MAUSAM, **57**, 2 (April 2006), 241-248

551.576.4

Heights of Cb clouds around Chhatrapati Shivaji International (C.S.I.) airport, Mumbai - Diurnal and seasonal variations

BIMAL KRISHNA BISWAS

Meteorological Office, C.S.I. Airport, Mumbai – 400 099, India

(*Received 20 April 2004, Modified 1 April 2005*)

सार – इस शोध–पत्र में 1990–99 के वर्षों के दौरान मौसम कार्यालय, छत्रपति शिवाजी अन्तरराष्ट्रीय (सी. एस. आई.) हवाई अड्डे में एकत्रित किए गए रेडार के आँकड़ों के आधार पर हवाई अड्डे के समीप 200 कि. मी. की परिधि में 6 कि. मी. से ऊपर अथवा इससे और अधिक ऊँचाई पर फैले कपासी मेघों (सी. बी.) का अध्ययन किया गया है। इसमें सी. बी. सैलों की कुल संख्या के मौसमी, मासिक और घंटेवार वितरण और उनकी ऊँचाइयों, सी. बी. सहित दिनों की संख्या, क्षोभमंडलीय सीमा की ऊँचाई तक पहुँचने वाले सी. बी. सैलों, विपुल सी. बी. मेघों के बनने के प्राथमिकता वाले स्थानों और उनकी गति की जाँच करके उन पर विचार–विमर्श किया गया है। सी. एस. आई. हवाई अड्डे मुम्बई के समीप सी. बी. मेघों के विकास के लिए उत्तरदायी सिनाप्टिक स्थितियों का भी पता लगाया गया है और उन पर विचार–विमर्श भी किया गया है।

ABSTRACT. Based on radar data collected at the Meteorological Office, Chhatrapati Shivaji International (C.S.I.) airport, Mumbai during the years 1990-99, a study has been made on cumulonimbus (Cb) clouds with their height of top 6 km or more over an area having a radius of 200 km around the airport. The seasonal, monthly and hourly distribution of the total number of Cb cells and their heights, number of days with Cb, Cb cells that reached tropopause height, the preferred places of formation of large Cb clouds and their movement have been examined and discussed. The synoptic situation(s) responsible for the development of Cb clouds around C.S.I. airport, Mumbai have also been identified and discussed.

Key words – Cumulonimbus, Frequency distribution, Monsoon, Tropopause, Synoptic situation, Tropospheric level.

1. Introduction

A Cumulonimbus (Cb) cloud, giving lightning and thunder, is one of the most important weather phenomena and is caused by great instability present in the atmosphere. Such clouds pose serious aviation hazards due to severe turbulence,heavy electric discharge, icing etc. Violent surface phenomena like squalls, hailstorms, heavy rainfall associated with Cb clouds may cause damage to property and even loss of life. As the vertical extent of Cb clouds has a direct bearing on the intensity of the associated weather phenomena, it is highly essential to have a precise knowledge of the height of top of Cb clouds, particularly in respect of those places where they develop frequently and have operational significance. Here Chhatrapati Shivaji International (C.S.I.) airport, Mumbai and 200 km around has been taken as the area of my study.

The study of echo tops by utilizing radar data done by various authors like Despande (1961, 1964), Kulshrestha (1962), De (1963), Bhattacharya and De (1966), Mukherjee and Kumar (1996), Biswas and Gupta (1989) and Hosalikar (2001) may be mentioned in this connection. An attempt has been made in this study to analyse and infer about the height of Cb clouds, its frequency of development in different months and seasons, its hourly distribution, number of days with daily maximum top height at different months, area of formation & their movement and synoptic situations(s) which facilitates the development of Cb clouds around C.S.I. airport, Mumbai.

