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Evaluation of a limited area model for short range prediction over Indian region : Sensitivity studies

U. C. MOHANTY, R. K. PALIWAL*, AJIT TYAGI* and A. JOHN

Centre for Atmospheric Sciences, IIT, New Delhi

सार – भारतीय क्षेत्र पर अल्प अवधि प्रागुक्ति के लिए बहुस्तरी पूर्वग समीकरण सीमित क्षेत्र निदर्श के निष्पादन पर विभेदन, पार्श्विक सीमा स्थिति और कपासी प्राचलीकरण प्रणाली के प्रभाव के अध्ययन के लिए बहुत से संख्यात्मक प्रयोग किये गये हैं। यह अध्ययन दर्शाता है कि भारतीय मानसून स्थितियों के अनुकूल संशोधित क्यूओ प्रणाली पर आधारित उच्चतर विभेदन, प्रवृत्ति संशोधन, पार्श्विक सीमा स्थितियाँ और गहन कपासी प्राचलीकरण सहित सीमित क्षेत्र निदर्श मानसून परिसंचरण के सही अनुकरण की ओर ले जाते हैं। विशेष रूप से वर्षा में उल्लेखनीय सुधार तीव्रता और मानसून अवदाब के पथ को प्रेक्षित किया है।

ABSTRACT. A number of numerical experiments have been performed to study the impact of resolution, lateral boundary conditions and cumulus parameterization scheme on the performance of a multi-level primitive equation limited area model for short range prediction over Indian region. The study shows that a limited area model with higher resolution, tendency modification lateral boundary conditions and deep cumulus parameterization based upon modified Kuo scheme as tuned to Indian monsoon conditions leads to better simulation of monsoon circulation. In particular, a considerable improvement in the rainfall, intensity and track of monsoon depression is observed.

1. Introduction

A number of regional multi-level primitive equations (PE) models have been developed during last two decades and detail review of such models is given by Anthes (1983). However, it is only in the recent past that a few research limited area PE models (LAMs) have been used for short range prediction of certain aspects of summer monsoon over Indian subcontinent (Singh & Sugi 1986, Mohanty *et al.* 1989). It is found that LAMs are capable to simulate/predict large scale monsoon features such as cross equatorial flow, low level Somali jet, monsoon trough and tropical easterly jet. However, underestimation of the rainfall and errors in the prediction of the movement of monsoon depression/cyclone have been noticed to be the common deficiency in short range prediction by LAMs. These deficiencies are mainly attributed to inaccuracies in the initial data over data sparse regions and conceptual weaknesses in the parameterization of physical processes, *viz.*, cumulus convection and boundary layer. In addition, the performance of LAM is sensitive to the lateral boundary conditions and resolution of the model.

In this paper attempt is made to study the impact of resolution, lateral boundary conditions and cumulus parameterization on the performance of a LAM (Mohanty *et al.* 1989) for short range prediction during monsoon season over Indian region.

An overview of the model and details of numerical experiments are given in Sec. 2. The impact of resolution on the prediction of track of a monsoon depression and associated rainfall is discussed in Sec 3. Sec. 4 deals with formulation of different lateral boundary conditions and their impact on LAM. Results on sensitivity of monsoon precipitation to cumulus parameterization is presented in Sec. 5. Conclusion and summary are given in Sec. 6.

2. Description of numerical experiments

A detail description on model formulation, horizontal and vertical discretization and time integration scheme used for the experiments is described by Mohanty *et al.* (1989). The horizontal domain of the model is bounded by 30° E-150° E and 30° S-60°N with a grid resolution of 1.875° Lat./Long. (except in the case of coarse resolution experiment).

The model has 10 sigma levels in the vertical and orography for the model is derived from 1°×1° US Navy data. The model incorporates a number of physical processes such as planetary boundary layer, dry and moist convective adjustment, deep cumulus convection and large scale precipitation.

