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CLIMATOLOGY OF THUNDERSTORMS AND SQUALLS OVER BANGALORE

1. Thunderstorms in tropical countries often arise due to intense heating and have a scale ranging from 1-10 kms and are short-lived. They are associated with severe weather like squall, dust-storms, heavy rain and flash floods, turbulence, hail and lightning. They are a severe threat to the aviation industry and result in losses to the agricultural crops and can disrupt day to day activities very badly. The north-eastern region of India experiences highest instances of severe weather associated with thunderstorms. The annual number of days with thunder activity exceeds 100 over Assam and its adjoining north-eastern state, Sub-Himalayan West Bengal and neighboring Bangladesh because of the complex topographical features. The extreme southern western part of the country, Kerala and adjoining areas is the zone which experiences second highest thunder activity. The annual number of days of thunder over this region ranges between 60 and 80. The frequency of thunderstorm over the central parts of the country is between 30 and 50 days and is lowest over the extreme western and northwestern parts of the country (Tyagi 2007). A number of studies have provided the climatological information about thunderstorm region wise (Pant and Rupa Kumar 1997, Manohar and Kesarkar 2003, Tyagi 2007, Singh *et al.* 2011). At the same time, it is also vital that climatological information of thunderstorms over a particular station is developed for its use in forecasting and aviation etc. Kumar and Mohapatra (2006) have studied the climatology of thunder and squall at the Guwahati Airport. Santosh *et al.* (2001) have studied the thunderstorm climatology of 3 major airports in Kerala, a state which experiences highest number of thunderstorms amongst the four southern states. Bangalore (12.58° N / 77.35° E) is an important city in peninsular India and is also known as the Silicon Valley of India. This city has 3 major airports out of which one is an international airport. Considerable number of industries have their base in and around this city. It is therefore very important that month wise thunderstorm climatology of this city should be known for aviation sector, power utilities and other operations. Mohapatra *et al.* (2004) have analyzed the data for a period of 10 years from 1985-1994 and studied the climatological characteristics of thunderstorm activity during pre and post monsoon seasons over Bangalore. They have shown that convective activity is maximum during May followed by October, April, November and March. As a detailed study about the climatological aspects of thunderstorms over Bangalore for relatively longer duration has not been made during recent times, an attempt has been made to find out the different climatological aspects of thunderstorms and squalls month wise based on the data from 1981 to 2010.

2. A day is categorized as a thunderstorm day when thunder is heard by the observer at the observatory site say up to a distance of 25-30 kms. The daily weather report and three hourly synoptic observations for the period 1981 to 2010 of Bangalore City have been collected from Meteorological Centre, Bangalore and analyzed. According to India Meteorological Department's criterion, a squall is reported when there is a sudden increase in the wind speed by at least 3 stages on the Beaufort scale and lasting for at least one minute. The annual, monthly frequencies, time of commencement, duration and the seasonal distribution of thunderstorms and their contribution to rainfall are extracted from the day summary of Bangalore city observatory and the results are presented in the section 3.

3.1. *Frequency distribution of thunderstorms*

3.1.1. *Annual frequency*

Fig. 1 shows the annual frequency of thunderstorms over Bangalore reported during 1981 to 2010. The maximum and minimum number of thunderstorms was 62 and 22 respectively and they were recorded in the years 1991 and 1990. The annual average is 44 days and does not show any trend.

3.1.2. *Seasonal and monthly frequency*

Fig. 2 shows the monthly frequency of thunderstorms in Bangalore during 1981-2010. Out of a total of 1327 number of events, 41.4% of the events occurred during southwest monsoon, 41% during pre-monsoon season and 17% of events occurred during post monsoon season respectively. The winter season (Jan-Feb) has insignificant number of thunderstorms. The thunderstorm frequency increases from March onwards; reaches first peak in May (10.1) and then it decreases sharply after the onset of southwest monsoon in June. The frequency increases again from August and reaches the secondary peak during cessation of southwest monsoon season in September (7.3) followed by October (6.6). During 1981-2010, there were 303 & 219 events in May and September which accounted for 23% and 17% of the annual frequency. These results are in agreement with Mohapatra *et al*. (2004) using 10 years data. The highest frequency of thunderstorm occurrence in May is due to the favourable synoptic conditions. During the pre-monsoon months, the convective activity is primarily due to heating of the land-mass due to which, a north-south trough is present from east Madhya Pradesh to south peninsula extending in lower levels. The large scale flow over

