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Forecasting the movement of tropical storms/depressions in the Indian region by a computer oriented technique using climatology and persistence

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ABSTRACT. A computer oriented technique for forecasting the movement of tropical storms/depressions in the Indian seas, based on half persistence and half climatology has been tested. The climatological components of the forecast is computed by a computer programme, by scanning the climatological tracks within a predetermined scan distance from the centre of the storm to be predicted.

The method had been tested on independent data for pre-monsoon and post monsoon storms/depressions during 1961-67, and performance of forecasts categorised. The accuracy of the forecast by the method compares favourably with other operational objective methods in use elsewhere. Probability ellipses of the errors have been constructed. Results of the forecasts based on experimental real time basis during 1968-70 are also discussed.

1. Introduction

Forecasters in India have been studying the problem of prediction of movement of tropical depressions and storms and several studies have emerged as a result of their efforts. The synoptic forecasters in India make their forecasts on the basis of the results of several such studies as well as their professional judgement on the movement of the storms using several of the synoptic and climatological factors in combination, which are essentially subjective in nature. There is a real need for developing objective methods for forecasting the position of the storms.

2. Objective of the present study

The purpose of the present study has, therefore, been to provide a method which can quickly assimilate information in the long series of climatological storm tracks data in an objective manner and use it with persistence to get a forecast. To this end we have tested a simple technique based on half persistence and half climatology using IBM 1620 computer.

The objective methods developed for the hurricanes of Atlantic and typhoons of West Pacific region use the upper air data obtained by aircraft reconnaissance near the centre of the storm in addition to the conventional data. However, in the absence of such facilities in the Indian seas at present one has to rely more on the surface data and satellite pictures. The method under discussion requires no more than the centre of the storm from the current synoptic chart or any other source of information on the location of the storm such as satellite photography and the centre's position 24 hours earlier and also a good climatology. Preliminary results with the method were earlier reported by the authors (1966) and testing on larger sample (1961-1967) has been done since then. The method was also verified on a real time basis during the storm season of 1968, 1969 and 1970.

3. Description of the method

The method assumes that the track followed by a disturbance in the previous 24 hours is due to the net effect of dynamical and steering forces that have been operating on it upto its present position. The assumption of the persistence in its motion for the next 24 hours forecast period means that the same forces will continue to act in the same manner. The dependence of the next 24 hour forecast on climatology assumes that a storm moving in the same general area during a particular month generally follows the climatological path under the influence of general circulation features of the area in that month. As the tropical disturbances in the Indian seas show a wide scatter of movement in their climatological tracks, a simple fusing of conventional climatology and persistence would be of lesser use. Therefore, a computer programme has been developed to evaluate the climatological motion component of the storm within the immediate present location of the storm to be predicted. For this purpose the information used for the preparation of the storm tracks for the

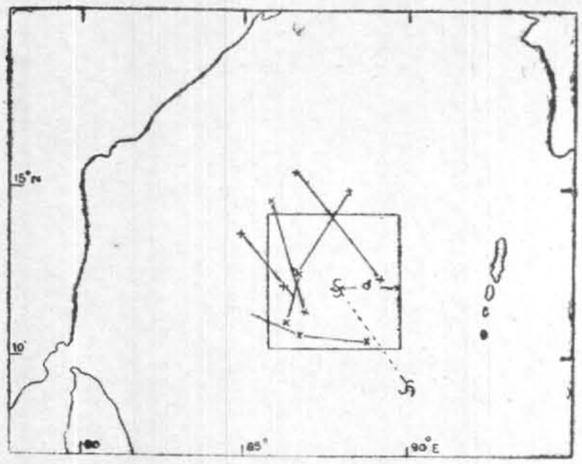

Fig. 1. Grid arrangement for computing climatological and persistence component

Vortex symbol within the square grid is the centre of the storm at the climatological storm positions used for computing the climatological component of the forecast. Dotted line indicates the past 24-hr persistence component of the motion. *d* is the scan distance.

