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Trends in the frequency of cyclonic disturbances and their intensification over Indian seas

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सार - बंगाल की खाड़ी और अरब सागर में 1891-1997 की अवधि में चक्रवातीय विक्षोभों की प्रवृत्तियों का अध्ययन किया गया। तूफानों की आवृत्ति में आश्वस्तता स्तर पर 99 प्रतिशत की उल्लेखनीय कमी की प्रवृत्ति देखी गई है। पिछले चार दशकों में बंगाल की खाड़ी और अरब सागर में चक्रवातीय गतिविधियों में अधिकतम कमी की प्रवृत्ति देखी गई है। चक्रवातीय गतिविधियों में कमी के कारणों में से एक कारण उपरितन क्षोभमंडलीय उष्णन की वजह से हेडली परिसंचरण का कमजोर पड़ना हो सकता है। हाल ही के कुछ समय में भी चक्रवातीय विक्षोभों की तीव्रता में कमी आई है।

ABSTRACT. Trends in cyclonic disturbances for the period 1891-1997 were studied over Bay of Bengal and Arabian Sea. It is noticed that there is a significant decreasing trend at 99% level of confidence in the frequency of storms. The slopes of decreasing trend in cyclonic activity over Bay of Bengal and that over Arabian Sea were found to be maximum during last four decades. Weakening of Hadley circulation due to upper tropospheric warming may be one of the cause of this decreasing trend. There appears to be decrease in intensification of cyclonic disturbances in recent period.

Key words – Trend, Hadley circulation, Cyclonic disturbances.

1. Introduction

In the context of much talked global warming and its impact on the changing climatic scenario, changes if any, in respect of frequency, intensity and occurrence of extreme events have assumed considerable importance. The present study regarding trends in the frequency of cyclonic storms over north Indian seas is one such step. Number of yearly cyclonic disturbances occurring between latitudes 5°N to 35°N, longitude 50°E to 100°E area, divided between Arabian Sea and Bay of Bengal has been studied. Significant decreasing trend at 99% level of confidence has been observed in the frequency of cyclonic storms over both Arabian Sea and Bay of Bengal.

Several studies are available which have dealt with the genesis and variability of cyclonic disturbances over Indian seas. In this paper, depressions, cyclonic storms and all cyclonic disturbances together for complete period 1891-1997 and for a smaller period 35 years each from the complete series have been studied to find out long term trend or epoch in cyclonic disturbances over Indian seas for the first time. Mooley and Mohile (1983, 1984) found that there were significant increase at 10% level in the frequency of storms incident on Bay of Bengal and Arabian Sea coast during the period 1965 to 1980. This increase for Bay of Bengal coast was confined to Bangladesh coast only while it was homogenous for the complete Arabian coast. They attributed the increase in storms to the better monitoring of the same. Mandal (1991) found that there is in general slight increase in tropical cyclones during westerly phase of QBO in the north Indian Ocean but it is not significant. De and Joshi (1995) and Joshi and De (1997) studied about frequency of depressions and storms during period 1891-1990 for each month and each decade during the period. They found that there was general variability in the number of cyclonic disturbances on annual as well as decadal scale. They also found that total number of cyclonic disturbances over Bay of Bengal and Arabian Sea were maximum in the decade 1941-50. When only cyclonic storms and severe storms were considered, maximum occurred in the decade 1921-30 and minimum during last decade of their study. De and Joshi (1999) further found that maximum number of cyclonic disturbances occurred during the decade 1941-50, the decade of least ENSO episode. Similar studies have been carried out for the Atlantic and Pacific oceans. Gray (1990) found that the Atlantic hurricane activity over the period 1970 to 1987 was less than half of that in the period 1947 to 1969. Studies for the north Pacific suggest a decrease in the number of very intense tropical cyclones. Landsea and Gray (1992), Goldenberg and Shapiro (1996) had shown, the decrease in hurricane activity crossing USA coast.

