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On the association of severe Bay-storms and climate change

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Abstract

North Indian Ocean shows a rising trend for 0-700m depth of oceanic layer with drops during 1965 and 2000. This change in ocean heat content has obvious effects on regional Sea Surface Temperature and so on the cyclogenesis over the Bay of Bengal and Arabian Sea. Distributions of genesis and dissipation locations of storms over the Bay of Bengal are studied during three seasons of cyclonic activity viz. March-April-May (MAM: Pre-monsoon), June-July-August-September (JJAS: Monsoon) and October-November-December (OND: Post-monsoon). Deviation in Genesis locations prominently change from -7 to +5 to 0 to +7 after 1975 latitudinaly. Longitudinal deviations are found to incline towards negative trends. Mean latitude location for genesis occurs at 15.7±5.20 suffers a shift to 11.06±4.36 after 1975. A decrement is observed in monsoon storm frequency after 1964 with a rise in post-monsoon storm number. Decade of 1976-1985 is observed to hold a transition phase for SST anomaly and storm frequency anomaly over the bay.

Keywords: Climate change, dissipation, genesis, seasonal occurrence, severe storms.

Introduction

The dependence of tropical cyclone activity on changing climate was firstly suggested by Bergeron[1]. These meso-scale atmospheric phenomena are considered to be an important element in global thermohaline circulation circuit[2,3]. They are often pictured as Carnot's engine operating on heat transfer between ocean and the atmosphere[2,4]. The efficiency of such energy transfer depends on the temperature difference between sea-surface and tropopause layer. Thus global rise in ocean heat content during the second half of the twentieth century is supposed to have significant effects on tropical cyclogenesis[5-7]. This change in ocean heat content has obvious effects on regional SST. The entire process of cyclogenesis is basin specific. Regional Sea Surface Temperature (SST), wind-shear or existence of characteristic atmospheric flows *viz.* easterly waves, monsoon low pressure troughs, sea level pressure anomalies *etc.* are some of the important indigenous factors[8-13]. Badrinath *et al*[14] supported the well-recognized association of SST with Cyclogenesis and declared the criteria value to be 299-299.5K extending up to 60 m oceanic depth. A temporary relation is also found between SST and wind speed both over BOB and South China Sea[14,15]. Climatological changes in these factors can largely contribute to modulation of annual cyclonic activity of a region[16-19]. Regional span of heat content also observed to trace the movement track of the storms[20,21]. Thus SST is considered as one of the most important factor in cyclogenesis[3,10,22]. BOB storms massively affect coasts of India, Bangladesh, Myanmar and Thailand with intense activity in May and November[23,24]. They are categorized in three intensity scales based on maximum sustained wind speed *viz.* Cyclonic Depression (CD ≤17knot), Cyclonic Storm (17<CS≤34knot) and Severe Cyclonic Storm (>34knot). Figure-1 gives the seasonal occurrences of cyclonic storms in 2.5º × 2.5º geographical grids. Like other active cyclonic basins of the world BOB also profiles an incremental trend of ~20% per hundred years[25-28]. The formation of these storms is very much dependent on large-scale atmospheric motions, oceanic circulations and instantaneous convection schemes. Present work considers such seasonal variability in terms of genesis and dissipation location. Climatological behavior of storm frequency is also addressed in relation with SST over BOB.

Methodology

The genesis and dissipation locations of the storms have been collected from Joint Typhoon Warning Centre for a period of 1951-2010. Numerical data for storm frequency has been obtained from India Meteorological Department for the period of 1891-2010. Sea Surface Temperature Anomaly (SSTA) data and NINO indices are obtained from National Oceanic and Atmospheric Administration. Statistical analysis has been performed by Minitab 16.0.

Results and discussion

Response to genesis and dissipation: Distributions of genesis and dissipation locations are studied during three seasons of cyclonic activity. Geographical co-ordinates for genesis and dissipation are extracted from the JTWC Track database. Their density of occurrence are represented through histograms for three seasonal segments *viz.* March-April-May (MAM: Pre-monsoon), June-July-August-September (JJAS: Monsoon) and October-November-December (OND: Post-monsoon).

Figure-2 shows distinct differences in the seasonal spread of peak occurrences of the storms especially during monsoon. Maximum density occurs at a northward shift of 9° and 5° in latitude than other two seasons for genesis and dissipation respectively. Longitude wise variation is comparatively less prominent in terms of genesis points. Yet dissipation zone appear at isolated latitudes in pre-monsoon. Table- gives the average locations of genesis and dissipation over 60 year period.

