*Indian J. Met. Hydrol. Geophys.* (1976), 27, 3, 303-308

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# Cumulonimbus tops around Bombay

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(*Received 5 August 1975*)

ABSTRACT. Cumulonimbus clouds around Bombay observed during 1972-74 with the help of 3 cm BEL radar equipped with RHI, were studied. The study revealed that high *Cb* tops crossing tropopause generally occur 300 km away north and south of Bombay during pre-monsoon and post-monsoon seasons. Generally the tops did not exceed 12 km in height around 100 km of Bombay. It was also confirmed that the tops crossing tropopause with a fair degree of accuracy can be forecast on the basis of morning ascent using the method suggested by Mukherjee and Choudhury.

## 1. Introduction

The existence of very high cumulonimbus over northern and northeastern India is fairly well known. Quite a number of studies have been reported in literature on this subject (De and Bhattacharya 1966; Deshpande 1961, 1964; Kulshrestha 1962, 1964; Mukherjee and Choudury 1970; Natarajan and Rama Sastry 1970; Cornford and Spavins 1973). These studies were possible mainly due to presence of radars which could measure heights accurately. Bedekar and Agarwal (1970) attempted to study the height of *Cb* tops with Decca radar. Since the vertical beam width of Decca radar was 4°, and it was not equipped with RHI, the results cannot be accepted to be very reliable. Recently, in May 1972, a radar with RHI has been installed at Bombay airport. The data collected from 1972 to 1974 may not be much but they were expected to give some indication about the distribution of heights of *Cb* clouds. In the present paper analysis of radar observations for months of May to October have been reported. Since during other months the weather was fair, no radar observations were taken.

## 2. Data used

A BEL radar* was installed on 25 May 1972. All available data upto 1974 were analysed. Since no jet aircraft cruise below 8 km and since clouds whose tops are less than this height may not have much charge separation to be classified as thunderclouds, the clouds with tops below 8 km were not taken into consideration.

To find out whether there are any preferred areas for high thunderstorms, these observations were plotted on a polar diagram and areas of high tops were marked. For the purpose of analysis, the clouds were grouped in intervals of two km. Such analysis for daily maximum tops gave the orientation of its monthwise variation for preferred area of very high tops. Analysis of hourly data not only gave the diurnal variation of the orientation, but also gave us variations and to some extent the movement of regions of highest clouds during the course of the day.

## 3. Limitation

It is necessary to mention the limitations of radar observations. They are :

(*a*) Heights of the clouds measured by radar are usually lower than the actual tops. Cornford and Spavins have found that ground based radar observations were often under estimates and that, therefore, the summaries of similar observations should be regarded as frequencies which can be expected to be exceeded (also *see* Table 1 for comparison with aircraft observations).

(*b*) Possibility of missing some clouds immediately after the passage of thunderstorm.

(*c*) The averages mentioned here are to be taken as first approximations since the number of samples were limited.

## 4. Results

The data revealed that in the months of May June, September and October, the *Cb* clouds observed reached 12 km height (31·7 per cent cases) and in 2 per cent cases they reached 16 km height which is just below the height of tropopause over Bombay. In July and August, however, there was no case of *Cb* cloud heights reaching

*Specifications : Wave length—X band ; Maximum range—400 km; Display—PPI, RHI and A-scope; Peak Power—200 kw, and Beam width—Conical 1°.

**TABLE 1**

**Comparison of radar and aircraft observations at distances of 200 km during October 1975**

| Date | Aircraft Report | | | | Radar Report | | | |
|---|---|---|---|---|---|---|---|---|
| | Time (GMT) | Flight | Point of reporting | Height observed | Time (GMT) | Azimuth | Distance (km) | Height observed (km) |
| 1 Oct 75 | About 1638 | IA107/79 (Boeing 707) | Just south of Baroda | 14 km | 1630 | 010° | 250 | 11 |
| 6 Oct 75 | 0154 | SR 316 (Boeing 707) | Near Bhavnagar | 41000 ft | 0230 | 330° | 270 | 12 |
| 8 Oct 75 | 0628 | SR 315 | 100 km north of Belgaum | 38000 ft | 0630 | (100 km north of Belgaum) | | 10 |

