

Probable storm motion in the Bay of Bengal in April and May

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ABSTRACT

Using data of cyclonic storm tracks for the period 1891 to 2000 over Bay of Bengal an attempt is made to find out the probable storm track and probable latitude of crossing of storms in pre-monsoon months of April and May. It has been found that in pre monsoon season the predominant direction of motion of storm is north-northeast in April and north in the case of May. In the month of April initial formation of storm mostly determines the location of crossing whereas in the case of May such prediction is not reliable. The relation between longitudes and latitudes of storm positions is expressed in terms different mathematical expressions during April and May. In the month of April whether the storm is in the easterly or in the westerly regime, the storm track is mostly parabolic. But in the case of May when the storm is wholly under the control of westerly regime, the tracks are in the form of logarithmic curves whereas when they are in easterly regime and then caught under westerly regime they are parabolic.

INTRODUCTION

The speed and direction of movement of the tropical cyclones and depressions are important tools to the forecasters in deciding the landfall point of the tropical storms. In deciding the direction of motion of a tropical storm, various methods are being employed by the forecasters namely climatological method, persistence method, climatological and persistence method (CLIPER), statistical method and dynamical method etc. Another technique to determine the direction of the motion of a tropical cyclone from satellite imagery is the extension of cloudiness. Ganesan, Muthuchami & Sukumar (1994b) pointed out that the highest probability of formation of non-severe cyclonic storms is obtained close to the extreme northern parts of Andaman Island in the month of April and in a cell 15° N and 16° N and 87° E and 88° E in the month of May. Ganesan, Muthuchami & Sukumar (1994a) found that the antecedent speed of the storms in the Bay of Bengal is the highest in the month of April and the lowest in the month of March. Holland (1983) has shown that the inclusion of vortex scale convergence changes the vorticity tendency propagation to a direction slightly pole-ward and westward. Libermann, Henden & Glick (1994) remarked that in northwest Pacific and Indian Ocean cyclones predominantly occur during the convective phase of the Madden-Julian oscillation. They cluster around the low-level cyclonic vorticity and divergence

anomalies (negative). These anomalies lay generally pole-ward and westward of the large-scale convective anomaly over the northwest Pacific and Indian Ocean. Various authors developed statistical techniques for predicting cyclone movement. Muthuchami (2000) concluded that during post monsoon season in the Bay of Bengal cyclonic storms have a particular annual behaviour in direction of motion in each year, i.e., the storms in a year tend to move in a particular direction.

The improvement in Numerical Weather Prediction (NWP) models is not only due to better model performance but also due to ensemble forecasting which reduces the influence of initial uncertainty on forecasts (Zhang & Krishnamurthi 1997). NWP ensemble predictions of tropical cyclone tracks are generated by two different methods. The first is a consensus forecast from ensemble of NWP models (Goerss 2000, Elsberry & Carr 2000) based on the idea that an error minimising forecast combination of independent forecasts improves, on average performance. The second procedure is based on an ensemble of initial condition that, for a single NWP Model, it can be provided by random, locally bred, or optimal growth vectors (Cheung 2001a & b). Ensemble mean forecast errors grow almost linearly with ensemble spread (Fraedrich Raible, & Sielmann 2003)

In this article, an attempt is made to study the tracks of the storms, which formed over the Bay of Bengal in the month of April and May using available past tracks of the cyclones.

DATA AND AREA OF DESCRIPTION

The data utilised for the study was collected from the tracks of storms and depressions in the Bay of Bengal and the Arabian sea for the years 1891 to 1990, India Meteorological Department (IMD) publication (1979,1996) and thereafter (upto 2000) from the Annual Cyclone Review Committee Meeting report of IMD. The study area covers the entire Bay of Bengal in the North Indian Ocean.

