

Sea surface temperatures as predictors of cyclonic activity over the North Indian Ocean

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ABSTRACT

Tropical Cyclone (TC) activities over the North Indian Ocean (Comprising Bay of Bengal (BOB) and Arabian Sea (AS)) constitute one of the major natural disasters for our country. Indian Coasts are very much vulnerable and susceptible to TCs. In order to understand the TC activities, estimations of their frequency and cyclone days (CD), are necessary. In this study, the Sea Surface Temperatures (SST) over the Indian Ocean region (50 ° E – 120° E and 30 ° S – 30 ° N) are used as predictors. The set of regression equations are formulated for the months of May, October and November, as they are the months with maximum frequencies of occurrences of cyclones over North Indian Ocean. The performances of these equations are also discussed.

INTRODUCTION:

Tropical Cyclones (TC) are the violent manifestations of nature and potentially deadliest of all weather phenomena causing loss and property. Hence there is a crying need for prediction and forecasting methods for minimizing the disastrous effects of TC. The frequency analysis and estimation of TC would be useful in the disaster management for the planners towards preparation of effective mitigation activities. TCs over Bay of Bengal (BOB) are generally higher both in terms of their frequency and intensity. Many authors have studied various trend patterns, epochal behaviour and coastal vulnerability considering different periods of TC over BOB based on climatology. Rao and Jayaraman(1958) have examined the trend pattern using the frequency data for the period of 1890 to 1955 but found to have no-trend. Raghavendra (1972) studied the periodicity considering the data for 1890 to 1969 and found the annual frequency to have a trend of 30 to 45 years. Other studies on the frequency analysis of TC over BOB include Bhalme (1972), Ghosh & Prasad (1982). The methodology used in most of all papers is based on the available climatology and analysis of TC over BOB for a sufficiently longer period employing Statistical methods. Nicholls (1985) used Sea Surface Temperature (SST) and Southern Oscillation Index (SOI) for prediction of the cyclone activities.

Prediction of the frequency of TC over the oceanic region are very important as they would be helpful for both short term and long term planners towards

disaster mitigation. The frequency of TC is generally dependent on the thermal, wind and the moisture fields over the ocean. According to Gray et al., (1992), two important parameters that influence the genesis of hurricane are the SST and wind field that contribute towards the thermal and dynamic potential for the growth and sustainability of TC. There was no study on prediction of TCs and their intensity based on the oceanic parameters, as most of the studies were of climatological in nature.

In this paper an attempt is being made to study and use the temperature over the Indian Ocean for the estimation of TC forming over BOB and Arabian Sea (AS).

PREDICTION METHODS

Generally, Cyclonic or hurricane (for Pacific regions) predictions include statistical, analog and qualitative adjustments methods. Statistical method combines climate factors of TC and linear regression analysis on the same. Analog method searches for the past years with actual similar values. These years are then called analog years and their mean values are used for the prediction. Qualitative adjustment methods include additional factors such as SST, winds, El-Nino, etc., being considered for determining the intense cyclones or hurricanes in a season (Gray's Hurricane Forecasts, CSU). Regression equations are widely used for predicting the cyclonic frequency, for egg. Solow & Nicholls (1990) and Gray et al., (1992). Nicholls (1979, 1985) has explored the predictability of inter

annual variations of Australian TC activity. Jury (1993) and Jury, Pathack & Parker (1999) have used a TC days' index and climatic determinants for the statistical prediction of TC days in the Southwest Indian Ocean. This index is correlated with the SST and the outgoing long wave radiation (OLR) and the tropospheric winds.

INDIAN OCEAN SST AND TROPICAL CYCLONES FORMING OVER BAY OF BENGAL

Over BOB the frequency of TC is comparatively higher during the months of May, October and November (Rao & Jayaraman 1958 and Bhalme 1972). Intensity of TC is more in the case of those forming over BOB than AS. The genesis and intensification of TC is dependent on the SST over the region and the movement caused by the wind flow pattern. Indian Ocean SSTs and TC are having a strong relationship for different lags (Jury, Pathack & Parker 1999) from -4 to +2 months. Further, wind vectors also show a good correlation for the increased TC days. A combination of these two predicts (Jury, Pathack & Parker 1999) with a skill score of 59 % for dependent data while 46 % for independent data.