A number of numerical experiments were carried out to examine the performance of the model over Indian monsoon region with different horizontal and vertical resolutions, lateral boundary conditions and parameterization of cumulus convection. A summary of the experiments is given below :

(A)	*Resolution*	*Horizontal*	*Vertical*
A_1	Coarse	2.5° Lat./Long.	5 levels
A_2	High	1.875° Lat./Long.	10 levels

* Directorate of Meteorology, Air Headquarters, Vayu Bhavan, New Delhi-110011.

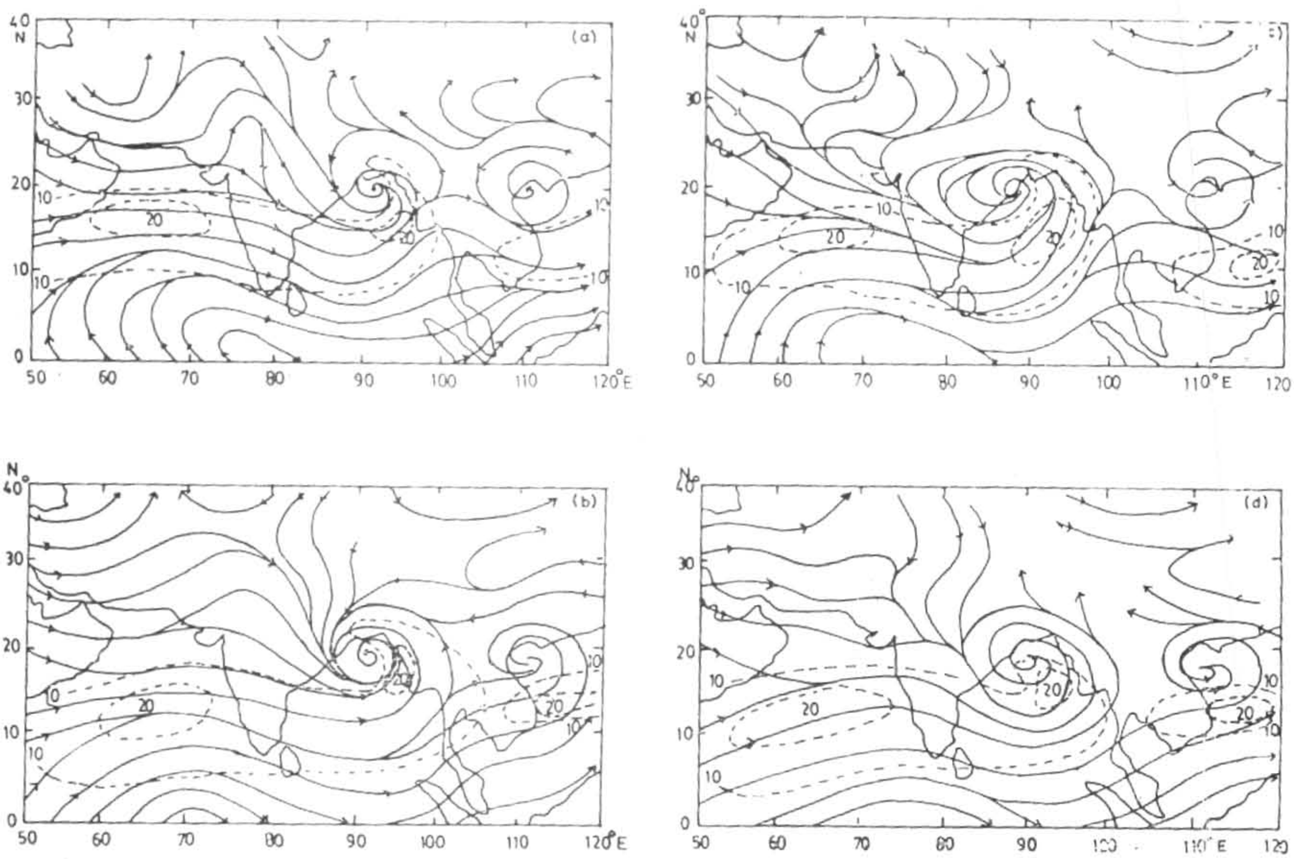

Fig. 1. Stream line isotach analysis (ms^{-1}) of wind field at 700 mb : (a) 24-hour forecast from 5 July 79 (12 GMT), (b) corresponding verification, (c) 48 hours forecast and (d) corresponding verification