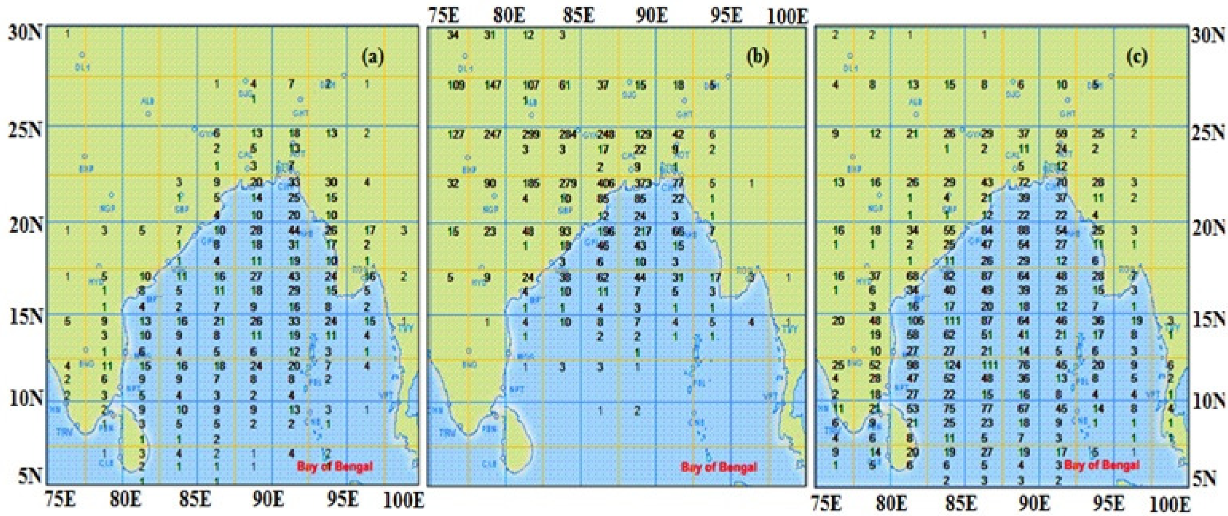

Figure-1: Numeric abundance of cyclonic storm over BOB at 2.5×2.5 geographical grid (Top – CD+CS+SCS, Middle CS, Bottom – SCS) during (a) Pre-monsoon, (b) Monsoon and (c) Post-monsoon for the period 1891-2010 (Cyclone e-Atlas).

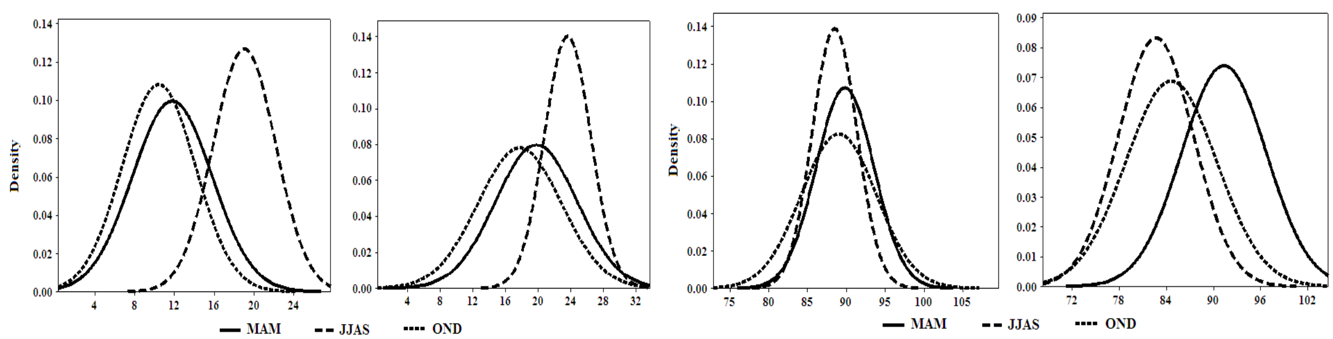

Figure-2: Density histograms of genesis and dissipation latitude wise (top two) and longitude wise (bottom two).

Table-1: Distribution of CSs over BOB.