TABLE 1

Summary giving trends over Bay of Bengal and Arabian sea

Period	D/DD		CS/SCS		Total disturbances	
	Bay of Bengal	Arabian Sea	Bay of Bengal	Arabian Sea	Bay of Bengal	Arabian Sea
1891- 1925	No significant trend	Decreasing trend significant at 99 % level of confidence	No significant trend	Decreasing trend significant at 99 % level of confidence	No significant trend	Decreasing trend significant at 99 % level of confidence
1926 - 1960	No significant trend	No significant trend	Decreasing trend significant at 99 % level of confidence	Decreasing trend significant at 99 % level of confidence	No significant trend	No significant trend
1961 - 1997	Decreasing trend significant at 99 % level of confidence	Decreasing trend significant at 99 % level of confidence	Decreasing trend significant at 99 % level of confidence	Decreasing trend significant at 99 % level of confidence	Decreasing trend significant at 99 % level of confidence	Decreasing trend significant at 99 % level of confidence
1891 - 1997	No significant trend	No significant trend	Decreasing trend significant at 99 % level of confidence	Decreasing trend significant at 99 % level of confidence	No significant trend	No significant trend

However, Thompson *et al.* (1992) found that the number of cyclones in the northeast and southwest Pacific have increased. In southeast Pacific also, where tropical cyclone activity is usually associated with El-Nino events, the frequency of occurrence have increased in recent decades. Gray (1993) has also documented the decrease in the frequency of cyclones over Australian region, Atlantic Ocean and south China Sea during El-Nino years while there was increase in the frequency of cyclones over north and south central Pacific ocean during the same.

2. Data used

Number of yearly cyclonic disturbances for the period 1891-1990 were collected from the India Meteorological Department publication (1979, 1997) "Tracks of cyclones and depressions in the Bay of Bengal and Arabian Sea", and for the period 1990 to 1997 from the track prepared by DDGM (WF) office.

3. Methodology

Mann-Kendall test has been applied to determine the long term trends in cyclonic storms and total cyclonic disturbances for the complete data set. In addition, the test has also been applied for the periods 1890-1925, 1926-1960, 1961-1997, separately to delineate trends over smaller time scale from the long term trend.

4. Results and discussion

Results of the trends in cyclonic activity for different periods are shown in Table 1. Long term trends (1891-1997) for the cyclonic storms over the Bay of Bengal and Arabian Sea both show deceasing trends significant at 99% level of confidence. However, when total cyclonic disturbances for the above period are considered, though it exhibit decreasing trends over both the seas but not statistically significant. The frequency of depression/deep depression does not show any trend for the entire period. This indicates clearly that tendency of depressions intensifying into cyclonic storms have decreased. While considering trends for the periods 1891 to 1925, 1926 to 1960, 1961 to 1997 for all cyclonic disturbances and cyclonic storms over Bay of Bengal and Arabian Sea, different scenario for both have been noticed.

4.1. *Trends over Bay of Bengal*

Over Bay of Bengal, for the period 1891 to 1925, total cyclonic disturbances, cyclonic storms, depressions separately do not show any significant increasing or decreasing trend. For the period 1926-60, although no significant trend has been noticed for the total number of cyclonic disturbances and depressions, but when only cyclonic storms over the period were considered it shows a decreasing trend significant at 99% level of confidence. This indicates that during the period 1926-60, less number of depressions intensified into cyclonic storms. For the

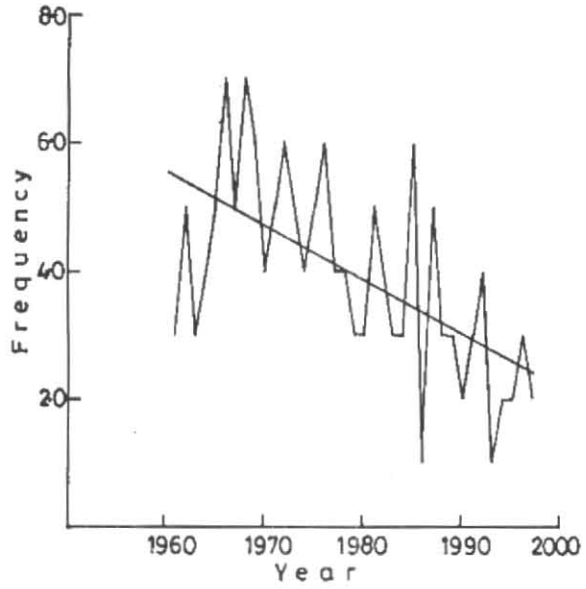


Fig. 1. Trend in cyclonic storms over the Bay of Bengal (1961-97) decreasing linear trend, $Y = -0.0848743\,X + 171.912$

