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A radar study of growth and decay of thunderstorms around Bombay during the pre-monsoon season

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ABSTRACT. Rates of growth and decay of '*Cb*' clouds as seen through 3 cm radar have been studied for Bombay and neighbourhood for April 1974. The rate of growth varied from 2 to 16 m.p.s. These were compared with those obtained from Tϕ-gram analysis. The observed values were lower than the calculated ones. Assuming lower value of observed rate of growth to be due to entrainment of environmental air by rising parcel, the amount of entrainment has been calculated for a particular case. The rates of decay are found to vary from 0·5 to 7 m.p.s.

1. Introduction

Thunderstorms occur around Bombay frequently during the pre-monsoon and the post monsoon seasons and occasionally during the monsoon season. These have been studied by Narayanan and Krishna murthy (1966) for preferred areas of formation and by Bedekar and Agarwal (March 1970) and by Mukherjee and Kumar (1976) with respect to heights of cumulonimbus tops reached. However, so far no attempt was made to study the vertical growth of clouds in this area. In 1972 a new BEL radar of 3 cm wave length was installed. It is fitted with RHI and hence it has been possible to study the vertical growth of '*Cb*' clouds. The results of such a study have been presented in this paper.

2. Data used

For the purpose of study the month of April was chosen as in this month the thunderstorms are widely scattered and hence the possibility of confusion among the cells is remote. After initial detection of cloud echo it was continuously followed and photographs were taken. Though in a number of cases growth was detected, only those cases for which photographic evidence was available have been taken into consideration. Two interesting sequences have been reproduced in in Figs. 1 and 2.

Fig. 1 shows a case when on 6 April 1974 at 1730 IST an echo was first seen at a distance of 160 km. This had a vertical depth of 2 km and top at 4 km. In 2 minutes time it developed to 6 km height and the base came down to 1·5 km.

Fig. 2 shows sequence of pictures taken on 5 April 1974. Here the cell at 180 km distance took 40 minutes to develop from 9 to 12 km (Fig. 2b) ; while this particular cell grew the one near it dissipated. After attaining a height of 12 km this cell also started dissipating (Fig. 2c).

The rates of growth and decay for all the cases observed have been calculated and given in Tables 1 and 2 respectively.

3. Limitations of data used

Keeping in view that heights reported by radar may not be very accurate at large distances due to errors of finite beam width and antenna positioning, the study has been kept confined to a distance of 200 km and the heights have been taken accurate upto 500 metres only. Further due to limitations of radar operation in an operational aviation office, the clouds were followed after their initial formation only. So it is quite possible that same portions of development of clouds would have gone unnoticed.

4. Discussion

After initial detection, the echo is found to grow both above and below. The growth is more above the freezing level. The cell develops quite fast initially but while approaching mature stage the rate of growth comes down significantly. Within 200 km of Bombay the growth rates are found to vary between 2 to 16 m.p.s. Koteswaram and De (1959) had undertaken a similar study for Calcutta. According to them the rates of growth vary from 7·5 m.p.s. to 19 m.p.s. with a maximum growth of 34 m.p.s. The maximum rate of decay

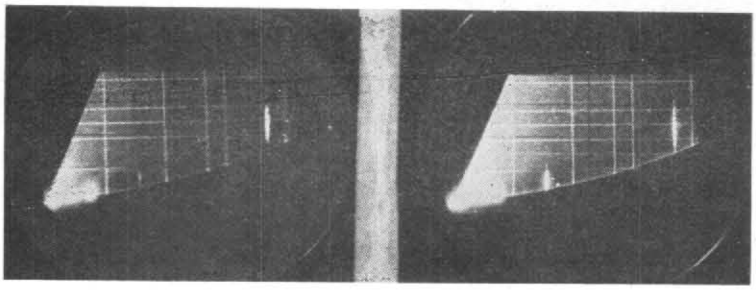

Fig. 1(a), 1730 IST, Az. 158° Fig. 1(b), 1732 IST, Az. 158°

Fig. 1 Sequence of photographs, taken on 6 April 1974, Max. range 400 km, horizontal and vertical markers each at 100 and 5 Km respectively.

