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Tracking tropical storms in the Bay of Bengal and calculation of probabilities of its striking east coast by storm analogue technique

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ABSTRACT. The storm analogue technique is used to determine the forecast position of the storm for next 72 hours. Based on these positions the various parameters for different probability ellipses are computed. These probability ellipses are then utilized to work out the probabilities of existing cyclone striking a particular area on the east coast of India.

The results of the above computations for three storms are presented in the paper.

1. Introduction

Sikka and Suryanarayana (1972) proposed a computer oriented objective scheme based on 50 per cent climatology and 50 per cent persistence to forecast the movement of tropical storm over Indian Seas. Further improvement of the scheme based on selection of storm analogue from past climatology was developed and put on operational use by the authors (Gupta and Datta 1971). This scheme has been giving useful advisory for the storm forecaster. Quite often the cyclone forecaster is posed with the problem of indicating the likelihood of a cyclone hitting a particular part of east coast of India while the same is still far in the Bay. In this paper we have extended the previous analogue scheme to work the various probabilities of the existing storm striking the particular spot over the east coast of India. The details of the scheme are discussed in the paper.

2. Data

The data for the climatology of the storm are based on the tracks of storms in the Bay of Bengal for the period 1877-1971 as published by the India Meteorological Department. In these tracks, the positions of the storms are given at intervals of 24 hr. For the present study, we have interpolated for intervals of 12-hr by linear interpolation. History data cards contain the direction and speed of movement, date, time and year and the location of the cyclone. The history of a single cyclone may be carried into a large number of cards depending upon the life of the storm from the date/time of its formation to the date/time of its striking the coast.

3. Selection of analogues

The details of the programme used for detection of analogues has been described in an earlier study (Gupta and Datta 1971). It may be mentioned in brief that the position, date of formation and movement etc of the existing storm are matched with the history storms such that the following criteria are satisfied.

(*a*) The analogue storm is located within 3° of the existing storm's position,

(*b*) Its speed of movement is within the prescribed limit*

(*c*) The direction of movement is $\pm 30°$ of the movement of existing storm, and

(*d*) The analogue storm was located in the position within 30 days of existing storm.

In case, however, analogue selected with the above criteria in view are less than two, then the scan radius for picking up analogues is increased to 3.5 degrees.

Keeping the above criteria the computer programme picks out the analogues which are used for working out the probability.

4. Prediction of storm movements

After the analogues have been selected, each analogue is transposed to the existing position of the current storm. The future movement or predicted velocity of movement (W_p) bas on that

Speed criteria

(i) If speed of existing storm is less than 13 km per hour, speed of the analogue could be (speed of existing storm) 5.5 km per hour.

(ii) If speed of existing storm is from 31 km per hour through 25 km per hour, speed of the analogue could be between 50-200 per cent of the existing storm speed.

(iii) If the speed of existing storm is more than 25 km per hour speed of the analogue could be between 66 and 150 per cent of the existing storm.

analogue is computed by the relation.

$$W_p = \frac{W_1 \times \mathbf{V}_A + W_2 \times \mathbf{V}_E}{W_1 + W_2} \qquad (4.1)$$

where W_1 and W_2 are weights given to the speed and direction of the analogues and existing storm respectively. These weights are so selected that W_1 is a increasing function varying from 0 to 36 where as W_2 a decreasing function from 36 to 0 after 36 hr. This means that we gradually decrease the influence of existing circulation and increase the climatological influence, so that after 36 hr the steering is expected to be mainly based on climatology. Using the above relation the different positions of the existing storm based on different analogues are determined separately after 12, 24, 36, 48, 60 and 72 hr.

On the basis of different positions obtained by various analogues separately for 12, 24, 36, 48, 60 and 72 hr, the probability ellipses are drawn for different probabilities. The details of the procedure are now discussed.

5. Evaluation of statistical probability

The different probability ellipses can be drawn by considering the bivariate normal probability density function (Yule and Kendal 1940).

$$f(x, y) = \frac{1}{2\pi \; \sigma_x \sigma_y \sqrt{1-\rho_{xy}}^2} \; e^{-G/2} \qquad (5.1)$$