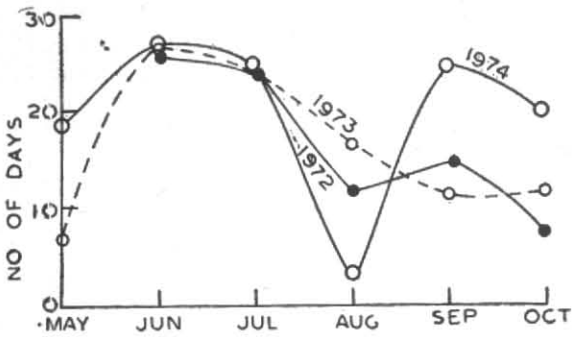


Fig. 1. Monthly variation of the number of days of *Cb* tops reaching 8 km during 1972 to 1974

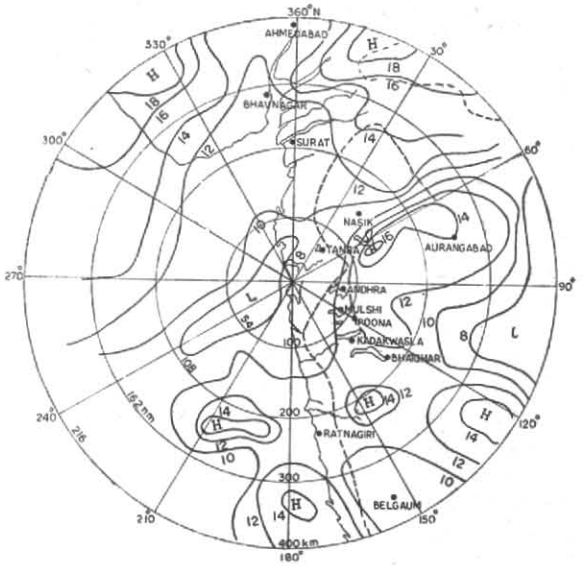


Fig. 2(b). June

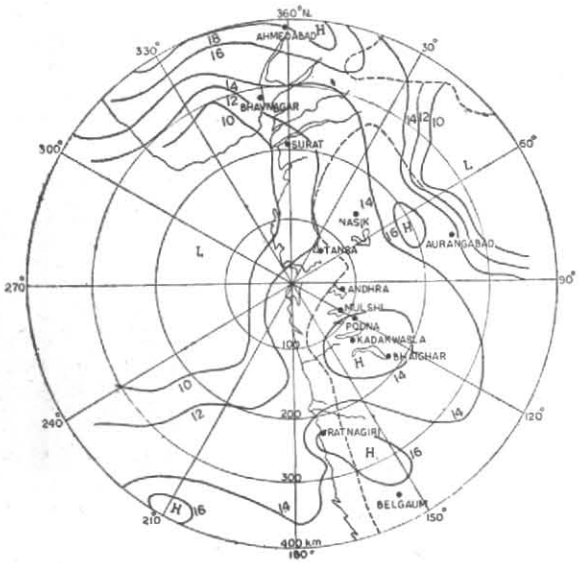


Fig. 2(a). May

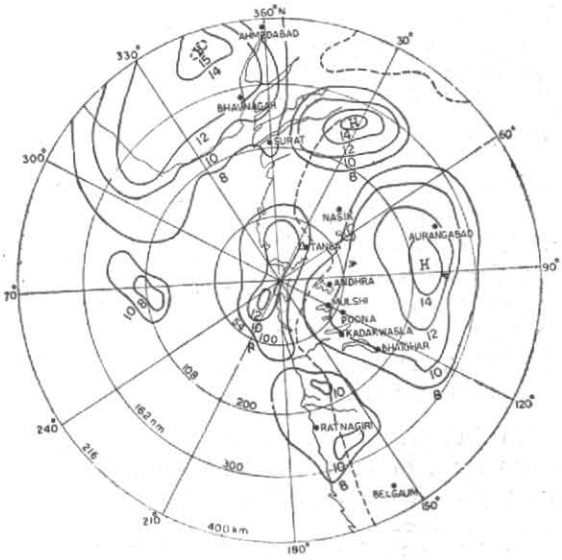


Fig. 2 (c). July

Figs. 2 (a-c). Maximum heights of *Cb* tops during different months

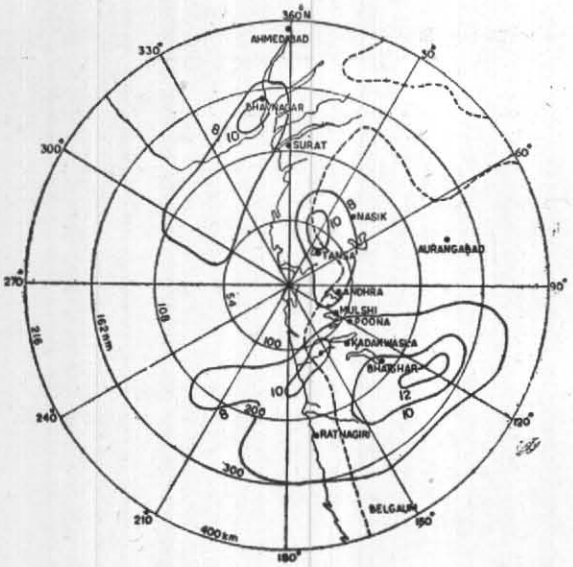


Fig. 2. (d). August

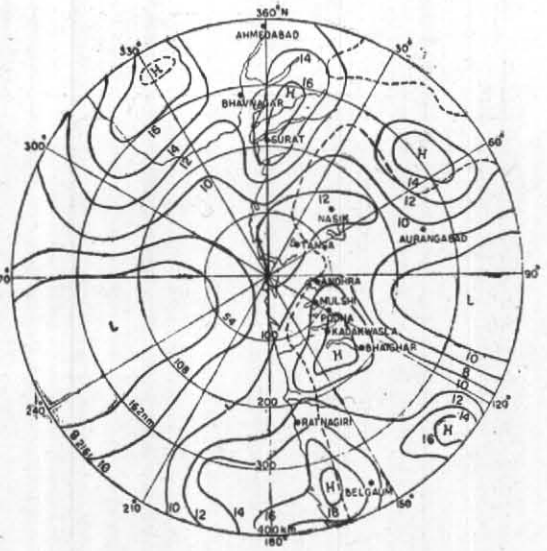


Fig. 2 (e). September

Maximum height of *Cb* tops during August and September

16 km and only in 2·3 per cent cases they reached 12 km. Fig. 1 shows year by year monthly variation of number of days of *Cb* activity. On an average there are 13, 27, 24, 11, 17 and 13 days in May, June, July, August, September and October respectively with *Cb* activity.

4.1. *Maximum heights*

Figs. 2 (a to e) show analysis of daily maximum height for the months, May to September. It can be seen that in May the highest *Cb* clouds (16-18 km tops) are north and south of Bombay around Ahmedabad and Belgaum respectively. In the southern sector the activity is generally confined between 120° and 180°. There are also pockets of clouds with tops 14-16 km at north of Ahmednagar and southwestern parts of Aurangabad. In June with the arrival of the monsoon over Bombay the heights come down but the pattern of their distribution remains the same as in May. Only in the southern sector the region of high tops along the coast over sea and land moves further inland. As the monsoon advances in July, the region of high tops of *Cb* south of Bombay disappears whereas *Cb* with tops 15 km are still seen north of Bombay. Also in this month there are two pockets of *Cb* clouds about 14 km high around Aurangabad and Nasik. In August the heights very much lower down but again in September the *Cb* tops start building up and similar to the month of June, the areas of highest *Cb* activity are at the north and south of Bombay.