Distribution of CSs over BOB		GP				DP			
		Mean	Std. Dev*	Skew*	Kurt*	Mean	Std. Dev	Skew	Kurt
LAT	MAM	11.78	3.96	0.37	0.21	19.76	4.95	-1.39	2.83
	JJAS	19.03	3.13	-1.38	5.71	23.59	2.83	-0.26	0.76
	OND	10.43	3.67	0.82	0.13	17.33	5.10	-0.21	-0.9
LONG	MAM	89.83	3.68	-0.13	-0.38	91.3	5.33	-0.77	-0.07
	JJAS	88.50	2.86	-0.61	5.19	82.7	4.77	0.14	0.35
	OND	89.04	4.81	0.59	1.62	84.64	5.77	0.33	-0.1

*Std. Dev: Standard Deviation, Skew: Skewness, Kurt: Kurtosis co-efficient.

Deviation in seasonal genesis (GPDEV) and dissipations (DPDEV) locations are evaluated for individual storm. Their variation is shown in three seasons for the period 1951-2010 for each calendar year. Latitude range of GPDEV values prominently change from -7 to +5 to 0 to +7 after 1975 (Figure-3 (top)). Negative DPDEV values are rare after that year also. On the contrary longitudinal deviations incline to wards negative trends. Mean Latitude location for GPs occurs at 15.7±5.20 shifting to 11.06±4.36 after 1975. Longitude wise there no such prominent change is observed. Genesis is observed more eastward after that particular year. GP range suffers a mild shift from 88.53±3.31 to 89.75±5.0 (Figure-3). Three monthly SSTA values, also known as NINO indices are co-related with annual GPDEV and DPDEV. The variation is shown in Figure-4. Feeble correlation is observed to exist. Latitude wise correlation falls for both GP and DP (Figure-4 (a)). A shift from negative to positive value is observed longitude wise for GP after early monsoon NINO indices (Figure-4 (b)).

Variation in temporal occurrences: Seasonal variations of CSs are analyzed for the period 1891-2010. Table-2 summarizes their distribution statistics. Variance of the total occurrence in the study period is least during pre-monsoon. Five yearly moving averages of seasonal to annual ratio are shown in Figure-5. It is observed that the storm-ratios for monsoon (JJAS) and post-monsoon (OND) follow opposite nature. Pre-monsoon (MAM) storm abundance is increasing after 1990 with a drop during 2002. It is interesting to find out that decrement in monsoon storm abundance after 1964 accompanied with a rise in post-monsoon storm number. A sharp fall is also identified after 2002 in post-monsoon storm ratio. The linear trends are found to follow seasonal trends given as

MAM: R = 0.0008 (year) -1.4855 (1)

JJAS: R = -0.0029 (year) + 6.1292 (2)

OND: R = 0.0021 (year) – 3.6436 (3)

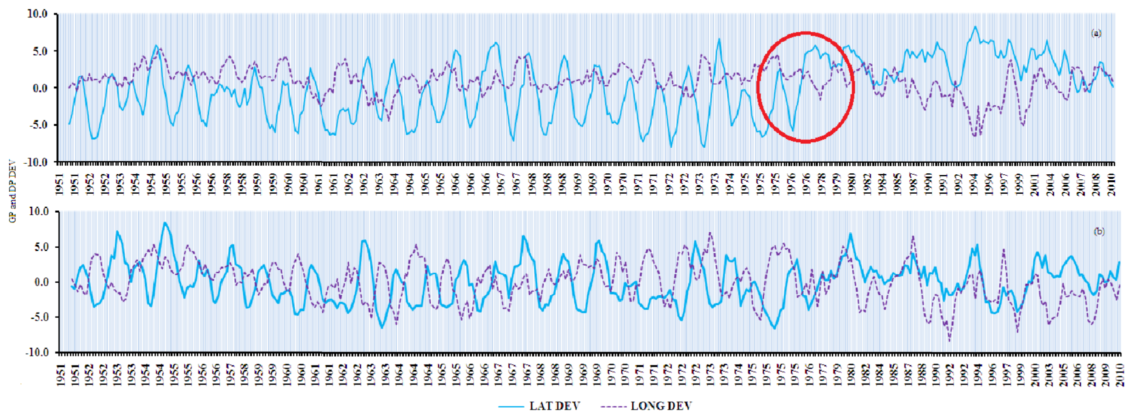

Figure-3: Five yearly moving averages of GPDEV (Top) and DPDEV (Bottom).

