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NUMERICAL SIMULATION OF WARM RAIN PROCESS

A. Mary Selvam and A.S.Ramachandra Murty
Indian Institute of Tropical Meteorology, Pune 411 005, India.

1. INTRODUCTION

Extensive aircraft cloud physical observations made in more than 2000 tropical cumulus clouds indicated new observational evidence viz. (1) horizontal structure of the air flow inside the cloud has consistent variations with successive positive and negative values of vertical velocity representative of ascending and descending currents, (2) regions of ascending currents are associated with higher LWC and negative cloud drop charges and the discending currents are associated with lower LWC and positive cloud drop charge, (3) width of the ascending and descending currents is about 100 m, (4) ratio of the measured LWC (q) to that of the adiabatic value (q_a) = 0.60 at cloud-base levels, (5) increase in the cloud electrical activity with LWC, (6) cloud drop size spectra is unimodal near the cloud-base and multimodal at higher levels, (8) in-cloud temperatures are colder than the environment, (8) environmental lapse rates are equal to the saturated adiabatic value while inside the cloud they are lower, (9) positive increments in the LWC are associated with the increments in temperature inside the cloud and the immediate environment and (10) variances of in-cloud temperature and humidity are larger in the regions where the values of the LWC are higher. The observed dynamical and physical characteristics of clouds cannot be explained by the presently available cloud models. A simple cloud model based on certain physical processes taking place in the atmospheric boundary layer (ABL) has been developed. A brief summary of the cloud model is presented below.

2. MODEL

The ABL consists of convective scale large and turbulent eddies (Fig.1). It was shown that the buoyant production of energy by the Microscale-Fractional-Condensation (MFC) in turbulent eddies is responsible for the sustenance and growth of the large eddies (vortex rolls). The MFC takes place in turbulent eddies even in the unsaturated environment. Under favourable synoptic conditions the turbulent eddies get further amplified due to enhanced MFC and lead to the growth of the large eddy in the vertical resulting in cloud formation above the LCL. Inside the cloud the turbulent eddies get amplified faster due to higher degree of condensation and generate cloud-top-gravity (buoyancy) oscillations which are responsible for vertical mixing in clouds (Mary Selvam et al., 1985). The theory relating to the dynamics of the ABL and a warm cloud model is presented below.

The circulation speed of the large eddy is related to that of the turbulent eddy according to the following expression (Townsend, 1956).

$$W^2 = \frac{2r}{\pi R} w^2 \qquad \ldots(1)$$

where W and w are respectively the r.m.s. circulation speeds of the large and turbulent eddies with radii R and r. For a large eddy with R = 10r the increase in W is 25% of w or $W \simeq 0.25\,w$.

The wind profile in the ABL is governed by the physical processes relating to the growth of the large eddy. It was shown (Mary Selvam et al., 1985) that the vertical wind (W) profile can be expressed as

$$W = \frac{w_*}{k} \ln z \qquad \ldots(2)$$

where w_* is the increase in the vertical velocity per second of the turbulent eddy resulting from the MFC process, z the normalised height, (R/r), k the Von Karman constant which has been shown to be equal to 0.4 and represents the fractional volume dilution rate of the large eddy by the turbulent scale eddies for z = 10 (Mary Selvam et al., 1984 a, b).

On the basis of the conceptual cloud model discussed earlier, theory relating to the prediction of different cloud parameters is briefly discussed in the following.

2.1 Vertical Profile of q/q_a

The fraction f of the air mass of surface origin which reaches the height z after dilution due to the vertical mixing caused by the turbulent eddy fluctuations can be expressed as (Mary Selvam et al., 1984 a).

$$f = \frac{W}{\omega_*}\frac{r}{R}$$

$$= \frac{W}{\omega_*}\frac{1}{z}$$

$$= \sqrt{\frac{2}{\pi z}}\; \ln z \qquad \ldots(3)$$

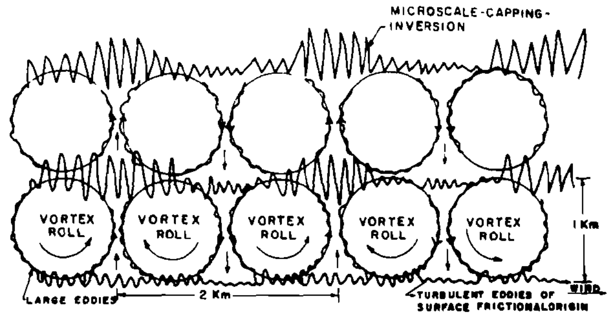

Fig. 1 : Schematic representation of the eddies in the Atmospheric Boundary Layer

In Eq. (3), f will be representative of the q/q_a. The model predicted profile of q/q_a is in close agreement with the observed profiles (Fig.2).