RESULTS

All the storms that reached the cyclonic storm intensity were used in this study. At least 10 points were taken from the tracks for each cyclonic storm including the place of crossing and the initial formation for the purpose of studying the track. As a first step for the month of April using positions of formation and crossing of the cyclonic storms various regression curves were identified to suit the best relation between longitude of formation and the latitude of crossing. For the purpose, the Bay was classified into three regions namely East of 90° E and North of 10° N where most of the cyclones form in the month of April. The second region is east of 90° E and south of 10° N and third one is west of 90° E.

In the third region only a few cyclonic storms formed and they affected Tamil Nadu coast only. In the second region it is found that a parabolic relationship exists between the longitude of formation and latitude of crossing. The corresponding equation is given by

$$Y^2 = 3.9 X \quad (1)$$

where X is the longitude of formation and Y is the latitude of crossing. The coefficient 3.9 has a standard deviation of 0.83. In this case the standard error in estimating the place of landfall is 1.81. While dealing with the first region the best curve relation between longitude of formation and latitude of crossing is found to be rectangular hyperbola. This rectangular hyperbola is not designed by routine least square method. For each cyclone the relation of the form (rectangular hyperbola) $XY = C$ was established between latitude of crossing and longitude of formation. The mean value of C of all the cyclones in the first region is considered to be a best estimate in establishing the relation between latitude of crossing and longitude of formation. It is found that the mean value of C is 1659.17 with a standard deviation of 89.55 and has coefficient of variation of

only 5%. In this case the standard error in calculating the predicted value is only 0.67 which is also considered to be very small. For the test of goodness of fit the calculated χ^2 value between the observed and estimated latitude of crossing is 0.01 and is significant at 1% level. Therefore the initial formation in the region consisting of east of 90° E and north of 10° N itself determines the location of place of crossing and it can be determined by the equation

$$XY = 1659.17 (\pm 89.55) \quad (2)$$

This prediction method will help the decision makers in identifying the area in which the preparedness measures are to be taken up.

For real time forecast of the probable track of the cyclone another technique is used. This technique is applicable only in the region north of 10° N. where the cyclone mostly forms. At the first instance various curves are identified by using the points on the tracks and initial position of the storm. Assuming the initial formation of the storm is at the origin and the relation assigns points on tracks

$$(X, Y) = (x, y) - (x_0, y_0) \quad (3)$$

where the longitude and latitude of formation is (x_0, y_0) and (x, y) are the points on the track of the cyclonic storm in terms of longitude and latitude. Two sets of curves namely one set of parabolic curves with its origin at the point of formation and another set of curve, which has its origin at the point where the zonal displacement is zero, can be identified.

At each point, the value

$$a = Y^2 / X \quad (4)$$

for the first set of curves and

$$b = (Y - Y_0)^2 / (X - X_0) \quad (5)$$

for the second set of curves were calculated, where (X_0, Y_0) is the position of the cyclonic storm at which zonal displacement is absent (Point of recurvature) and X, Y are its displacement along east and north with respect to origin respectively.

The mean values of 'a' and 'b' and their standard deviations of the cyclone tracks were computed. It is found that mean value of 'a' have a linear relation with the longitude of formation. Their linear relationship is found to be

$$a = 49.3 - 0.433 x_0 \quad (6)$$

where x_0 is the initial longitude of a cyclonic storm with a standard deviation of 3.08 and the test of

goodness of fit between the observed value and the calculated value is significant at 5 % level. But in the case of portion of the curve north of the point of recurvature, no such relation based on initial formation exists. However some relation exists between mean value of 'b' and the points where the zonal displacement vanishes.

The mean value of Y^2 / X for all the points of the tracks of the cyclonic storms is estimated to be 5.58 for the full track and 6.19 for track under easterly influence and 5.35 for the track under westerly influence with the coefficients of variation 50%, 41% and 58% respectively. Thus the reliability of forecast based on this method will be more in the westerly (when the storm is under the influence of easterly) track than in the easterly track (when the storm is under the influence of westerly). While considering cyclone tracks, which are fully under westerly regime from the beginning, the values of 'b' of the parabolic tracks are comparatively larger than the tracks of the cyclones, which are initially under easterly influence. 10.24 give its mean value of all the cyclones, which is almost double the value of cyclones with initial westerly track. If we consider the variation of 'b' within the track of westerly regime it is found to be small. This variation also seems to be due to initial fluctuation in the storm position. The best-fit curve

suited (based on least value) for all the tracks in the case of easterly tracks (Track of the cyclones which are under westerly regime from the initial stage) is given by

$$Y^2 = 9.34 X \quad (7)$$

and the coefficient having standard deviation of 1.1.

