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Use of Sea Surface Temperatures over the Indian Ocean in the Estimation of Tropical Cyclone Activity over Bay of Bengal

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Abstract

An estimation of Tropical Cyclone (TC) activities over the Bay of Bengal(BOB) in terms of frequency and cyclone days (CD) using regression equations employing Sea Surface Temperatures (SST) over the Indian Ocean region (50 ° E - 1200 E and 30 0 S - 30 0 N) based on period of 1950 - 2001 is being attempted in this paper. The set of equations are formulated for the months of May, October and November, as they are the months with maximum frequencies over BOB. The performance of these equations is found to be 60 to 70 % in the case of frequency estimation while 60 % in the case of CD.

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 disaster management for the planners towards preparation of effective mitigation activities. TC over the 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 have a trend of 30 to 45 years. Other studies on the frequency analysis of TC over the Bay of Bengal include Bhalme(1972), Ghosh and Prasad(1982). The methodology used in most, papers is based on the available climatology and analysis of TC over BOB for a sufficiently long 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

Key words: *Indian Ocean, Sea Surface Temperatures, Bay of Bengal, Tropical Cyclones, Cyclone days, Estimation, Regression equations*

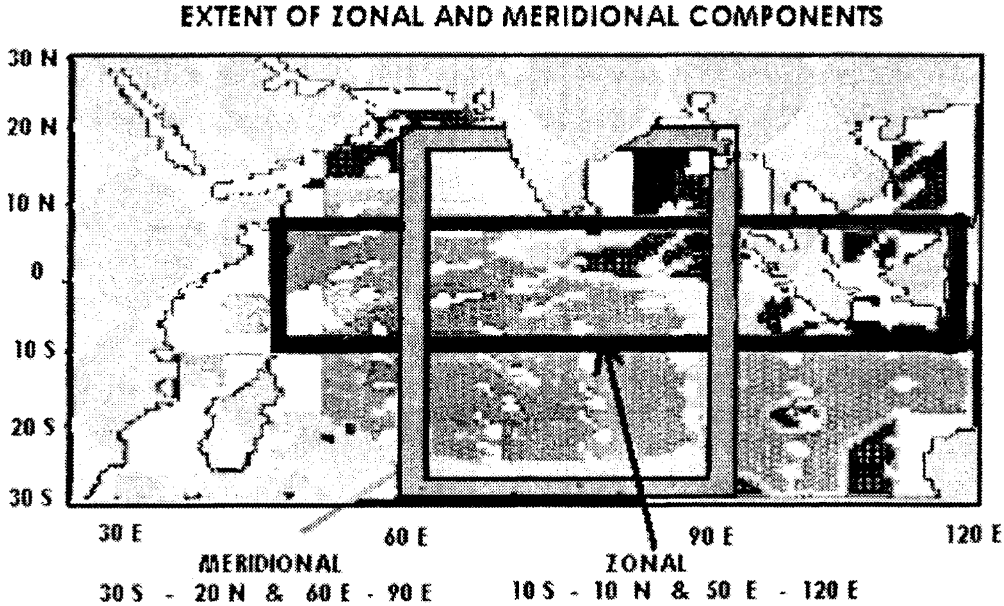

Fig. 1

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 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.

In this paper an attempt is being made to study and use the temperature and winds over the Indian ocean for the estimation of TC forming over BOB.

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 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 eg., Solow and Nicholls (1990) and Gray et al., (1992)). Nicholls (1979, 1985) has explored the predictability of inter annual variations of Australian TC activity. Harr et al. have studied on the intra-seasonal variability of TC over the Western North Pacific Oceanic regions, using canonical correlation prediction and based on wavelet analysis.