2.2 In-Cloud Vertical Velocity and Excess Temperature Profiles

The logarithmic wind profile (Eq.2) can be expressed as

$$W = w_* \, fz \qquad \ldots(4)$$

As there is a linear relationship between the vertical velocity perturbation W and the temperature perturbation θ.

$$\theta = \theta_* \, fz \qquad \ldots(5)$$

Thus W and θ follow the fz distribution.

The in-cloud temperature lapse rate can be expressed as follows (Mary Selvam et al., 1984 a).

$$\Gamma_s = \Gamma - \frac{d\theta}{dz}$$

$$= \Gamma - \frac{\theta_* f_z}{r} \qquad \ldots(6)$$

where Γ is the dry adiabatic lapse rate.

2.3 Total Cloud Liquid Water Content (q_t) Profile

Analogous to Eq.(5) the expression for q_t can be given as

$$q_t = q_* \, fz \qquad \ldots(7)$$

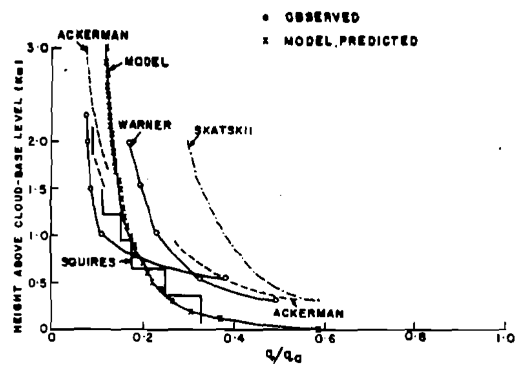

Fig.2 : Observed vertical profiles of the ratio of cloud liquid water content to its adiabatic value (q/q_a). Profile predicted by the present model for r = 1 m is also given.

Where q_* is the production rate of the LWC at the cloud-base level and is equal to $C_p\ \theta_*/L$. The q_t profile follows the fz distribution. The computed fz profile is shown in Fig.3.

2.4 Cloud Growth Time

The cloud growth time, t , can be expressed as

$$t = \frac{z_0}{\omega_*}\sqrt{\frac{\pi}{2}}\; li\left(\sqrt{z}\right)_2^z$$

Where li is the Soldner's integral

or the logarithm integral. The computed cloud growth time for different cloud thicknesses is shown in Fig. 4.

2.5 Cloud Drop Size Spectra

It was shown that the cloud drop number concentration decreases with height according to the f distribution due to eddy mixing (Mary Selvam et al., 1985). The total water content increases with height according to the fz distribution. The cloud drop spectrum at any level will consist of the drops transported from the lower levels and the large size drops formed on less number of nuclei at that level.

It was shown that the cloud drop spectrum at any level z consists of drops of radii r_1, r_2... r_z with respective concentrations of n_1, n_2 ... n_z. r_z and n_z can be expressed as follows.

$$n_z = n_* \left(z + \frac{\sum^{z-1} f_z}{f_z} \right)$$

$$n_z = \frac{c f_z}{\sum_2^z f_z} \qquad \ldots(9)$$

Where $C = N_* f_z$

The N_* at level z can be expressed as

$$\sum_1^z n_z = N_* f_z \qquad \ldots(10)$$

The computed cloud drop size spectra at different levels in the cloud are shown in Fig. 5.