In the month of May the predominant direction of motion of tropical storms in the Bay of Bengal is northward only. But when the storm forms west of 85 E they have the tendency to move with more westward component than in the remaining area. To study the tracks of the past cyclones, they are classified into two categories as in the case of April namely the eastward moving system (systems under the influence of westerlies) and the westward moving system (system under the influence of easterlies) before crossing. It is found that in the case of storms, which are in the westerly regime, the mean direction of motion before crossing is 32 degrees with a standard deviation of 24 degrees. The storms, which are in easterly regime, have the mean direction 322 degrees with a standard deviation of 40 degrees.

While trying to establish the relation between the location of formation and the place of crossing, it is found that the correlation coefficient between

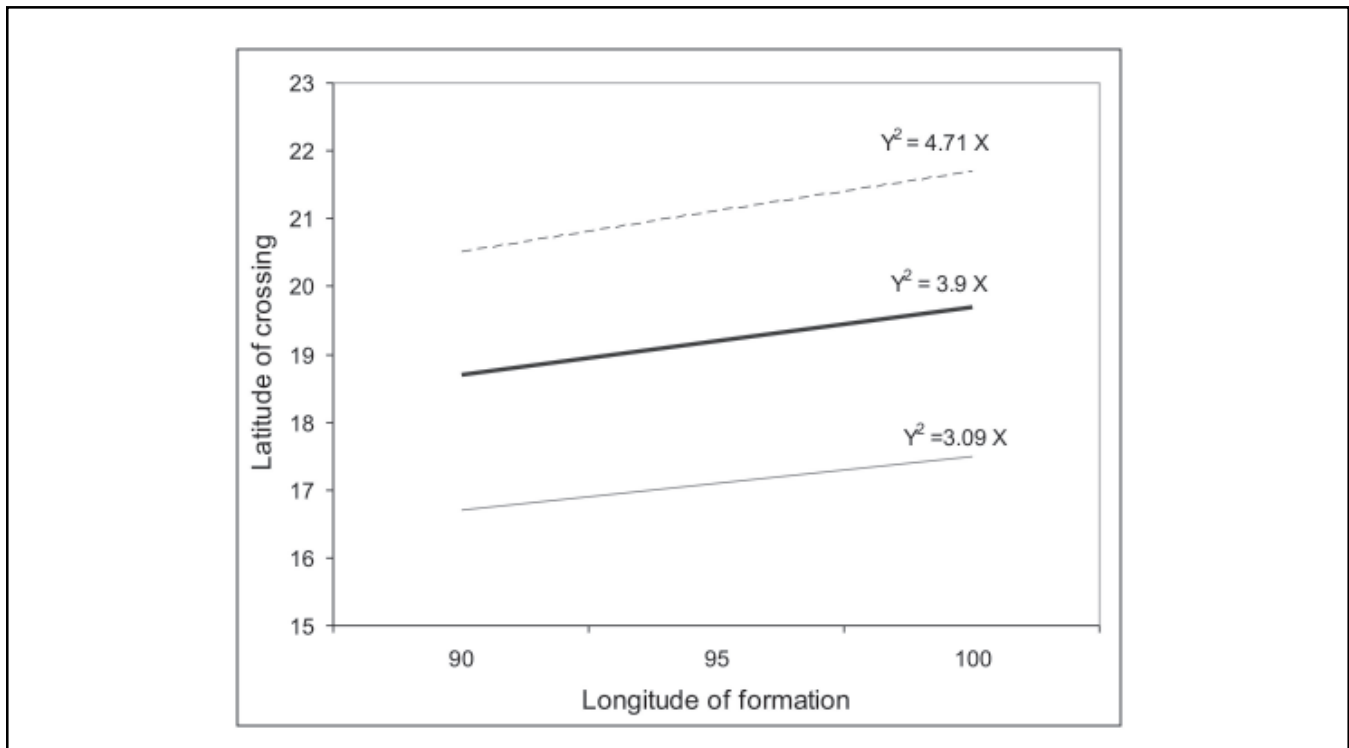


Figure 1. The relation between longitude of formation and latitude of crossing for the storms formed in the region two in April

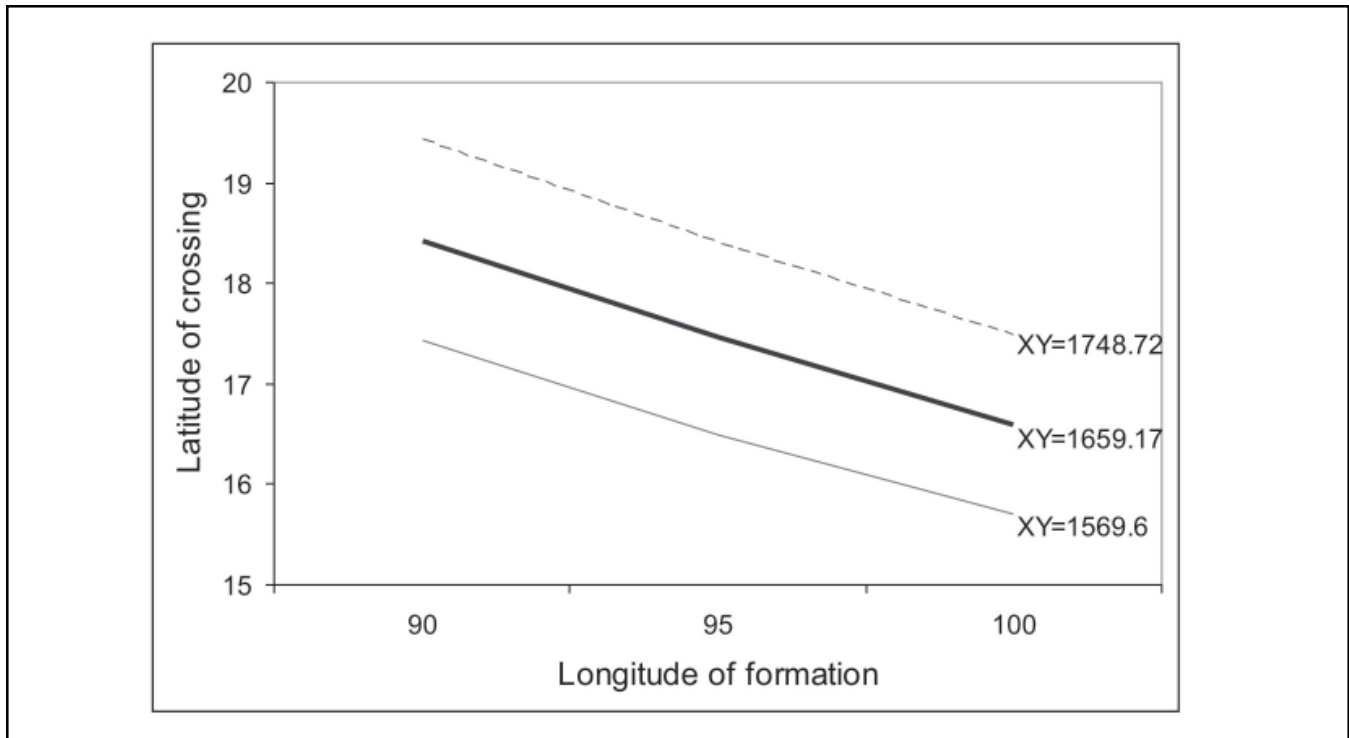


Figure 2. The relation between longitude of formation and latitude of crossing for the storms formed in the region three in April

longitude of formation and longitude of crossing is 0.52 which is significant at 1 % level whereas the latitude of formation and the latitude of crossing have the correlation coefficient of 0.68 which is also significant at 1% level. The correlation coefficient between the latitude of crossing and longitude of formation is not significant.