Table 1

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

↓ SST / TC→	MAY		OCT		NOV	
MONTHS	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$	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	0.519	0.33	0.55	0.36*
AUG	0.29	0.19	0.45*	0.21	0.43*	0.24
SEP	0.32	0.12	0.539	0.27	0.47*	0.31
OCT	0.41	0.30	0.37*	0.13	0.549	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; $ - Significant at 5 % levels*

Jury (1993) and Jury et al. (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 Bay of Bengal the frequency of TC is comparatively higher during the months of May, October and November (Rao and Jayaraman, 1958 and Bhalme, 1972). Intensity of TC is more in the case of those forming over BOB than Arabian Sea. 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 et al., 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 et al., 1999) with a skill score of 59% for dependent data while 46% for independent data.

Data and Methodology

For this study, 2°x 2° data of SST (re-analysed NCEP, USA) of Indian Ocean (50° E - 120° E & 30° S - 30° N) for 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. Three warm regions have been identified

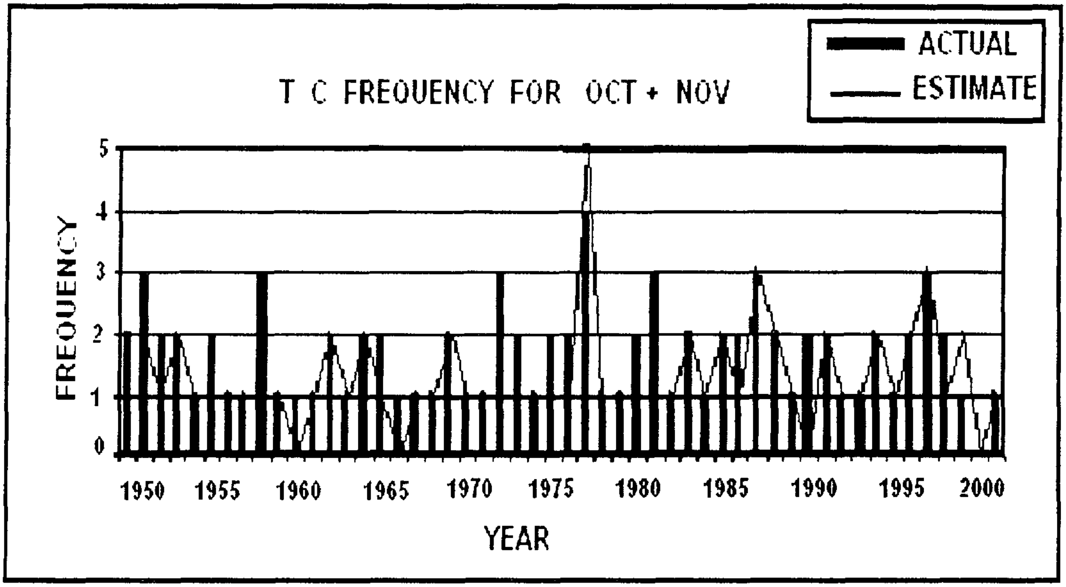

Fig. 2

with mean SST ≥ 26°C and were named as W_1 (50° E - 60° E & 10° S - 20° N), W_2 (65° E - 100° E & 15° S - 25° N) and W_3 (100° E - 120° E & 20° S - 10° S). These regions were found to have periodicity of 2.5 years to 7.5 years. The oceanic parts satisfying the conditions of both SST ≥ 26° C and wind stress ≥ 40 $M2S^{-2}$ (Gray et al., 1992) were named Zonal (Z) and Meridional (M) regions and the extents of these regions are demarcated in Fig. 1. 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 were computed between the monthly SST over both Z and M regions and the warm zones (viz., W_1, W_2 and W_3). 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.

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 and Nicholls (1992). Jury et al. (1999) have used the regional SST tele-connection 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. 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 (may)= -0.365+0.0731*Z(apr)+ 0.101 *M(mar) ...(1)

TC (oct+nov) = -0.163 + 0.08 *Z (oct)+0.054 * Z(sep) +0.0814*Z(jul) +0.013 *M (jul) ...(2)

Where

Table 2

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	T.NADU
1995	NOV	4	A.P.
1994	APRIL-MAY	4.5	BANGLADESH
1993	DEC	4	T.NADU
1992	NOV	6.5	T.NADU
1991	NOV	5	T.NADU
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	W.B.
1987	OCT	4	A.P.
1985	OCT	4	A.P.
1985	SEP	4	ORISSA
1984	NOV-DEC	4.5	T.NADU
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	W.B.