Generally, in October with the withdrawal of monsoon the *Cb* activity around Bombay ceases. But in 1974 in this month there was exceptionally high *Cb* activity. Due to this, a large number of thunderstorms occurred in this month. Since it was for only one year that *Cb* activity continued throughout the month, the data obtained were not analysed.

4.2. *Diurnal variation*

This has been shown in Table 2 (a-f) for different months under study. The summary of the observations is given below:

*May* — The cumulonimbus clouds start growing between 06 and 07 GMT. The region of growth is generally 100 km away southeast of Bombay. As the afternoon approaches the activity increases over land and by 10 GMT tops as high as 16 km could be seen near Belgaum. Also very high *Cb* tops build up in Saurashtra. Cumulonimbus clouds with height 18 to 19 km are observed about 100 km west of Ahmedabad. However 100 km around Bombay the heights remain upto 13 km only. The activity subsides by 18 GMT.

*June* — In this month with the arrival of monsoon in the areas over sea which were free of *Cb* activity in May cloud with tops 8 to 9 km are observed. Over the southern coast upto 07 GMT the height of *Cb* clouds remain within 10 km southeast of Bombay but in northeast and east of southeast they cross 12 km and reach between 14-16 km north and south of Aurangabad. By 12 GMT the development reaches maximum and shifts inland. In Saurashtra 50 km northwest of Bhavnagar *Cb* with tops 18 km are seen