In the month of May we cannot establish a curve of relation as in the case of April. However, while finding out a probable track in the month of May similar method was adopted as in the case of April. In this case excluding the initial fluctuation within a distance of one degree, tracks in the westerly regime fits to be a logarithmic curve rather than parabolic unlike in the case of April. The logarithmic relation is given by

$$Y = 4.4 \log X \quad (8)$$

where $Y = (y - y_0)$ and $X = (x - x_0)$. The coefficient 4.4 has the standard deviation of 1.2 for all tracks in westerly regime under study. While calculating the χ^2 test between this curve and the westerly tracks the value varies from 0.56 to 2.6, which is good, fit at 1% level of significance.

In the case of storms, which are initially under easterly regime, they are approximated to parabolic

tracks. It is found that the tracks are having higher latus rectum when they are caught by westerly regime and lower latus rectum when they are in the easterly regime. The parabolic relation in the easterly regime is given by

$$Y^2 = CX \quad (9)$$

where the value of C is 5.5 with a standard deviation of 1.8 and for the tracks caught under westerly regime the values of C is 7.3 with standard deviation 3.83.

DISCUSSION

Fig.1 gives the relation between longitude of formation and latitude of crossing in the month of April for the storms, which formed, in region two. It can be visualised from this figure that the deviation of latitudes of crossing from mean curve is about two degrees at one standard deviation level. This value will lead to large error in forecasting the storm landfall. Apart from this, since the storms formed in this region are few in number the relation (1) is not depend on sufficient data. Fig 2 gives the relation between longitude of formation and latitude of crossing for the storms formed in the region three. In this figure one can see that the deviation of the latitudes of crossing

from the mean curve is less than one degree and the relation (2) depends on sufficient data as most of the storms formed in this region in April. Hence the forecast based on the relation (2) will be more reliable. Fig.3a and 3b gives the regression line between the formation longitude and latitude of crossing and formation latitude and latitude of crossing respectively in the month of May. It can be seen from the figures that in both cases predicted latitudes vary between 17.0° N and 21.5° N. It is to be noted that Bay of Bengal has Indian east coast on the west and Bangladesh and Maynmar coast on the east. The estimated latitude may lie on either in Indian east coast on the western side of Bay of Bengal or

Bangladesh and Maynmar coast in east. Therefore the latitude alone is not sufficient to estimate the place of crossing and hence prediction of longitude is also equally important. But in the case of April most of the storm crossed either in Bangladesh or Maynmar coast and so the latitude alone is sufficient to determine the place of crossing. Fig 3c and 3d gives the regression line between formation longitude and longitude of crossing and formation latitude and longitude of crossing respectively in the month of May. In first case crossing longitudes vary between 87.5° E to 90.0° E and in the second case they confine to a small extent which vary between 88.5° E to 89° E. If we look at these longitudes of crossing