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 are 0.581 and 0.732 and the standard error (S.E.) of these are 0.0348 and 0.0912. The performance of equation (2) for the combined frequency of TC during October and November is given as Fig. 2. It is found that the above equations provide 60 to 70%.

Prediction of Cyclone Days

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 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 and methodology. The correlations were worked out for the CD and the maximum SST zones of 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. A table 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.

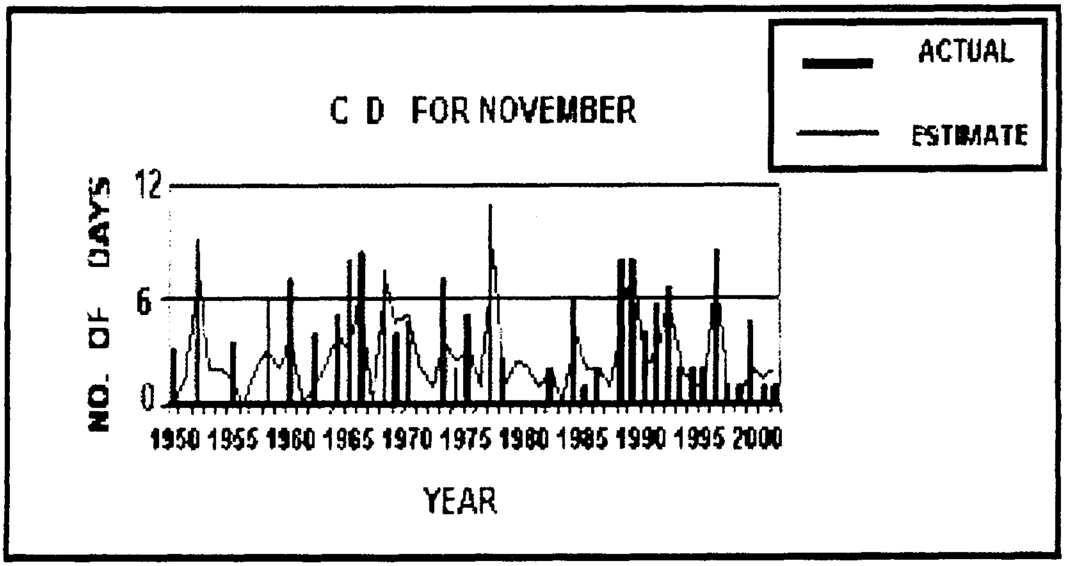

Fig. 3

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

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

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

$$CD(nov) = -1.903+0.077 *W_1(oct)+ 0.017 *W_3(oct) \quad (5)$$

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 Fig 3(a) and Fig 3 (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. Further, above equations for CD provide estimates up to 60% as may be seen in the estimate for October.

Considering the results of Nicholls (1979) Jury et al. (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. This may, perhaps, be due to the fact 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 over the Indian Ocean favourable for the cyclone activity and its sustenance are employed in the above set of equations.