DATA AND METHODOLOGY

For this study, $2^\circ \times 2^\circ$ data of SST (re-analysed NCEP, USA) of Indian Ocean ($50^\circ \text{E} - 120^\circ \text{E}$ & $30^\circ \text{S} - 30^\circ \text{N}$) and the monthly averaged wind stress data (Florida State University) for the period 1950 – 2001

were considered. The mean SST and wind charts for all the months were analysed. The oceanic parts satisfying the conditions of both annual variations of $\text{SST} \geq 4^\circ \text{C}$ and wind stress $\geq 40 \text{ M}^2\text{S}^{-2}$ were named Zonal (Z) and Meridional (M) regions and the extents of these regions are demarcated in Fig. 1. Three warm regions have been identified with mean $\text{SST} \geq 26^\circ \text{C}$ and wind stress $\geq 40 \text{ M}^2\text{S}^{-2}$ (Gray et al., 1992) were named as W1 ($50^\circ \text{E} - 60^\circ \text{E}$ & $10^\circ \text{S} - 20^\circ \text{N}$), W2 ($65^\circ \text{E} - 100^\circ \text{E}$ & $15^\circ \text{S} - 25^\circ \text{N}$) and W3 ($100^\circ \text{E} - 120^\circ \text{E}$ & $20^\circ \text{S} - 10^\circ \text{S}$). These regions were found to have periodicity of 2.5 years to 7.5 years. Fig. 2 presents the extent and location of these warm regions over the India Ocean. The frequency values of TC over BOB for the corresponding period were taken from the publications of IMD Cyclone Track Atlas (1950 – 1970), its addendum (up to 1990) and the Mausam editions for the remaining period. Correlations (CC) were computed between the frequency of TCs and monthly SST over Z, M and the warm zones (viz., W1, W2 and W3). Similarly, CCs were also worked out between the SST and the cyclone days. Table 1 presents the SST correlation with TC for Z and M regions. It can be seen that significant correlations exist up to a lag of -4 months. Different sets of regression equations were prepared using the SST as parameters to estimate the TC frequency and days in respect of cyclone activity over BOB. The study is then extended to those forming over AS. The statistics of the equations in terms of Multiple Correlation Coefficient (MCC) and the root mean square error (RMSE) were computed and compared for these equations.

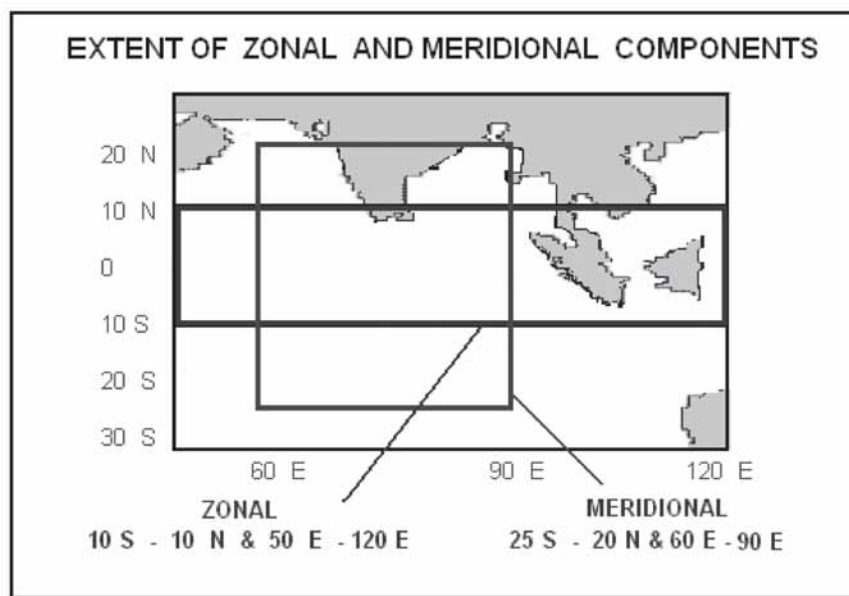


Figure 1. Location of Two SST Modes over the Indian Ocean

Table 1. Correlation Coefficient between SSTs (of Zonal (Z) and Meridional (M) regions) and Frequency of TC over Bay of Bengal.