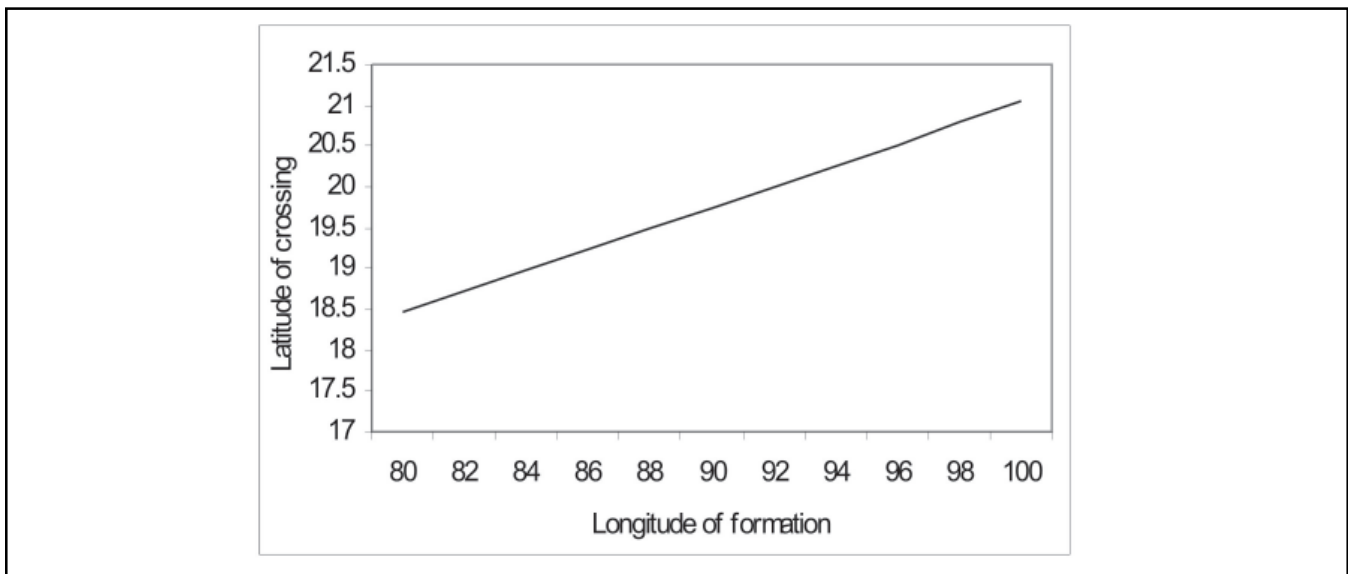


Figure 3a. The relation between longitude of formation and latitude of crossing for the storms formed in May

