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A TEST OF A CUMULUS PARAMETERIZATION MODEL USING THE GATE DATA

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ABSTRACT

Two parametric, ensemble cloud models have been tested with data obtained during GATE (1974). The first model is an adaption of the Arakawa-Schubert scheme which uses an entraining jet to represent individual cumulus cloud types. The second model consists of an ensemble of cylindrical cells to represent the convective cloud field.

INTRODUCTION

An important feature of synoptic-scale numerical prediction models and for planetary-scale general circulation models is the parameterization of cumulus convection. For integrations over short time periods, it is possible to treat subgrid-scale convection in an extremely artificial way, or ignore it altogether. However, when the period is large, and especially in the tropics, convection is an important mechanism for the vertical transport of heat, moisture and momentum. Even when the period is short ($\lesssim$1 day) and the large-scale flow is not influenced by convective activity, the prediction of convective rainfall and cloudiness are still important objectives of the local weather forecast and climate of a region.

In preparation for a study of parameterized convection in a predictive model where physical processes are not free to be chosen arbitrarily, we have studied several parameterization models in a diagnostic sense, using observations of synoptic-scale variables to determine the characteristics of convection rather than the reverse. If these models give reasonable results, their ultimate application will be in a prediction scheme in NWP and GCM models.

The first part of the study investigates the sensitivity of the Arakawa-Schubert parameterization method. Lord (1978) has completed a more extensive study using a different numerical procedure ("overadjustment"). We have also compared our more limited results with those obtained using an overadjustment procedure by Schubert and Silva-Diaz (personal communication).

The second part of the study is a test of an ensemble of cellular convective elements (Cheng, 1978; Rodenhuis and Cheng, 1979). The results of this model are compared to those of Nitta (1977) who also used the entraining jet cloud model of Arakawa and Schubert (1974) to explain the residual term in a budget calculation.

RESULTS

Sensitivity Tests of the Entrainment Model

Figure 1 shows the results of computing the detrainment level for each cloud type which is identified by a constant entrainment coefficient, λ. The input data is the composite of Nitta (1977) for unorganized convection in GATE (6 September 1974). (The radiational heating rate, Q_R=0 for these studies.) Three cases are shown corresponding to different conditions at the cloud base:

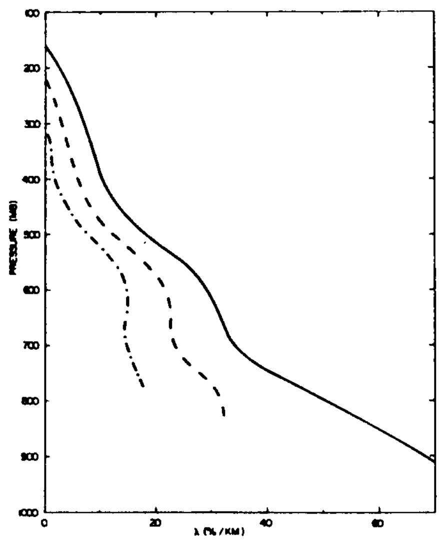

Fig. 1. The detrainment level of model clouds as a function of the detrainment rate (λ). Case 1 (solid); Case 2 (dashed); Case 3 (dash-dotted).

Case 1: Cloud base and top of the mixed layer all identical; cloud elements are neutrally buoyant at cloud base.

Case 2: Cloud base is identical with Case 1, but the top of the mixed layer is assumed to be 25 mb below; cloud elements have the properties of the environment within the mixed layer.

Case 3: Cloud base and the top of the mixed layer are identical; cloud elements have the same properties as the environment at the cloud base ($\Delta h = \Delta s_v = 0$).

These rather small changes in conditions which are applied at the cloud base strongly influence the spectra of convective cloudiness as shown in Fig. 2. Only in Case 1 is there a large number of small cumuli which are considered to be so essential for the moisture budget of an atmosphere with imbedded deep convection.

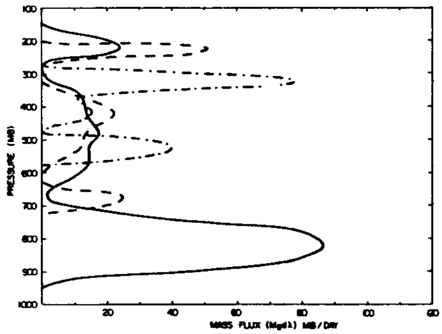

Fig. 2. The cloud mass flux spectrum as a function of detrainment level for the three cases shown in Fig. 1.