**TABLE 2**

**Diurnal variation of height of cumulonimbus clouds near Bombay**

| Ht. (km) | Hours (GMT) 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | (a) MAY 1973-74 | | | | | | | | | | | | | |
| 8 | 3 | 1 | 3 | 2 | 3 | 2 | 1 | 2 | 4 | 4 | 1 | 2 | 0 | 0 | 2 | 2 | 6 | 5 | 1 | 4 | 2 | 3 | 1 | 1 | 55 |
| 9 | 0 | 2 | 1 | 0 | 2 | 0 | 2 | 2 | 0 | 1 | 2 | 0 | 2 | 0 | 0 | 0 | 0 | 1 | 3 | 2 | 1 | 0 | 1 | 1 | 23 |
| 10 | 1 | 0 | 1 | 2 | 3 | 3 | 4 | 4 | 4 | 2 | 7 | 5 | 6 | 3 | 3 | 7 | 4 | 4 | 1 | 3 | 4 | 1 | 2 | 2 | 76 |
| 11 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 2 | 2 | 2 | 2 | 1 | 1 | 7 | 2 | 1 | 0 | 1 | 0 | 0 | 3 | 0 | 0 | 29 |
| 12 | 1 | 3 | 2 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 3 | 1 | 5 | 6 | 2 | 4 | 3 | 1 | 2 | 0 | 0 | 1 | 2 | 2 | 45 |
| 13 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 3 | 5 | 6 | 7 | 7 | 4 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 40 |
| 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 5 | 2 | 3 | 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 17 |
| 15 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 2 | 3 | 2 | 1 | 2 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 16 |
| 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 3 | 0 | 1 | 2 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 11 |
| 17 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 18 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| 19 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| | | | | | | | | | | | | (b) JUNE 1972-74 | | | | | | | | | | | | | |
| 8 | 12 | 10 | 17 | 9 | 13 | 12 | 19 | 21 | 11 | 13 | 12 | 14 | 9 | 11 | 11 | 12 | 16 | 16 | 17 | 16 | 15 | 17 | 14 | 11 | 331 |
| 9 | 8 | 5 | 7 | 13 | 5 | 10 | 8 | 8 | 10 | 18 | 11 | 12 | 5 | 7 | 8 | 13 | 11 | 15 | 10 | 9 | 9 | 8 | 4 | 4 | 210 |
| 10 | 4 | 10 | 3 | 2 | 6 | 8 | 5 | 10 | 11 | 13 | 14 | 10 | 10 | 10 | 15 | 13 | 14 | 5 | 4 | 2 | 5 | 2 | 9 | 7 | 197 |
| 11 | 3 | 0 | 1 | 3 | 3 | 3 | 1 | 4 | 4 | 3 | 3 | 6 | 10 | 6 | 7 | 6 | 5 | 4 | 1 | 2 | 0 | 2 | 0 | 1 | 80 |
| 12 | 0 | 0 | 0 | 2 | 3 | 2 | 1 | 1 | 5 | 3 | 5 | 7 | 5 | 7 | 6 | 2 | 1 | 1 | 2 | 0 | 2 | 0 | 0 | 0 | 55 |
| 13 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 2 | 5 | 5 | 6 | 8 | 6 | 5 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 45 |
| 14 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 2 | 1 | 1 | 3 | 5 | 2 | 2 | 2 | 2 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 25 |
| 15 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 4 | 3 | 2 | 3 | 5 | 2 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 23 |
| 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 2 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 |
| 17 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| 18 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| | | | | | | | | | | | | (c) JULY 1972-74 | | | | | | | | | | | | | |
| 8 | 13 | 18 | 17 | 19 | 18 | 19 | 18 | 18 | 17 | 18 | 16 | 14 | 14 | 13 | 15 | 10 | 12 | 9 | 9 | 7 | 9 | 11 | 12 | 7 | 333 |
| 9 | 2 | 4 | 2 | 7 | 5 | 11 | 10 | 7 | 7 | 5 | 6 | 5 | 7 | 5 | 6 | 6 | 3 | 6 | 8 | 8 | 3 | 6 | 7 | 5 | 141 |
| 10 | 5 | 5 | 4 | 4 | 7 | 8 | 6 | 4 | 5 | 3 | 5 | 6 | 6 | 6 | 5 | 2 | 5 | 1 | 2 | 0 | 5 | 3 | 0 | 5 | 102 |
| 11 | 3 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 2 | 1 | 1 | 0 | 1 | 1 | 1 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 18 |
| 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 2 | 1 | 2 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 2 | 14 |
| 13 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 7 |
| 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| 15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| | | | | | | | | | | | | (d) AGUSUT 1972-74 | | | | | | | | | | | | | |
| 8 | 7 | 3 | 5 | 6 | 4 | 5 | 7 | 5 | 8 | 7 | 9 | 5 | 6 | 5 | 3 | 5 | 4 | 4 | 1 | 5 | 3 | 4 | 5 | 5 | 121 |
| 9 | 0 | 2 | 2 | 4 | 2 | 2 | 3 | 5 | 2 | 4 | 1 | 3 | 3 | 1 | 1 | 0 | 2 | 2 | 6 | 1 | 0 | 0 | 1 | 0 | 47 |
| 10 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 2 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 |
| 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 2 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 7 |
| 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| | | | | | | | | | | | | (e) SEPTEMBER 1972-74 | | | | | | | | | | | | | |
| 8 | 7 | 4 | 7 | 6 | 5 | 6 | 8 | 6 | 4 | 7 | 7 | 3 | 5 | 3 | 4 | 3 | 5 | 7 | 7 | 4 | 4 | 4 | 3 | 5 | 123 |
| 9 | 4 | 5 | 4 | 4 | 3 | 2 | 4 | 5 | 4 | 2 | 2 | 3 | 1 | 4 | 3 | 5 | 3 | 6 | 4 | 4 | 6 | 2 | 5 | 3 | 87 |
| 10 | 7 | 7 | 5 | 3 | 3 | 4 | 6 | 7 | 5 | 7 | 2 | 4 | 5 | 5 | 6 | 6 | 8 | 6 | 6 | 5 | 3 | 6 | 4 | 9 | 129 |
| 11 | 1 | 1 | 1 | 1 | 3 | 1 | 0 | 3 | 4 | 4 | 2 | 0 | 3 | 4 | 3 | 5 | 7 | 3 | 3 | 2 | 1 | 3 | 4 | 1 | 60 |
| 12 | 2 | 1 | 4 | 2 | 8 | 4 | 1 | 3 | 6 | 4 | 5 | 7 | 11 | 8 | 8 | 6 | 6 | 4 | 6 | 5 | 6 | 4 | 2 | 1 | 109 |
| 13 | 1 | 0 | 3 | 3 | 0 | 2 | 0 | 1 | 2 | 4 | 7 | 7 | 3 | 3 | 4 | 1 | 1 | 2 | 0 | 2 | 0 | 0 | 0 | 0 | 44 |
| 14 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 4 | 7 | 5 | 5 | 3 | 6 | 3 | 1 | 2 | 1 | 1 | 1 | 2 | 0 | 1 | 0 | 46 |
| 15 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 2 | 2 | 7 | 4 | 3 | 2 | 2 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 31 |
| 16 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 7 |
| 17 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 8 |
| 18 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |