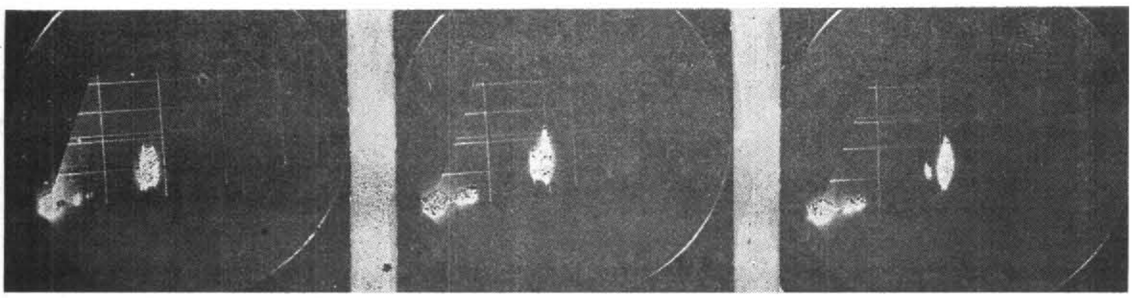

Fig. 2(a). 1515 IST, Az. 153° Fig. 2(b). 1555 IST, Az 153° Fig. 2(c). 1640 IST, Az 153°

Fig. 2. 5 April, 1974, legend same as Fig. 1.

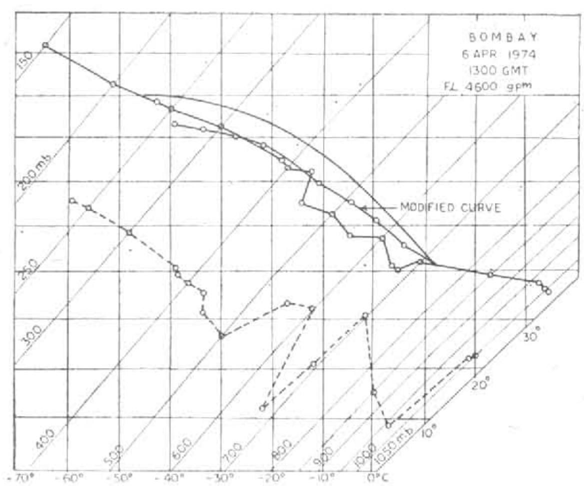

Fig. 3

reported by them is 22·5 m.p.s. Their observations were based on data with Decca radar which had no RHI facility. The larger rates reported by them may be attributed to vigorous convection which is often experienced in NE India during pre-monsoon season.

The cells on reaching mature stage, *i. e.*, after reaching maximum growth are found to retain height for a period of 2—3 minutes and then start decaying. The decay rates are variable. They vary between 0·5 and 7 m.p.s. As can be seen from Tables 1 and 2, the decay rates are lower

TABLE 1

Rate of growth of convective cells

Date (Apr 1974)	Time (IST)	Azimuth (°)	Range (km)	Height increase (km)	(min)	Rate of growth (mps)
3	1525	121	80	1	7	2
5	1515	153	180	3	40	1·5
5	1548	096	180	0·5	3	3
6	1730	158	160	2	2	16
11	1643	104	170	1	2	8

TABLE 2

Rate of dissipation of convective Cells

Date (Apr 1974)	Time (IST)	Azimu-th (°)	Range (km)	Height decrease (km)	Time (min)	Rate of dissi-pation (mps)
3	1519	121	90	2·5	6	7
5	1515	153	160	1·5	40	0·6
				1·0	45	0·3
5	1515	096	180	1·5	12	2
5	1840	118	145	0·5	5	2
20	1605	043	200	0·5	2	4
3	1515	121	090	No change in ht of 8·5 km for 4 min and then dissipated.		
11	1643	104	200	No change in ht. of 9·0 km for 2 min.		