SST MONTHS	TC frequencies during					
	MAY		OCT		NOV	
	Z	M	Z	M	Z	M
JAN	0.16	0.21	0.13	0.08	0.30	0.10
FEB	0.31	0.36*	0.23	0.11	0.27	0.29
MAR	0.45*	0.41*	0.36*	0.32	0.37*	0.41*
APR	0.53 ^a	0.44*	0.41*	0.34	0.31	0.32
MAY	0.44*	0.39*	0.40*	0.42*	0.36*	0.38*
JUN	0.21	0.27	0.43*	0.47*	0.41*	0.44*
JULY	0.17	0.22	0.51 ^a	0.33	0.55 ^a	0.36*
AUG	0.29	0.19	0.45*	0.21	0.43*	0.24
SEP	0.32	0.12	0.53 ^a	0.27	0.47*	0.31
OCT	0.41*	0.30	0.37*	0.13	0.54 ^a	0.33
NOV	0.24	0.24	0.33	0.19	0.42*	0.26
DEC	0.12	0.28	0.22	0.20	0.34	0.18

Note : * - Significant at 1% level ; ^a - Significant at 5 % levels

RESULTS AND DISCUSSIONS:

ESTIMATION OF FREQUENCY OF TC OVER BOB:

The linear regression model for predicting the seasonal frequency of TC over the Australian region based on Southern Oscillation Index (SOI) was examined as suggested by Solow & Nicholls (1992). Jury, Pathack & Parker (1999) have used the regional SST teleconnection pattern in the prediction model. The regression model is, therefore, developed for predicting the frequency of TC. The averaged SST over the areas of Z and M regions were found to have a good correlation up to 0.55 and 0.47 respectively. The significant CCs at 95% and 99% were found to be 0.36 and 0.48 respectively. Using the regression coefficients, estimates were prepared for various months. However, due to space constraints, the estimations for the months of May and October + November are given here below:

$$TC \text{ (may)} = - 0.365 + 0.0731 * Z \text{ (apr)} + 0.101 * M \text{ (mar)} \quad \dots\dots\dots(1)$$

$$TC \text{ (oct+nov)} = - 0.163 + 0.08 * Z \text{ (oct)} + 0.054 * Z \text{ (sep)} + 0.0814 * Z \text{ (jul)} + 0.013 * M \text{ (jul)} \quad \dots\dots\dots(2)$$

Where

Z (apr) represents the maximum SST value over the Z region in the month of April;
M (jul) represents the maximum SST value over the M region in the month of July and so on.

The Multiple Correlation Coefficient (M.C.C) for these estimates respectively is 0.581 and 0.732 and the standard error (S.E.) of these is 0.0348 and 0.0912. The performance of equation (2) for the combined frequency of TC during October and November is given as Fig.3. The root mean square errors (RMSE) of these are found as 8.31 % and 11.9 %. The results for AS are discussed separately.

PREDICTION OF CYCLONE DAYS OVER BOB

An attempt also has been made to predict the cyclone-days (CD) in a month over BOB using the SST values over the Indian Ocean. CD in a month is defined to be period of cyclonic activity (since the forming over the ocean and period of sustenance till its landfall or