G is such that its value in x-y plane is an ellipse and is given by relation

$$G = \frac{1}{1-\rho_{xy}^2} \; [\; (x-\mu_x)^2/\sigma_x^2 - \; 2\rho_{xy}(x-\mu_x)$$
$$(y-\mu_y)/\sigma_x\sigma_y \; + (y-\mu_y)^2/\sigma_y^2]$$

where,

μ_x= Mean of the (x) longitude coordinates

μ_y= Mean of the (y) latitude coordinates

σ_x= Standard deviation of the x coordinates

σ_y= Standard deviation of the y coordinates

σ_x^2= Variance of the x coordinates

ρ_{xy}= Correlation coefficient between x and y coordinates

Now the probability of a randomly selected point (x, y) falling within the region S of the (x-y) plane is given by

$$P\,(s) = \iint_s f(x, y)\, dx\, dy \qquad (5.3)$$

The locus of $G{=}C^2$ where C is constant, defines on equi-probability ellipse, and for each values of $C, f(x, y)$ is a constant. The relation between probability ellipse and C can be expressed in the form

$$P = 1 - e^{(-C^2/2)} \qquad (5{\cdot}4)$$

Such that for $P = 0.3$, $C = 0.845$

To get the standard deviation along the major and minor axes, it is necessary to rotate the axis say by ψ relation to the latitude-longitude grid in such a way that the cross product term in Eq. (5.2) disappears. The components along the rotated axis are then uncorrelated.

Now to determine the value of ψ, let us consider the general equation of an ellipse.

$$Ax^2 + Bxy + Cy^2 F = 0 \qquad (5.5)$$

A rotated set of coordinate axis is made to coincide with that of the ellipse by rotating it through an angle ψ defined by —

$$\tan\, 2\psi = \frac{B}{A-C} \qquad (5.6)$$

In terms of Eq ($5{\cdot}2$), this expression becomes

$$\tan 2\psi \; = \frac{2\rho_{xy}\sigma_x\sigma_y}{\sigma_x^2 - \sigma_y^2} \qquad (5.7)$$

The variance along the rotated axis are computed from the determental equation.

$$\begin{vmatrix} S_x^2 - k & \gamma_{xy} S_x S_y \\ \gamma_{xy} S_x S_y & S_y^2 - k \end{vmatrix} = 0 \qquad (5.8)$$

Solving for K one obtains

$$K = \tfrac{1}{2}[S_x^2 + S_y^2 \pm \{(S_x^2 + S_y^2)^2$$
$$- 4S_x^2\, S_y^2\, (1 - \gamma_{xy}^2)\}\tfrac{1}{2}] \qquad (5.9)$$

The larger value of K, K_a is the variance along the major axis and smaller value, K_b is the variance along the minor axis of the ellipse. The same length of these axis are then computed by multiplying the standard deviations K_a and K_b by the appropriate value of C obtained from Eq. (5.4).

In short,

$$\text{Length of major axis} = C\sqrt{k_a} \qquad (5.10)$$
$$\text{Length of minor axis} = C\sqrt{k_b}$$

The centroids of these ellipses are given by their respective means of x and y coordinates, *i.e.*, μ_x and μ_y. If angle ψ is + ve, it is measured from east towards north. If the angle ψ is — ve, it is measured from east towards south. The major and minor axes will be decided by magnitude of the standard deviations. This is to say that σ_x is greater than σ_y then major axis will be towards axis only.

6. Method of computations

Manually the value of C have been calculated from Eq. (5.4) for different values of probability (P) , *i.e.*, $P{=}0.1$, 0.3, 0.5, 0.7 and 0.9

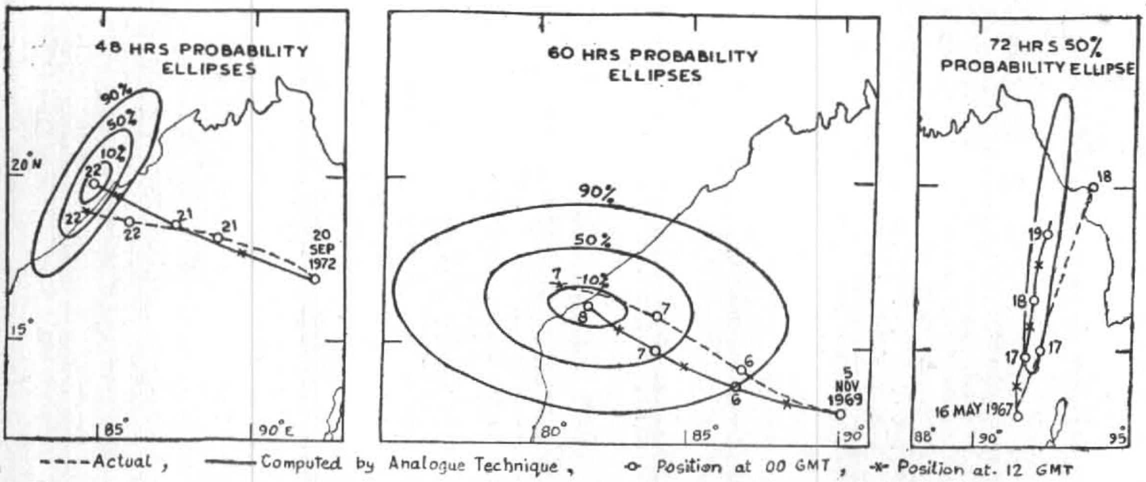

Fig. 1. 00 GMT of 20 Sep. 1972

Fig. 2. 00 GMT of 5 Nov. 1969

Fig. 3. 00 GMT of 16 May 1967

Figs. 1—3. Storms movement forecast using analogue technique

respectively. The existing storm forecast position is determined for the next 12, 24, 36, 48, 60 and 72 hr.