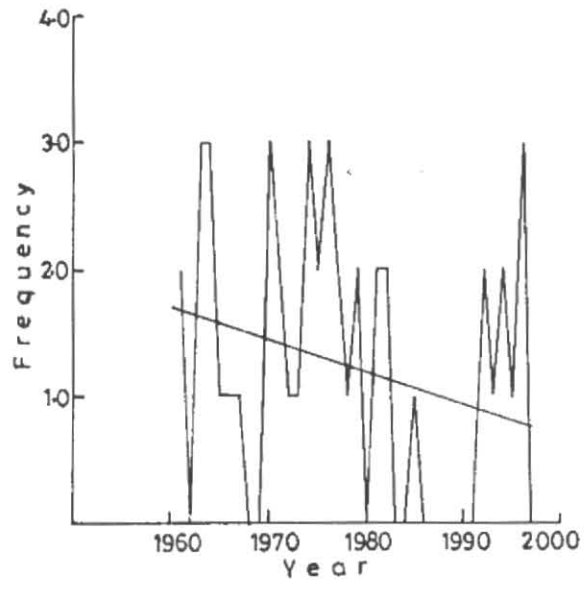


Fig. 2. Trend in cyclonic storms over the Arabian Sea (1961-97) decreasing linear trend, $Y = -0.0256046\,X + 51.8876$

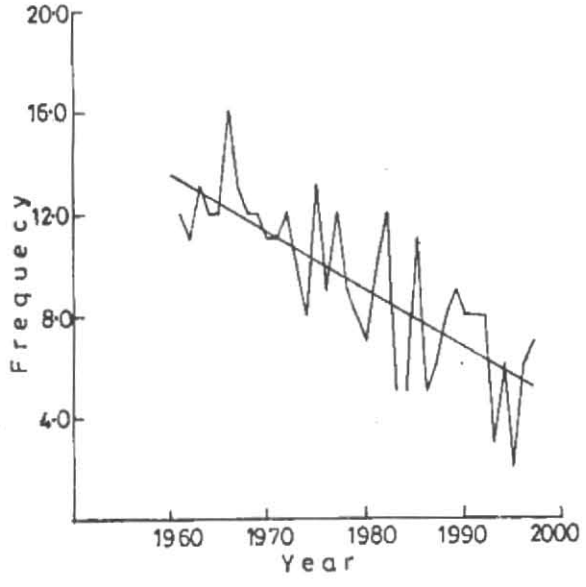


Fig. 3. Trend in total cyclonic disturbances over Bay of Bengal (1961-97) decreasing linear trend, $Y = -0.227359\,X + 459.187$

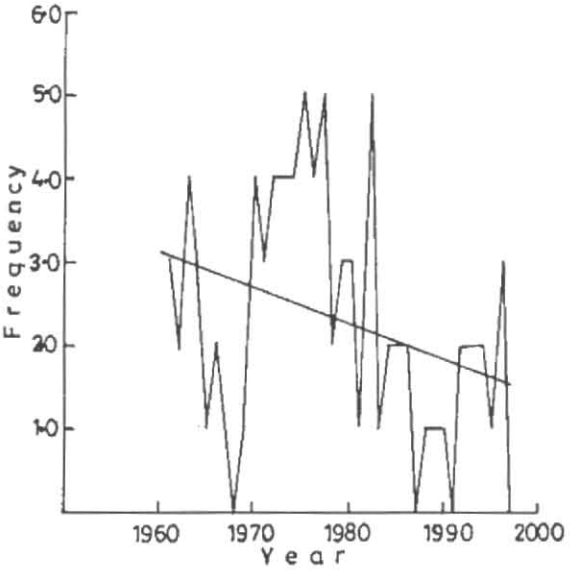


Fig. 4. Trend in total cyclonic disturbances over Arabian Sea (1961-97) decreasing linear trend, $Y = -0.0429113\,X + 87.2188$

period 1961-97, all cyclonic disturbances, cyclonic storms and depressions show decreasing trend significant at 99% level of confidence.

4.2. *Trends over Arabian Sea*

Over Arabian Sea, for the period 1891 to 1925 and 1961 to 1997 all cyclonic disturbances, cyclonic storms and depressions show decreasing trend significant at 99% level of confidence. However, for the period 1926-60 cyclonic storms reflect decreasing trend significant at 99% level of confidence but when all cyclonic disturbances and depressions are considered, they do not show significant decreasing trend which indicates that for the period 1926-60, less number of depressions intensified into cyclonic storms.