TABLE 2 (*contd*)

| Ht. (km) | Hour (GMT) 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | (f) OCTOBER 1972-74 | | | | | | | | | | | | |
| 8 | 4 | 8 | 4 | 4 | 5 | 4 | 2 | 5 | 4 | 3 | 2 | 3 | 3 | 5 | 6 | 4 | 3 | 7 | 5 | 4 | 4 | 7 | 4 | 5 | 105 |
| 9 | 3 | 5 | 5 | 4 | 3 | 3 | 3 | 2 | 1 | 1 | 4 | 0 | 2 | 1 | 1 | 2 | 3 | 5 | 3 | 2 | 7 | 1 | 1 | 4 | 66 |
| 10 | 5 | 1 | 4 | 3 | 2 | 2 | 5 | 6 | 4 | 3 | 4 | 6 | 8 | 5 | 7 | 5 | 7 | 6 | 6 | 5 | 2 | 3 | 5 | 3 | 10 |
| 11 | 1 | 0 | 0 | 2 | 2 | 1 | 1 | 3 | 3 | 4 | 3 | 4 | 3 | 3 | 1 | 4 | 3 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 42 |
| 12 | 0 | 1 | 2 | 1 | 2 | 3 | 1 | 0 | 3 | 7 | 5 | 6 | 5 | 5 | 6 | 5 | 0 | 1 | 1 | 2 | 0 | 1 | 1 | 1 | 59 |
| 13 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 2 | 3 | 4 | 1 | 3 | 4 | 0 | 4 | 0 | 2 | 1 | 1 | 1 | 0 | 0 | 0 | 28 |
| 14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 |
| 15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 2 | 5 | 1 | 1 | 0 | 0 | 2 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 14 |
| 16 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 17 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |

Also around Khadakwasla and south of Nasik about 110 km west of Bombay *Cb* grow between 14 to 16 km. Pockets of *Cb* reaching 14 km are also seen around Aurangabad and Belgaum.

Thereafter the activity shifts westwards inland and by 15 GMT the land areas except for a few pockets become free of *Cb* clouds.

*July* — With the further strengthening of monsoon in general the heights lowering down except for a few cases the tops remain within 10 km but their frequency of occurrence within 100 km of Bombay very much increases. These are isolated cases when tops reaching 14 to 15 km are observed at 100 km west of Ahmedabad and 150 km east of Surat. They develop by 10 GMT and dissipate by 12 GMT.

*August* — This is a period of very low activity; the tops remain within 8 km. Only on a small number of occasions they grow upto 12 km around Bhatghar lake 200 km southeast of Bombay between 11 and 12 GMT.

*September* — This month is similar to May. With the withdrawal of monsoon from north India, the *Cb* tops start growing up around Bombay. The development starts at 8 GMT and by 12 GMT the tops reach mature stage. The build up is highest in south of southeast of Bombay at a distance of 300 to 400 km. Also *Cb* tops as high as 18 km are seen around Ahmedabad.

### 4.3. *Crossing of tropopause*

Overshooting of tropopause is one of the important events. For this purpose all available data were analysed and diurnal variation was studied. The average height (15·8 km) was taken as standard. It was found that whereas in May, June, September and October cases of overshooting tropopause were quite common there was no case in July and August. Fig. 3 shows the diurnal variation of *Cb* tops crossing tropopause for months of May, June and September. It can be seen that the frequency of overshooting tropopause is maximum at and around 12 GMT. This agrees with observations of Calcutta reported by Mukherjee and Choudhury (1970).