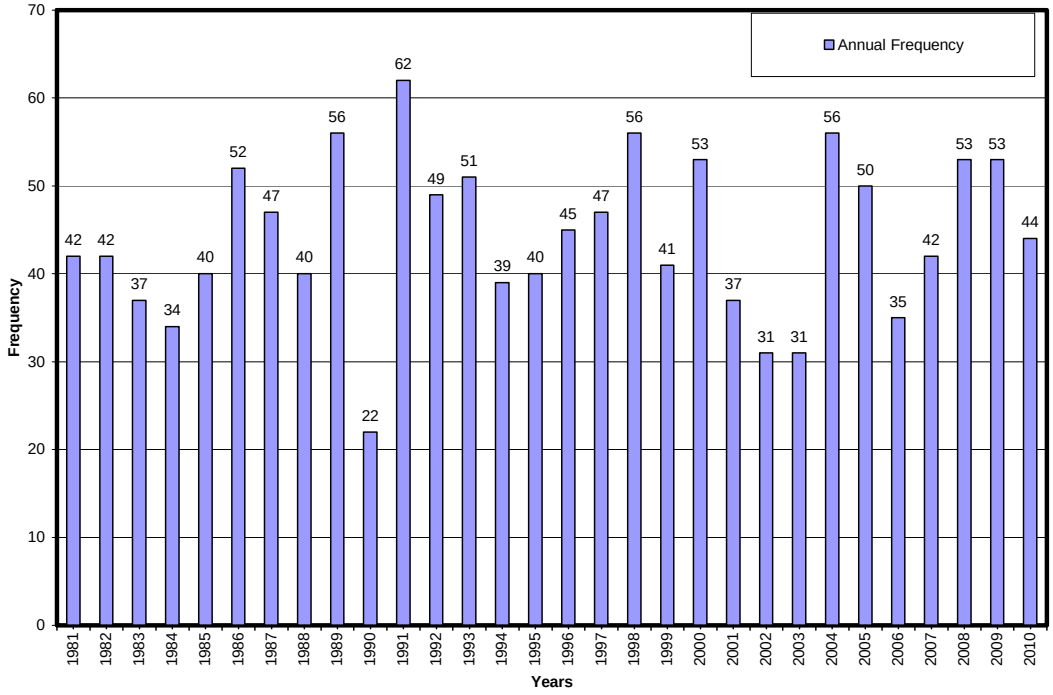

Fig. 1. Annual frequency of thunderstorms over Bangalore

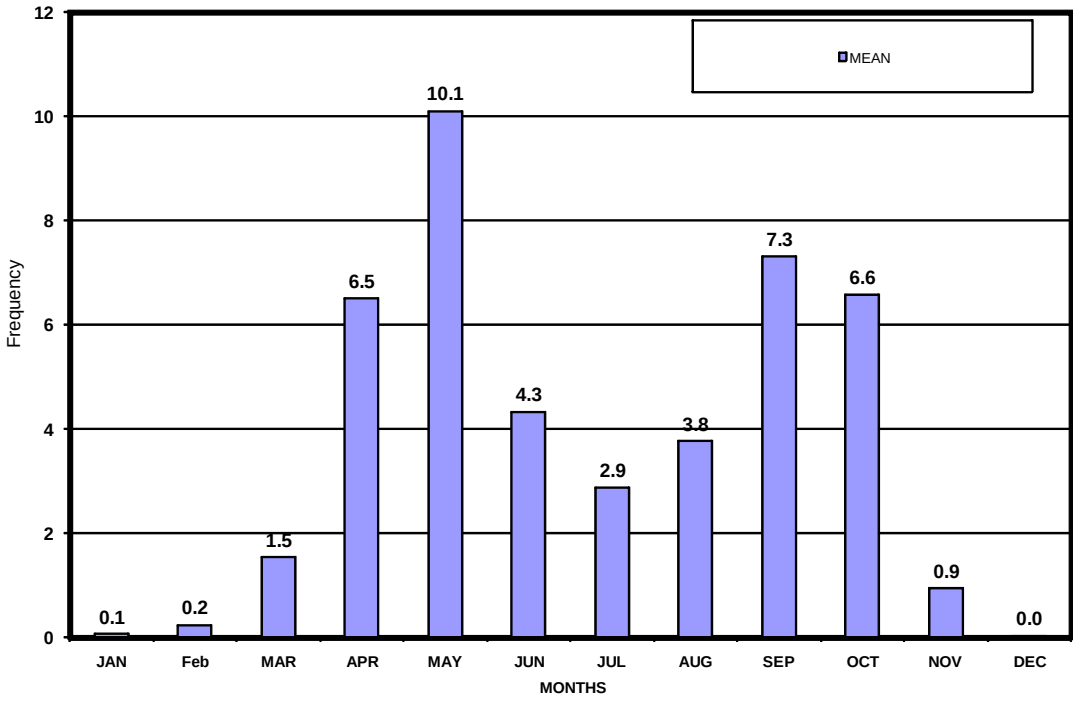

Fig. 2. Monthly Frequency of thunderstorm days over Bangalore

southern peninsula is predominantly westerlies in the levels above 300 hPa during this season (Rao and Ramamurty 1972). This results in large wind shear of the horizontal wind speed which is essential for the growth of a thunder cloud (Basu and Mondal 2002). A number of times, the thunderstorms are also associated with low level

TABLE 1

Month wise distribution of number of thunderstorms according to time of commencement over Bangalore

Time in IST	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0001-0300	1	0	11	32	44	31	11	19	**57**	38	1	0
0301-0600	0	1	0	5	6	0	0	1	5	1	0	0
0601-0900	0	0	0	1	0	1	0	1	1	0	0	0
0901-1200	0	0	0	0	1	0	0	0	0	1	0	0
1201-1500	0	0	7	17	26	4	6	8	23	31	5	0
1501-1800	0	2	**12**	**72**	**128**	**40**	26	**42**	50	**62**	**12**	1
1801-2100	0	2	**12**	53	66	34	**30**	21	55	44	7	0
2101-2400	1	2	4	21	28	15	13	13	28	19	3	0

wind discontinuity that runs from Kerala or south Tamil Nadu up to Maharashtra. The location of this wind discontinuity depends on the position and strength of the two anticyclones in Bay and Arabian Sea. Thunderstorm activity in June is associated with the onset of monsoon which takes place over coastal Karnataka around 5 June. The frequency decreases after the onset of monsoon and is least in July as the monsoon rainfall over this city is generally due to the stratiform clouds which are formed down slope due to the westerly and south-westerly winds. It starts to increase again from August and reaches the secondary peak during September. The number of thunder events during October was 197 which accounted for 15% of the annual total.

