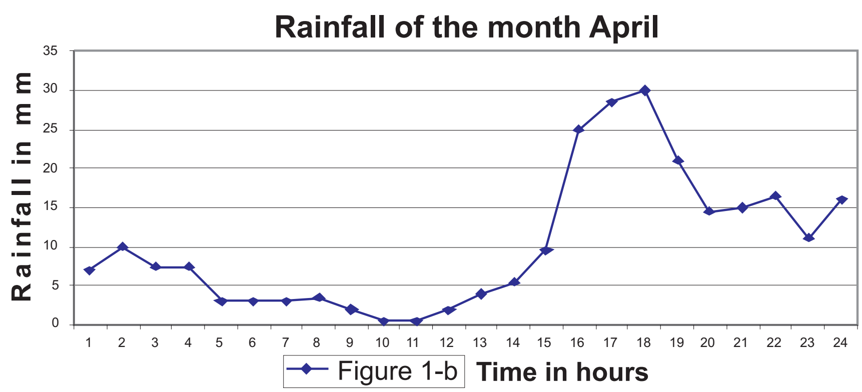
3.1. Return period analysis

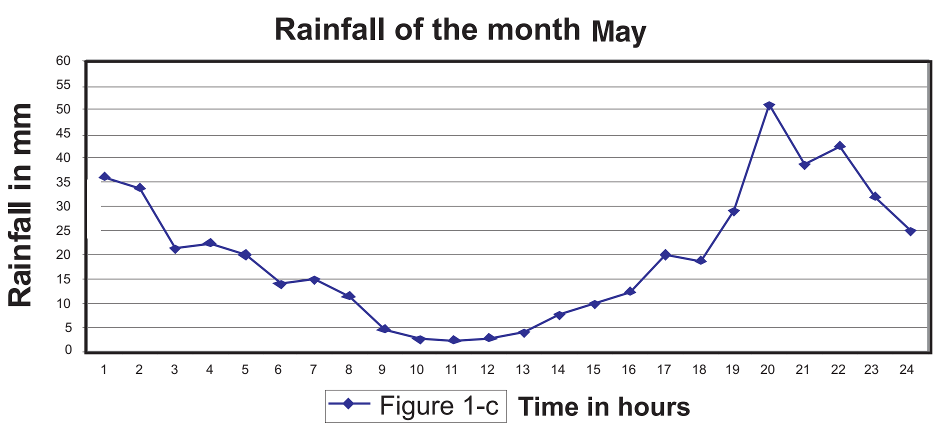
One- day highest record rainfall during pre monsoon season for the period 1979-1998 is 176 mm on 7th May, 1983. The return period estimates of 24-hour peak rainfall are computed by applying Gumbel distribution. According to Gumbel[7], the cumulative probability that any extreme value will be less than the given quantity 'x' approaches the double exponential expression given by

$$Q(x) = \exp[-\exp\{-a-(x-u)\}] \quad (1)$$

$$= \exp[-\exp(-y)],$$







Figs. 1 (a-c).

TABLE 2
Mean and extreme monthly rainfall (mm) totals

Month	Normal	Highest amount	% Departure	Year	Lowest amount	% Departure	Year
March	112.1	228.1	+103	1994	2.5	-98	1979
April	251.2	407.6	+62	1984	65.2	-74	1989
May	438.3	890.6	+103	1996	237.4	-46	1986

Where, $y = a(x-u)$

Or $x = u + y.1/a$ (2)

In which y is known as reduced variate, u is mode of the extremes and 1/a is equal to 0.7796968 times the standard deviation of the extremes 'x' i.e. extreme maximum rainfall. Equation (2) can be written as

$$x = A + By \qquad (3)$$

Where, A and B are parameters. These are estimated by the method of least squares.

The return period (T) of an extreme rainfall value equal to or exceeding 'x' is given by

$$T = \frac{1}{1 - Q_{(x)}} \qquad (4)$$

The extreme values of one-day rainfall for different return periods are computed by applying the above distribution and presented in Table 3. From the above analysis, the return period of highest 24-hour recorded rainfall 176 mm during pre monsoon season is 31 years.

TABLE 3
One-day rainfall estimates (mm) for different values of return period

Return period (T) in Years	Rainfall estimate (X) in mm
5	123.0
10	144.0
25	170.7
50	190.4
100	210.0

4. Conclusions

(i) Hourly rainfall at Gangtok sharply increases from afternoon (1500hrs. IST) to early night (2000hrs IST) and decreases from night to late morning hour during the pre-monsoon season. The feature of rainfall is mostly associated with thundershowers which develop in the afternoon to early night as result of orographic effect. Convective and cooling phenomenon in afternoon to night can be considered to be more probable for maximum rainfall.

(ii) Mean hourly rainfall in each month March to May is maximum in evening and early night. The mean hourly rainfall is high in the month of May.