Figure 3 shows a comparison of our results (University of Maryland [UM]) with those from a calculation of W. Schubert and P. Silva-Diaz (Colorado State University [CSU]; personal communication). For this comparison, identical input data was used. The differences are due almost entirely to the method of integration in the calculation of $\lambda(z)$:

$$\overline{h^*} = h_c(z,\lambda) = \frac{1}{\eta(z,\lambda)} \left[h_c(z_B,\lambda) + \lambda \int_{z_B}^{z} \eta(z',\lambda)\bar{h}(z')dz' \right] \quad (1)$$

where $\overline{h^*}$ and h_c	are the moist static energy in the environment and cloud, respectively. The * indicates scattered values.
$\eta(z,\lambda)$	is specified exponential function of height and λ.
z_B	is the height of the cloud base.

Note that there is a gap in the spectrum of the CSU results between 875 and 925 mb (dashed line) which does not occur in the UM calculation.

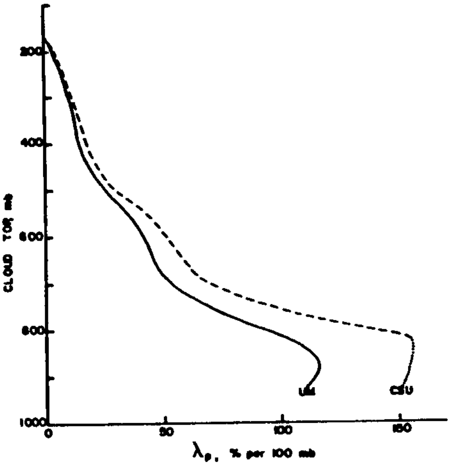

Fig. 3. The detrainment level of model clouds as a function of detrainment rate (λ) computed with two different methods.

This discrepancy accounts for some of the differences in the cloud spectra seen in Fig. 4. In addition, the UM results have been simply minimizing the residual term in the equation (the equilibrium hypothesis):

$$\frac{dA}{dt} = \int K(\lambda,\lambda') \, M_B \, d\lambda + \overline{F} \doteq 0 \qquad (2)$$

where A is the cloud work function
$\underline{K}$ is the cloud:cloud interaction matrix
$\overline{F}$ represents the large-scale forcing function
and M_B is the cloud base mass flux.

However, Schubert uses a different method (described by Lord, 1978), which modifies $\overline{F}$ to accommodate changes in A which occur over a small arbitrary period of time, Δt. Thus, Schubert's results depend on Δt, as can be seen in Fig. 4 for the 2 cases of CSU results.

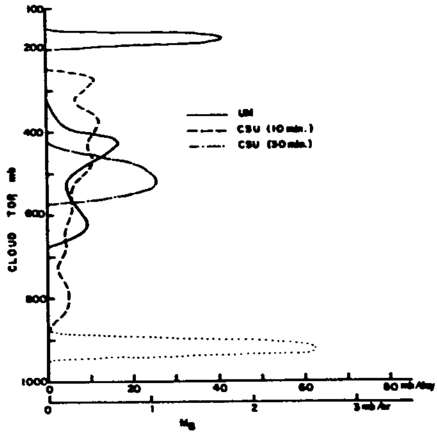

Fig. 4. The cloud mass flux spectrum as a function of detrainment level for three cases.

Note that the UM results do not prohibit low cloud types (Fig. 3), but they are not required for the solution of (2). However, we do require high clouds detraining at 175 mb. By way of control, the CSU results of 875 mb (dotted curve) prohibit cloud tops at that level, but not more shallow clouds. Therefore, a large number of shallow clouds are required to satisfy the equilibrium condition, at least for Δt=10 min.

Comparison with the Cellular Model

Figure 5 (top) shows the results of cloud spectra obtained by using an ensemble of cellular convective elements (Rodenhuis and Cheng, 1979). This result also differs from those in Figs. 2 and 4, because an entirely different method is used to compute the cloud number density and mass flux. Rather than imposing the equilibrium hypothesis (2), the net-heating-and-moisture-deficit budget is satisfied:

$$Q_1-Q_2-Q_R= -\frac{\partial}{\partial p}(F_\theta)-L\frac{\partial}{\partial p}(F_q) \qquad (3)$$

where Q_1 = net cumulus heating
Q_2 = net cumulus moisture deficit
Q_R = radiational heating rate
F_θ = net cumulus heat flux
F_q = net cumulus moisture flux.