3.1.3. *Time of commencement*

In order to analyze the time of commencement of the thunderstorm, a day is divided into eight 3 hourly periods. It is found that 34% of thunderstorms have occurred during 1501-1800 hrs (IST) followed by 25%, 11% and 10% during 1801-2100, 2101-2400 and 1201-1500 hrs IST respectively. This suggests that heating plays a dominant role in their initiation. The month wise distribution of the number of thunderstorm events in each of 8 intervals for the period 1981-2010 is shown in the Table 1. Month wise highest frequency over different periods of time have been highlighted. The season wise distribution shows that during all the three seasons, most of the thunderstorms have occurred in the afternoon and late evening periods.

3.1.4. *Duration of thunderstorms*

The monthly frequency distribution of the thunderstorms with respect to its duration in hours is shown in Table 2. It is observed that 78% of the storms have their life up to 3 hrs and 20% of the total have their life cycle between 3 and 6 hrs. The duration of their life cycle in excess of 9 hrs is practically nil. The highest frequency is found to be in the month of May followed by September.

TABLE 2

Number of thunderstorms per year w.r.t. duration (hrs) over Bangalore

Month	Time in hours				
	00-03	03-06	06-09	09-12	12-15
Jan	0.1	0	0.0	0.0	0.0
Feb	0.2	0.0	0.0	0.0	0.0
Mar	1.3	0.2	0.0	0.0	0.0
Apr	5.3	1.3	0.1	0.0	0.0
May	**7.2**	2.3	**0.4**	0.0	0.0
Jun	3.1	1.1	0.1	0.0	0.0
Jul	2.6	0.3	0.0	0.0	0.0
Aug	3.1	0.4	0.0	0.0	0.0
Sep	6.1	**1.7**	0.2	0.0	0.0
Oct	5.2	1.2	0.2	0.0	0.0
Nov	0.8	0.1	0.0	0.0	0.0
Dec	0.0	0.0	0.0	0.0	0.0