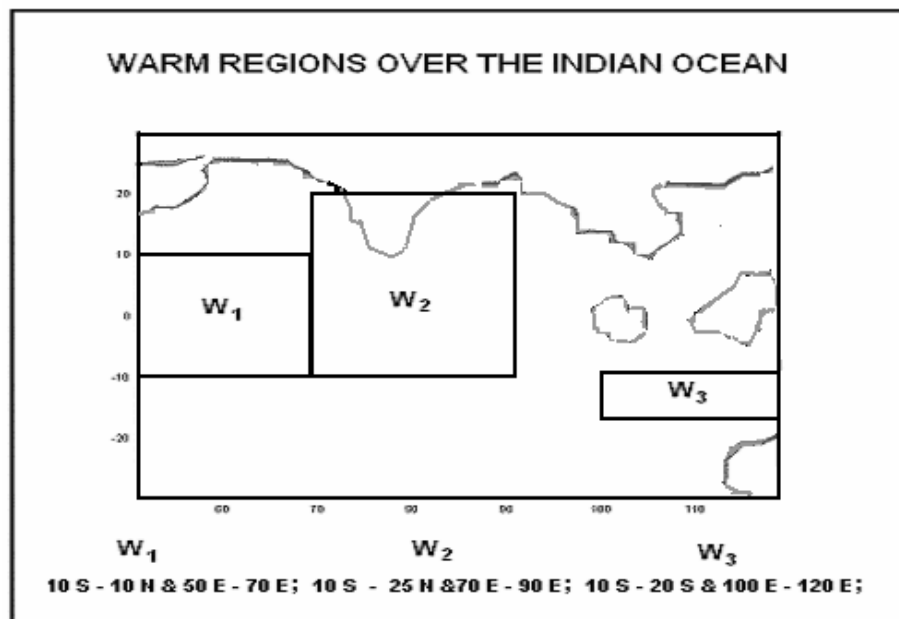


Figure 2. Locations of warm regions over the Indian Ocean

decay over the ocean) by single or more number of cyclonic systems. For this study, the data (of days) of all disturbances formed and remained over the oceanic region till its landfall were collected for the period considered from the references mentioned in the data (Table 2) and methodology. The correlations were worked out for the CD and the maximum SST of zones W_1 , W_2 and W_3 discussed in the earlier paragraph. A strong relation was found to exist between CD and the maximum SST up to a lag of -2 months. Maximum frequencies and CD over BOB were found to be in the months of May, October and November with a maximum of 8.5 days. Table 3 showing the $CD \geq 4$ days and the coast where damage is largely felt for some severe TC over BOB during the last two decades is provided. It can be seen from the Table that Andhra Pradesh State has witnessed the maximum number of severe TC particularly in the months of October and November during the two decades.

The estimates for the CD for various months were worked out. However, the estimates for the months of May, October and November are given below:

$$CD \text{ (may)} = 0.371 + 0.059 * W_1 \text{ (mar)} + 0.091 * W_3 \text{ (apr)} \quad \dots\dots\dots (3)$$

$$CD \text{ (oct)} = -2.519 + 0.081 * W_1 \text{ (aug)} + 0.015 * W_2 \text{ (sep)} \quad \dots\dots\dots (4)$$

$$CD \text{ (nov)} = -1.903 + 0.077 * W_1 \text{ (oct)} + 0.017 * W_3 \text{ (oct)}$$

.....(5)

Where W_1 (mar), W_2 (sep), W_3 (apr), etc., in the above equations denote the maximum SST over the respective regions of W_1 , W_2 and W_3 in the months specified as subscripts in the brackets. The estimations of CD using (4) and (5) are presented for the months of October and November in figs 4(a) & 4(b). The M.C.C of the estimates are 0.573, 0.498 and 0.636. The S.E. of the above equations respectively are 0.0026, 0.0097 and 0.0082. The root mean square errors of the above equations respectively are 16.2 %, 9.8 % and 10.5%..

Considering the results of Nicholls (1979) Jury, Pathack & Parker (1999), the above equations (1) to (5) of estimates perform better both in the cases of frequency and CD respectively. The lead – time taken for the predictions are very much comparable with the results presented in this paper. However, the skill scores computed show larger variations for different seasons if the composites of the monthly predictions were considered. It may further be noted that the data periods taken for the prediction belong to the dependent period. i.e., the prediction period lies within the study-period. Otherwise, the skill score might fall slightly in both the cases of frequency and cyclone days. The skill of the predictions may even go up provided the climatological adjustments with some suitable global parameters or weekly based SST

Table 2. Correlation Coefficient between SSTs (of Warm regions W1, W2 and W3) cyclone days (CD) of TC over Bay of Bengal

SST MONTHS	Cyclone days during					
	MAY		OCT		NOV	
	W1	W3	W1	W2	W1	W3
JAN	0.21	0.24	0.14	0.12	0.21	0.07
FEB	0.33	0.34	0.27	0.16	0.19	0.25
MAR	0.44*	0.38*	0.29	0.22	0.33	0.31
APR	0.34*	0.42*	0.31	0.30	0.32	0.33
MAY	0.28	0.29	0.35	0.28	0.35	0.35
JUN	0.19	0.27	0.28	0.27	0.42*	0.40*
JULY	0.22	0.22	0.33	0.33	0.35	0.28
AUG	0.19	0.19	0.41*	0.46*	0.36	0.24
SEP	0.23	0.14	0.50 ^a	0.44*	0.42*	0.31
OCT	0.31	0.25	0.38*	0.27	0.51 ^a	0.44*
NOV	0.14	0.17	0.31	0.21	0.40*	0.39*
DEC	0.26	0.25	0.28	0.19	0.27	0.29