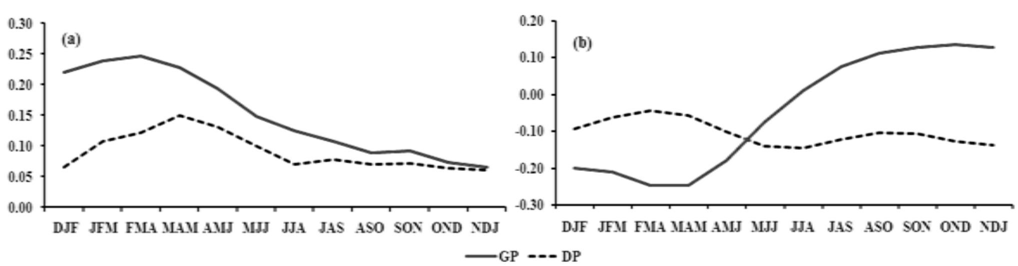

Figure-4: Monthly progression of correlation between NINO index and GP and DP deviation for (a) latitude and (b) longitude.

Table-2: Distribution statistics of CSF.

	Mean	*Std. Dev.	Variance	*Skew	*Kurt
MAM	2.83	1.73	2.99	0.38	-0.0002
JJAS	6.45	3.36	11.32	0.22	-0.13
OND	6.63	3.19	10.21	0.11	-0.30
Annual	15.37	4.89	24.00	-0.003	-0.32

*Std. Dev: Standard Deviation, Skew: Skewness, Kurt: Kurtosis co-efficient.

Each of three classes is analyzed in decadal scale to highlight strength based climatological variation of these storms. The following figure shows decadal histograms of three intensity classes mentioned earlier (Figure-6). Three decades from 1921 to 1950 hold the maximum occurrences of storms over this bay region portraying an immensely active period. It appears that CD category storms suffer a drastic decrease in monsoon after that active spell. CSF fluctuates during pre-monsoon for each strength class. Abundance of SCS category increases during the period of 1961 to 1980 in all seasons. After that it falls as observed except during pre-monsoon.

Storm Frequency and Sea Surface Temperature: Rise in SST influences ocean characteristics a lot and thus its variation is strongly supposed to be a key factor in deciding the path of these storms[29,30]. Thus SST-modulation of genesis and dissipation location and their numeric abundance is really a matter of concern. Shift of genesis location to southern bay regions lengthen storm tracks and thereby allowing to strengthen more[13,23]. Table-3 gives five yearly changing pattern of SST Anomaly (SSTA) over BOB. Storms generating over BOB never are able to reach their potential due to vicinity of land. But recurvature in their tracks can allow them to travel long distances. In this context seasonal CSF anomalies are computed for all three strength class in pentad year segments. Cumulative value of SST anomalies (SSTA) is evaluated for forty chosen locations covering the entire bay region. Simultaneous variations of Cumulative SSTA (CSSTA $=\sum_{i=1}^{40} SSTA$) are analyzed (Figure-7). CSSTA evidently portrays a prominent shift from negative to positive values. Table-3 surely reflects the rise of temperature over the bay. Present study enlightens some interesting facts about the pattern of variation position of generation and landfall of CS and associated SST environment over BOB.

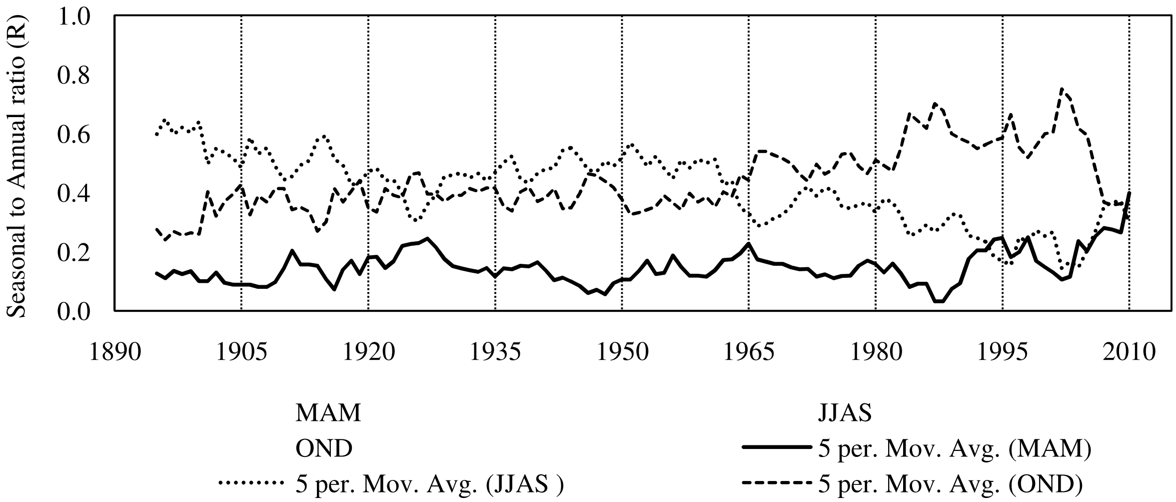

Figure-5: Seasonal to Annual ratio of CSF.

