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Computation of rainfall rates in typical monsoon cases by the semi-prognostic method

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सार — क्यूओ की प्राचलीकरण योजना पर आधारित तीन विवरणों द्वारा विशिष्ट मानसून क्षेत्र में वर्षा दरों के परिकलन के लिए एक अर्ध-पूर्वानुमान दृष्टिकोण (एक समय में स्तर प्रागुक्ति) का प्रयोग किया गया है। वर्षा दरों के पूर्वानुमान प्रायः बढ़ा-चढ़ा कर किये हुए हैं। एक विवरण जिसमें लघुक्षेत्र आर्द्रता अभिसरण प्राचल शामिल है अन्य विवरणों की अपेक्षा उत्तम पूर्वानुमान देता है। अति प्रागुक्ति, न्यून प्रागुक्ति और परिकलित वर्षा का अभाव, ये तीन वर्ग पाए गए हैं। इन वर्गों के संभावित कारणों पर चर्चा की गई है।

ABSTRACT. A semi-prognostic approach, *i.e.*, one time step prediction is used to compute rainfall rates in typical monsoon region by three versions based on Kuo's parameterization scheme. Rainfall rates are generally over-predicted. One version which includes mesoscale moisture convergence parameter gives better prediction than other versions. Three categories are found, over-predicted, under-predicted and no computed rainfall. The possible reasons for these categories are discussed.

1. Introduction

Forecast models designed for the monsoon region should be capable of predicting rainfall rates. For this, a reliable method of cumulus parameterization is vital. Both in the tropics and extra-tropics the method based on Kuo's scheme has been widely applied (Kuo 1965, 1974; Krishnamurti *et al.* 1980, 1983). However, this method has not been tested extensively in the monsoon region although some studies have been made for specific case-studies (Krishnamurti *et al.* 1976; Ramanathan 1976; Singh 1985). The purpose of this paper is to test the efficacy of Kuo's scheme in the first instance by the so-called semi-prognostic approach (Lord 1982) which is a one time step prediction.

The different variations of the method used in the study are :

(*i*) *Version* 1

(Kuo 1974; Krishnamurti *et al.* 1980)

(*ii*) *Version* 2

(Krishnamurti *et al.* 1983)

(*iii*) *Version 3*

Same as version 2 but using regression coefficients as given in the Florida State University, Limited Area Regional Model.

Brief details of Kuo's scheme used in the computations are in section 2. Section 3 describes the data used and the method of computation. The results are discussed in section 4. A list of symbols is given below in Sec. 2.

2. Brief details of Kuo's scheme

List of symbols used

a_1, b_1, c_1	coefficients of the multi-regressed planar surface of the ratio of the rainfall rate to the large scale supply of moisture
a_2, b_2, c_2	coefficients of the multi-regressed planar surface of the ratio of the moistening rate to the large-scale supply of moisture
b	moistening parameter
I	total supply of moisture
I_L	large-scale supply of moisture
M	moistening rate
P_T	pressure at cloud top
P_B	pressure at cloud base
P	pressure
q	specific humidity
R	rainfall rate
$\mathbf{V}$	horizontal wind vector
ω	vertical *p*-velocity
$\bar{\omega}$	vertically integrated vertical velocity
ξ	700 mb relative vorticity
η	meso-scale convergence parameter
∇	horizontal vector gradient operator

TABLE 1

Version	a_1 $(10^5 s)$	b_1 $(10^8 mb^{-1} s)$	c_1 (Dimensionless)	a_2 $(10^5 s)$	b_2 $10^8 mb^{-1} s$	c_2 (Dimensicnless)
II	0.158	0.304	0.476	0.107	0.107	0.870
III	—0.2795	—0.144	0.08959	0.11	0.892	0.8938

Kuo (1965) related the intensity of convective forcing to the instantaneous rate at which the moisture is supplied at the grid point. In this scheme, Kuo used the same partition coefficient for heating and moisture storage. Since this scheme under-estimated the rainfall rates, Kuo (1974) introduced a flexible moistening parameter 'b' which is the fraction of moisture going into storage. However, besides presenting some observational evidence to suggest that b is close to zero but very much less than 1, Kuo did not present any functional form. Krishnamurti *et al.* (1980) using this scheme in a semi-prognostic approach for GATE phase III data obtained a close agreement between the observed and computed rainfall rates setting the parameter b to zero. However, during model integrations drying for the middle levels was noticed. To overcome this, Krishnamurti *et al.* (1983) proposed a two-parameter scheme in which there was an additional meso-scale moisture parameter (η) besides the partition parameter b. Thus, the total moisture supply is :

$$I = I_L (1 + \eta) \tag{1}$$

where, I_L (the large-scale part)

$$= \frac{1}{g} \int_{P_B}^{P_T} \omega \frac{\partial q}{\partial p} dp \tag{2}$$

The part going into storage :

$$M = I_L (1 + \eta)\, b \tag{3}$$

and the part for condensation and rainfall :

$$R = I_L (1 + \eta) (1 - b) \tag{4}$$

A screening regression technique chose the two variables — vertically integrated vertical velocity $(\overline{\omega})$ and 700 mb relative vorticity (ξ) – for estimating M and R from the data sets. The regression equations are :

$$\frac{M}{I_L} = a_1 \xi + b_1 \overline{\omega} + c_1 \tag{5}$$

$$\frac{R}{I_L} = a_2 \xi + b_2 \omega + c_2 \tag{6}$$

The coefficients used by Krishnamurti *et al.* (1983) in version 2 and in the Florida State University model (1987) in version 3 are given above in Table 1.

