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Impact of global warming on cyclonic storms over north Indian Ocean

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The impact of global warming on the cyclonic storms over the north Indian Ocean have been studied using a suite of multiple datasets that includes the NCEP/NCAR Reanalysis, the extended reconstruction sea surface temperature (ERSST) and tracks of storms over the north Indian Ocean for the period 1951 to 2007. Results suggest that the frequency of storms and severe storms do not show a dramatic rise in-spite of substantial increase in the sea surface temperature in the Bay of Bengal from 1951-2007 compared to the 1901-1951. This prompted us to conclude that, the frequency of storms is related to the changes in a couple of atmospheric parameters over the north Indian Ocean during the global warming period. It is identified that there is a large decrease in the mid-tropospheric humidity over the Bay of Bengal during the latter period (1951-2007). The relationship between the SST over the Bay of Bengal and the maximum wind speed of the cyclonic systems is complex and there is no preferred range for the formation of cyclonic or severe cyclonic storms over the north Indian Ocean. Examination of various aspects related to storms in the present study revealed that warm SST's alone are not sufficient for the initiation of convective systems over the Bay of Bengal. The present study thus suggests that atmospheric parameters, such as low-level vorticity, mid-tropospheric humidity and vertical wind shear, play an influential role on the genesis and intensification of storms over the north Indian Ocean. The present study assumes significance due to the large contribution of rainfall over India from storms that form over the north Indian Ocean during the summer and the winter monsoons.

[**Keywords**: Global warming, Arabian Sea, Bay of Bengal, Sea surface temperature]

Introduction

Tropical cyclones are among the most destructive natural disasters of the world. About 7% of the global tropical cyclones form in the north Indian Ocean. Further, more number of cyclones form in the Bay of Bengal (about three to four times higher) than in the Arabian Sea. In the north Indian Ocean, there are two important seasons for their formation, namely, a) Pre-monsoon (March-May) and b) Post monsoon (October-December).

According to the India Meteorological Department, the convective systems over the north Indian Ocean are classified as follows:

a) A low pressure system [with sustained maximum surface wind speed (SMSWS) less than 17 knots]
b) Depression (SMSWS between 17-27 knots)
c) Deep Depression (SMSWS between 28-33 knots)
d) Cyclonic Storm (SMSWS between 34-47 knots)
e) Severe Cyclonic Storms (SMSWS between 48-63 knots)
f) Very Severe Cyclonic Storms (SMSWS between 64-119 knots)
g) Super Cyclonic Storm (SMSWS equal to or greater than 120 knots).

An important concern about the consequences of the global warming scenario is its impact on the frequency, the intensity and the duration of tropical cyclones. Theoretical and modeling studies[1-4] indicates that tropical cyclone winds would increase with increasing ocean temperature. Though direct observational evidence of this relationship over the tropical Oceans is lacking, it has been brought out in the recent study over the Atlantic Ocean[5] that higher sea surface temperatures (SST's) over this region increase the intensity of Atlantic tropical cyclones.

In the present study, we focus on the question of whether there is any significant influence of climate change on the frequency and the intensity of cyclonic storms over the north Indian Ocean. The importance of the topic lies in the fact that cyclonic storms over the north Indian Ocean play an important role in the summer and winter monsoons over India. To address the question, various datasets, such as the NCEP/NCAR Reanalysis dataset[6], the ERSST[7] and the tracks of storms and depressions over the north Indian Ocean[8-9] for different seasons based on the period 1901-2007, has been used. The findings are based on the comparison between the changes that occurred during the period 1951-2007 and the previous period, 1901-1951.

Materials and Methods

Data

The data regarding the number of cyclones and severe cyclonic storms have been procured from the tracks of storms and Depressions in the Bay of Bengal and the Arabian Sea[8,9]. The data pertaining to the zonal and the meridional winds at 850 hPa and 200 hPa, the mid-tropospheric humidity (i.e R.H. at 500 hPa) have been extracted from the NCEP/NCAR Reanalysis data. Extended Reconstruction for Sea Surface Temperature (ERSST) data has been used. The ERSST was constructed using the most recently available International Comprehensive Ocean-Atmosphere Data Set (ICOADS) and improved statistical methods that allow stable reconstruction using sparse data[7].

Results and Discussion

An attempt has been made to study the impact of global warming on the Bay of Bengal convective systems. The reason for selecting the Bay of Bengal region is the higher frequency of convective systems as compared to the Arabian Sea. Towards this goal, we have used data pertaining to cyclones and severe cyclonic storms as defined by the IMD for the two epochs viz. 1951-1978 (hereafter, referred as epoch I) and 1979-2007 (hereafter, referred as epoch II). Further to elucidate the changes in various cyclogenesis parameters, we have examined the SST, the low level vorticity, the mid-tropospheric humidity and the vertical wind shear between the lower and the upper troposphere over the Bay of Bengal region during the two epochs partitioned in the data period.

