Indian J. Met. Hydrol. Geophys. (1975), **26**, 3, 323-325

551·509·25 : 551·515·1

Forecasting the movement of tropical cyclones in the Indian seas by non-divergent barotropic model

D. R. SIKKA

Indian Institute of Tropical Meteorology, Poona

ABSTRACT. Numerical forecasting of the tropical storms in the Bay of Bengal and the Arabian Sea has been attempted by non-divergent barotropic model using wind as the basic input at 500 mb. The model has been tested on a large number of cases and the results of verification of the forecasts reveal that operationally usable forecasts are possible on majority of the cases.

1. Introduction

Forecasting the movement of tropical storms in the Indian seas is one of the most important functions of the storm warning organisation in India. The operational forecasters working in the storm warning centres have to depend heavily upon their experience as well as to draw support from the considerable research work done in the past several years on synoptic methods of forecasting the movement of the storms. There has been a need for developing numerical prediction methods for this purpose.

Das (1957) applied geostrophic barotropic vorticity equation for forecasting the movement of a monsoon depression that formed in the Bay of Bengal. He used observed height field as the input and hand relaxation was performed to obtain the forecasts. Datta and Pradhan (1969) applied a modified version of geostrophic equations for forecasting a few storms in the Bay of Bengal. With the introduction of fast computers in India, interest in dynamical prediction of flow patterns received an impetus and Shukla and Saha (1970) used the non-divergent barotropic model with the stream function obtained from the observed winds as the input for forecasting the movement of a monsoon depression. Shukla, Sikka and Saha (1970) have subsequently tested the applicability of this model and found that it was able to adequately forecast the large scale flow patterns at 500 mb over the Indian region. The present study was undertaken to test the efficacy of this model for forecasting the movement of tropical storms. Test forecasts have been obtained for a large number of tropical storms and depressions which formed in the Bay of Bengal and the Arabian Sea during the storm seasons (May, September, October, November and December) of the years 1970, 1971 and 1972.

2. Description of the model used

Considerable work has been done in USA and Japan on the application of barotropic vorticity equation in forecasting the movement of typhoons and hurricanes (Birchfield 1960, 1961; Itoo and Nitta 1962). Basically two methods have been used; *viz.*, (*i*) the steering flow method and (*ii*) the total flow method. In the present study we have used the 'total flow method' as applied to the non-divergent part of the wind flow at 500 mb. In this method the storm is retained as an integral part of the initial flow and the total flow is predicted as such. The available data density in the Indian seas is very inadequate and with the total lack of aircraft reconnaisance report make it extremely difficult to define the vortex field. Hence its removal from the total field is not easy. A consistent analysis of the flow features is done by simultaneous use of ship data, satellite pictures and wind reports along the coastal belt. Attempt was also made in this study to control the truncation errors by subjectively reducing the intensity of the severe storms.

The governing equation is the usual vorticity equation for the horizontal non-divergent flow applied at 500 mb.

$$\nabla^2\left(\frac{\partial \psi}{\partial t}\right) = J\left(\nabla^2\psi + f,\ \psi\right) \qquad (1)$$

where ψ is the stream function, ∇^2 is the Laplacian operator, J is the Jacobian operator, f is the Coriolis parameter and t is the time. The stream function ψ is obtained from the vorticity (ξ) of observed winds:

$$\nabla^2\psi = \xi = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y} \qquad (2)$$

The boundary conditions for solving Eq. (2) are the same as used by Shukla and Saha (1970).

Having obtained ψ field at the initial time Eq. (1) is solved by keeping $\partial\psi/\partial t$ to be zero, at the boundary. Nine-point Laplacian (∇^2) and Jacobian (J) operators have been used in numerical computations. The area of integration extended from 40°E to 120°E and 2.5°N to 45°N and the grid length was 2.5° latitude/longitude. Time interval used was 1 hour, first step being forward and subsequent steps centred.

The computed centre of the vortex in the vorticity and the stream function fields at the initial time in every case was found to be within 0.5° of the estimated centre in the streamlines chart. Initial stream function field agreed very well with the streamline-isotach field although the maximum wind in circulation near the storm centre was generally about 20 per cent less than the initially analysed wind speed.

The position of the centre of storm both in the initial and the forecast field was identified as the maximum in the relative vorticity field. This was done because in the forecast field the centre was found to be better defined in the relative vorticity field compared to the stream function field. The position of the maximum relative vorticity in the initial and forecast vortex pattern was obtained by interpolation as has been done by Itoo and Nitta (1962) and Sanders and Burpee (1968). There may be some discrepancy in fixing the centre in the initial analysis due to lack of data as well as in interpolating the centre in the initial and forecast relative vorticity fields. The combined effect of such discrepancies may lead to an error of about 50 n.m. in the forecast positions which is not very serious as errors of this order arise from errors in the initial analysis and fixation of the centre.

3. Discussion of the results

The input data for all the cases considered in this study consisted of 00 GMT wind analysis at 500 mb and forecasts were obtained for 24 hours and 48 hours. The forecast tracks for all the storms were plotted in their life history. Examination of all the predicted tracks with respect to the actual tracks revealed the following:

(1) There was no particular bias in the predicted track with respect to the actual path of the storm. Some predicted positions lay to the left whereas others lay to the right of the actual track.