Note : * - Significant at 1% level ; ^a - Significant at 5 % levels

Table 3. Cyclone Days (CD) for some severe Tropical Cyclones during 1981-2000

YEAR	MONTH	CD (in days)	COAST
1999	OCT	6.5	ORISSA
1996	NOV-DEC	8.5	TNADU
1995	NOV	4	A.P.
1994	APRIL-MAY	4.5	BANGLADESH
1993	DEC	4	TNADU
1992	NOV	6.5	TNADU
1991	NOV	5	TNADU
1991	APRIL	5.5	BANGLADESH
1990	MAY	4.5	A.P.
1989	NOV	8.5	A.P.
1989	MAY	5	ORISSA
1988	NOV	7.5	WB.
1987	OCT	4	A.P.
1985	OCT	4	A.P.
1985	SEP	4	ORISSA
1984	NOV-DEC	4.5	TNADU
1984	NOV	4	A.P.
1984	OCT	5	ORISSA
1982	OCT	4.5	A.P.
1982	OCT	7	A.P.
1982	MAY	4	ORISSA
1981	DEC	6.5	WB.

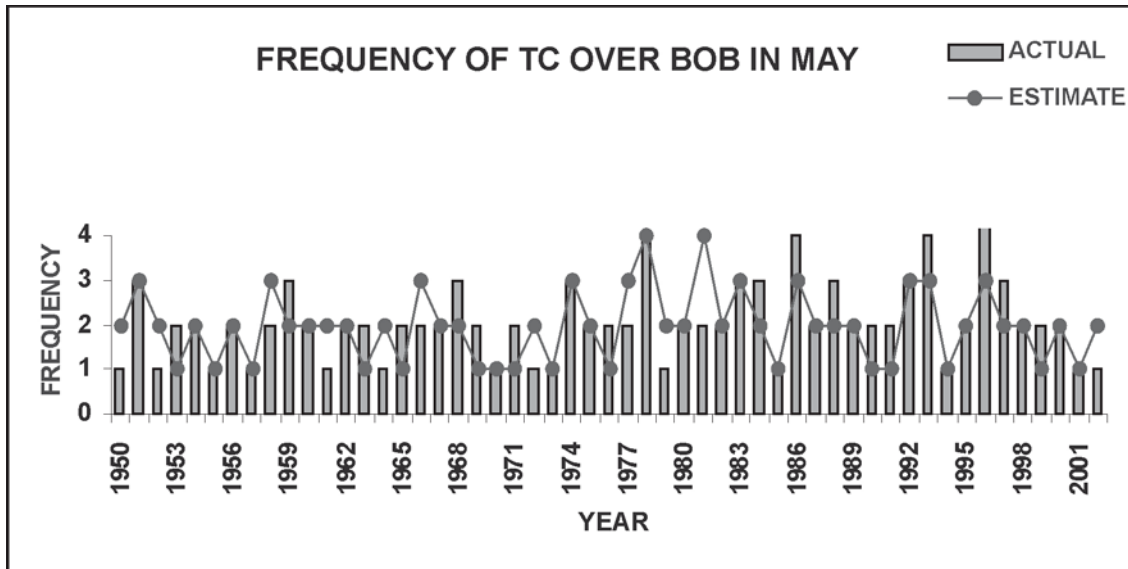


Figure 3a. Verification of TC Over BOB.