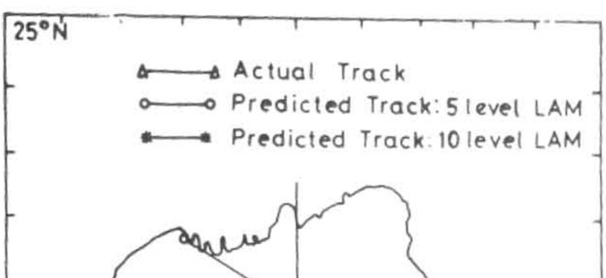

Fig. 2. Track of monsoon depression (5-7 July 1979)

TABLE 1

Root mean square errors of 24 and 48-hr forecast from 5 July 1979, 12 GMT for different resolutions

Level	Parameter	2.5° Lat./Long. 24 hr	2.5° Lat./Long. 48 hr	1.875° Lat./Long. 24 hr	1.875° Lat./Long. 48 hr
300 mb	*u*	4.1	4.9	3.7	4.8
	v	4.2	7.5	3.9	6.3
	T	2.3	2.9	2.0	2.7
500 mb	*u*	2.7	6.9	2.6	5.6
	v	1.9	3.1	1.7	2.7
	T	1.4	1.4	1.2	1.3
700 mb	*u*	2.9	3.9	2.3	3.0
	v	1.7	3.9	1.5	3.6
	T	1.1	1.5	1.0	1.6
850 mb	*u*	2.7	3.1	2.5	2.9
	v	1.9	2.4	1.9	2.3
	T	1.5	1.3	1.4	1.5

u and *v* in m sec^{-1}, *T* in °C and p_s in mb

(*B*) *Lateral boundary conditions*

B_1 Linearly interpolated boundary scheme

B_2 Okamura (1975) type boundary scheme

B_3 Time varying boundaries obtained from persistence

B_4 Tendency modification scheme of Perkey and Kreitzberg (1976)

(*C*) *Cumulus parameterizatian* (*Anthes 1977*)

Here the partitioning factor β is defined in Eqn. (4)

C_1 with $N=3$

C_2 with $N=5$

C_3 with $N=6$. Here N is an exponent used for evaluating partitioning parameter in Eqn. (4)

C_4 with $N=8$

All experiments were carried out using FGGE level IIIb data for 12 GMT of 22 May 1979 and 5 July 1979 produced at European Center for Medium Range Weather Forecast.

3. Resolution

The need for finer resolution has been widely recognised for realistic prediction of weather by numerical models (Williamson 1978). However, due to the constraints of computer resources and lack of data at higher resolution, there is a limit up to which finer resolution can be achieved. In order to examine the performance of the model with different resolutions, root mean square errors (RMSE) at 24 and 48 hours forecasts of u, v, T and p_s over an interior domain (2.5° N- 30°N, 45°E-95° E) is presented in Table 1.

The results in Table 1 clearly demonstrates that the RMSE decreases with increase in resolution of the model over the entire troposphere, though the maximum reduction in RMS vector error of wind does not exceed ·5 m sec^{-1} and reduction of temperature error is only 1 to ·3° C.