For each one of the analogue, the forecast position of the existing cyclone is determined (for the next 12 and multiple of 12 hr) by using the relation (4.1). The mean of the position based on various analogues gives the centriod of the ellipse for the respective time interval.

Knowing K_a, K_b and ψ as determined by Eqns. (5.7), (5.8) and (5.9) the various probability ellipses are drawn.

To calculate the probability for the storm to strike the particular area of the coast, we require the number of storms passing through each degree latitude grid around the required coastal area. Using the required history data cards (*i.e.*, those three month data cards which have used for selecting the analogues) the number of storms passing through each degree latitude grid is calculated. This is achieved by the use of a separate routine.

The probability (P) for the existing storm to strike the particular coastal area after fixed time interval is determined using the relation.

$$P = B\,N/N_t \qquad (6{\cdot}1)$$

where,

B=contribution of the area under the particular consideration to the total area of 99 per cent ellipse. This could be determined using planimeter.

N=Total number of analogues from which the ellipse was computed.

N_t = Total number of storms passing through that particular box.

7. Results and discussions

The results of the scheme on three test storms which were selected at random are presented in 1 to 3.

The first storm of September 1972 hit the east coast, 20 km south of Gopalpur on the evening of 22 September 1972. The prediction and computation of various parameters for the probability ellipse was based on 00 GMT of 20 September. Fig. 3 gives the prediction and the relevant probability ellipses. Various terms for computation of probabilites of the storm striking coast between Kakinada and Bilaspur are shown in Table 1 (*cf.* Eq. 6·1).

The total probability comes to be 95.5 per cent which gives us a good indication for the storm to strike the coast within Kakinada and Bilaspur. Actually as already mentioned the storm did strike coast near Gopalpur.

The second storm of November 1969 which hit the coast 30 km north of Masulipatnam on the morning of 8 November. The prediction and computation of various parameters for the probability ellipses were based on 03 GMT of 5 November 1969. Fig. 2 gives the prediction and the relevant probability ellipses. Various terms for computation of probability of the storm to strike the coast between Madras and Calingapatnam are shown in Table 2.

The total probability in this case comes out to be 94.1 per cent which gives good indication for the storm to strike the coast between Madras

TABLE 1

Grid Long. (°E)	Lat. (°N)	B	N	N_t	P
83	17	10·8	4	6	7·2
84	17	0·9	4	10	0·2
83	18	13·3	4	6	8·9
84	18	10·2	4	10	4·0
85	18	1·0	4	8	0·5
83	19	4·5	4	2	9·0
84	19	19·0	4	3	25·3
85	19	8·1	4	10	3·2
85	20	18·2	4	2	36·4
86	20	2·0	4	10	0·8

TABLE 2

Grid Long. (°E)	Lat. (°N)	B	N	N_t	P
80	14	1·75	12	5	4·2
80	15	4·2	12	2	25·2
81	16	5·2	12	4	16·6
82	16	4·6	12	10	5·5
82	17	3·2	12	1	38·4
83	17	1·4	12	4	4·2

and Calingapatnam and actually, the storm did strike coast near Masulipatnam.

The third storm was of May 1967 which hit the Burma coast at 93.8° E, 20.0°N on the morning of 18 May. The prediction and computations of various parameters for the probability ellipses were based on 00 GMT of 16 May. Fig. 3 gives the prediction and the relevant probability ellipses. Various terms for computation of probability of the storm to strike the coast between 92°E, 21°N and 93°E, 22°N are shown below :

B=12 per cent, N=4, N_t=2

$P=BN/N_t$=24 per cent

Thus, there was only 24.0 per cent chances of the storm to strike the coast between 92° E, 21° N and 93°E, 22°N and it did not strike between the above coordinates but hit the Burma coast at 93.8° E, 20.0°N.

8. Conclusion

From the result of the three cases presented in the study, it is seen that the present scheme can be used as a guidance for restricting the warning area for the purpose of general preparedness of the public on the coastal area.

While using the results of this scheme for the day to day operational use it may be, however, proper to mention a word of caution that this scheme like such other objective schemes used for tracking storm is very sensitive to the accuracy of the centring of the existing cyclone, specially the present and previous 12/24 hr position.

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