year 1891-1960 (India met. Dep. 1964) have been punched on the cards. The punched cards of climatological storms thus contain (*i*) year and month of the storm, (*ii*) date and position of the beginning of the track and (*iii*) subsequent 24-hourly position of the storm centre for each day till the end of the track. The cards of the particular month (±15 days from the current date) are first loaded in the computer memory. The present position of the storm and its position at the previous 24-hour is also fed to the computer. The programme then scans the climatological positions with the present position of the storm located at the centre of the square grid whose sides are equal to twice the specified scan distance. The climatological storms which are positioned within this square grid are grouped together and the mean resultant vector of the subsequent 24 hours movement of all such storms is calculated to get the climatological component of the forecast. Fig. 1 illustrates this grid arrangement and the method of grouping the climatological storm data. The grid moves with the movement of the storm so as to keep storms always at its centre. The component due to the persistence is composited with the climatology with equal weightage assigned to both and the resultant is computed. The forecast includes the direction and speed of motion for the 24-hr forecast period as well as its coordinates. All the distance calculated in the programme are great circle distances on the spherical earth as follows —

$$\cos(AB) = \sin\ \phi_A \sin\ \phi_B + \cos\ \phi_A\ \cos\ \phi_B . \cos(\lambda_A - \lambda_B)$$

where, AB is the great circle distance, ϕ and λ are the latitude and longitudes with corresponding suffixes. The programme has the flexibility to change the scan distance as well as assign different weightages to persistence and climatology.

In order to determine the optimum size of the scan distance for grouping the climatological storms, experiments were tried on all the storms that occurred in the month of November during 1961-1967 with different scan distances such as 1·5, 2·0, 2·5 and 3·0 degrees. If the scan distance is 1·5 degrees the number of climatological storms of similar position history are very much reduced and in some cases we would not get a storm in the climatology in certain regions. Large grid distance increases the climatological information. A distance of 2·0 degrees besides being sufficiently small for determining the climatology of the storms in the vicinity of the storm to be forecasted. This also groups together a fair number of storms and the calculated climatological component of the forecast motion does not differ much (about 0·5 degree) by increasing the scan distance to 2·5 or 3·0 degrees in cases when the climatological storms in the 2·0 degrees scan are at least five. Thus 2·0 degrees was preferred as the scan distance and further tests were conducted with this only.

4. Discussions of results

In verifying the method, tests were conducted on the independent data of the positions of all tropical depressions and storms having a life duration of at least 3 days for May, October, November and December of the 7-year period (1961—67). The storm positions on the basis of the best track were obtained from the Office of the Deputy Director General of Observatories (Forecasting), Poona.

In all 195 forecasts were verified against the actual location of the storm centres (in the best track data) at the end of the 24-hour forecast period. The parameters used as the verification measures were (*i*) position vector error in nautical miles & (*ii*) deviation in the direction of movement forecast and that actually followed by the storm in terms of 16 points of the compass. Table 1 and 2 show the frequency distributions of these errors respectively.

The position errors were found to be less than 120 nautical miles on about 70 per cent of the occasions in May, November and December and 58 per cent of the occasions in October. The directions were within two points of the compass on about 90 per cent of the occasions.

The location of the storms in the Bay of Bengal and the Arabian Sea are based on synoptic reports from ships. Due to the sparsity of ships' data, the location of the storm centre is at best accurate within 30 n. miles (half a degree). As we have used extrapolation in our method there is an inherent error in the forecast caused due to inaccurate determination of the storm track in the past 24 hours. Gentry (1964) has shown that the error in the forecast based on extrapolation is a function of the vector error of the present and past location of the storm. For a 24-hour extrapolation if $\triangle_0$ and $\triangle_1$ are the errors in the previous and current positions of the storm centres respectively, the error caused in the forecast position will be between $2\triangle_0 - \triangle_1$.