2. Data and methodology

The study is based on hourly observation of echoes from convective clouds within 200 km around Mumbai (Fig. 1) made during the period of 10 years from 1990-99 with the storm detection radar (X - band) installed at C.S.I. airport, Mumbai. All convective cells (hereinafter called cases) whose top reached a height of 6 km or more are taken as Cb and considered for this study. All observed cases are counted and tabulated hour-wise and month-wise against heights (km) of the tops. The preferred areas of formation of high Cb cells (10 km or more) of a particular month, their orientation and movement are examined by plotting the hourly maximum tops in polar diagram and their monthly direction-wise frequency is tabulated. The cases of penetration of tropopause by the Cb clouds are determined by

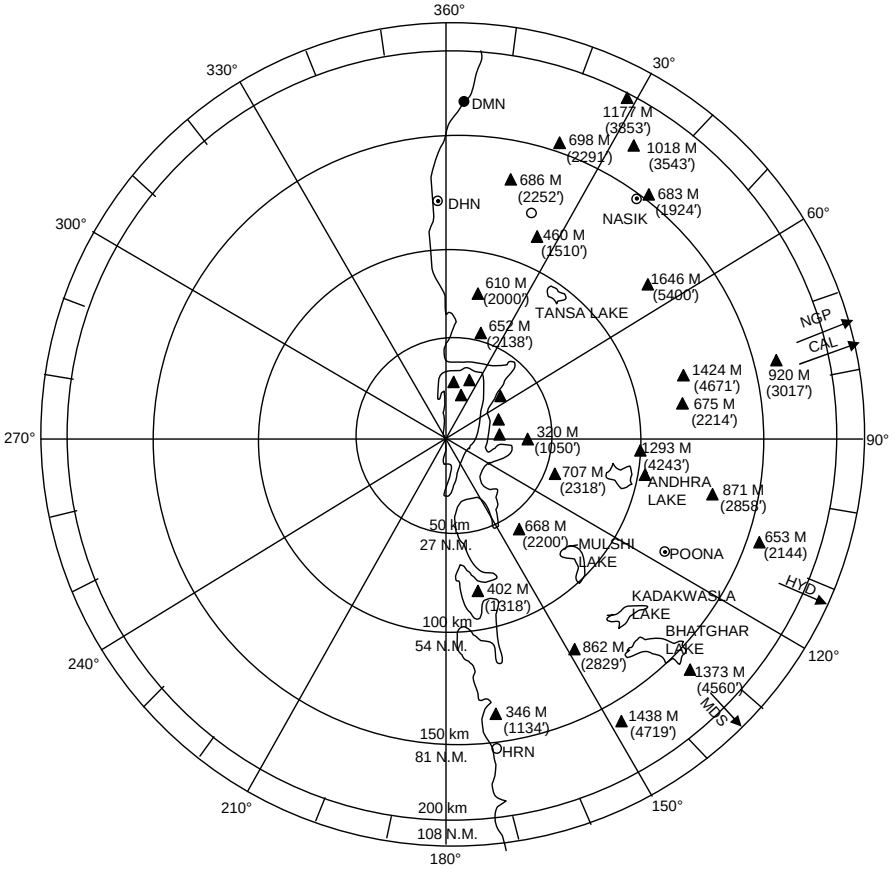

Fig. 1. Bombay airport

considering the average height of tropopause which is taken as 16 km for Mumbai. India Weather Bulletin (IWB) issued by India Meteorological Department and synoptic charts of Meteorological Office, Mumbai are studied to identify the synoptic situation(s) responsible for the development of Cb clouds around C.S.I. airport, Mumbai.

3. Analysis and discussions

3.1. *Total number of cases*

Table 1 shows the monthly and hourly frequency distribution of total number of cases for the period 1990-99. It is seen that no case has been reported in the month of February. The number of cases was very few in the months of January, March and December and was associated with Western Disturbance. Some cases were reported in April, May and November which are related to cyclonic storms developed over Bay of Bengal and Arabian Sea. It was occasional in the month of October and frequent in the SW monsoon months. In Fig. 2, it is clear that the total number of cases have been shown as percentage of the yearly one.