(iii) During the pre-monsoon season, the lowest monthly total rainfall recorded 2.5 mm in March of the year 1979 while highest monthly total rainfall occurred 890.6 mm in May of the year 1996. The variation in monthly total rainfall is order of high magnitude in the month of May. Pre-monsoon seasonal highest rainfall was recorded 1303.7 mm in the year 1996. The rain in month May has significant contribution in pre-monsoon season rainfall.

(iv) The return period of 24-hour peak rainfall 176 mm in pre-monsoon season for Gangtok is found to be 31 years.

Acknowledgements

Authors are thankful to Director General of Meteorology to accomplish the study. Authors are also thankful to Sh. Thakur Prasad, DDGM(C) and Sh. P.K.Sharma, A.M. for providing valuable suggestions in preparation of manuscript.

References

1. Iyer, V.D. and Das, I., 1946, 'Diurnal variation of rainfall at Mahabaleshwar', India Met. Dep. Sci. Note, 9 pp 35-42.
2. Prasad, B., 1970 'Diurnal variation of rainfall in India', Indian J. Met. & Geophys., 21, pp 443-450.
3. Ananthakrishnan, R. and Rajan, C. K., 1987, 'Some features of the southwest monsoon rainfall of Cochin and Minicoy', J.Climatol., 7, pp 355-372.
4. Puri, S.R., Duggal, Y.M., Lal, B., and Rajanikant, 1994, 'Some features of hourly rainfall during southwest monsoon season at Delhi', Mausam, 45,1,pp 35-42.
5. Bhadram, C.V.V. and Narayanaswamy, R.,2000, 'Rainfall over Hyderabad- A Climatological study', Vayu Mandal, 30, 1-2, pp 27-31.
6. Unkasevic, M. and Radinovic, D., 2000, 'Statistical analysis of daily maximum and monthly precipitation of Belgrade', Theor. Appl. Climato., 66, pp 241-249.
7. Gumbel, E. J., 1958, 'Statistics of extremes', Columbia University Press, New York, p 375.

Climatological study of thunderstorm/duststorm over major airports of Rajasthan

R.C. Vashisth and S.C. Bhan
Regional Meteorological Centre, New Delhi

ABSTRACT

A climatological study of duststorms/thunderstorms has been presented in the paper using data of Jodhpur, Jaipur, Kota and Udaipur airports for the period 1981-90. The study reveals that maximum thunderstorms occur in the month of July and August but duststorms are maximum in the month of May and June. There is no significant difference in diurnal variation as maxima for both lies between 0900-1200 UTC. The study further reveals that the life span of duststorms is much shorter than that of thunderstorms. There is no case of duststorms at Udaipur during the period of study.

Key words : *Thunderstorm-TS, Duststorm-DS, Sandstorm-SS, Climatology, Frequency, Current Weather Register-CWR and Monthly Meteorological Register-MMR.*

1. Introduction

Thunderstorm / duststorm is a mesoscale phenomenon and is a manifestation of convective instability in the atmosphere. On many occasions, they remain undetected on synoptic weather charts. Thunderstorm activity over Punjab, Haryana and Rajasthan in northwest India is more pronounced in pre-monsoon and monsoon seasons. Duststorms are most common in Rajasthan and occur during pre-monsoon months when the moisture is insufficient. The occurrence of duststorm/sandstorm/dust raising winds in the state is associated with pressure gradient and large convective instability over the region. DS/TS are the most common hazards for aviation. At the time of occurrence of duststorm/sandstorm over a particular area, the visibility reduces considerably (sometimes less than 100m), paralysing all aviation and other human activities. This phenomenon over northwest India is also commonly known as ANDHI.

The characteristics of thunderstorm over different parts of the country have been studied by Sen and Basu[1], Raman and Raghavan[2], Vishwanathan and Faria[3] and Krishnamurty[4]. Joseph, *et al.*[5] studied 40 cases of Andhi at Delhi Airport during the period 1972-77.

The informations about Climatology of thunderstorm/duststorm are useful aid to the aviators and weather forecasters. The climatological features of thunderstorm/duststorm over major airports of Rajasthan viz. Jodhpur, Jaipur, Kota and Udaipur (Dobak AP) for the period 1981-1990 have been presented here.

2. Data used

The data for the period 1981-1990 from the current weather registers and Monthly Meteorological Reports of respective stations available at Meteorological Centre, Jaipur have been used for the study.

3. Results and discussions

3.1. Seasonal distribution

The frequency of occurrence, commencement and duration of thunderstorm/duststorm have been analysed statistically for Jodhpur, Jaipur, Kota and Udaipur (Dabok AP) for the period 1981-1990. Table 1 indicates month & season wise distribution of TS/DS days. Analysis of data shows that thunderstorm activity continues to occur throughout the year. It increases from April to August attaining a maxima in August (on an average 6 days in Jodhpur, 9 days in Jaipur, 7.8 days in Kota and 4 days in Udaipur). From the month of September when the monsoon starts withdrawing, the thunderstorm activity decreases. It becomes insignificant during November-December (one day or less in each month) due to dry continental wind flow pattern over the state. During January month, some thunderstorm activity is seen which increases slightly in February in association with western disturbances. The build up of solar insolation starts from March onwards over northwest India. Thunderstorm activity continues to increase from April onwards and reaches maximum in the month of August as monsoon covers the entire state. On an average, the yearly thunderstorm days (Table1) are 33.9 at Jaipur, 30.1 at Kota, 28.6 at Jodhpur and 15.5 at Udaipur.