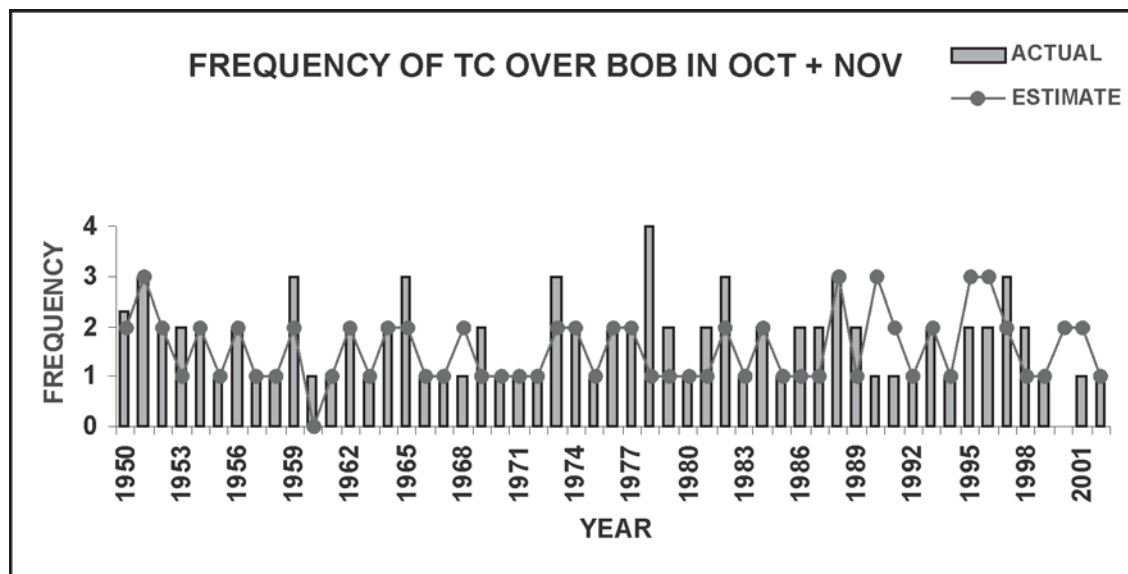


Figure 3b. Verification of TC Over BOB.

over the Indian Ocean favourable for the cyclone activity and its sustenance are employed in the above set of equations.

ESTIMATION FOR THE AS REGIONS:

The following list gives the details of the model equations pertaining to the AS region for estimation of TC frequencies and the CD for the respective months (as discussed for BOB). However, the performance of these equations (although satisfactory, requires further refinements to enhance the skill.

TC FREQUENCIES (ARABIAN SEA):

$$TC (May) = 0.015 + 0.028 * Z (Apr) + 0.09 * M (Mar) \dots\dots\dots(6)$$

The MCC and RMSE values are 0.461 and 18.2 % respectively;

$$TC (Oct+Nov) = - 0.041 + 0.004 * Z (Oct) + 0.04 * Z (Sep) + 0.07 * Z (Jul) + 0.002 * M (Jul) \dots\dots\dots(7)$$

(MCC = 0.842 and RMSE = 16.4%)

CD ESTIMATION (ARABIAN SEA) :

$$CD \text{ (May)} = 0.621 + 0.009 * W1 \text{ (Mar)} + 0.0461 * W3 \text{ (Apr)} \quad \dots\dots\dots(8)$$

(MCC = 0.665 and RMSE = 11.4%);

$$CD \text{ (Oct)} = 0.0341 + 0.31 * W1 \text{ (Aug)} + 0.004 * W2 \text{ (Sep)} \quad \dots\dots\dots(9)$$

(MCC = 0.728 and RMSE = 17.6%);

$$CD \text{ (Nov)} = -0.043 + 0.471 * W1 \text{ (Oct)} + 0.113 * W3 \text{ (Jul)} \quad \dots\dots\dots(10)$$

(MCC = 0.718 and RMSE = 21.6 %)

SUMMARY AND CONCLUSIONS:

Understanding the patterns of the frequency of cyclonic disturbances over the Tropical oceans assumed importance in the scenario of global climate change (Rao & Jayaraman (2001). They found that in association with an increasing trend in the global temperatures, TC has been decreasing. The fact that cyclonic systems provide most of the annual rainfall essential for the agriculture and water resource management, the oceanic disturbances over the Indian regions gain importance. These analyses and methods for predicting the frequency and the intensity measured, as the cyclone days would help both in skill and understanding from the operational and disaster mitigation and management planning point of view.