Figure 1 illustrates the scatter plot of the storms and the SST over the Bay of Bengal for the period, 1951-2007. Storms and severe storms used in this plot have been described in terms of maximum wind speed. It is observed from the figure that there is no direct relationship between the intensity of storms (Figure 1 a) or severe cyclonic storms (Figure 1b) with the SST over the Bay of Bengal. In order to investigate if there is any preferred SST range for cyclo-genesis over the Bay of Bengal, the classification of cyclonic storms and STS into different SST ranges is made. The frequencies of cyclonic storms and STS in the SST range of 1°C are put to one category. The lowest SST range starts from 25°C and the highest from 30.0°C. Table-1 provides the frequencies of

Table 1—The occurrence of cyclonic and severe cyclonic storms over the Bay of Bengal in different sea surface temperature range for the study period

SST Range (° C)	Cyclonic Storms	Severe Cyclonic Storms	Total Systems	% of SCS
25.0 – 25.9	2	1	3	33.3
26.0 – 26.9	1	2	3	66.7
27.0 – 27.9	7	6	13	46.2
28.0 – 28.9	11	5	16	31.3
29.0 – 29.9	13	8	21	38.1
30.0 – 30.9	4	3	7	42.9

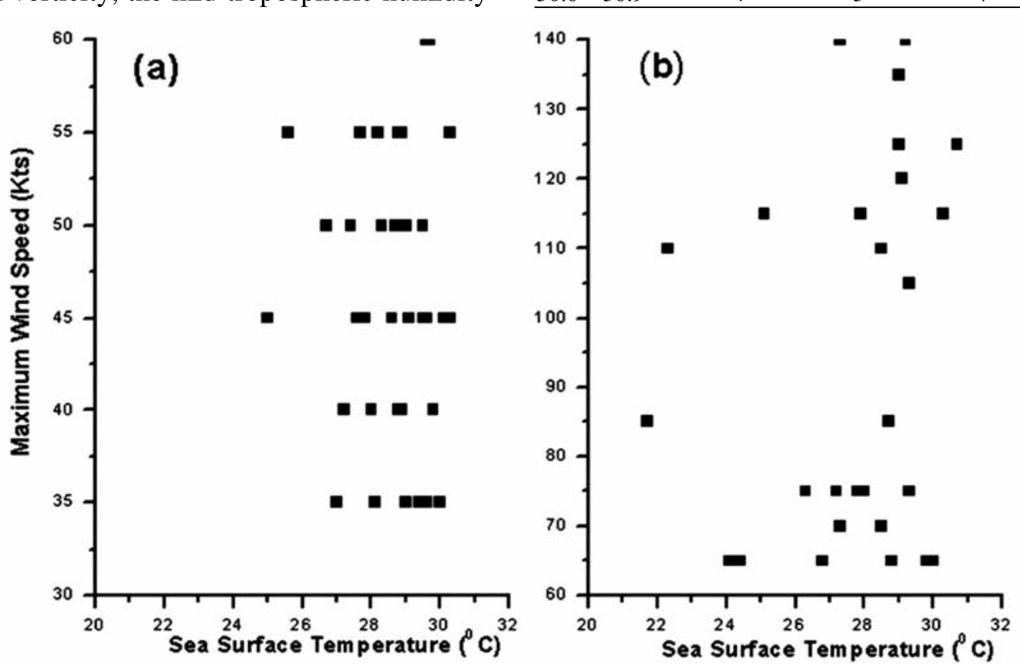

Fig. 1—Scatter diagram of the sea surface temperature (SST) in °C against a) cyclonic storms b) severe cyclonic storms in the Bay of Bengal.

cyclonic storm and STS over the Bay of Bengal categorized over various SST ranges. It is seen majority of the storms occur in the SST range 27.0° - 30.0°C.

Further, to examine if there are significant changes between the two epochs in the frequency of the storms and the various environmental parameters, such as SST, vertical wind shear (VWS) between 850 hpa and 200 hpa, low level vorticity (RV) at 850 hpa and mid tropospheric humidity (MTH) at 500 hpa, we have partitioned the Bay into three regions, namely, the southern Bay (5°N - 11°N; 80°E - 100°E), the central Bay of Bengal (11°N - 17°N; 80°E - 100°E) and the northern Bay of Bengal (17°N - 23°N; 80°E - 100°E).

Table 2 gives the frequency of storms and severe storms in two epochs over three regions, namely, the southern, the central and the northern Bay of Bengal. It is seen that the number of both storms and severe storms, have decreased largely over the Bay of Bengal. The more substantial reduction is observed over the northern Bay of Bengal, as compared to that over the central and the southern Bay.