The inherent error caused in the direction of forecast due to inaccurate location of the storm centre depends upon the speed of the storm and is higher in slow moving storms compared to the faster ones. Raghavan (1967) has calculated this error for different storm speeds at the time of forecast only. As the speed of the storms in the Indian seas is generally about 2·0 to 2·5 degrees per day (reducing at times to 1·0 to 0·5 degrees during recurvature), the direction error due to wrong positioning of the storm at the forecast time alone is about 15 degrees. Keeping these errors into consideration we have used the following criteria for classifying the performance of the forecasts made in this study on the basis of combined error in position as well as direction of movement—

Criteria	*Classification*
(*a*) No error in the direction of movement but position error less than 60 n.m.	Very good
(*b*) Error in the direction of movement by one point of compass but position error less than 60 n.m.	
(*c*) No error in the direction of movement but position error between 60 to 120. n.m.	Good
(*d*) Error in the direction of movement by one point of compass but position error 60-120 n.m.	
(*e*) Error in the direction of movement by two points of compass but position error less than 60 n.m.	Satisfactory
(*f*) Error in the direction of movement by two points of compass but position error between 60 to 120 n.m.	
(*g*) Higher errors in the direction of movement and/or position	Poor

The performance of the forecasts verified on the above classification are given in Table 3, which shows that for the four months considered together about 67 per cent of the forecasts are of satisfactory or higher category and the remaining of poor quality.

TABLE 1

Frequency distribution of positicn error (n. miles)

	No. of fore-casts	Frequencies of error (n.m.)					
		0-59	60-119	120-179	180-239	240-299	299
May	47	16 (34)	16 (34)	11 (24)	3 (6)	1 (2)	0 (0)
Oct	40	10 (25)	13 (33)	10 (25)	4 (10)	2 (5)	1 (2)
Nov	57	17 (30)	23 (40)	12 (21)	5 (9)	— (0)	— (0)
Dec	51	18 (35)	19 (37)	10 (20)	3 (6)	1 (2)	0 (0)

Figures in brackets are percentages

TABLE 2

Frequency distribution of direction error (in terms of 16 points cf the compass)

	No. of fore-casts	Frequencies of errors (in points of compass)					
		0	1	2	3	4	4
May	47	21 (45)	17 (36)	8 (17)	1 (2)	0 (0)	0 (0)
Oct	40	12 (30)	14 (35)	10 (25)	2 (5)	1 (2·5)	1 (2·5)
Nov	57	21 (37)	22 (39)	8 (14)	3 (5)	1 (2)	2 (3)
Dec	51	15 (29)	19 (37)	10 (20)	4 (8)	1 (2)	2 (4)

Figures in brackets are percentages

TABLE 3

Performance classification of the precasts verified

	No. of fore-casts verified	Very good	Good	Satis-factory	Satis-factory and above	Poor
May	47	15	15	2	32	15
Oct	40	8	11	4	23	17
Nov	57	17	18	5	40	17
Dec	51	14	15	7	36	15
May & Oct. to Dec	195	54 (28)	59 (30)	18 (9)	131 (67)	**64** **(33)**

Figures in brackets are percentage of total forecasts

TABLE 4

Position error (n.m.) statistics for 24-hr forecast period (1961-1967)

	No. of forecasts verified	Statistics on position error (n.m.)						
		Mean	Median	Standard Deviation	Upper quartile	Lower quartile	Range	
							Lowest	Highest
May	47	93	90	63	136	55	5	245
Oct	40	126	105	76	165	65	37	361
Nov	57	98	99	56	133	55	0	222
Dec	51	97	96	55	123	51	11	278
May & Oct to Dec	195	104	96	63	136	55	0	361

On examination of the errors in the forecasts in the life history of each storm, it is seen that higher errors in position and/or direction of movement generally occur when the storm is in the recurvature stage or when it shows sudden acceleration or deceleration. The method of forecasting the movement with half persistence and half climatology obviously would not hold good in such cases. It is a common experience that the storm considerably slows down at the time of recurvature and gets accelerated immediately after the recurvature has taken place. Therefore, the persistence factor is likely to speed up/slow down the forecast just before recurvature/after recurvature. If the storm recurves much to the south of the normal zone of recurvature the climatological component is likely to cause greater error in the direction of movement. Gentry (1964) has stated that the superiority of any objective technique based either on synoptic-climatological statistical or dynamical considerations over those of persistence and climatology in tackling the recurvature aspect has not yet been reflected in the forecasts.