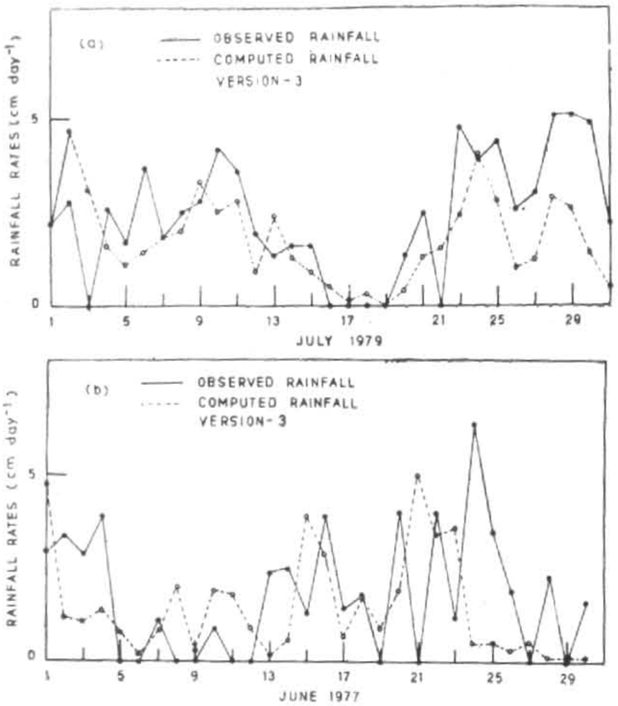

Fig. 1. Observed and computed rainfall rates for (a) July 1979 & (b) June 1977

3. Data and computation

(a) *Data used in the study*

The upper wind and temperature data for 1977 and MONEX-1979 for the months of the June and July respectively of the island stations : Minicoy (08.18°N, 73.00°E), Mangalore (12.52°N, 74.51°E) and Trivandrum (08.29°N, 76.57°E) are the basic data. The observed rainfall figures were from the archives of India Meteorological Department. The variables were computed at the centre of the triangular area.

(b) *Computations of* ω *and* ξ

The planar surface $ax + by + c$ is fitted over triangular arrays of weather stations for the zonal velocity u and meridional velocity v :

$$u = ax + by + c \tag{7}$$

$$v = px + qy + r \tag{8}$$

The regression approach consists of determining a, b, c, p, q and r by the least square method. This entails solution of the normal equations :

$$\Sigma u_i = cN + a\Sigma x_i + b\Sigma y_i \tag{9}$$

$$\Sigma x_i u_i = c\Sigma x_i + a\Sigma x_i^2 + b\Sigma x_i y_i \tag{10}$$

$$\Sigma y_i u_i = c\Sigma y_i + a\Sigma x_i y_i + b\Sigma y_i^2 \tag{11}$$

Similarly, equations can be written for v component

TABLE 2

Version	No. of over-predicted cases	No. of under-predicted cases	Computed *minus* observed daily rates averaged for the month (cm day^{-1})	Average observed daily rainfall rate (cm day^{-1})
		MONSOON-June 1977		
1	16	14	0.728	1.47
2	16	14	0.791	1.47
3	16	14	0.003	1.47
		MONEX-July 1979		
1	24	7	2.336	1.77
2	24	7	2.264	1.77
3	21	10	0.609	1.77

N is the number of stations and (x_i, y_i) is the location of station $i(=1, 2, \ldots, N)$

Divergence (D) and vorticty (ξ) are obtained from :

$$D = a + q \tag{12}$$

$$\xi = p - b \tag{13}$$

The vertically integrated divergence :

$$\int_{1000}^{0} \nabla \cdot \mathbf{V}\, dp$$

will not be identically zero. A correction factor, is used to modify the value of divergence.

$$(\nabla \cdot \mathbf{V})_c = \nabla \cdot \mathbf{V} + \epsilon \mid \nabla \cdot \mathbf{V} \mid \tag{14}$$

$$\epsilon = - \frac{\int_{1000}^{0} \nabla \cdot \mathbf{V}\, dp}{\int_{1000}^{0} \mid \nabla \cdot \mathbf{V} \mid dp} \tag{15}$$

The vertical velocity at any level p comes from the integration of :

$$\frac{\partial \omega}{\partial p} = - (\nabla \cdot \mathbf{V})_c \tag{16}$$

$$\omega\,(p) = - \int_{0}^{p} (\nabla \cdot \mathbf{V})_c\, dp \tag{17}$$

4. Discussion of results

Table 2 gives the statistics of the predicted and observed rainfall rates for two data sets by the three versions.