3.1. *Prediction of monsoon depression*

Monsoon depression is one of the important aspects of summer monsoon. The short range prediction of the intensification of depression, its movement and associated rainfall is of great importance, Therefore, a monsoon depression case (5-7 July 1979) is examined in this context. The streamline isotach analysis of 24 and 48 hours forecast fields at 700 mb from 1200 GMT of 5 July 1979 and corresponding verification fields are presented in Fig. 1. The system was observed as a feable vortex in the lower troposphere on 5 July. It moved slowly in SW direction and intensified into depression on 6 July and into deep depression on 7 July. The intensification of the cyclonic circulation is predicted very well up to 48 hours. Fig. 2 shows actual and predicted track of monsoon depression with coarse and high resolution model. Depression had unusual southwestward movement from 5 July to 6 July and then westwards. Both the models have predicted general direction of the movement quite well. However, vector error of motion between the forecast and actual track is quite large for coarse model as compared to high resolution model. The improvement in the prediction of movement is due to better simulation of circulation features such as intensity and slope in high resolution model. Fig. 3 depicts the 24-hr forecast of the rainfall for the period ending at 00 GMT of 7 July 1979. On comparison with the actual rainfall (Fig. 3a), it can be seen that the performance of high resolution model in predicting the rainfall amount and its spatial distribution is more realistic. The model with coarse resolution has failed to simulate or has underestimated rainfall over SE Asia, eastern Himalayas, Sri Lanka and adjoining oceanic areas. The forecast shows a spurious region of rainfall over Gujarat and adjoining areas. High resolution model shows improvement in the spatial distribution and amount of rainfall (Fig. 3c).

4. Lateral boundaries

Formulation of appropriate lateral boundary conditions for limited area models is an intrigue problem which requires uniqueness and well posedness of fluid flow across the boundary. Davies (1983) has presented underlying theoretical concepts and problems for treatment of lateral boundaries. In this study the performance of the following types of lateral boundary schemes were examined for the LAM.

In the scheme (B_1), the prognostic variables at the boundaries are extrapolated from the two interior grid points :

$$P_I = 2\,P_{I-1} - P_{I-2} \qquad (1)$$

where P is any dependent variable. In the scheme B_2, the normal velocity V_n is prescribed so as to control the divergence at the boundaries. In the third scheme (B_3) it is assumed that the tendencies of the dependent variables for the preceding 12 hours persist during the subsequent 12 hours :

$$\frac{(P_t - P_{t-\triangle t})}{\triangle t} = \frac{(P_{t+\triangle t} - P_t)}{\triangle t} \qquad (2)$$

During the integration of the LAM tendencies of preceding 12 hours are supplied to determine the new boundary values of the prognostic variables.

In scheme B_4 the model calculated tendencies at the two interior grid points are extrapolated to obtain the boundary values. The values at the boundaries and the two interior grid points are modified using a porous sponge as :

$$P_n(I) = P_p(I) + W(I)\,\delta P_m/\delta t \triangle t\, I \qquad (3)$$

where the subscripts n and p denote the new and the previous boundary values, m denotes the model calculated tendency and $W(I)$ is the sponge weightage factor whose values are assigned as 0.4, 0.7 and 0.9 for the boundaries, the first, second and the third interior grid points respectively.

