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ON FORECASTING VERY LARGE *Cb* CLOUDS

1. It was from Calcutta Airport that the existence of very large cumulonimbus clouds penetrating the tropopause and going much above it was first reported (De 1959). The existence of such high tops of these clouds has been confirmed by later observations from other places. Roach (1967) reported some observations at Oklahoma and tried to examine whether it is possible to satisfactorily forecast these high tops by simple parcel theory. He has come to the conclusion that simple parcel theory is adequate for most of the cases, but sometimes it fails to forecast last 1 to 1.5 km of the top. Some observations of high tops at Dum Dum (Calcutta Airport) also confirm the finding of Roach (1967). The purpose of the present note is to investigate qualitatively the reason for the failure of simple parcel theory and forward an approximate method of forecasting the heights of tops of very large cumulonimbus clouds.

2. The tops of convective clouds can be forecast by the following three methods—(a) Parcel Method (b) Slice Method (c) Method of relative tops shear (Rao and Dekate 1967). Of these three methods, simple parcel method of ascent of undiluted parcel forecasts the highest top.

The actual method of forecasting by this method is shown in Fig. 1. The environmental ascent curve is denoted by CCL  $Z_e$   $Z_t$  X and the undiluted parcel ascent curve is denoted by CCL  $Z_e$   $Z_p$ . Assuming that the parcel did not require any energy for lifting upto the convective condensation level (CCL), we find that the parcel receives energy from CCL to  $Z_e$ , the level where the temperature of the parcel is equal to that of the environment. The energy thus acquired by the parcel will be manifested by the kinetic energy. The undiluted parcel will, therefore, go on rising against the buoyancy above  $Z_e$  till all the energy is spent up. It will, therefore, go upto the level  $Z_p$ . This level will be determined by making the area (B) within the two ascent curves between  $Z_e$  and  $Z_p$  equal to the area (A) within the ascent curves between CCL and  $Z_e$ .  $Z_p$  is the forecast top of the cumulonimbus clouds. In case of very vigorous convection, we can assume that the core of the convective system rises undiluted (Malkus 1960).

Four examples given by Roach (1967) and the two examples from observations at Dum Dum presented in Table 1 show that this theory is still inadequate and cannot forecast the last leg of 1 to 1.5 km of the *Cb* top. It may be pointed

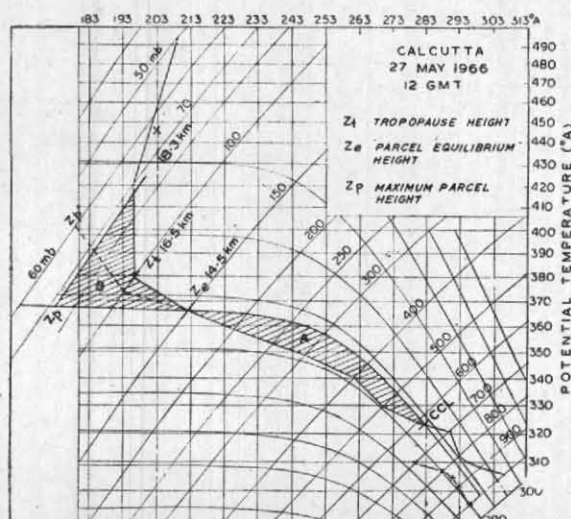


Fig. 1. Environmental and parcel ascent curves  
The ascent curve is representative for undiluted ascent throughout the journey

out here that the heights given by Roach were from observations by U2 aircraft and, therefore, very accurate, whereas the observations at Calcutta Airport were by radar and cannot claim the same accuracy.

Now, we shall make an attempt to modify this approach to remove the inadequacy of the above theory.

3. Let us first assume that the parcel entrains some environmental air. In that case entrainment between CCL and  $Z_e$  would modify the parcel ascent curve in such a way that the area (A) is reduced. Consequently the area (B) should also be reduced, so that  $Z_p$  will be less than that shown in Fig. 1.