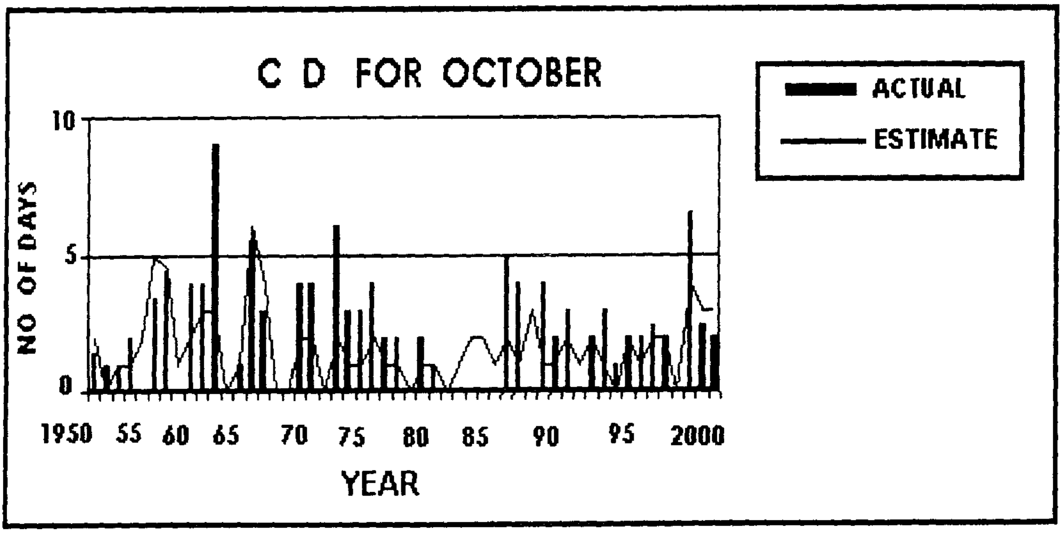

Fig. 4

Summary and Conclusions

From the earlier paragraphs on the estimation of tropical cyclones over Bay of Bengal, it may be concluded that

(1) SST over the select areas or regions over the Indian Ocean show strong relationship (0.55) with the cyclone activity over BOB.

(2) Most of the severe TC over BOB generally have more than 4 days as CD

(3) The lead time of the parameters used for the estimates generally vary from - 4 months to 1 month.

(4) The skill score has been found to be 60 to 70% in the case of frequencies while 60 in the case of CD for the dependent data set.

(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 enhancing the skill score.

References

Bhalme H.N. (1972) : "Trends and Quasi-Biennial Oscillations in the series of Cyclonic disturbances over the Indian Region", Ind. Journal of Met. and Geophy. Vol. 23, Pp 355 - 358

Ghosh S.K. and K.Prasad (1982) : "On vulnerability of Orissa Coast to cyclonic Storms", Vayu Mandal Vol. 12, Pp. 444 - 448

Raghavendra V.K., (1973) : "A statistical analysis of the number of tropical storms and depressions in the Bay of Bengal during 1890 - 1969", Ind. Journal of Met. and Geophys., Vol. 24, Pp125 - 130

Rao K.N. and S. Jayaraman (1958) : "A statistical study of frequency of depressions / Cyclone in the Bay of Bengal", Ind. Journal of Met. and Geophys., Vol 9, Pp 233 -250

Jury, M.R., B. Pathack and B.Parker (1999) : "Climatic Determinants and Statistical Prediction of Tropical Cyclone Days in the Southwest Indian Ocean" Journal of Climate, 12, pp. 1738- 1746.

Gray, W.M, C.W. Landsea, Mielke Jr. and K.J. Berry (1992) : "Predicting Atlantic Seasonal Hurricane Activity 6-11 Months in Advance", Weather Forecasting, 7, pp. 440 - 455

Jury, M.R. (1993) : "A Preliminary Study of Climatological Associations and Characteristics of Tropical Cyclones in the S.W. Indian Ocean", Meteor. Atmos. Phys., 51, pp. 101115

Nicholls, N (1985) : "Predictability of Interannual Variations of Australian Seasonal Tropical Cyclone Activity", Month. Wea. Rev., 113, 1144 -1149

Nicholls, N (1979) : "A Possible Method for Predicting Seasonal Cyclone Activity in the Australian Region, Mon. Wea. Rev., 107, 1221 -1224

Solow, A and N.Nicholls (1990) : "The Relationship between the Southern Oscillation and Tropical Frequency in the Australia region", Journal of Climate, 3, 1097 - 1101

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