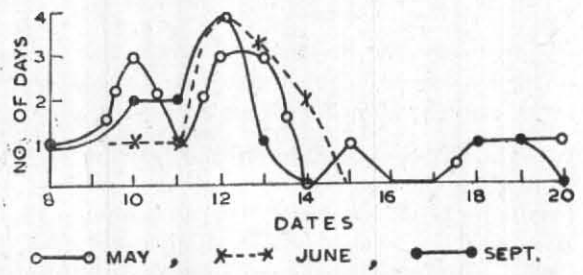


Fig. 3. Diurnal variation of cumulonimbus tops crossing tropopause

### 5. Problem to forecasting

Recent studies by Roach (1967), Mukherjee *et al.* (1971, 1972) on the occurrence of very high thunderstorms have focussed attention on the use of classical parcel method for determining the top of *Cb* cloud. The same techniques were used to find out the tops of *Cb* when they cross the tropopause levels.

Since except for one day (6 June 1973) on all the other occasions radiosonde ascent fell short of tropopause, the average heights and temperatures of tropopause, from average climatological data for 150 and 100 mb over Ahmedabad (since on most occasions the cases were near that station), were used. On the occasions when these averaged data were used, the heights obtained using method suggested by Mukherjee did not agree with the observed ones whereas on the occasion when data were available the observed and the calculated heights were in agreement. The occasions of

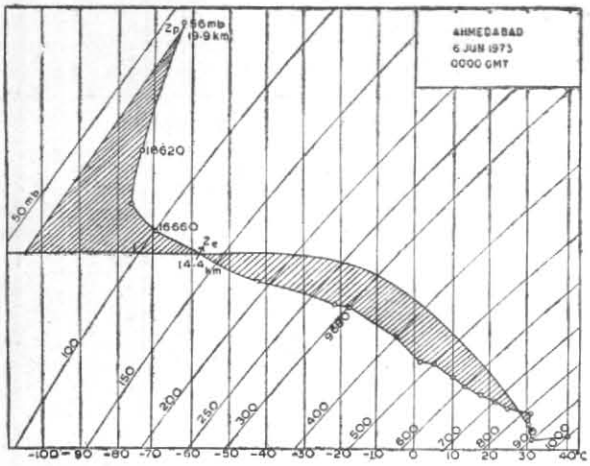


Fig. 4. Tephigram showing expected ht ($Zp$) of development of *Cb* clouds using equal area method

disagreement may be attributed to the inaccuracy of the averages which were based on data obtained using clock and fan type radiosondes.

The analysis of 6 June 1973 is shown in Fig. 4. Here $Z_e$ is the equilibrium height and $Z_p$ is the maximum possible height. It may be noted that $Z_e$ is also the level at which anvil forms (Roach 1967). At Ahmedabad on all the days of study $Z_e$ was below the height of tropopause (Table 3).

TABLE 3

| Date | Average ht. of tropopause over Ahmedabad (km) | $Ze$ (km) | $Zp$ (km) | Max. ht. observed (km) | Remarks |
|---|---|---|---|---|---|
| 6 Jun 73 | 16·6 | 14·4 | 19·9 | 18 | Based on data obtained with 403 MHz A type radiosonde |
| 5 May 74 | 16·7 | 12·8 | 17·9 | 18 | Ascent fell short of tropopause level. Av. ht. based on data obtained with clock type radiosonde used |
| 27 Jun 74 | 16·7 | 9·4 | 14·4 | 18 | Do. |

As pointed out by Mukherjee, Rakshit and Choudhury (1972) these thunderstorms must have caused an exchange of air between stratosphere and troposphere.

*Acknowledgement*

The authors wish to sincerely thank Shri S. Banerjee of the radar unit Bombay Airport for rendering invaluable help in collection of the data.

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