TABLE 3

Characteristics of '×' band radar at Bombay

(1)	Wave length	3·2 cm
(2)	Peak power	200 KW
(3)	Beam width	1° Conical
(4)	Scope	PPI and RHI
(5)	Maximum range	400 km
(6)	Pulse width	0·5 and 3 Micro sec

TABLE 4

6 April 1974 at 1730 IST

Rate of growth (mps) obs.	cal.	Entrainment (dm/m) 700-600 (mb)	600-500 (mb)	500-400 (mb)	400-300 (mb)	300-230 (mb)	Total dm/m	Modified rate of growth (mps)
16	47·5	0·7	0·9	1·2	2·6	6	11·4	28·6

than the rates of growth. For an occasion when growth was noted an attempt has been made to correlate the rate of growth to that expected from tephigrams. Bombay tephigram was taken as representative of conditions within 200 km of Bombay. The vertical velocity of parcel is given by.

$$1-\frac{W^2}{2}=g\int_{ccl}^{z}\frac{\triangle T}{T}dz$$

where,

W=Vertical velocity

T=Temperature in degrees absolute

$\triangle T$=Difference between parcel temperature and environmental temperature.

z=Height

Fig. 3 shows the tephigram of 6 April 74. The rate of growth observed on the basis of this tephigram has been calculated using the above formula. Values calculated from this formula are given in Table 4. As expected the theoretical rate of growth is more than the observed rate. This lower rate of growth can be attributed to one of the following reasons:—

(*a*) Interference from adjacent cells.

(*b*) Saturated adiabatic ascent of air in an environment of dry adiabatic descent (slice method)

(*c*) Entrainment of environmental air by the rising parcel.

The first method is not applicable to the case under consideration, as widely scattered cells have been chosen and hence the possibility of interference is eliminated. The slice method cannot also be used as it has been found that this method is not suitable for explaining the growth of *Cb* cloud (Newton 1963). Hence the only explanation can be the entrainment of environmental air in the rising parcel. An attempt to calculate the amount of entrainment was made. It is assumed that:

(*i*) The cloud and the air entrained by it are thermodynamically isolated systems so that no external sources of heat need be considered.

(*ii*) Cloud has uniform horizontal distribution of temperature, water vapour and liquid water.

Now a sample of saturated cloud mass m at temperature T while ascending a distance dz will entrain a mass dm of unsaturated environmental air at temperature T . The cloud will have to give heat $=c_P('T-T')\ dm$ to warm the entrained air and heat$=L(w_s-w)dm$, (where w_s and w are respectively the saturation and environmental air mixing ratios, L the latent heat of evaporation and c_p the specific heat at constant pressure) to evaporate part of liquid water in order to saturate the entrained air. The cloud will gain heat$=-mLdw_s$, as a result of condensation of part of vapour in ascending a distance dz. Then according to Hess (1959) the first law of thermodynamics for the cloud can be written as :

$$-c_p(T\text{-}T')Tm\text{-}L\,(w_s\text{-}w)\,dm\text{-}mLdw_s=m\,(c_pdT+gdz)$$

Using this equation the amounts of entrainment between the various levels have been calculated and values obtained are reproduced in Table 4. As can be seen from the table the rising parcel of air would have entrained air equal to eleven times its original mass on 6 April during ascent to about 11 km.

As a result of this entrainment the parcel will lose temperature and the temperature of entrained air will rise. Resultant temperature after entrainment has been calculated and modified path followed by the parcel is shown by curve on the tephigram marked modified curve. On the basis of the modified curve the rate of growth has been calculated and value obtained is given in Table 4. It is seen that even when the entrainment is taken into account the rate of growth calculated on the basis of $T\phi$gram is higher than that observed. It may be due to the fact that the clouds are generally found to extend higher than the heights given by radar, *i.e.*, the radar underestimates the heights (Cornford and Spavins 1973). So the rates of growth may be slightly higher than those given by radar. Moreover skin friction and mass of water substances inside the cloud may also reduce the rate of growth.

5. Conclusions

From the above discussion, the following conclusions can be drawn —

(*a*) The rates of growth of *Cb* cloud near Bombay vary from 2 to 16 m.p.s.

(*b*) The rates of decay are highly variable. They vary between 0·5 and 7 m.p.s..

(*c*) The observed rates of growth are lower than those calculated theoretically. The entrainment of air by rising parcel seems to be the most probable reason to account for lower observed growth rates.

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