Duststorms are mostly observed in pre-monsoon season contributing 55- 60% of the annual value over Jodhpur, Jaipur and Kota (Table1). May month has highest incidence of duststorms (34%) followed by April (16%). Duststorms are also seen significantly during June (30%) and July (6-7%) in monsoon season.. These cases of duststorms in the month of July are confined to the years when onset of monsoon is delayed and dry weather continues to prevail upto middle of July in the state. There is no case of duststorm/sandstorm at Udaipur airport during 1981-90. No occurrence of duststorms are seen at Kota during August and September.

On comparison of Table 1 & 2, it is evident that during a day there are occasions of one or more TS/DS events as the number of TS/DS days are less than the frequency of total TS/DS.

Maximum number of thunderstorm days and frequency are in monsoon season(65-70%), followed by pre-monsoon(20-25%). Duststorms are significant in pre-monsoon (nearly 60%), followed by monsoon season(nearly 35-40%). During post monsoon season rare occurrences of duststorms are seen at Jaipur only. Jodhpur and Kota do not experience duststorms in post-monsoon season.

3.2. Diurnal variation

Figs.1(a & b) shows the frequency distribution of commencement of thunderstorm/duststorm during a day at 3 hourly intervals(viz. 0000-0300, 0300-0600, ... 2100-2400 UTC). Thunderstorm activity is significant during 0600-1500 UTC with its maxima during 0900-1200 UTC. It is found that about 28% of the TS at Jodhpur and Jaipur, 39% at Kota and 53% at Udaipur commence during 0900-1200 UTC. About 15-20% of thunderstorms originate between 0600 & 0900 UTC and 1200 & 1500 UTC except over Udaipur where only 4% of the thunderstorms originate between 1200-1500 UTC. Further, some significant thunderstorm activity continues to occur upto 1800-2400 UTC. The least occurrences are during interval 0000-0600 UTC. Duststorm activities are significant during 0600-1500 UTC at Jaipur and Kota, whereas at Jodhpur, it is mainly during 0900-2100 UTC, (Fig.1b).

3.3. Duration of DS/TS

Table 3 indicates for different lengths of time the duration of thunderstorm/duststorm. The maximum number of thunderstorms are of duration less than 3 hours in all the seasons. Further, the long duration of thunderstorms (greater than 9 hours) are found during the monsoon season only. As compared to thunderstorm, the life span of duststorm is shorter. In view of this, the duration of duststorm has been analysed at half hourly intervals. The maximum number of duststorms in pre-monsoon season at Jodhpur, Jaipur and Kota are of duration less than 1/2 hours. It is followed by monsoon season, in the life span 1/2 to 1 hour at Jodhpur, Jaipur and Kota. Frequency (percent) of duration 1-1.5 hours is less and it reduces further with the increase in duration greater than one and half hour.

4. Conclusions

(i) Major thunderstorm activity takes place during May to September with its maxima in August, whereas duststorms are maximum during May and June.

(ii) With the approach of monsoon currents, the duststorm activity decreases over the state.

(iii) Thunderstorm activity is significant during 0600-1500 UTC with its maxima between 0900-1200 UTC.

(iv) Duststorms are significant in pre-monsoon during 0600-1500 UTC at Jaipur and Kota whereas at Jodhpur in west Rajasthan, these are significant between 0900-2100 UTC. There is no case of duststorm at Udaipur.

(v) Thunderstorms of duration less than 3 hours are maximum and occur throughout the year. Most of the DS are of half hour duration.

(vi) The thunderstorm activity at Udaipur is relatively less as compared to other Airports of Rajasthan that may be due to its geophysical features.

Acknowledgement

Authors are thankful to Sh. Pradeep Sharma, S.A. for compilation of the data and typing the manuscript.

References

1. Sen, S.N. and Basu , S.C., 1961, "Premonsoon thunderstorms in Assam and Synoptic Conditions favourable for their occurrence", Indian J. Met. & Geophysics 12, No.1 p.15-20.
2. Raman, P.K. and Raghavan, K.,1961, " Diurnal variation of thunderstorm in India during different seasons", Indian J. Met. & Geophysics 12, 1, 115-130.
3. Vishvanathan, T.R. and Faria, S.F., 1962, "A climatological study of thunderstorms at Bombay Airport", Indian J. Met. & Geophysics 13, 3 , 377-382.
4. Krishnamurty, V. ,1965 , "A statistical study of thunderstorms over Pune", Indian J. Met. & Geophysics 16, 3, 484-487.
5. Joseph, P.V., Raipal, D.K., and Deka, S.N., 1980, "Andhi, the convective duststorm of Northwest India" Mausam 31, 3 , 431-442.