Table 3a to 3d gives the areal averages over the Bay of Bengal of various environmental parameters such as the SST, the RV at 850 hPa, the VWS and the MTH for different seasons in the two epochs (1951-1978 (I) and 1979-2007 (II)) respectively. From Table 3a, it can be clearly seen that the Bay of Bengal has been warming throughout the year during epoch II compared to epoch I, with the maximum warming occurring in the southern Bay.

An analysis of the RV at 850 hPa (Table 3b) shows reduction during epoch II, clearly indicating that the conditions are not conducive for a cyclogenesis during epoch II. The MTH (Table 3d) which is an important parameter, has been decreasing throughout

Table 2—Genesis of cyclones over different parts of the Bay of Bengal for the two recent epochs

Period	North Bay		Central Bay		Southern Bay	
	Storm	Severe Storm	Storm	Severe Storm	Storm	Severe Storm
1951-1978	25	25	12	12	12	12
1979-2007	7	7	11	12	10	10

Table 3a—Mean value of the sea surface temperature for different seasons for the two epochs over different regions of the Bay of Bengal

Season	North Bay		Central Bay		Southern Bay	
	1951-1978	1979- 2007	1951-1978	1979- 2007	1951-1978	1979- 2007
Winter	25.42	25.73	26.88	27.22	27.74	28.11
Pre Monsoon	28.22	28.41	29.12	29.30	29.33	29.58
Monsoon	28.83	29.11	28.55	28.91	28.38	28.76
Post Monsoon	27.66	27.93	28.17	28.48	28.23	28.57

Table 3b—Mean value of the relative vorticity at 850 hPa for different seasons of the two epochs over different regions of the Bay of Bengal

Season	North Bay		Central Bay		Southern Bay	
	1951-1978	1979- 2007	1951-1978	1979- 2007	1951-1978	1979- 2007
Winter	-0.53	-0.25	-0.51	-0.55	0.23	0.17
Pre Monsoon	-0.25	-0.10	-0.21	0.16	0.33	0.32
Monsoon	0.91	0.87	0.46	0.41	0.03	0.11
Post Monsoon	-0.25	-0.16	0.02	-0.11	0.6	0.6

Table 3c—Mean value of the VWS between 850 hPa and 200 hPa for different seasons for the two epochs over different regions of the Bay of Bengal

Season	North Bay		Central Bay		Southern Bay	
	1951-1978	1979- 2007	1951-1978	1979- 2007	1951-1978	1979- 2007
Winter	-27.98	-28.46	-13.21	-0.55	-2.21	-3.02
Pre Monsoon	-14.93	-4.28	-4.28	0.16	5.27	4.79
Monsoon	16.49	24.81	24.81	0.41	28.72	28.2
Post Monsoon	-14.60	-1.48	0.02	-1.48	8.97	6.9

Table 3d—Mean value of the MTH at 500 hPa for different seasons for the two epochs over different regions of the Bay of Bengal

Season	North Bay		Central Bay		Southern Bay	
	1951-1978	1979- 2007	1951-1978	1979- 2007	1951-1978	1979- 2007
Winter	19.36	16.44	25.28	20.70	41.55	37.60
Pre Monsoon	22.63	19.07	29.65	23.91	44.70	37.84
Monsoon	62.95	58.5	62.72	57.13	57.83	54.72
Post Monsoon	35.73	31.2	45.55	42.36	55.07	53.86

all the seasons and all the regions in the second epoch, confirming the similar result that conditions were not favourable for a cyclogenesis in second epoch in these regions. The change in the VWS (Table 3c) is not coherent over the different regions. It increases in some areas while decreases in some regions. Less VWS is favorable for cyclo-genesis.

Figure 2 shows the 11year running mean of the seasonal sea surface temperature anomaly (SSTA) and the storm frequency anomaly (SFA) for the seasons a) Pre Monsoon, b) Monsoon, and c) Post Monsoon averaged over the Bay of Bengal (8°N-28°N; 80°E-100°E) for the period 1951-2007. From the figure, it can be seen that the SFA is small and positive for all the three seasons during epoch I (1951-1978). During the same period (epoch I), the SSTA over the Bay of Bengal is small and negative.

During epoch II (1979-2007), the SSTA is small and positive over the Bay of Bengal, but the SFA is small and negative for the study area. It can be seen that the SFA is decreasing in spite of increased SSTA's. The SSTA and the SFA are out of phase. Thus, we feel that atmospheric parameters, such as, the MTRH at 500 hpa, the VWS between the lower and the upper troposphere, and the low level vorticity, all play an equally important role in the cyclogenesis over the Bay of Bengal.