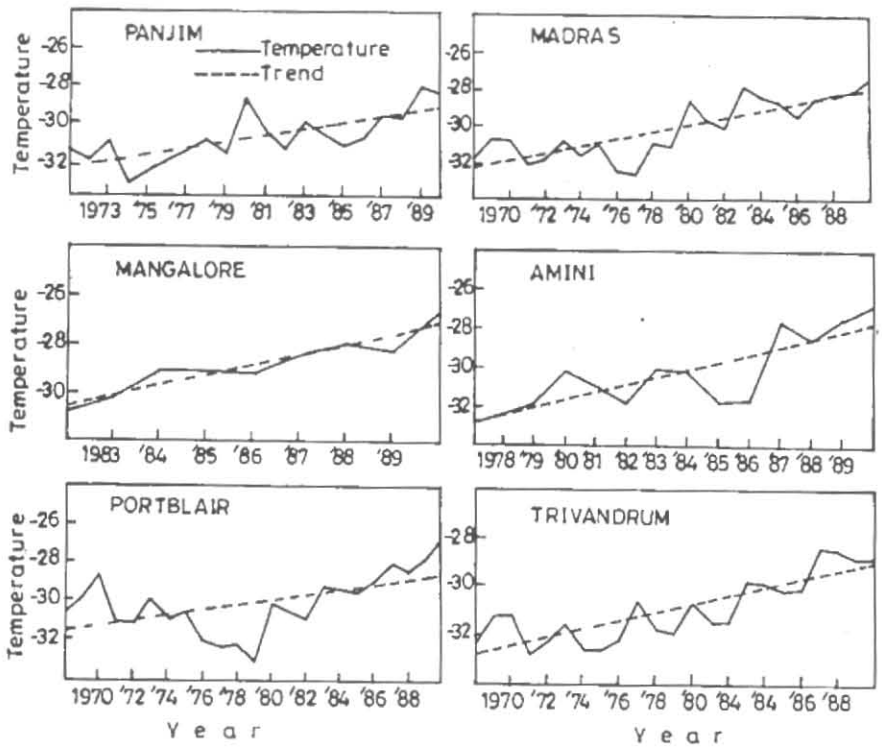


Fig. 5. Trend in annual mean temperature at 300 hPa over different stations of India

4.3. *Trends in recent years over Bay of Bengal and Arabian Sea*

It is also noticed that decrease in the number of cyclonic storms as well as all cyclonic disturbances are more in recent years. Figs. 1 & 2 show the best linear regression line for frequency of cyclonic storms during 1961-97 over Bay of Bengal and Arabian Sea. Figs. 3 & 4 show the regression line for the frequency of total number of disturbances during the same period over Bay of Bengal and Arabian Sea respectively. Rates of decrease in cyclonic storms and total cyclonic disturbances for the period 1961 to 1997 over Bay of Bengal are 0.08/year and 0.23/year respectively and same over Arabian Sea are 0.026/year and 0.043/year. The rate of decreasing trend over Bay of Bengal is more than that over Arabian Sea.

If we look into possible causes of this decreasing trend, it is desirable to see whether there were some changes over years in respect of Sea Surface Temperature (SST), which is one of the favourable parameter for the genesis of cyclonic disturbances. Sinha Ray *et al.* (1998) found that except during monsoon season (where significant increasing trend was observed in SST over some parts of Bay of Bengal), there was no significant trend in SST over Bay of Bengal and Arabian Sea. Lighthill *et al.* (1994) in their study have emphasized that global warming need not increase the frequency and intensity of tropical cyclones.

Bengtsson *et al.* (1995) using GCM model for simulation of hurricane vortices over Atlantic seas found that higher number of storms was normally associated with a more active Hadley circulation. In the above context it is imperative to know that whether Hadley cell is weakening ? The answer is probably yes. Sadourny (1994) has shown that Hadley circulation is weakened in the LMD model in a climate which is either warmed by enhanced insolation or by an increased concentration of greenhouse gases. It is to be mentioned that increase in upper tropospheric temperatures have been reported in several studies like Angell (1986), Sellers and Liu (1988). To confirm the upper tropospheric warming over Indian region, authors have also studied the trend in mean annual temperature at 300 and 200 hPa over different coastal and island stations of India *viz.* Bombay, Calcutta, Panjim, Amini, Port Blair, Madras, Mangalore and Trivandrum. Temperature data of 300 and 200 hPa over above mentioned stations for the period 1968-90 were subjected to Mann-Kendall analysis to see the trend and its significance. It may be mentioned that data prior to the year 1968 was not taken for trend analysis, as Indian radiosonde stations changed over to audio-modulated type

of instruments after 1967 and some authors (Verma, 1980) have reported that upper air temperatures recorded prior to 1968 were 2° to 3° C higher than those of later period. Increasing trend significant at 1% level were found over all stations for both levels except over Bombay and Calcutta which although showed increasing trend but was not found statistically significant. Trend lines at 300 hPa over the stations Madras, Panjim, Trivandrum, Amini, Port Blair and Mangalore are shown in Fig. 5. Further to see the upper tropospheric warming over cyclogenesis area over Indian ocean particularly over Bay of Bengal, the temperature data of 300 hPa level of Singapore and Hong Kong for the period 1961-90, collected from climate data of the world, were also analysed and significant increasing trend at 1% level was found over both the stations. These results are shown in the Fig. 6. Hence, it could be concluded that upper tropospheric temperatures have increased over Indian seas and surrounding areas, which is in conformity with the findings of Angell (1986) and Seller and Liu (1988).

