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A note on convective precipitation in numerical models

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ABSTRACT. With the help of the observed radiosonde and convective rainfall data for two Indian stations, three methods of computing convective rainfall in numerical models were compared. It was found that the rainfall computed by all the methods is comparable to the observed rainfall. However computed rainfall differs considerably from one method to the other.

1. Introduction

Precipitation due to small scale convection is important in the energetics of the real as well as any of the various numerical model atmospheres. Some models predict the convective precipitation by certain simple physical methods. We shall be concerned with three of such methods. They are (1) Convective adjustment method, (2) Kuo's method, & (3) Arakawa method. An attempt is made here to compare these methods and apply them for local convective precipitation forecasting.

2. Notation

The notation to be used is given below :

ρ — Density

p — Pressure

T — Temperature

χ — Humidity mixing ratio

s — A suffix indicating saturation

χ_s — Saturation humidity mixing ratio

δT — Change in T at a level due to adjustment

$\delta\chi$ — Change in χ at a level due to adjustment

b — A suffix to indicate the bottom of an unstable layer

t — A suffix to indicate the top of an unstable layer

K — R/c_p

R — Gas constant

c_p — Specific heat of dry air at constant pressure

g — Acceleration due to gravity

L — Latent heat of condensation

c — A suffix indicating the cloud

b_c — A suffix indicating the bottom of the cloud

t_c — A suffix indicating the top of the cloud

RHC — Relative humidity control parameter

$f(Z)$ — A non dimentional function of height

δ_q — Total condensation in Kuo's model

e — Vapour pressure

ϵ — 0·622

B — A suffix indicating the lower boundary

1,2,3,4 — Suffixes indicating levels in Arakawa's model, they correspond to 300, 500 700 and approximately 1000 mb levels

h — $c_p\,T + g\,Z + L\,\chi$

h^* — $c_p\,T + g\,Z + L\,\chi_s$

S — $c_p\,T + g\,Z$

η — entrainment parameter

C — Total upward mass flux from the boundary layer into the cloud

$\triangle p = p_3 - p_1$ (700—300) mb

$\triangle p_B = p_B - p_4$

γ_1 — $\dfrac{L}{c_p}\left(\dfrac{d\chi_s}{dT}\right)_1$

γ_3 — $\dfrac{L}{c_p}\left(\dfrac{d\chi_s}{dT}\right)_3$

τ — Relaxation time of free cumulus convection

3. Convective Models

A brief description of the three methods will be given below.

(*a*) *Convective adjustment method* — Two types of adjustment (1) dry and (2) moist, are used in this method. A layer is considered for dry or moist adjustments, as per conditions below :

(1) Dry adjustment conditions

$$\chi < \chi_s \qquad (1)$$

and

$$\frac{\partial}{\partial Z}\left(c_p\, T + g\, Z \right) < 0 \qquad (2)$$

(2) Moist adjustment conditions

$$\chi > \chi_s \qquad (3)$$

and

$$\frac{\partial}{\partial Z}\left(c_p\, T + g\, Z + L\, \chi \right) < 0 \qquad (4)$$

adjustment is done such that

$$\int_{Z_b}^{Z_t} \rho\, c_p\, \delta T \,.\, dZ = 0 \qquad (5)$$

for dry adjustment, and

$$\int_{Z_b}^{Z_t} \rho\, (c_p \delta T + L\, \delta \chi)\, dZ = 0 \qquad (6)$$

for moist adjustment.

The adjustment is repeated until stability is reached throughout the total column of the atmosphere. After the adjustment, the vertically integrated $\delta\chi$ from top to bottom of the entire atmosphere considered, gives the precipitation. For the actual method of calculation of $\delta\chi$ one can refer to the references given at the end of this note. The precipitation depends on χ_s used. If one introduces a relative humidity control parameter RHC, one can consider the saturation to be reached at different values of RHC, say RHC $= 1{\cdot}0,\ 0{\cdot}9,\ 0{\cdot}8,\ 0{\cdot}7$ etc. The smaller the RHC the greater will be the computed precipitation.

This method does not take into account the effect of large scale convergence. Neither it is explicity concerned with entrainment. Free dry and moist convection only, seems to be treated by this method.