The number of over-predicted cases are more than the under-predicted ones especially during MONEX-79 period. Rainfall rates obtained in model runs, represent an average for the grid area and hence generally are under-predicted in comparison with the observed spot values. In the semi prognostic approach the computed values pertain to spot values in some sense and hence, there are more over-predicted cases. The version 3 statistics reveal improved forecasts than the other versions. The discussions hereafter are with reference to version 3 computations.

TABLE 3

Day	Observed rain (cm day^{-1})	Computed rain (cm day^{-1})	Large scale convergence (day^{-1})
	MONSOON-June 1977		
2	1.24	3.44	0.08
3	1.07	1.94	0.04
4	1.43	3.92	0.08
13	0.23	2.41	0.06
14	0.65	2.52	0.07
16	2.93	3.86	0.09
17	0.66	1.43	0.03
20	1.91	3.96	0.12
22	3.36	4.00	0.09
24	0.47	6.43	0.13
25	0.47	3.50	0.15
26	0.34	1.87	0.09
28	0.11	2.28	0.06
30	0.13	1.58	0.03
	MONEX-July 1979		
4	1.60	2.59	0.07
6	1.41	3.66	0.14
10	2.50	4.15	0.10
11	2.80	3.61	0.09
12	0.90	1.88	0.08
21	1.30	2.55	0.09
23	2.40	4.79	0.09
25	2.80	4.36	0.09
26	1.00	2.60	0.15
27	1.20	3.02	0.12
28	2.90	5.14	0.19
29	2.60	5.06	0.10
30	1.40	4.95	0.10
31	0.50	2.22	0.11

Fig. 1 shows the observed and computed rainfall rates for (a) July 1979 and (b) June 1977. The forecasts in 1979 are generally in phase with the observed trend with larger rates in the first and last weeks and less rainfall during the middle period. In June 1977 the forecasts are out of phase during the last week. However, in both the data sets there are case of over-prediction, under-prediction and no rainfall prediction (against observed rainfall).

(a) *Over-predicted cases*

Table 3 shows the statistics of the typical cases using version 3 when the rainfall rates were much over-predicted compared to observed values. The large scale convergence values are also given in the table. It is seen that the computed rainfall rates unlike observed rates are related to the moisture covergence. This relationship is quite prominent in 1977. However, other

TABLE 4

MONSOON-June 1977			MONEX-July 1979		
Day	Observed rain (cm day^{-1})	Computed rain (cm day^{-1})	Day	Observed rain (cm day^{-1})	Computed rain (cm day^{-1})
1	4.70	2.91	2	4.70	2.84
15	3.94	1.26	9	3.30	2.83
23	3.61	1.20	13	2.40	1.28

parameters like the cloud area and environmental conditions are likely to influence. In this scheme only the vertical advection of moisture is considered for the computation of moisture convergence. It is possible that horizontal moisture divergence may exist in a few cases. One reason why 3-dimensional grid scale moisture convergence is not considered, is because Betts (1978), Frank (1979) noted a lag of several hours between the moisture supply computed this way and precipitation.

(b) *Under-predicted cases*

Typical cases of the category are shown in Table 4 wherein two cases stable rain criteria (relative humidity 90%) are also satisfied at some levels. The moisture storage parameter b becomes very large as much as 0.50. This happens because vorticity at 700 mb used for computation of meso-scale convergence is negative. Whether in a convergence situation this is realistic has to be further explored. In this particular case if the vorticity value is taken as zero for the regression then the convective rainfall increases to 2.48 cm (observed value on 13 July 1979 is 2.4 cm).

(c) *No rain cases*

Table 5 gives details of cases when rainfall was observed but computed rainfall rates (both convective and stable) were zero. On some days like 21 June 1977, and 3 July 1979 the observed amount were substantial. On most of these cases the vertical velocity was downwards in the lower layers even though the relative humidity was above 80%. In some cases the vertical velocity at middle cloud levels was upwards but the relative humidity criteria were not satisfied. It is possible that in these cases rainfall might have occurred at a different time during 24-hr interval preceding raingauge observation, than the radiosonde observation time. More cases, however, have to be studied before firm conclusions could be drawn.

TABLE 5

MONSOON-June 1977			MONEX-July 1979		
Day	Observed rain (cm day^{-1})	Computed rain (cm day^{-1})	Day	Observed rain (cm day^{-1})	Computed rain (cm day^{-1})
5	0.82	0.00	3	3.10	0.00
8	2.03	0.00	16	0.50	0.00
11	1.79	0.00	17	0.10	0.00
12	0.90	0.00	18	0.30	0.00
19	0.86	0.00	22	1.50	0.00
21	5.04	0.00			

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