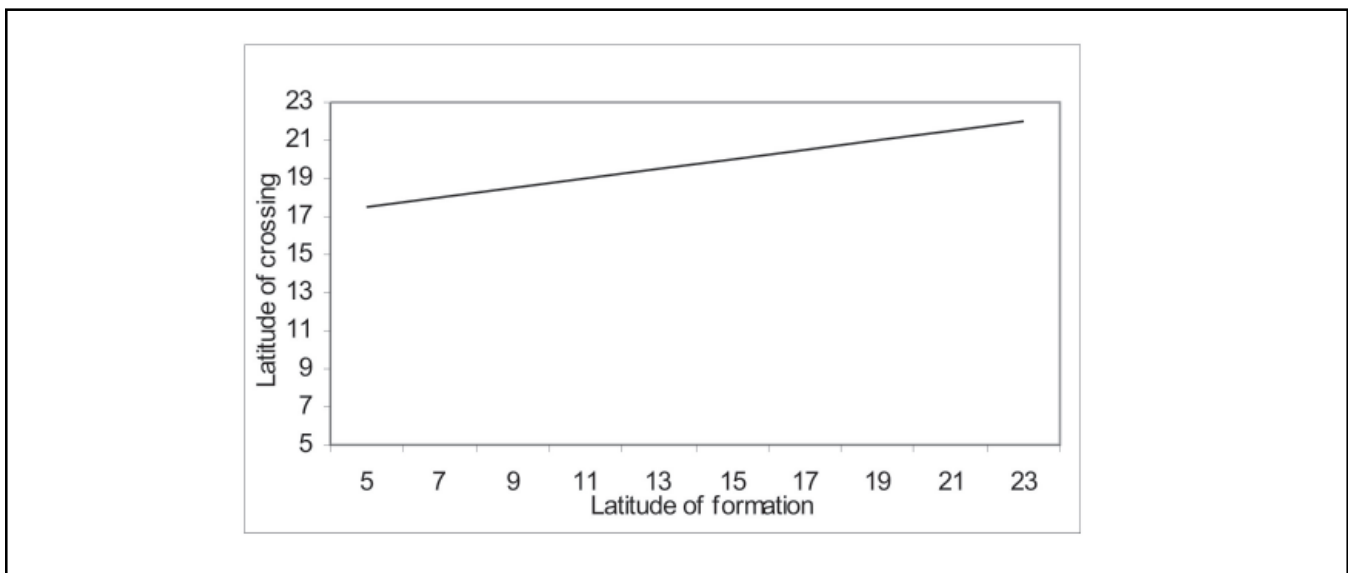


Figure 3b. The relation between latitude of formation and latitude of crossing for the storms formed in May

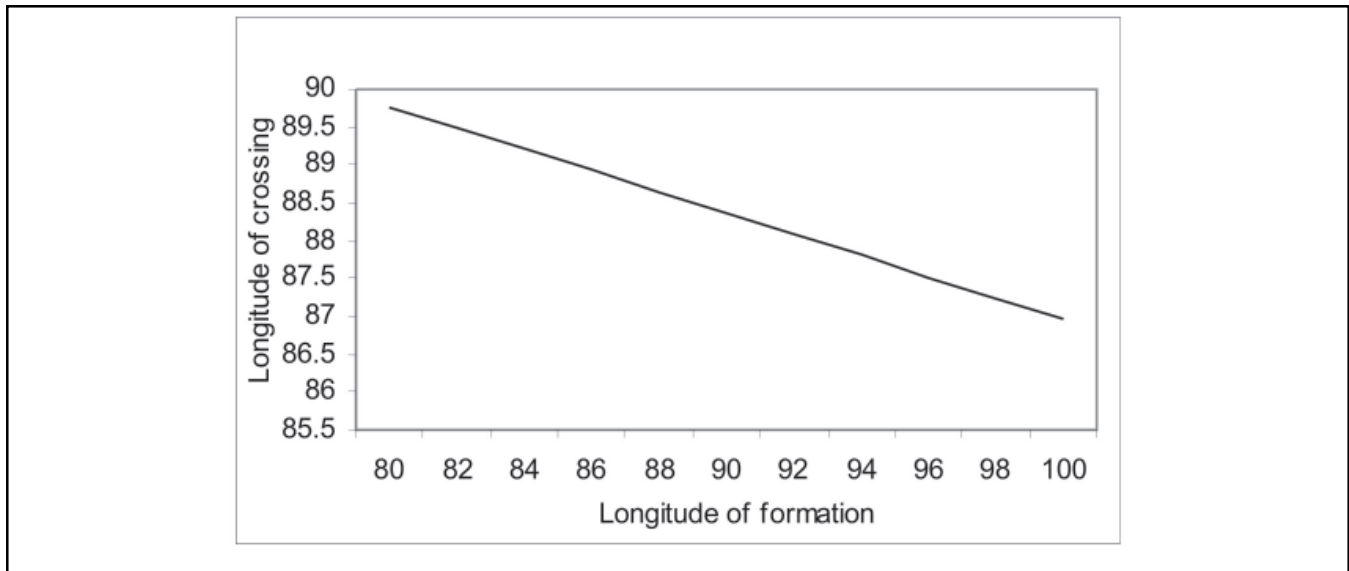


Figure 3c. The relation between longitude of formation and longitude of crossing for the storms formed in May