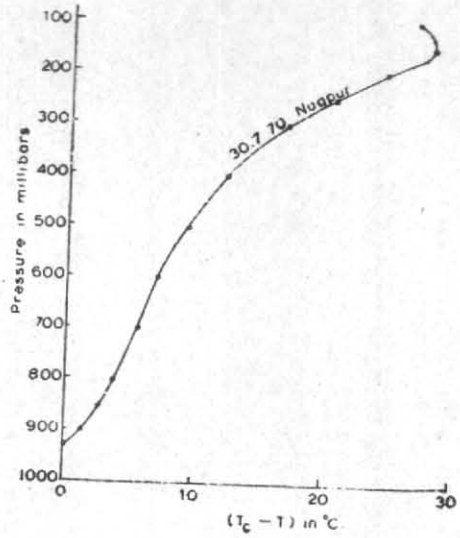

Fig. 1

(*b*) *Kuo's model* — Kuo (1965) introduced a method according to which the condensation δ_q is given by

$$\delta_q = \frac{c_p f(Z)}{gL} \int_{p_{bc}}^{p_{tc}} (T_c - T)\, dp \qquad (7)$$

The temperature at the lifting level of condensation is calculated numerically after solving by iteration the following algebraic transcendental equation.

$$T_{bc} = \left[\frac{1}{273} + \frac{R}{\epsilon L} \log \frac{6{\cdot}11}{e_B} + \frac{R}{\epsilon LK} \log \frac{T_B}{T_{bc}} \right]^{-1} \qquad (8)$$

The corresponding pressure p_{bc} is calculated by solving the adiabatic equation

$$T_{bc}\, p_{bc}^{\,(-R/c_p)} = T_B\, p_B^{\,(-R/c_p)} \qquad (9)$$

This level p_{bc} is taken to be the bottom of the cloud.

In this model condensation occurs only where there is large scale convergence of water vapour. $f(Z)$ depends on the large scale convergence. It can be interpreted as a sort of cloud amount and is like (1—RHC) of the previous method.

A typical profile of $(T_c - T)$ is shown in Fig. 1. It can be seen that the upper layers which are relatively dry, tend to contribute more to the condensation. Kuo suggests weighting of $f(Z)$ with respect to large scale convergence profile in the vertical. Except in a numerical experiment it is difficult to accurately calculate the convergence, especially with the real data.

In this paper $f(Z)$ is not calculated from large scale convergence. Large scale convergence is assumed (because the method is applied when there is convection and precipitation). To scale down the upper level contribution we simply let,

$$f(Z) = (p/p_{bc})^{\alpha}\ , \quad \alpha > 0 \qquad (10)$$

Here α is taken to be equal to unity.

This method takes into consideration, only C.I.S.K. type of instability. Thus it differs fundamentally from the earlier method.

(c) *Arakawa method* — Arakawa uses four level model. He allows for entrainment, indicated by η parameter. Precipitation results when two types of convection occur. These are P.C. (Penetrative Convection) and M.C. (Middle level Convection).

For M.C., the parameters ηC and η are given by

$$\eta C = \frac{\triangle p}{g\tau}\,\frac{1+\gamma_1}{2+\gamma_1}\,\frac{(h_3 - h_1^*)}{(h_3 - h_1^*) + \frac{1}{2}(1+\gamma_1)(S_1 - S_3)} \qquad (11)$$

$$\eta = \infty, \quad \frac{1}{\eta} = 0 \qquad (12)$$

for P.C. they are given by

$$\eta C = \frac{\triangle p}{g\tau}\,\frac{(h_B - h_1^*)}{\frac{\triangle p}{\eta \triangle p_B}(h_B - h_4) + \frac{(1+\gamma_1)}{2}(S_1 - S_3)} \qquad (13)$$

$$\eta = (h_B - h_3)\ /\ (h_1^* - h_3) \qquad (14)$$

In both cases condensation is computed by :

Total condensation =

$$\tau\,\frac{\eta C}{L}\left[\frac{1}{1+\gamma_1}(h_c - h_1^*) + (S_1 - S_3) + \frac{1}{\eta}(S_3 - S_B)\right] \qquad (15)$$

Rainless convection is represented by L. C. (Low level Convection).

Ideally the level 4 must be as close to the lower boundary as possible, in this model. However the nearest data level to the lower boundary, which in general is about 50 mb pressure difference from it, is taken as level 4 in this note.

This method considers both large scale convergence and entrainment. Even free convection can occur in this model. Thus this method seems to be a physically clear and realistic combination of the above said two methods.