Bengtsson *et al.* (1996), while studying the influence of green house warming using high resolution (T 106) GCM model, found that, at the time when CO_2 concentration in this atmosphere had doubled, the number of storms were significantly reduced. The model shows weakening of Hadley cell, and warming of upper troposphere. Model also shows decrease in evaporation and precipitation, comparatively more over the equatorial belts than over the subtropics. They proposed that due to this subtropical energy deficit weakens and the Hadley circulation must reorganize itself to transport less energy towards subtropics and consequently, it is weakening.

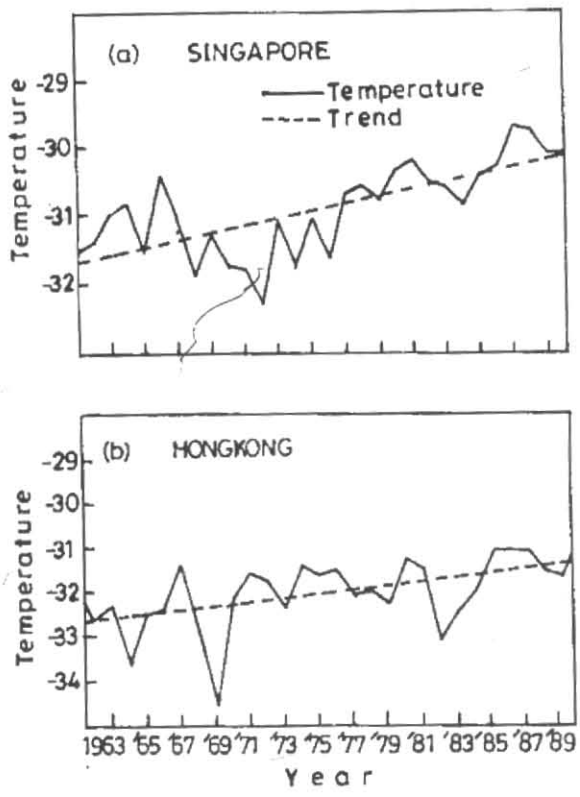
Emanuel (1988) in his succinct theory proposed hurricanes as the mechanisms, driven by a large scale Carnot Cycle, confined by the temperature difference of the ocean surface temperature T_s and tropical upper tropospheric temperature T_0 . According to Carnot's theorem, the total amount of mechanical energy available from closed circuit through the storm system is

$$E = K T_s (S_c - S_a)$$

where $K = \dfrac{T_s - T_0}{T_s}$ is efficiency factor

and S is total entropy per unit mass of air. Subscript 'c' represents the condition in the center of the storm and 'a' inflow region, which could be some thousand kilometers away.

Applying the same theory over Indian seas, it is clearly seen that efficiency of cyclonic disturbances are



Figs. 6(a&b). Trend in mean annual temperature at 300 hPa level over stations (a) Singapore and (b) Hong Kong

decreasing with the rise of upper tropospheric temperature T_0, since increase of T_0 makes numerator of the expression smaller, T_s remaining unchanged. However, data regarding maximum sustained wind speed in cyclones over Indian seas could not be obtained due to lack of observations. The maximum wind obtained by estimation from INSAT satellite pictures could not show any conclusive results since the data is available for very short period.

5. Conclusions

(*i*) There is no significant trend in the numbers of cyclonic disturbances for the whole period 1891-1997, though intense systems (cyclonic storms/severe cyclonic storms) show discernible trend during this period.

(*ii*) The number of cyclonic storms over north Indian seas for the period (1891-1997) show a significant decreasing trend at 99% level of confidence.

(*iii*) The decrease in the occurrence of cyclonic storms is maximum during last four decades.

(*iv*) Rate of decrease in the frequency of cyclonic activity over Bay of Bengal is more compared to that of Arabian Sea.

(*v*) Weakening of Hadley circulation may be one of the causes of decreased cyclonic activity.

(*vi*) Theoretical results indicate a decrease in intensification of cyclonic disturbances making the decreasing trend in cyclonic storms more compared to that of depressions.

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