(2) The predicted track in most of the cases of recurvature did not show the recurvature

TABLE 1

Verification statistics on the forecast movement of tropic cyclones in the Indian seas

(May and September to December)

Year	No. of forecasts	Type of statistics	Obs. speed S_0 (n.m.)	Pred. speed $Sp/$ (n.m.)	$Rs=\frac{Sp}{S_0}$	$\vec{Ev}=\vec{S_0}\ \vec{Sp}$ (n.m.)
		24 hours Forecasts				
1970	41	Average	153	127	1·03	81
		Highest	298	258	2·21	134
		Lowest	30	30	0·24	30
1971	36	Average	165	145	0·98	91
		Highest	280	250	2·25	150
		Lowest	50	60	0·31	42
1972	28	Average	160	140	0·94	83
		Highest	260	200	1·88	145
		Lowest	60	60	0·27	27
1970-72	105	Average	160	138	0·98	85
		48 hours Forecasts				
1970	34	Average	290	265	0·96	128
		Highest	540	600	1·90	250
		Lowest	90	115	0·29	54
1971	28	Average	305	280	0·94	123
		Highest	560	525	1·75	230
		Lowest	110	100	0·31	40
1972	23	Average	290	275	0·92	130
		Highest	520	500	2·20	210
		Lowest	120	130	0·27	60
1970-72	85	Average	297	269	0·94	127

TABLE 2

Frequency distribution of vector errors in forecast storm position in Indian seas

(May and September to December)

	Validity of forecast (hr.)	Frequency distributions(n.m.)						
		0-30	31-60	61-90	91-120	121-150	151-180	>180
1970	24	1	10	12	14	4	0	0
1971	24	0	9	12	10	5	0	0
1972	24	1	6	10	7	4	0	0
1970	48	0	2	6	11	3	6	6
1971	48	0	2	6	5	7	6	2
1972	48	0	1	3	5	8	4	2

on the same day as it occurred in the case of the actual track but the recurvature was forecast generally 24 hours later. However, in a few cases the recurvature was well forecast.

In order to study the forecast behaviour more quantitatively, the following parameters were computed:

(*i*) the magnitue of the observed displacement (S_0).

(*ii*) the magnitude of the predicted displacement (S_p).

(*iii*) the magnitude of the error vector from the observed to the predicted position at the end of the forecast period $|E_v| = \mathbf{S}_p - \mathbf{S}_0$

(*iv*) the ratio between the predicted and the observed displacments $R_s = S_p/S_0$

R_s measures the relative speed error and should be unity for a good forecast. E_v is influenced by the error in predicted direction of the movement. Table 1 summarises the results of verification value of R_s for 24 and 48 hours forecasts. The averge value of R_s for 24 hour forecast which is a little lower than unity and the average observed displacment is about 22 n.m. higher than the predicted displacment. However, on individual cases R_s is found to be much larger than unity. This occurred because in some cases the observed storms were very nearly stationary though the forecasts showed movement. There was no systematic tendency of either under or over forecasting as far as the displacements were concerned.

The average vector error of the storms in 24 hours forecast is about 85 n.m. and in 48 hours forecast 127 n.m. The average vector error both in 24 hours and 48 hours forecasts is larger than the average displacement error which is due to errors in the forecast direction of movement Table 2 shows the frequency distribution of vector errors for 24 and 48 hours forecasts.

To sum up the results of verification, the 24 hours forecasts were very successful (vector error <60 n.m.) for nearly 25 percent of the cases, good (60 n.m. $\geqslant$ vector error $<$ 90 n.m.) for nearly 35 per cent of the cases and satisfactory (90 n.m. $\geqslant$ vector error $<$ 120 n.m.) for nearly 30 per cent of the cases. About 10 per cent of the 24 hour forecasts were of poor quality (vector error $>$ 120 n.m.). The performance of 48 hour forecasts are generally much less satisfactory compared to 24 hour forecasts, the primary cause for this deterioration being possibly the boundary conditions in the integration process.

4. Conclusion

A large series of experimental forecasts on the movement of tropical cyclones in the Bay of Bengal and the Indian seas by the application of non-divergent barotropic model with the initial input being the stream function derived from the analysis of the observed wind field have been made and their results evaluated. Keeping in view the paucity of data in the region and consequent limitation of the analysis, comparatively larger grid size used and the truncation error involved, the results of this study show that, satistically speaking, it is possible to obtain reasonably good forecasts on the movement of tropical storms by the barotropic model up to 24 hours. It is hoped that such forecasts in the hands of experienced operational forecasters when used judiciously along with other aids would improve the operational capability of the forecast. Further experiments either with different levels/shorter grid interval or the vertically averaged wind data as input can also be done to study whether further improvements are possible with this model.

REFERENCES

Birchfield, C. E.	1960	*J. Met.*, **17**, pp. 406-414.
	1961	*Ibid.*, **18**, pp. 402-409.
Das, P. K.	1957	*J. met. Soc. Japan*, 75th Ann. Vol., pp. 275-279.
Datta, R. K. and Pradhan, S. K.	1969	*Proc. WMO/IUGG Symp. N.W.P.*, Tokyo, pp. III 103-106.
Itoo, H. and Nitta, T.	1962	*Proc. NWP. Symp.*, Tokyo, 1960, pp. 309-327.
Sanders, F. and Burpee, R. W.	1968	*J. appl. Met.*, **7**, pp. 313-323.
Shukla, J. and Saha, K. R.	1970	*J. met. Soc. Japan*, **48**, pp. 405-410.
Shukla, J., Sikka, D.R. and Saha, K. R.	1970	*Proc. Symp. Trop. Met.*, pp. H. IV. 1-4.