4. Data

The 12 GMT radiosonde data at two Indian stations were taken for some days of local convection and thunderstorm precipitation. In deciding whether there was local convection or not, the thermographic, hygrographic, Dines P. T. anemographic records along with the rainfall records, were taken into consideration. In the selection of the data, it was stipulated that — (1) The rainfall, which may be heavy to moderate or only a trace of it, must occur only after 12 GMT without any rainfall before it during the day; (2) No large scale system should be influencing the precipitation at the station, because in such situations one cannot distinguish between large scale and convective scale precipitation.

5. Results

The results are given in Table 1. The following inferences can be drawn.

(1) In the first method for RHC=1·0, only in rare cases the adjustment yields some precipitation.

(2) The orders of computed and observed rainfalls are same for RHC=0·8 or 0·7 in this adjustment method. So for numerical models RHC=0·8 or 0·7 seems to be a reasonable compromise.

(3) The rainfall obtained by Kuo's method is comparable to that obtained by the first method. But in general the precipitation is more than that given by the first method with RHC=0·8. There seems to be little correlation between the two sest of computed rainfall. Kuo's method shows little correlation with observations.

(4) Arakawa method too predicts higher rainfall than the first method in general. Highest rainfalls are predicted by this method. In all cases, excepting three, penetrating convection occurred. This method too shows little correlation with observations.

6. Comments

This is only an indicative pilot study. Correlation analysis cannot be conducted with such scarce data. Neither can good correlation be expected between observations and computed rainfall, for the following reasons, in that order of importance.

(1) The convective rainfall predicted by numerical models is an average over a wide area. Aerial averages of observed convective rainfall are not easily obtained.

TABLE 1

Date	Adjustment C.R./RHC 1.0	0.9	0.8	0.7	Kuo C.R.	Kuo η	Arakawa T.C.	Arakawa C.R.	Arakawa O.R.
					NAGPUR				
4 Jun 70	0·00	0·56	2·38	6·62	13·20	∞	M.C.	1·00	4·70
20 Jun 70	0·00	0·72	2·69	5·90	15·60	5·82	P.C.	—	0·00
11 Jul 70	0·10	2·62	6·74	11·47	12·93	∞	M.C.	11·53	17·00
17 Jul 70	2·36	4·99	9·78	16·21	15·70	3·50	P.C.	31·22	51·50
24 Jul 70	0·00	1·19	2·70	5·80	13·44	4·35	P.C.	11·32	0·30
30 Jul 70	0·00	2·27	5·15	11·09	14·64	32·98	P.C.	41·08	12·60
7 Aug 70	0·00	1·80	4·75	10·69	14·71	7·72	P.C.	26·89	0·00
12 Aug 70	0·00	3·71	6·96	13·12	26·55	9·95	P.C.	44·56	36·10
					BANGALORE				
7 May 70	0·00	0·00	2·05	2·05	10·92	27·35	P.C.	26·99	0·00
8 May 70	0·00	0·84	2·51	6·67	2·82	∞	M.C.	3·64	3·20
14 Jul 70	0·00	0·32	1·36	3·37	3·17	1·26	P.C.	2·91	36·00
8 Aug 70	0·00	0·00	0·00	1·67	6·97	3·26	P.C.	25·38	46·70
28 Aug 70	0·00	0·03	0·07	2·32	9·40	2·48	P.C.	20·50	0·00
14 Sep 70	0·00	0·47	1·81	4·19	9·63	3·07	P.C.	9·26	0·70
18 Sep 70	0·00	0·00	0·00	0·39	9·25	2·48	P.C.	14·15	2·31
15 Apr 71	0·00	0·00	0·00	0·44	7·34	1·32	P.C.	8·86	0·00
16 Apr 71	0·00	0·00	0·00	0·93	4·25	1·32	P.C.	2·71	1·20
18 Apr 71	0·00	0·68	2·62	5·36	11·13	8·54	P.C.	28·27	0·70

O.R.=Observed rainfall (mm) T.C.=Type of Convection τ=10 min for Arakawa method
RHC—Relative Humidity Control α=1·0 for Kuo method C.R.=Computed rainfall (mm)

(2) The atmosphere might have adjusted to some extent by 12 in GMT.

This study indicates that the first method predicts less convective precipitation than the other two methods. Arakawa method predicts highest values. Whether such differences mean different statistics over tropics in a general circulation model or not, has to be seen.

From the point of view of observations, all the three methods are equally preferable. It will be useful to conduct this type of study with larger amount of radiosonde data and better network of rainfall observations, so that one can arrive at some correlation coefficients for prediction of local rainfall.

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