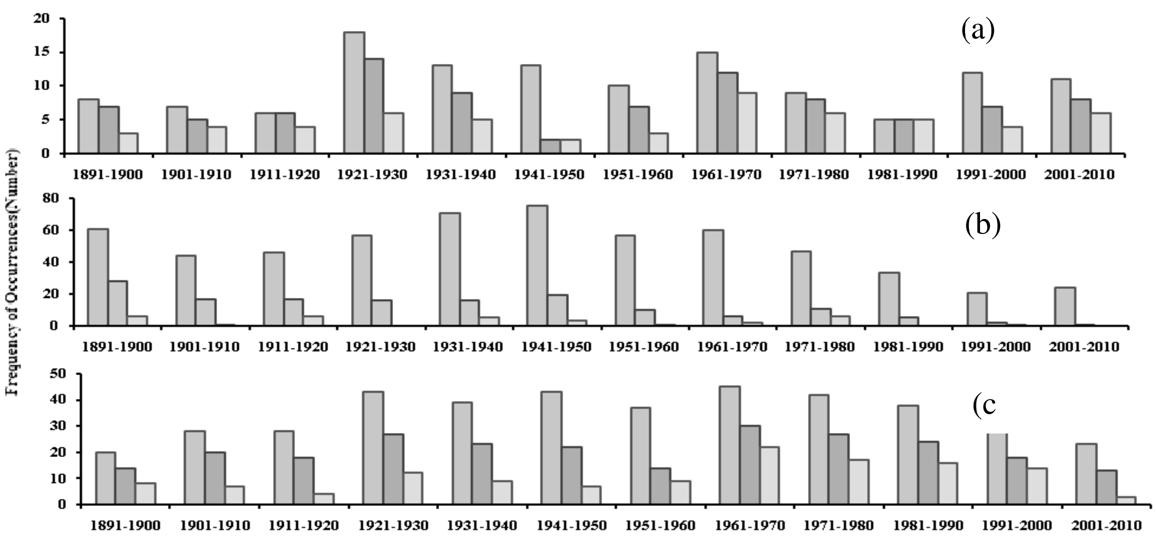

Figure-6: Decadal histograms of CSF for (a) pre-monsoon, (b) monsoon and (c) post-monsoon.

Table-3: Statistical verification of Pentad SST change.

	Pair (P_i, P_{i+1})	Significance	CI of differences of means	P
MAM	P_1, P_2	Y	-0.323 to -0.220	0.00
	P_2, P_3	N	0.086 to 0.192	1.00
	P_3, P_4	Y	-0.254 to -0.164	0.00
	P_4, P_5	N	0.227 to 0.320	1.00
	P_5, P_6	Y	-0.306 to -0.197	0.00
	P_6, P_7	Y	-0.12 to -0.018	0.014
	P_7, P_8	Y	-0.105 to -0.053	0.00
	P_8, P_9	N	-0.014 to -0.064	0.747
	P_9, P_{10}	Y	-0.106 to -0.064	0.00
	P_{10}, P_{11}	-	-0.070 to 0.190	0.169
	P_{11}, P_{12}	N	-0.0106 to 0.040	0.834
JJAS	P_1, P_2	Y	-0.221 to -0.192	0.00
	P_2, P_3	N	0.187 to 0.235	1.00
	P_3, P_4	Y	-0.317 to -0.264	0.00
	P_4, P_5	N	0.173 to 0.213	1.00
	P_5, P_6	Y	-0.178 to -0.123	0.00
	P_6, P_7	Y	-0.041 to -0.001	0.042
	P_7, P_8	Y	-0.250 to -0.190	0.00
	P_8, P_9	Y	-0.112 to 0.074	0.00
	P_9, P_{10}	Y	-0.058 to -0.016	0.003
	P_{10}, P_{11}	N	0.040 to 0.096	1.00
	P_{11}, P_{12}	Y	-0.076 to -0.022	0.002
OND	P_1, P_2	Y	-0.317 to -0.297	0.00
	P_2, P_3	N	-0.170 to 0.220	1.00
	P_3, P_4	Y	-0.197 to -0.145	0.00
	‘P_4, P_5	N	0.101 to 0.139	1.00
	P_5, P_6	Y	-0.443 to -0.355	0.00
	P_6, P_7	N	0.162 to 0.248	1.00
	P_7, P_8	Y	-0.449 to -0.345	0.00
	P_8, P_9	N	0.154 to 0.192	1.00
	P_9, P_{10}	Y	-0.373 to -0.304	0.00
	P_{10}, P_{11}	N	-0.007 to 0.103	0.942
	P_{11}, P_{12}	Y	-0.075 to -0.005	0.028