3.1.5. *Contribution to rainfall*

The month wise distribution of the total monthly rainfall and rainfall on thundery days during 1981-2010 is

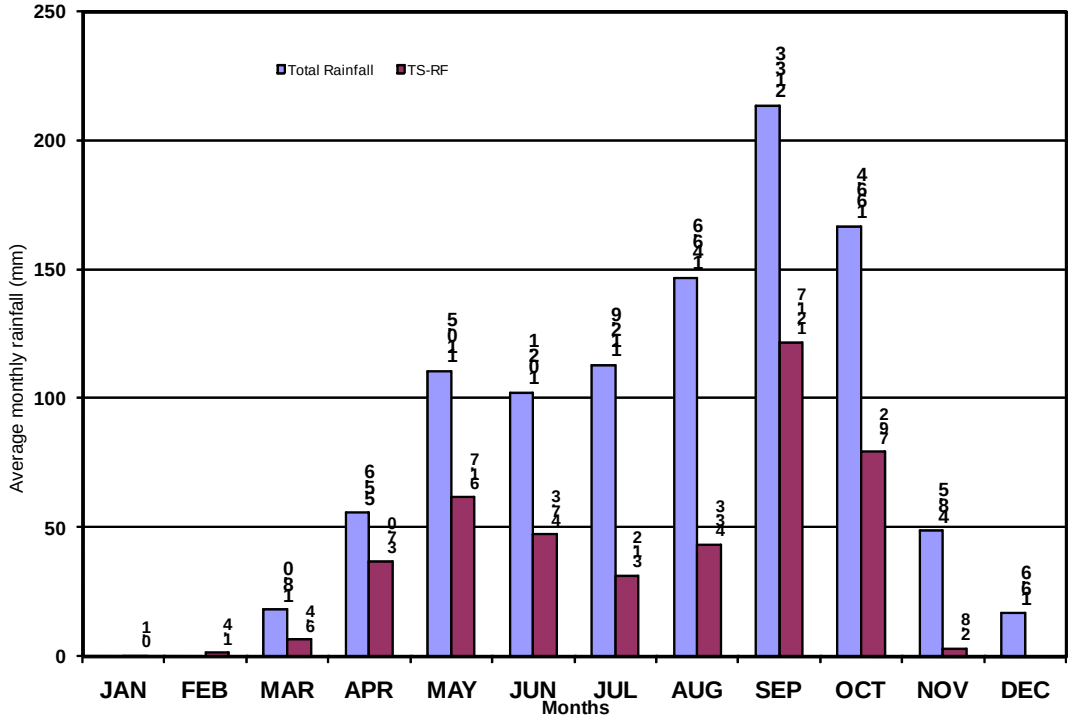

Fig. 3. Average monthly rainfall and monthly rainfall in thundery days over Bangalore during 1981-2010

TABLE 3

24 hrs accumulated rainfall in association with thunderstorms over Bangalore

Month	no rain	No. of days with rainfall (mm) within						Heaviest R/F		
		0.1 - 2.4	2.5 - 7.5	7.6 - 35.5	35.6 - 64.4	64.5 - 124.4	124.5 - 244.4	Amt (mm)	Date	Year
Jan	1		1					4.3	26	2004
Feb	4			3				25.8	26	2000
Mar	29	5	3	8	1			54.1	6	2006
Apr	113	34	23	24	5	3		108.6	19	2001
May	149	50	38	61	5	3		91.9	10	1991
Jun	54	18	19	32	8	3		89.6	11	2009
Jul	32	22	10	12	9	4		100.7	6	1988
Aug	33	24	17	28	6	3		91.6	2	2000
Sep	57	38	33	58	15	17	2	177.6	12	1988
Oct	54	43	26	55	13	5	1	178.9	1	1997
Nov	12	7	5	4				28.3	2	2010
Dec	1							0 (tr)	13	1987