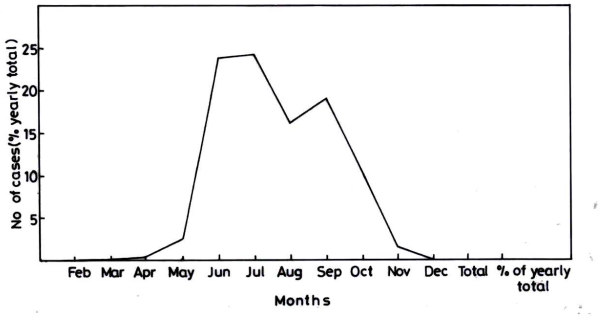

Fig. 2. Monthly total no. of cases shown as percentage of yearly total

From Table 1 and Fig. 2, it is clear that the four months of SW monsoon season contributed 83% of the yearly total number of cases whereas the first five and last two months of the year together contributed only 4.7% of the same.

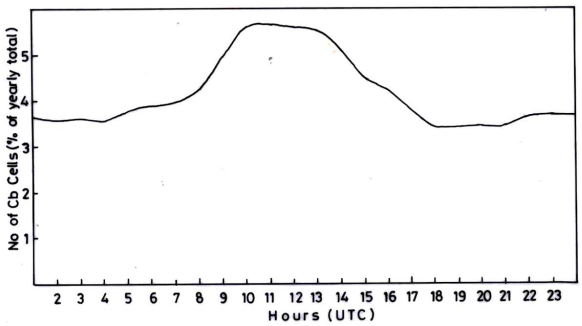

Fig. 3. Hourly variation of total no. of Cb cells around Mumbai (shown as Percentage of yearly one)

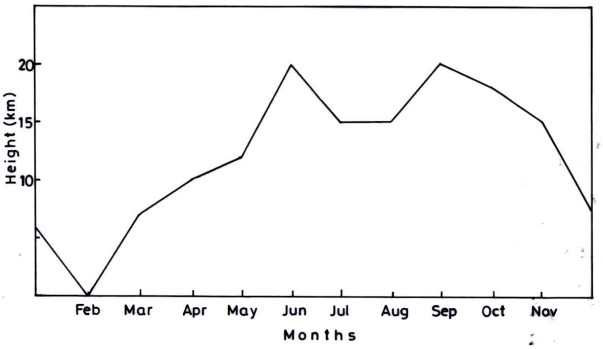

Fig. 4. Month wise maximum top height of Cb cells around Mumbai

TABLE 1

Hourly distribution of total number of cases with top height at 6 km or more during 10 years 1990-99

Hour (UTC)	Month												Total	% of yearly
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		
1				1	5	64	79	46	49	11			255	3.64
2				1	6	60	78	47	50	8			250	3.57
3				1	8	69	72	46	48	9			253	3.62
4				1	6	63	77	46	47	9			249	3.56
5				2	6	68	81	47	49	9	1		263	3.76
6				2	7	68	86	54	50	4	1		272	3.89
7				2	7	62	90	55	51	8	2		277	3.96
8	1				7	66	95	55	60	9	3		296	4.23
9				1	11	86	95	56	60	33	3		345	4.93
10			1	1	15	86	92	55	86	49	6		391	5.59
11	1		1	2	16	82	84	52	81	62	15		396	5.66
12	1			2	14	76	78	54	78	75	14		392	5.60
13			1	3	10	81	83	47	68	82	13		388	5.54
14			1	3	14	75	73	47	63	73	11		360	5.14
15				1	9	69	73	46	54	57	6	1	316	4.52
16					5	67	72	45	57	44	5	2	297	4.24
17					3	62	69	34	57	34	6	1	266	3.80
18					3	60	61	36	47	27	5	1	240	3.43
19					6	60	57	43	43	25	5		239	3.42
20				1	4	63	62	43	42	24	2		241	3.44
21				1	7	64	62	41	44	20	2		241	3.44
22				1	4	72	66	46	49	15	2		255	3.64
23				2	4	67	77	46	48	12	2		258	3.69
24				2	4	72	75	41	50	13	1		258	3.69
Total	3		4	30	181	1662	1837	1128	1331	712	105	5	6998	
% of yearly total	0.04	0	0.057	0.43	2.58	23.74	24.24	16.11	19.01	10.17	1.5	0.07		