Table 4 summarises the statistics of the forecasts under discussion. This shows that on the average the position vector error is somewhat higher in the month of October than in the other three months which may be due to greater variability of storm tracks in October caused by larger day to day changes in the general circulation features when the transition from the summer to winter circulation pattern occurs.

The average position error by the present objective scheme is comparable in performance to the various objective schemes in various parts of the world, *e.g.*, Bell (1963), Arakawa (1964), Wilkie (1964), Tracy (1966) etc.

5. Probability ellipses of the position vector errors

The position vector errors have been also analysed by the use of probability ellipses on the basis of method adopted by Veigas, Miller and Howe in 1958 and later followed by Tracy (1966). The method assumes that the errors when resolved into the latitude and longitude components are normally distributed for each coordinate and when taken jointly may be also represented by a normal distribution. The hypothesis of the bivariate normal distribution is then checked against standard statistical test. The resulting equations for determining the ellipses of probability from the probability density function are the following:

$$a^2 = \frac{2\,(1-\rho^2)\log_e(S)}{\dfrac{1}{\sigma_u{}^2} - \dfrac{\rho}{\sigma_u\,\sigma_v}\tan\,\phi} \tag{1}$$

$$b^2 = \frac{2\,(1-\rho^2)\log_e(S)}{\dfrac{1}{\sigma_v{}^2} - \dfrac{\rho}{\sigma_u\,\sigma_v}\tan\,\phi} \tag{2}$$

$$\tan 2\,\phi = \frac{2\rho\,\sigma_u\,\sigma_v}{\sigma_u{}^2 - \sigma_v{}^2} \tag{3}$$

where a is the semi major axis and b is the semi minor axis of the ellipse. The terms used to calculate a and b are defined as follows—

ϕ — Angle which the semi major axis of an ellipse makes with horizontal coordinate axis of the figures depicting the error distribution.

σ_u — Standard error of population longitude error

σ_v — Standard error of population latitude error

ρ — Linear correlation coefficient between the longitude and latitude components

S — Measure of probability given by $S=1/(1\text{-}p)$ where p is probability of the joint distribution of longtitude and latitude error such as 10 per cent, 30 per cent etc.

The distribution of errors in latitudinal and longitudinal components of the combined sample of four months under consideration were tested by Chi-square. These errors were found to be non-significant at 5 per cent and 1 per cent levels respectively. Various parameters required for constructing the probability ellipses for probability levels of 10 to 90 per cent at an interval of 10 per cent were then calculated by a computer programme. These are given below:

$$\sigma_u = 1{\cdot}62 \text{ degrees}, \qquad \sigma_v = 1{\cdot}20 \text{ degrees},$$
$$\rho = 0{\cdot}084 \text{ degrees} \quad \text{and } \phi = 7{\cdot}7 \text{ degrees}.$$

Fig. 2 shows the probability ellipses for different percentage levels indicated on them. The origin (cross) in the figure represents the observed position of the storm and each point is the forecast position relative to the observed position. The centre of the ellipses in the figure is shown by thick dot and its co-ordinates are the mean longitude and latitude error of the sample.

If we number the various quadrants in the figure with reference to the coordinate axes from 1 to 4 in clockwise fashion then the error distribution represented by the figure may be interpreted in the following way—

Quadrant 1—Observed position too far N and E
Quadrant 2—Observed position too far S and E
Quadrant 3—Observed position too far S and W
Quadrant 4—Observed position too far N and W

If the assumption of bivariate normal distribution is correct each ellipse should contain within it the specified percentage of the sample distribution for which the ellipse is drawn, *e.g.*, the ellipses A, B and C should contain 30, 50 and 70 per cent of the vector error respectively. This has been tested by Kolmogrow-Smirnov test (Miller and Kahn 1962) and the distribution appears, to be valid bivariate normal within the limits of the test (5 per cent level). Table 5 summarises the information about the ellipses and the result of the Kolmogrov-Smirnov test applied.