TABLE 4

Details of month wise squalls during 1981-2010

Month	Frequency of squall, duration (mts) and time of occurrence (IST)								
	NE	E	SE	S	SW	W	NW	N	Total
Jan									0
Feb									0
Mar	1, 1,1708								1
Apr	1,1,1754	1,1,1645				1, 2,2048	1,1,1715		7
	1,1,1520	1,1,1658				1,1,1052			
May	1,2,1610	1,1,1535	1,1,2010	1,2,1556	1,1,2130	1,1,1514	1,2,2005	1,2,2158	18
	1,1,1610	1,1,2018	1,1,1625					1,1,2010	
	1,1,1925		1,2,1648						
	1,2,2112		1,2,2013						
			1,1,1634						
			1,1,1620						
Jun					1,4,1510	1,1,1915	1,1,1625		5
							1,1,1455		
							1,1,1440		
Jul					1,1,1815				1
Aug					1,1,1428	1,1,1707			2
Sep									0
Oct	1,1,1650				1,2,1905				2
Nov									0
Dec									0

shown in Fig. 3. This figure shows that the percentage (%) contribution of rainfall due to thunderstorms is maximum during April (67%), September (57%) and May (55%) showing that these months have higher potential to produce rainfall. It is clear from the Table 3 that while severe thunderstorms associated with heavy rain occur during September and October, the maximum frequency of thunderstorms with light to moderate rainfall occurs during May.

3.2. *Frequency distribution of squalls*

The kinetic energy associated with the thunderstorm is manifested in the form of squalls. A total of 36 number of squalls were reported during the last three decades. Table 4 provides the details of total squalls during 1981-2010, their direction, the dates of their occurrence, duration (in minutes) and time when they occurred. It is clear that pre-monsoon season witnesses maximum number of squalls with its peak during May followed by southwest monsoon season with maximum frequency in June. During other months of the year, squalls are very less. Majority of squalls during May have wind direction as southeasterly and northeasterly lasting mostly for one minute with occasional maximum of 2 minutes. The squall having maximum duration of 4 mts has occurred on 2 June 1985. It is also noted from Table 4 that most of squalls have occurred during 1500-2100 hrs IST.

3.3. *Comparison with long term mean during 1961-1990*

Month wise average frequency of thunderstorms has been compared with the climatological normals for the periods of 1951-80 and 1961-90 and shown in Table 5. On comparing these two, it is found that the number of thunderstorm days have increased though, not

TABLE 5

Comparison of mean number of thunderstorm days (IMD climatology record of 1951-80, 1961-90 with current study 1981-2010)

Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1951-1980	0.0	0.3	1.1	6.7	10.6	4.0	2.3	2.4	5.9	5.9	1.0	0.1
1961-1990	0.0	0.3	1.2	6.3	10.3	4.0	2.9	2.4	6.8	5.3	1.0	0.1
1981-2010	0.1	0.2	1.5	6.5	10.1	4.3	2.9	3.8	7.3	6.6	0.9	0.0

significantly during southwest and northeast monsoon season during the period 1981-2010.

4. Based on the analysis of last 3 decades data (1981-2010), following conclusions are drawn:

(*i*) The annual average frequency of thunderstorms over Bangalore is 44 days. The maximum numbers of thunderstorm and squall occur in the month of May. Pre-monsoon and southwest monsoon season experiences 41% of annual total each and post monsoon season experiences 17% of thunderstorm events. The winter season has insignificant number of thunderstorms. Bangalore experiences two peaks in frequency of thunderstorm; first one is during pre monsoon season in May with 10.1 days and secondary peak is in September during monsoon season with 7.3 days respectively.

(*ii*) The 34% of thunderstorms over Bangalore have occurred between 1501 and 1800 hrs (IST) followed by 25%, 11% and 10% during 1801-2100, 2101-2400 and 1201-1500 hrs (IST) suggesting that heating plays a dominant role in their initiation. It is found that 78% of the storms have a short life span up to 3 hrs and 20% have a life span of 3-6 hrs.

(*iii*) The contribution of rainfall due to thunderstorms is maximum during April (67%), September (57%), and May (55%) showing that these months have higher potential to produce rainfall while severe thunderstorms associated with heavy rain occur mostly during September and October, maximum frequency of thunderstorms with light to moderate rainfall occur during May.

(*iv*) The squalls occur primarily in the month of May followed by April and are mostly from the southeast and northeast directions. Most of the squalls occur during 1500-2100 hrs (IST).

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