We may assume that upto  $Z_e$  the parcel has undiluted ascent but above it the entrainment takes place. The assumption of such a preferential level of entrainment may not, however, be justified. In that case warm air enters into the cold parcel. Thus the buoyancy of the parcel increases. Besides for mass entrainment we have to assume momentum entrainment also. As the environmental air has no upward motion, such entrainment would mean a reduction of upward velocity of the parcel. This would in turn reduce the kinetic energy of the rising parcel which is proportional to the square of the velocity. This consideration would mean that the area (B) will be less than area (A) and consequently the height of top will be less than  $Z_p$ .

The parcel, is, therefore, not modified by entrainment since actual heights were greater than  $Z_p$ . The other alternative is that the modification

TABLE 1

Date	Place	$Z_t$	$Z_c$	$Z_p$	$Z_{p'}$	Z (observed)	Anvil deck
24 May 1962	Oklahoma	38,000 ft	40,400 ft	53,300 ft	—	57,000 ft	40,000 ft
25 May 1962	Do.	38,000	42,200	57,500	65,000 ft	61,000	42,000
5 Jun 1962	Do.	42,000	43,000	55,200	—	60,000	44,000
31 May 1963	Do.	37000	38,600	48,300	—	51,000	42,000
30 May 1963	Calcutta	16.5 km	14.0 km	18.0 km	19.2 km	19.2 km	—
27 May 1966	Do.	16.5	14.5	18.3	19.5	20.0	—

occurs in the environment in which the undiluted parcel rises. Such modification is envisaged by Slice method. It has been shown by later workers (Roy Choudhury 1952) that in case of vigorous convection, Slice method is not applicable, since the unsaturated descent of compensating air does not take place in the immediate vicinity of rising parcel.

This may be true for convective rise between CCL and  $Z_c$ . But above  $Z_c$  the heavier parcel has to descend after going upto  $Z_p$ . Since convection is vigorous, descending air will move downwards on the periphery of ascending parcel. This air will go down upto  $Z_c$  and spread to form anvil. This has been confirmed by Roach who observed that the anvil level is generally at  $Z_c$  (Table 1). The upwards and downward motion is represented schematically in Fig. 2 (after Roach 1967).

This immediately means that the ascending parcel above  $Z_c$  moves in a surrounding whose thermodynamic condition is not represented by the environmental ascent curve  $Z_c Z_t X$  but by, say,  $Z_c Z_{p'}$ , assuming mixing of equal amounts of environmental and descending air. This later by itself should be warmed dry adiabatically during descent from the level  $Z_p$ . We may however, assume mixing of descending and environmental air by any other proportion and in that case  $Z_c Z_{p'}$  line will be different.

The modification of environment in that way would mean that the rising parcel in the modified environment would go higher than  $Z_p$  and upto

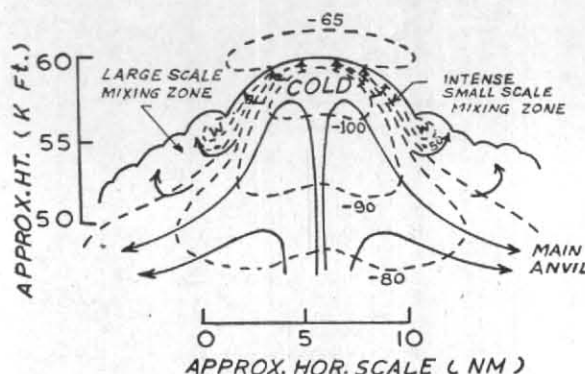


Fig. 2. Tentative model given by W.T. Roach showing movement of a parcel above  $Z_c$

$Z_{p'}$  so that the area (B) within parcel ascent curve and the modified environmental thermodynamic curve between  $Z_c$  and  $Z_{p'}$  becomes equal to area (A).

There is no method of measuring the modification of environment. For operational use we may arbitrarily assume that equal amounts of descending air and environmental air get mixed. This leads to a quick computation.  $Z_{p'}$  for three cases have been calculated and they are given in Table 1. The agreement with observed height of top is very good.

4. Simple parcel method is not always adequate for forecasting heights of tops of very high cumulonimbus clouds as in many cases it fails to explain the last 1 to 1.5 km of the top. This can be explained by assuming modification of environmental air near the upper part of the cumulonimbus.

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13 March 1970

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