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FORECASTING THE TRACKS OF MONSOON DEPRESSIONS BY NON-DIVERGENT BAROTROPIC MODEL*

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ABSTRACT

A non-divergent barotropic model, for which the input consists of stream function derived from the observed wind, is used for predicting the flow patterns over Indian region. Following the usual methodology of 'total flow' method of predicting the hurricane-track, stream function minimum is recognized as the centre of the monsoon-depression and its trajectory is found from the forecast stream function field available at successive time steps. The input stream function retains the steering field as well as the vortex field and, therefore, the interactions are accounted for.

The results of verification for two monsoon depressions, consisting of several map-times is presented.

INTRODUCTION

In an earlier paper by Shukla and Saha (1970), the feasibility of forecasting the flow patterns over Indian region using observed wind as input was established. As an extension of this work, in this paper, the results of forecasting the movement of Monsoon-Depressions using the same model have been presented.

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The methodology which has been so far adopted for the dynamical prediction of the movements of hurricanes and typhoons using the barotropic model may be broadly classified in the following two groups :

1. Steering flow method or Trajectory method.
2. Total flow method.

In steering flow method, the cyclonic vortex is removed from the total pattern and only the residual field is integrated. Based on the evolution of the residual flow, trajectory calculation is made to track the centre of the cyclonic system. The greatest limitation of this method is its inability to account for the interaction between the vortex and the general steering field, which may be an important factor in governing the direction of the movement of the vortex.

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In total flow method, vortex is not removed from the initial observed field and the evolution of total flow is obtained to track the centre of the vortex. In the present study total flow method has been adopted to forecast the movement of Monsoon depressions. Since the hurricanes and typhoons are very intense systems, one is faced with the problem of large truncation errors in the vicinity of the centre of the system, in total flow method. This difficulty, however, does not arise in the case of monsoon-depressions especially at 500 mb level. The level at which the flow is predicted is 500 mb. The choice of this level is on the following grounds:

(i) At lower levels, the general field is very much disturbed by the vortex field and is almost dominated by the latter.

(ii) Since the area of integration includes the Himalayan mountains, integration at any lower level necessiates the stipulation of very artificial boundary conditions at the interface between that isobaric level and the mountains.

In the total flow method, although the method of finding the evolution of the total field is objective and based on a dynamical model, the method of recognising the centre of the vortex is subjective. This subjectivity is mainly due to coarse grid network used for numerical computations. Since, the forecast fields of stream-function and vorticity are available at every time step, it is a matter of choice whether the minimum stream-function or maximum positive vorticity should be recognised as the centre of the vortex. In the present study the centre of the depression is recognised as the centre of the associated stream function minima.

The Dynamical Model

The dynamical model used in the present study is the barotropic vorticity prediction equation. The governing equation is given as:

$$\nabla^2\left(\frac{\partial\psi}{\partial t}\right) = J(\nabla^2\psi + f, \psi)$$

where ψ is the stream function and f is the coriolis parameter. The time integration is carried out with one hour as the time step using forward differencing scheme at the first time step and the centred time differencing scheme at the subsequent time steps. The finite difference expressions for Laplacian and Jacobian have been given in the earlier paper by Shukla and Saha (1970).

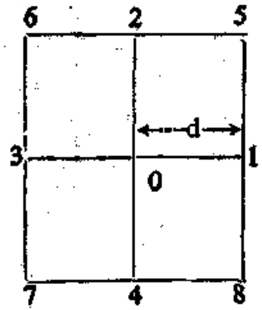
Boundary conditions for $\frac{\partial\psi}{\partial t}$ and $\frac{\partial}{\partial t}(\nabla^2\psi)$:

$\frac{\partial\psi}{\partial t}$ is assumed to be zero at the boundary for the entire period of integration. Following the purely heuristic arguments put forward by Charney, Fjortoft and Neuman (1950), $\frac{\partial}{\partial t}(\nabla^2\psi)$ is assumed to be zero at the inflow points of the integration domain and is linearly extrapolated at the boundary from inside, at the outflow points of the domain.

Smoothing and Filtering :

In order to suppress the short waves which may appear in the course of integration a 9-point smoothing operator as suggested by Shuman (1957) was used. The formula used for smoothing is given as :

$$\psi = \psi_0 + 0.5\nu\,(1-\nu)\,(\psi_1 + \psi_2 + \psi_3 + \psi_4 - 4\psi_0) + 0.25\nu^2\,(\psi_5 + \psi_6 + \psi_7 + \psi_8 - 4\psi_0)$$



where ν is the smoothing element and has been taken to be 0.5 in the present case.

It may be incidentally remarked that although the smoothing operation performed in order to suppress the spurious high frequency waves which are generated due to the inherent limitations of the numerical treatment, in the process of smoothing, it reduces the amplitude of the main meteorological modes also. It is therefore necessary to make a judicious choice before applying the smoothing operator.