At 0.05 significance level with 90% confidence; Y-Yes, N-No, CI-Confidence Interval of the differences.

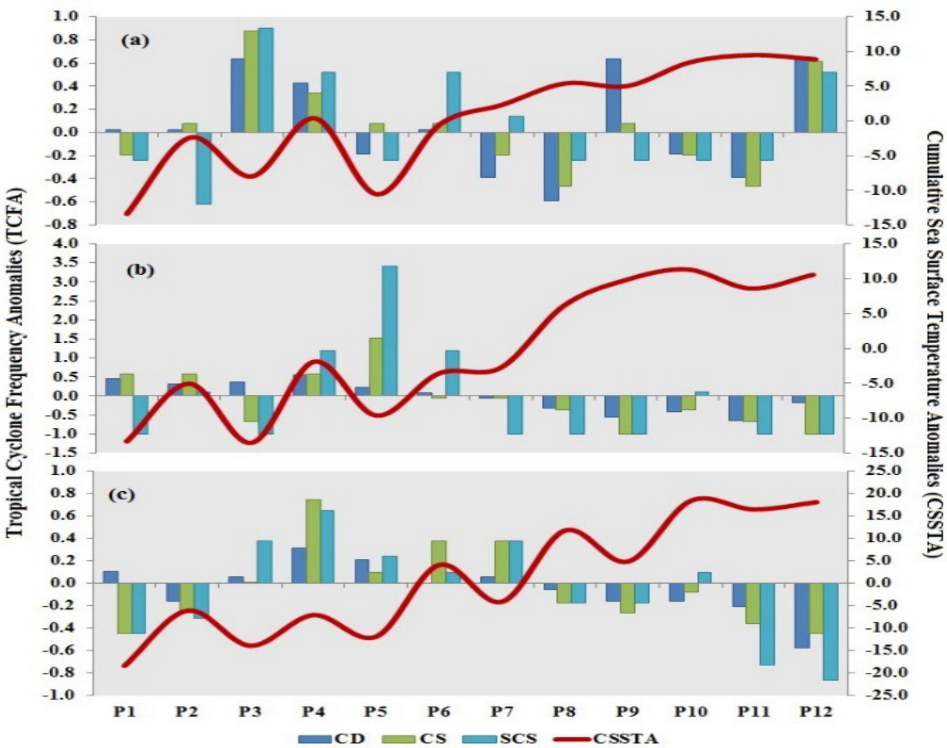

Figure-7: Simultaneous variation of CSFA and CSSTA (a) Pre-monsoon, (b) Monsoon, (c) Post-monsoon.

Conclusion

There are a good number of modulating agents those govern the occurrence and intensity of the cyclonic storms over NIO but all of them do so by influencing the SST status. Thus it is of prime importance to monitor the variation of SST as it is rising with the changing climate over this region. Some of the important findings of this study are as follows: i. Seasonal genesis and dissipation areas are identified. Domains of dense occurrences are also recognized. ii. Latitudinal deviation in genesis and dissipation suffers a positive shift after 1975. Thus storms are occurring more close to land. It reduces the potency of intensification but increases threats of heavy rainfall. Such shift is not likely prominent longitude wise. iii. Variation of Seasonal to annual storm occurrence ratio for the study period reveals the out of phase behavior between monsoon and post monsoon storms. Pre-monsoon storm show increment after 1990. CSF variation for each category storm during consecutive decades is highlighted. iv. Decade of 1976-1985 is observed to hold a transition phase for SST anomaly and storm frequency anomaly over the bay.

These features about cyclonic activity over BOB on climatological scale[24] may be allied with variation of other oceanic parameters *viz.* mixing depth, heat content, thermosteric conditions *etc.* to get a more clear view on the scenario.

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