TABLE 2

Monthly and seasonal distribution of total number of Cb cells (around Mumbai) attaining a certain height (6 km) or more during the period 1990-99

	Height (km)															Total
	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
Jan	3															3
Feb																0
Winter season	3															3
Mar		4														4
Apr	6	8	2	9	5											30
May	59	64	26	14	13		5									181
Hot weather season	65	76	28	23	18		5									215
Jun	548	522	263	68	136	3	60	6	15	18	13	1	8		1	1662
Jul	758	623	290	66	74	4	9	9	2	2						1837
Aug	510	366	185	33	19	2	5	2		6						1128
Sep	573	407	171	50	77	4	19	5	1	15	2	5	1		1	1331
Monsoon season	2389	1918	909	217	306	13	93	22	18	41	15	6	9		2	5958
Oct	142	150	115	36	106	7	46	27	12	42	7	11	11			712
Nov	41	27	21	7	2	2		2		3						105
Dec	2	3														5
Post monsoon season	185	180	136	43	108	9	46	29	12	45	7	11	11			822
Annual total	2642	2074	1073	283	432	22	144	51	30	86	22	17	20		2	6998

TABLE 3

Total number of days with daily maximum tops of Cb cells around Mumbai reaching the height × (km) or more during 1990-99

Month	Height × (km)															Total
	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
Jan	1															1
Feb																0
Mar		1														1
Apr	3	2		1	2											8
May	11	10	8	5	6		3									43
Jun	20	56	52	13	25	1	13	1	5	9	2	1	1		1	200
Jul	28	73	50	15	15	3	3	2	2	1						192
Aug	56	46	33	8	7	1	2	1		2						156
Sep	39	39	33	9	24	2	4	2	1	5		2	1		1	162
Oct	9	16	13	3	13	4	12	7	3	14	2	5	6			107
Nov	5	6	7	2	1		1			1	3					26
Dec		3														3

TABLE 4

Month-wise and hour-wise distribution of the number of Cb cells when they reached or crossed the average height (16 km) of tropopause during 1990-99

Month	Hours (UTC)															Total
	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
Jun	1	1	1	1	1	1	1	1	1	1						10
Sep								1		1	1	2	2			7
Oct						1	3	2	1	3	4	3		1	1	19
Total	1	1	1	1	1	2	4	4	2	5	5	5	2	1	1	36

3.2. *Diurnal variation of development of Cb clouds*

Regarding diurnal variation of total number of annual cases we see that the minimum number occurred during 1800 to 2100 UTC and the maximum number during 1000 to 1300 UTC. In Fig. 3 the hourly variations of total number of cases for every month have been shown as percentage of the yearly total. It is clear that the total number of cases increased after 0800 UTC and became maximum at 1100 UTC.

It is interesting to note that about 57% of the cases occurred during the period from 0600 to 1700 UTC and about 32% during 1000 to 1500 UTC. The reason may be the temperature effect which is most prominent in the afternoon hour of the day while the moisture effect is prominent at any time as per synoptic situation.

3.3. *Heights of top of Cb clouds*

Table 2 shows the monthly distribution of total number of cases attaining a height 6 km or more. The month-wise maximum heights are plotted in Fig. 4. It is seen that the maximum height of top of Cb clouds around Mumbai was 6 km in January, 7 km in March and December, 10 km in April, 12 km in May, 15 km in July, August & November, 18 km in October and 20 km in June & September.

Seasonal distribution of cloud top heights (≥ 6 km) is also presented in Table 2.

3.4. *Seasonal distribution of top heights*

Winter season (January & February) - During winter season, development of Cb clouds was rare (0.04%) and its height was also minimum.

Hot weather season (March to May) - About 3% of the annual total number of cases occurred during this season . Out of this seasonal total, nearly 30% developed to 6 km, 35% to 7 km, 13% to 8 km, 11% to 9 km, 8% to 10 km and 2% to 12 km.