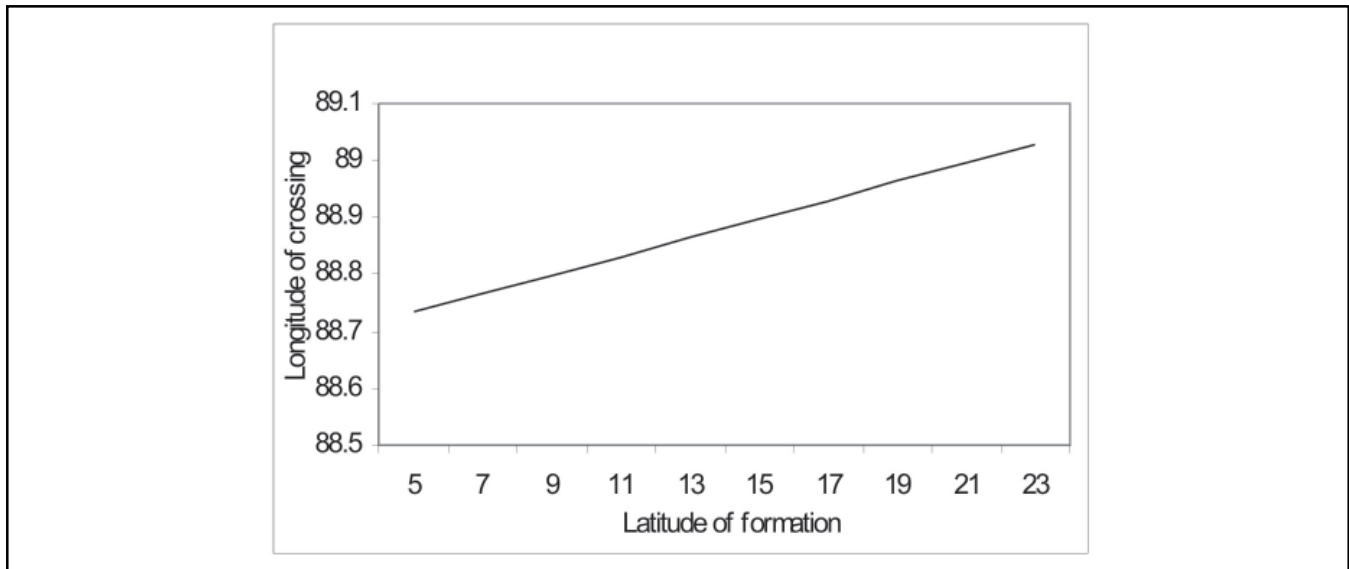


Figure 3d. The relation between latitude of formation and longitude of crossing for the storms formed in May

they mostly confine to Indian coast and a small portion of western Bangladesh coast. Therefore in both cases the major portion of the Bangladesh and Maynmar coast is left out of prediction. Hence the prediction of place of crossing based on formation position is not reliable as in the case of April.

As regards to the probable tracks, the tracks in April are divided into two groups, one with both westerly and easterly movement and another with only westerly movement. In the case of first group the single track is broken into two portions one with westerly movement and another with easterly movement which is to the north of point of recurvature. The portion of the curve in the westerly movement follows the

relation $Y^2 = aX$ where the parameter 'a' have linear relation with the initial longitude of the cyclonic storms as given in (6). The second portion of the curve has the relation $(Y-Y_0)^2 = b(X-X_0)$. The parameter 'b' is a constant and does not depend on the initial formation positions either in terms of latitude or longitude. The second group of tracks which have only easterly movement have the relation as given in (7).

In the month of May, the tracks with only easterly movement from the beginning have the logarithmic relation as described in (8) whereas the tracks with both westerly and easterly movement have the relation as described in (9). Since very few cyclonic storms formed in the month of March no analysis is made.

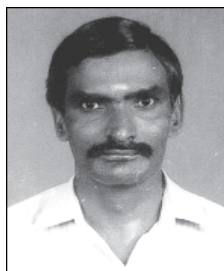
CONCLUSIONS

In pre-monsoon season storms move mostly in the direction of north-northeast in April and north in May. Initial position of formation of storm itself mostly determines the location of crossing whereas in the case of May such a concept is not reliable. In the month of April whether the storm is in the easterly or in the westerly regime, the storm track is mostly parabolic. During the May when the storm is wholly under the control of westerly regime, the tracks are in the form of logarithmic curves whereas when they are in regime and then caught under westerly regime they are parabolic.

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(Accepted 7th September 2007. Revised received 2nd September 2007; in original form 2007 March 20)



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