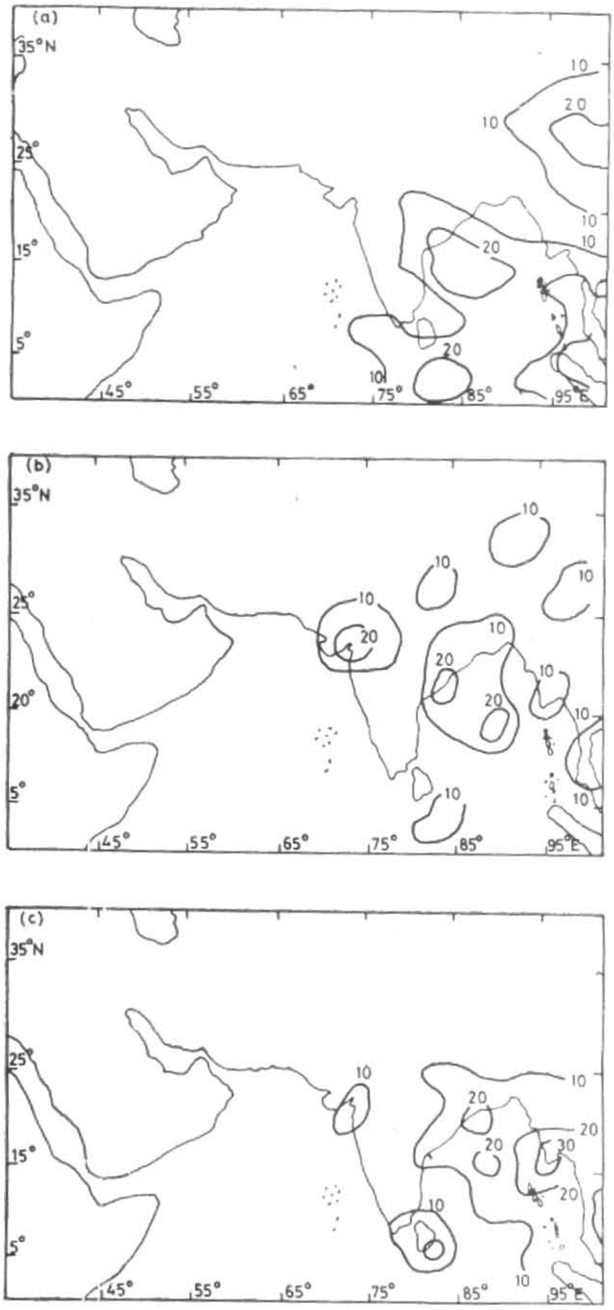

Fig. 3. Rainfall (mm) for 24 hours ending 7 July 1979 (00 GMT): (a) observed, (b) forecast with 2.5° resolution and 5 levels and (c) forecast with 1.875° resolution and 10 levels

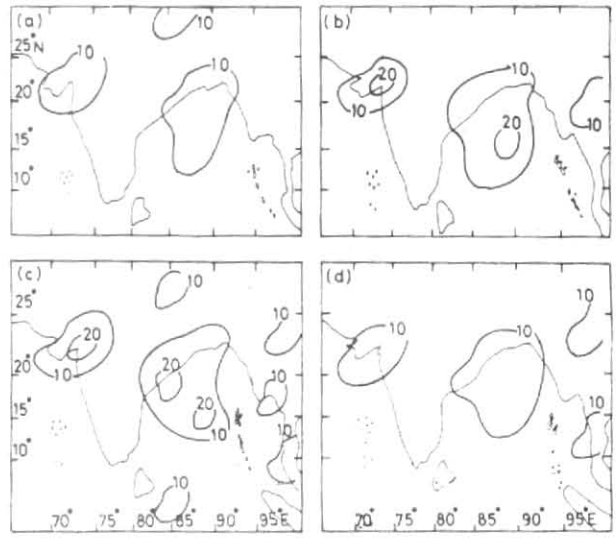

Fig. 4. 24 hours accumulated precipitation (in mm) ending at 00 GMT of 7 July 1979 with the forecast from the initial data for 12 GMT of 5 July 1979 with value of '*N*' as (a) 3, (b) 5, (c) 6 and (d) 8

TABLE 2

RMS errors of forecasts with different lateral boundary formulations

F/C (hr)	Variables	R.m.s. error with lateral boundary scheme			
		B_1	B_2	B_3	B_4
12	*u*	4.8	4.5	4.0	4.4
	v	1.9	1.8	1.6	1.7
	T	1.3	1.4	1.1	1.3
24	*u*	2.4	2.3	2.3	2.1
	v	3.1	3.0	3.1	2.8
	T	1.2	1.2	1.2	1.0
48	*u*	8.5	7.5	7.8	7.0
	v	3.8	2.9	3.2	2.3
	T	1.6	1.4	1.5	1.4