South west monsoon season (June to September)- About 83% of the annual total number of cases occurred during this season. Out of the seasonal total about 40% developed to 6 km, 32% to 7 km (*i.e*., 72% cases developed up to 6 to 7 km), 15% to 8 km, 4% to 9 km, 5% to 10 km and 4% to 11 km or more. The number of cases developed was maximum in July followed by June. But the highest top heights attained were maximum in June followed by September.

Post monsoon season (October to December)- About 12% of the annual total number of cases developed during this season. Out of this seasonal total nearly 87% of the cases developed in the month of October. About 11% cases developed in November. 33% cases of the seasonal total developed to 10 km or more and 9% cases to 15 km or more. However, the development of large Cb cells (height 10 km or more) were confined only in October.

3.5. *Number of days with cases*

A day with Cb cells is counted against the maximum top height (km) attained the cells during that particular day. Such a maximum top height may be considered as “Daily maximum height”. The total number of days in each month during the period under study is counted and tabulated against the respective daily maximum height’ (Table 3) The total number of days and cases with Cb clouds was maximum in June followed by July but the number of days with daily maximum height reaching 10 km or more was higher in October followed by June.

TABLE 5

Month-wise frequency distribution of development of large Cb cells (top height ≥ 10 km) in different directions

Month	Directions								Total
	N	NE	E	SE	S	SW	W	NW	
May	1	I	4	5	1	I	0	0	13
June	6	9	10	17	8	8	I	2	61
July	2	6	5	7	5	8	2	3	38
Aug	3	3	6	2	0	2	0	0	16
Sep	5	12	16	18	II	7	3	4	76
Oct	8	40	35	42	14	5	1	9	154

3.6. *Cases that reached tropopause height*

The monthly and hourly distribution of the number of cases when the top height reached or crossed the average height of tropopause (16 km) over Mumbai and neighbourhood has been shown in Table 4. A total number of 10 cases occurred in June, 7 in September and 19 in October during the years 1990-99. The average frequency per year was 3.6 out of which 1.9 was in October.

3.7. *Preferred places of formation of high Cb clouds (≥ 10 km) and their movement*

In order to examine weather there is any preferred places (directions) of Cb to grow very high, month-wise frequency of development of very high Cb cells are plotted on polar diagram and direction-wise frequency distribution is presented in Table 5.

It is seen that in the transition periods that is before onset of south west monsoon (end of May to middle of June) and after the withdrawal of the same (middle of September to the end of October), most of the echoes of high Cb cells developed between 0900 and 1800 UTC at NE to S sector of Mumbai airport within the range of 80 km over main land near Tansa, Andhra and Mulshi lakes. This was due to intense convection that took place at the meeting zones of dry and warm air from west / northwest with moist southerly air from the Arabian Sea during these periods. High echoes were also found to develop over the Western Ghat areas. They drifted with the westerly winds and stroke the station with over head patch. That is they were found to move from land to sea (N/NE to S/SW).

On the other hand, after the onset, the development of Cb cells took place within the monsoon air (airmass type) under favourable synoptic conditions. However, these were not well developed (Cb top 6 to 7 km only) as winds were sheared between lower and upper levels (easterly in upper level and westerly in lower level). These echoes moved from W/SW to E/NE direction *i.e*., from sea to land. However on a few occasions intense convection also took place (development of large Cb cells) along the coastal areas under the influence of monsoon disturbances.

4. Synoptic situation(s) responsible for the development of Cb cells

It is observed that the development of Cb clouds around C.S.I. airport, Mumbai was associated with the formation of one or more of the following synoptic situation(s):

(*i*) An upper air cyclonic circulation (UACC) / low pressure area (LOPAR)/depression/cyclonic storm (CS) over N/NW/SW sector of Bay of Bengal and its west north west ward movement across the country.

(*ii*) A trough of low pressure off west coast/off shore vortex.