Method of solution :

The governing equation is numerically solved for evaluating the tendency at each time step. Accelerated Liebmann relaxation technique is adopted using 0.7 as the value of over relaxation coefficient. For relaxation at any time step, the values of tendency at the previous time step are used as the first guess.

Preparation of Data

In the present study, 24 and 48-hour forecast have been prepared using the input data for a series of 10 successive days in the month of July 1963. From the hand analysed streamline isotach charts for 500 mb level the values of wind direction and wind speed are picked up at latitude longitude intersections of 2.5° interval for the area bounded between the latitudes 2.5° N and 40.0°N and longitudes 50.0°E and 100.0°E. The computational network therefore, consists of 21 × 16 grid points.

From the observed winds, vorticity is calculated by finite difference method.

$$\zeta = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}$$

Knowing the values of vorticity at all the interior points, relaxation is performed to solve the posson equation :

$$\nabla^2\psi = \zeta$$

in order to get the value of ψ under suitable boundary conditions. Such boundary condition is considered to be suitable for this purpose which maximizes the kinetic energy in the reconstructed wind.

The stream function which is thus calculated from the observed winds is fed as the input to the barotropic model.

FORECAST RESULTS

48-hour forecasts have been prepared for one series of ten successive days (1-10 July 1963) and another series of four days (15-18 June 1966). Except in one case on 9 July 1963, Vortex could be recognised in the stream function field upto 48 hours. From the available values of forecast stream function at the grid points, the point of minimum stream-function is subjectively interpolated. Tables 1 and 2 give the forecast and observed positions of the centre of the depression for Series I and II respectively. The average value of the error for 24 and 48-hour

TABLE 1. *Forecast and observed positions of the centre of the Depression* (I)

Date	24-hr. forecast position	48-hr. forecast position	Observed position	Error for 24-hr. forecast (Km)	Error for 48-hr. forecast (Km)
1-7-63	—	—	15.0°N, 86.5°E	—	—
2-7-63	16°N, 85°E	—	15.5°N, 85.0°E	50	—
3-7-63	17.5°N, 85°E	16.0°N, 83.5°E	18.0°N, 87.0°E	206	403
4-7-63	18.0°N, 88.5°E	19.0°N, 85.0°E	18.5°N, 87.5°E	112	255
5-7-63	19.5°N, 87.5°E	18.5°N, 89.5°E	20.0°N, 85.0°E	255	475
6-7-63	20.5°N, 83.0°E	20.5°N, 87.0°E	20.0°N, 83.0°E	50	403
7-7-63	20.5°N, 82.5°E	21.0°N, 81.0°E	20.5°N, 82.5°E	0	158
8-7-63	21.0°N, 83.0°E	21.0°N, 81.5°E	21.0°N, 82.5°E	50	100
9-7-63	22.5°N, 82.5°E	22.0°N, 84.0°E	22.0°N, 81.5°E	112	250
10-7-63	23.0°N, 81.5°E	—	26.0°N, 82.5°E	316	—
Mean	—	—	—	128	292

TABLE 2. *Forecast and observed positions of the centre of the Depression* (II)

Date	24-hr. forecast position	48-hr. forecast position	Observed position	Vector error for 24-hr. forecast	Vector error for 48-hr. forecast
15-6-66	—	—	18.5°N, 91.0°E	—	—
16-6-66	20.5°N, 90.0°E	—	22.0°N, 90.0°E	150	—
17-6-66	23.0°N, 89.5°E	20.5°N, 92.0°E	24.0°N, 91.0°E	180	360
18-6-66	25. 0°N, 91.0°E	25.0°N, 91.5°E	24.5°N, 91.5°E	70	50
Mean	—	—	—	140	205

forecasts is 152 Km and 324 Km respectively for Series I and 140 Km and 205 Km respectively for Series II.

Concluding Remarks

The major problems in the dynamical prediction of the movement of the depressions and cyclones are the modelling approximations in the governing equation, numerical truncations and the paucity of the observations near the centre of the disturbance. The choice of the governing equation is the most serious problem because of the mutual interaction between three distinctly different scales *i.e.*, cumulus scale, cyclone scale and large scale (or steering scale) which is taking place simultaneously. It is, however, interesting to note that so far the success achieved with the use of barotropic model is more than that of baroclinic models.

In addition to the above problems, the problem of the definition of the vortex and its separation from the total observed field poses additional problems in the integration. In order to circumvent this problem total field has been integrated in the present case. The results in the present case seem to be encouraging and they may be further improved by reducing the grid-length for the whole area or at least in the region of the vortex. The present case studies, although small in number, establish the justification for using barotropic model to forecast the tracks of the monsoon depressions and therefore do not support the view expressed by Rao and Rajamani (1968) that barotropic model can not be used to forecast the movement of monsoon-depressions. It may be noted however, that this conclusion was arrived at by Rao and Rajamani on the basis of computations for only one day. It is, however, suggested that more trials should be made with more refined atmospheric models which may predict the speed as well as acceleration of the monsoon-depressions.

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