Note : *u* and *v* in ms^{-1} and *T* in °C

Table 2 presents RMSE of the 500 mb forecasts obtained from each of the above mentioned boundary schemes for 12, 24 and 48 hr (22 May 1979). It is seen that the RMSE of *u*, *v* and *T* for 48 hours forecasts are least for scheme B_4 and largest for scheme B_1. Fig. 5 depicts geopotential height field differences of 24 hours forecasts form the observed fields at 500 mb for all the schemes. It is observed that the least forecast error is obtained with scheme B_4, while it is maximum with B_1.

5. Cumulus parameterization

Detailed intercomparison of different versions of Kuo scheme by Das *et al.* (1988) with 1977 and Monex-1979 data during different epoch of Indian summer monsoons with one dimensional model has shown that Kuo (1974) scheme as modified by Anthes (1977) yields better results ($RH_c = 0$, $N = 5$). Similar conclusions for the tropics were also demonstrated by Mohanty *et al.* (1985) using an ECMWF global spectral model. In this study, a modified Kuo scheme (Anthes 1977) has been used for parameterization of cumulus convection.

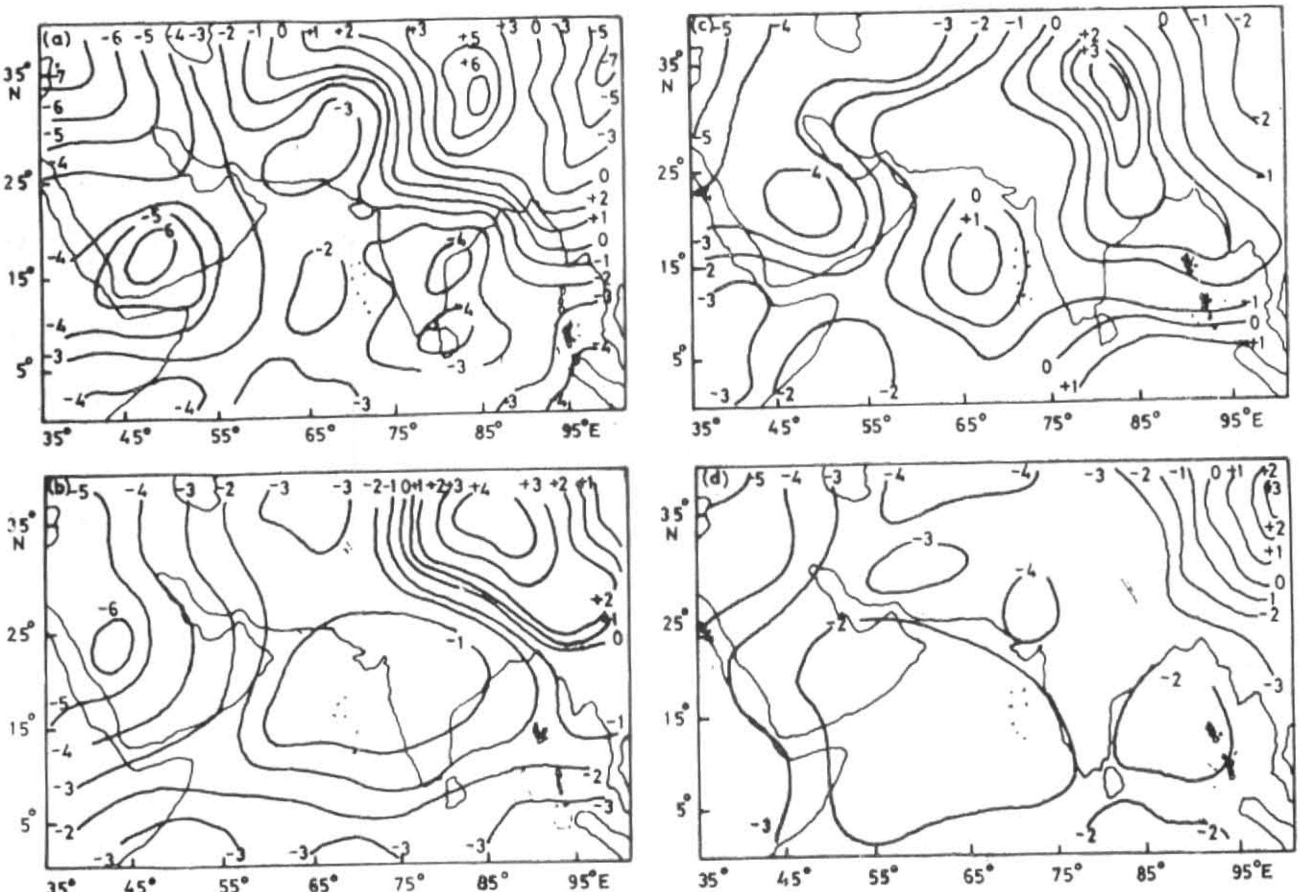

Fig. 5. Geopotential (in decametres) difference field of 24 hours forecast (for the case of 12 GMT, 22 May 1979) field obtained with lateral boundary scheme (a) B_1, (b) B_2, (c) B_3 and (d) B_4

Anthes (1977) defined the partitioning moistening factor as :

$$b = \left(\frac{1 - \langle RH \rangle}{1 - RH_c}\right)^N \quad \text{for } \langle RH \rangle \geqslant RH_c \quad (4)$$

$$= 1 \text{ for } \langle RH \rangle \leqslant RH_c$$

where $\langle RH \rangle$ is the mean relative humidity in the column RH_c is a critical relative humidity, N is an integer ($RH_c = 0.5$, $N = 1$, Anthes 1977).

In this study, a number of experiments were performed with varying values of RH_c and N with a view to do the optimum tuning for prediction in the Indian monsoon regions. Besides evaluating convective precipitation, a scheme is also included to compute large scale stratified precipitation. A dry convective adjustment is also carried out to remove occurrence of absolute instability.