2.6 In-Cloud Raindrop Spectra

In the model it was assumed that the bulk conversion of cloud water to rain water takes place mainly by collection and the process is efficient due to rapid increase in the cloud water flux with height. Analogous to the cloud drop size spectrum the raindrop size spectrum at any level z above the cloud-base will consist of z categories of raindrops of radii R1, R2, ...Rz with respective concentrations n1, n2 ... nz respectively. nz and Rz can be expressed as follows.

$$n_z = \frac{c^{f_z}}{\sum_2 f_z} \quad \text{where } c = N_* f_z$$

$$R_z = R_* \left(\frac{\left[f_z^2 z^2 + \left(1 + \frac{\sum f_z}{f_z}\right)\right]}{\left[f_z^2 z^2 - f_{z-1}^2 (z-1)^2 \right]} \right)^{1/3}$$

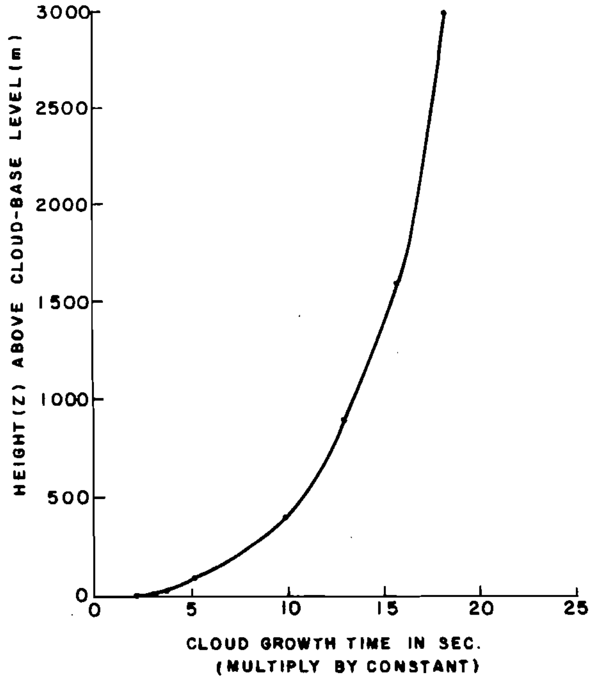

Fig. 4 : Computed cloud growth time

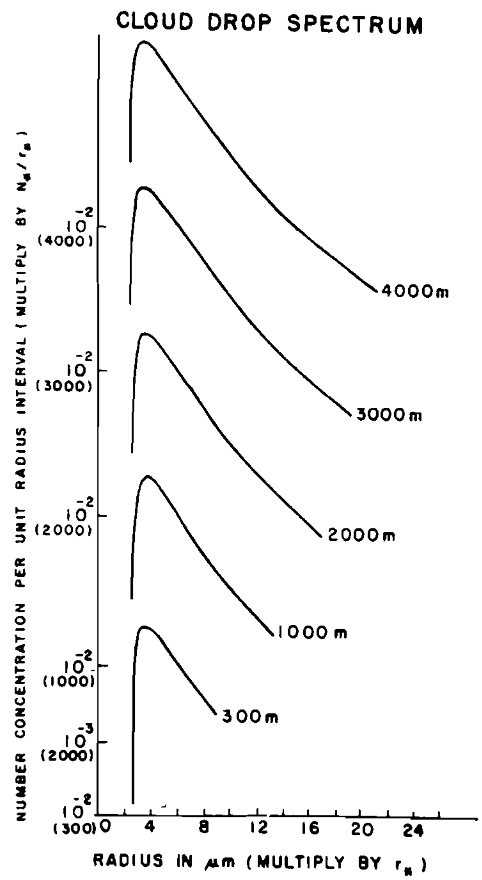

Fig.5 : Computed cloud drop spectra at different heights in the cloud

3. WARM CLOUD RESPONSES TO SALT SEEDING

In the previous sections it was shown that the buoyant production of evergy by MFC in turbulent eddies is mainly responsible for the formation and growth of the cloud. When warm clouds are seeded with salt particles the turbulent buoyant production of energy increases due to enhanced condensation and results in enhancement of vertical mass exchange. This would enhance the convergence in the sub-cloud layer and result in the invigoration of the updraft in the cloud. If sufficient moisture is available in the sub-cloud air layer the enhanced convergence would lead to increased condensation and cloud growth. The salt seeding can thus alter the dynamics of warm clouds.

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