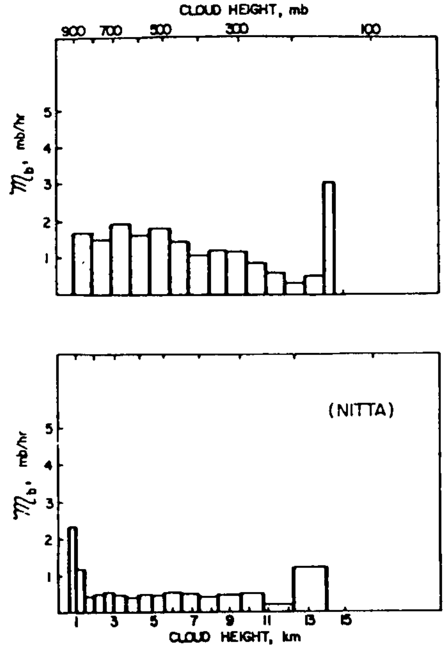

Fig. 5. A comparison of cloud base mass flux determined from the cellular model (upper) and determined by Nitta (1977). Input data (6 September 1974, GATE) for both results are identical.

Although there are some similarities between Figs. 2, 4, and 5, there are serious discrepancies in every case. (Some differences are due to different values of Q_R.)

Comparison with the Entrainment Model

The entrainment cloud model has also been used with (3) by Nitta (1977) to determine the cloud spectra. These results are shown in Fig. 5 (lower). The relatively large number of lower cloud agrees (perhaps fortuitously) with Case 1 of Fig. 2. There is some similarity between the upper and lower parts of Fig. 5, but the bimodal distribution does not occur with the cellular model because of the increased mass flux of middle-level clouds.

CONCLUSIONS

The spectra of the cloud base mass flux has been calculated by two different methods: (1) by an application of the equilibrium hypothesis, equation (2), and (2) by using the bulk budget method, equation (3). In each cse we have shown two independent calculations using different computational schemes (UM and CSU), or using different models (entrainment model and the cellular model). Our results using the equilibrium hypothesis show that the spectra are very sensitive to the conditions at the cloud base. Furthermore, the results depend on the computational scheme which is used. Finally, the spectra do not agree very well with those calculated from the budget method, although differences in Q_R account for some of this discrepancy.

When the cellular model is used with the budget method, the results are in general agreement with Nitta's spectra, although there is not a strong bimodal mass flux distribution. The rainfall estimate with the model is 10.21 mm/day, as compared to 10 mm/day from the average of the shipboard observations during the period. Other evidence (Cheng, 1978) shows that the cellular model behaves reasonably over a wide range of conditions.

In addition, the ensemble cellular cloud model can diagnose the cloud areal fraction and number density of each cloud type. Figure 6 shows these new spectra for the same period of analysis as has been used throughout this study. These results may be used to compare with independent, direct measurements of cloud dimensions from radar or satellite radiometers. This is an extremely useful link between cloud parameterization in numerical models and direct observations of clouds, especially from satellite platforms.

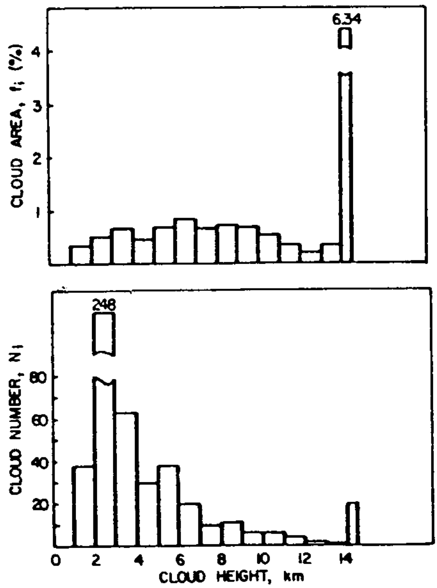

Fig. 6. Spectra of cloud areal fraction and number density as a function of closed height determined from the ensemble cellular model.

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