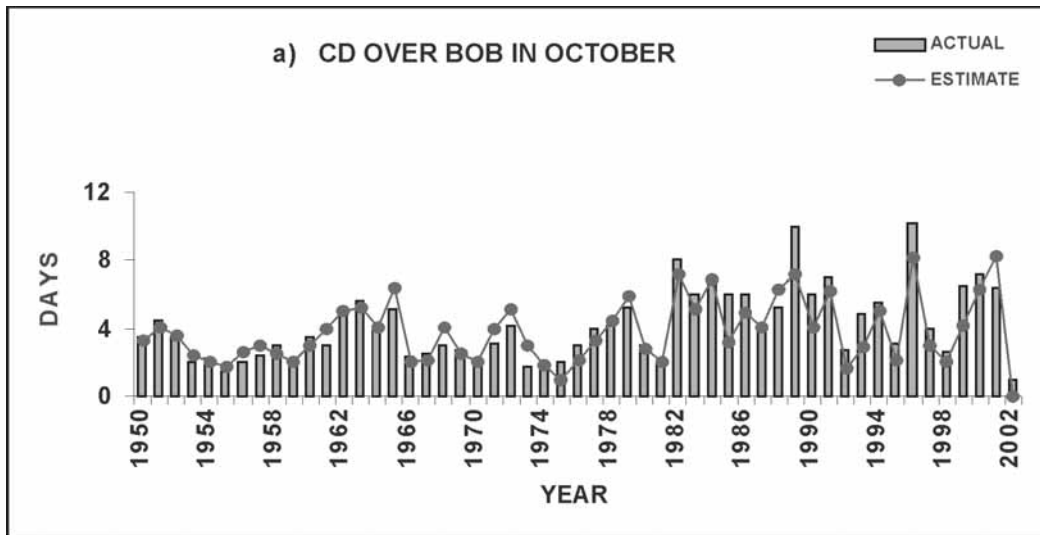


Figure 4a. Verification of CDs Over BOB.

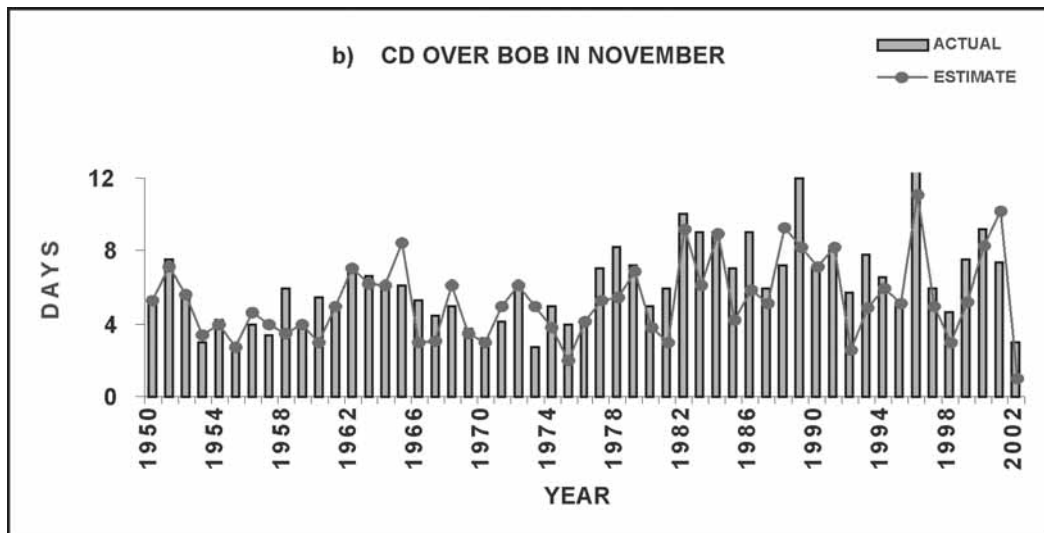


Figure 4b. Verification of CDs Over BOB.

From the results and the discussions enlisted above on the prediction of estimation of TC frequency and cyclone days over BOB and AS oceanic regions, the following may be concluded:

1. The two modes Z and M described earlier in combination with the warm regions do exhibit linkages with the genesis of TC over the Indian Oceans and are found to be useful in the prediction models.
2. The warm regions (W1, W2 and W3) over the regions over the Indian Ocean show strong relationship (up to 0.55) with the TC over BOB & AS. It is seen that they provide predictive potentials for the estimation of no. of cyclones and cyclone days.
3. The lead-time of the parameters used for the estimates generally varies from - 4 months to 1 month.
4. All the models perform satisfactorily with high MCC values. In the case of TC frequency estimations, the highest MCC was found as 0.84 and the least of RMSE was 8.3 %. For the estimation of CD, the same are found as 0.73 and 9.8 % respectively.
5. Suitable global parameters or weekly SST may be employed in the estimations in the case of frequency and CD for a better skill score. An in-depth study on analyzing the global climatological parameters is required for the selection of suitable favourable elements to be employed in the predictive equations for an enhanced performance.

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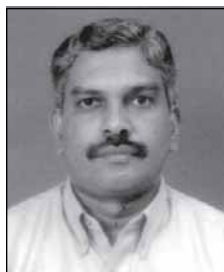
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