(*iii*) An UACC/LOPAR/depression/CS over EC Arabian Sea over Lakshadweep area/Karnataka - Goa coast/ Maharashtra-Gujarat coast.

(*iv*) Mid. Tropospheric Cyclone (MTC) over NE Arabian Sea and adjoining north Maharashtra south Gujarat coast.

(*v*) An UACC/LOPAR over Madhya Pradesh and Maharashtra- Gujarat region.

(*vi*) An UACC over Maharashtra state.

(*vii*) A trough in lower tropospheric level extending from Madhya Pradesh to south Maharashtra.

(*viii*) An east - west trough in Mid. tropospheric level from WC Bay off Andhra coast to Karnataka coast across peninsular India.

(*ix*) A trough in easterlies in lower tropospheric level off and along Konkan - Karnataka coast.

However, the development of Cb cells of large height ($\geq$ 10 km) were limited mostly at the onset and withdrawal phase of SW monsoon when the above mentioned one or more synoptic situations developed. Development of large Cb during SW monsoon season was associated with the formation of (a) MTC over NE Arabian Sea and adjoining areas or (b) Well Marked LOPAR/depression over NW/SW Bay of Bengal with simultaneous presence of trough of low pressure off west coast or (c) when an UACC/LOPAR/depression reached at Madhya Pradesh and adjoining areas initially originating at Bay of Bengal and moved northwest wards.

5. Conclusions

From the above study the following conclusions can be drawn :

(*i*) Maximum number of Cb cells develops around C.S.I. airport, Mumbai during July followed by June. They are rare in January, February, March and December.

(*ii*) Cb cells develop maximum during 0900 to 1600 UTC and minimum during 1800 to 2100 UTC. Cb top may reach up to 20 km in June and September when favourable synoptic situation develops.

(*iii*) Though the population of Cb cells of height 6 km or more develop in SW monsoon season is 85% of total cases, the number of Cb top 10 km or more is only 9% of seasonal total and develop only due to the formation of significant synoptic situation(s).

(*iv*) Transitional effects during June (dry summer to wet SW monsoon) and October (wet SW monsoon to dry post monsoon) are similar to wards formation of large Cb cells around C.S.I. airport, Mumbai.

(*v*) Cb cells generally develop over the land / hills in the eastern sector of Mumbai and drift over the station due to easterly winds during premonsoon and post monsoon seasons . During monsoon season Cb cells develop over the coastal areas in the western sector of the station due to monsoon disturbance and move eastward by the prevailing westerly winds.

(*vi*) The Cb tops may cross the tropopause during the months of June, September and October though such occurrences are very rare.

Acknowledgements

The author is thankful to India Meteorological Department for providing data and other facilities to carry out the study. He is also thankful to the referee for his valuable remarks and suggestions on the study.

References

Bhattacharya, P. and De, A. C., 1966, "Study of height of radar cloud top in the Gangetic valley of West Bengal", *Indian J. Met. Geophys*., **17**, 591-596.

Biswas, B. and Gupta, K., 1989, "Heights of Cb clouds around Calcutta airport - Diurnal and seasonal variations", *Mausam*, **40**, 2, 169-174.

De, A. C., 1963, "High radar clouds above 10 km", *Indian J. Met. Geophys.*, **14**, 327-330.

Despande, D. V., 1961, "Heights of top of Cb clouds over India", *Indian J. Met. Geophys*., **12**, p29.

Despande, D. V., 1964, "Heights of Cb clouds over India during south west monsoon season", *Indian J. Met. Geophys*., **15**, 47-54.

Hosalikar, K. S., 2001, Proc. of Tropmet-2001, India Met. Society, "A study of post monsoon convective cloud developments around Mumbai airport", 520-524.

Kulshreshtha, S. M., 1962, "Heights of cumulonimbus cloud tops over north India : A radar study", *Indian J. Met. Geophys*., **13**, p167.

Mukherjee, A. K. and Kumar, S., 1976, "Cumulonimbus tops around Bombay", *Indian J. Met. Geophys*., **27**, 303-308.