Summary

The effect of global warming on the frequency of storms and severe storms in the north Indian Ocean

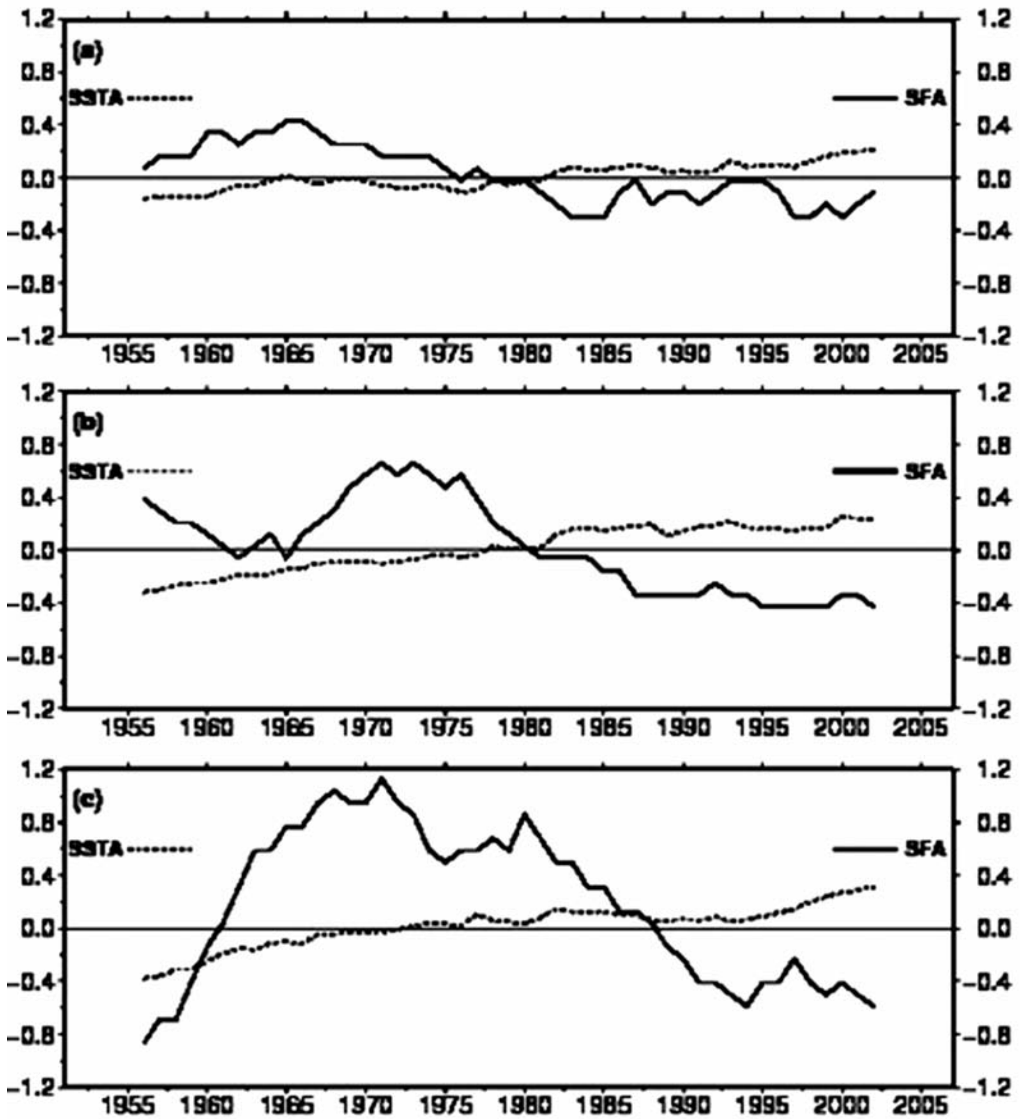

Fig. 2—The SST anomaly (SSTA) and the storm frequency anomaly (SFA) over the Bay of Bengal during a) the pre monsoon, b) the monsoon and c) the post monsoon seasons for the period 1951-2007.

has been examined by analyzing multiple datasets. Results obtained in the present study suggest decreasing trend in the frequency of storms over the Bay of Bengal, contrary to the popular belief that there will be an increase. The frequency of storms is shown by several authors to be increasing in the global warming scenario.

The relationship between the SST and the maximum wind speed is quite complex and there is no preferred range for the formation of cyclonic or severe cyclonic storms over the north Indian Ocean. Results clearly indicate that warm SST's alone are not sufficient for the initiation of convective systems over the Arabian Sea and the Bay of Bengal. However, other environmental parameters, such as the low-level vorticity, the mid tropospheric humidity and the vertical wind shear, also play an equally important role in their genesis and intensification.

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