It is found that better estimates of rainfall over Indian monsoon region are obtained with a value of $RH_c = 0.2$ and N=6. As an illustration to demonstrate this finding, 24-hr accumulated rainfall estimates ending at 00 GMT of 7 July 1979 from the LAM for the case of a monsoon depression (5-7 July 1979) for $N = 3$, 5, 6 and 8 are presented in Fig. 4. It may be pointed out that in another study by Mohanty *et al.* (1985), the best results were obtained with N=3, and $RH_c = 0$ with the ECMWF T_{63} spectral model. However, the combination of N and RH_c was tuned by the authors for the data set obtained from GATE.

6. Conclusions

This study has concentrated on the impact of the resolution, lateral boundary conditions and modification to deep cumulus convection on short range prediction of monsoon circulation by LAM. Based on the results presented in the sections 3-5, the results are summarised as follows:

An increase in the horizontal and vertical resolution of the model leads to general improvement in the prediction of monsoon circulation and, in particular, in simulation of the finer structure in the precipitation pattern and circulation around monsoon disturbances.

In the case of LAM, the performance of the model is very sensitive to lateral boundary formulation. It is found that time varying boundary condition based on tendency modification provides reasonably good approximation compared to other schemes discussed in the study.

Tropical precipitation is mainly convective in nature and thus simulation of monsoon precipitation is very much sensitive to parameterization of deep cumulus convection in the model. In this study it is found that the optimal value of $N = 6$ and $RH_c = 0.2$ provide the best results. Similar approach for the improvement of precipitation prediction by modification of partitioning parameter has been favoured over monsoon region by Das *et al.* (1988).

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