According to the theory of bivariate normal distribution the probability ellipses approach closely circular or straight line shape if there is either no or perfectly linear correlation between the component errors. The correlation coefficient between the component errors in our sample has been tested and was not found to be significantly different from zero at 5 per cent level. Therefore, we can assume that there exists very little relationships between the latitude and longitude errors. Consequently the eccentricity of the ellipses is also small and the validity of the bivariate normal distribution already tested implies that the forecast errors are randomly distributed.

6. Results of real time verification of forecasts

Experimental real time 24-hr forecasts using the method were prepared during the months May, September, October, November and December for the years 1968, 1969 and 1970. The method was put to real time operational use from October 1970. The initial and verifying positions of all the systems from depression stage upwards were obtained from the bulletins issued by the Weather Central, Poona.

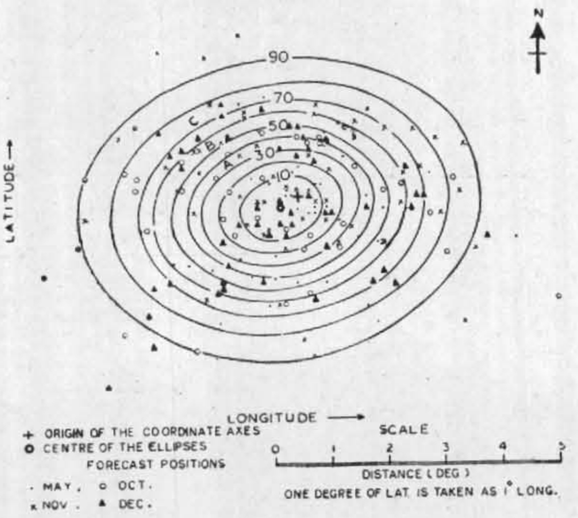

Fig. 2. Position errors probability ellipses

TABLE 5

Semi-major axis (*a*), semi-minor axis (*b*) of the probability ellipse and percentage of forecasts contained within each ellipse. Bivariate normal percentage (5 per cent level)

		a		*b*			
P	(n*S*)	Deg	n.m.	Deg.	n.m.	Actual	M*
0·10	0·1054	0·75	45	0·56	34	15	9.3
0·20	0·2231	1·08	65	0·80	48	26	9·3
0·30	0·3567	1·37	82	1·01	61	32	9·3
0·40	0·5108	1·64	98	1·21	73	41	9·3
0·50	0·9631	1·91	115	1·41	85	49	9·3
0·60	0·9163	2·20	132	1·62	97	58	9·3
0·70	1·2040	2·51	151	1·85	111	73	9·3
0·80	1·6094	2·91	175	2·14	128	84	9·3
0·90	2·3026	3·49	209	2·56	154	91	9·3

M* = Max. allowable absolute difference of the test (%)

Table 6 shows the results of the verification of this series of forecasts. About 75 per cent of the

TABLE 6

Verification of 24-hr forecast for the years 1968-70

	Vector error (n.m.)			Frequency distribution of errors (n.m.)				
No of cases	Average	Highest	Lowest	0-60	61-120	121-180	181-240	>240
93	87	273	12	48	56	24	7	2

forecast errors were within 120 n. miles. The forecast directions were within 45 degrees of the true direction for over 90 per cent of the cases.

7. Conclusion

The method under discussion has been found to give comparable results with respect to other objective methods used in other parts of the world. Large errors in some cases have occurred during the stages of recurvature, sudden acceleration and retardation of the storm. It may be possible to reduce them by incorporating suitable modification of weights to climatology and persistence at different stages of the storm history and introducing weightage to some synoptic criteria usually considered favourable for recurvature such as, position of the approaching trough in the westerlies, the sub-tropical ridge in the vicinity of the storm and the distribution of isallobaric field etc.

Recently Hope and Neumann (1970) have reported an analogue technique for forecasting hurricane movement in which instead of taking all climatological storms within the scan area only a few storm of analogous history are chosen. The method has advantage over normal climatology but requires at least five analogues to give satisfactory results. This they could get only in about 50 per cent of the cases. Gupta and Datta (1971) have also tested an analogue technique for two storms in the Bay of Bengal and have reported encouraging results.

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