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Trends and fluctuations of the cyclonic systems over North Indian Ocean

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सार - 1877 से 1998 तक की अवधि के हिन्द महासागर के उत्तर में चक्रवातों की मासिक आवृत्तियों के आँकड़ों का विश्लेषण उनकी दीर्घकालिक प्रवृत्तियों तथा अनियमितताओं का अध्ययन करने के लिए किया गया है। वार्षिक आवृत्तियों के साथ-साथ मानसून वर्षा ऋतु से पूर्व, मानसून वर्षा ऋतु के दौरान एवं उत्तर मानसून वर्षा में बने अवदाबों और चक्रवातों का अलग-अलग विश्लेषण किया गया है। इन आँकड़ों की 11 वर्ष के गतिमान औसतों के साथ जाँच की गई है और इनके बढ़ने एवं घटने की प्रवृत्ति की अवधियों का पता लगाया गया है। 1950 के बाद निरंतर घटती हुई प्रवृत्ति एक उल्लेखनीय विशेषता है।

21 वर्षों से अधिक के काल-खंडों के विलोपन के लिए चक्रवात की मासिक आवृत्ति के काल-खंडों को हाई पास फिल्टर के माध्यम से उपयुक्त बनाया गया है और फिर प्रमुख आवर्तिताओं का पता लगाने के लिए अधिकतम एंट्रापी (ENTROPY) पद्धति के उपयोग से इनका अनुक्रम विश्लेषण किया गया। 2.2 से 2.8; 3.5 से 6.5 और 10 से 15 वर्षों की तीन महत्वपूर्ण आवर्तिताओं का पता लगाया गया है जिन्हें अर्द्धवार्षिक दोलन (क्यू.बी.ओ.) एन्सो और दस वर्षीय आवृत्तियों के रूप में माना जा सकता है।

ABSTRACT. The data of the monthly cyclone frequencies over North Indian Ocean for the period 1877-1998 has been analysed to study the long-term trends and fluctuations. Analysis has been made separately for depressions and cyclones for the pre-monsoon, monsoon and post-monsoon seasons along with the annual frequencies. The data was subjected to 11-year moving averages and the epochs of increasing and decreasing trends have been identified. A consistent decreasing trend after 1950s is a notable feature.

The time series of the monthly cyclone frequency were passed through a high-pass filter to eliminate periods greater than 21 years and then subjected to spectrum analysis using Maximum Entropy Method to obtain dominant periodicities. Three significant periodicities at 2.2-2.8; 3.5-6.5 and 10-15 years have been identified which could be attributed to QBO, ENSO and decadal frequencies.

Key words - Cyclones, Long-term trends, Periodicities.

1. Introduction

Understanding the patterns of the frequency of cyclonic systems over the tropical oceans assumed importance in the scenario of global climate change. In association with an increasing trend in the global temperatures, it is of interest to examine the frequency of cyclonic systems. For the Indian region surrounded by the North Indian Ocean, cyclonic systems provide most of the annual rainfall essential for agriculture and water resources management. The frequencies of depressions (maximum wind speed between 16-33 knots) is more during the summer monsoon season and provide well distributed rainfall for a major part of the country which is useful for agricultural operations. Cyclonic storms (maximum wind speed greater than 33 knots), generally form during the pre and post-monsoon seasons, cause devastation but also provide substantial rainfall to the coastal regions useful for water resources management.

In this background, a study of the trends and variability in the frequency of the cyclonic systems for individual Ocean basins is useful for understanding the various effects of climate change. Recent studies report conflicting results such as that the global warming may not contribute for increase either in frequency or intensity

TABLE 1

Mean and standard deviation (SD) of total cyclonic systems (C. S.), depressions (D) and storms (S)

Region	Category	Pre-monsoon		Monsoon		Post-monsoon		Annual	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Bay of Bengal	C. S.	0.95	0.73	5.43	2.18	3.52	1.54	10.11	2.88
Arabian Sea	C. S.	0.27	0.50	0.39	0.66	0.65	0.81	1.33	1.25
North Indian Ocean	C. S.	1.20	0.85	5.84	2.32	4.17	1.74	11.43	3.27
	D	0.36	0.69	4.11	2.17	1.70	1.38	6.29	3.09
	S	0.84	0.74	1.72	1.37	2.47	1.37	5.15	2.15

of tropical cyclones (Lighthill *et al*., 1994) and that the doubling of carbon dioxide affects to the reduction of cyclonic storms from general circulation model experiments (Bengtsson *et al*., 1996).

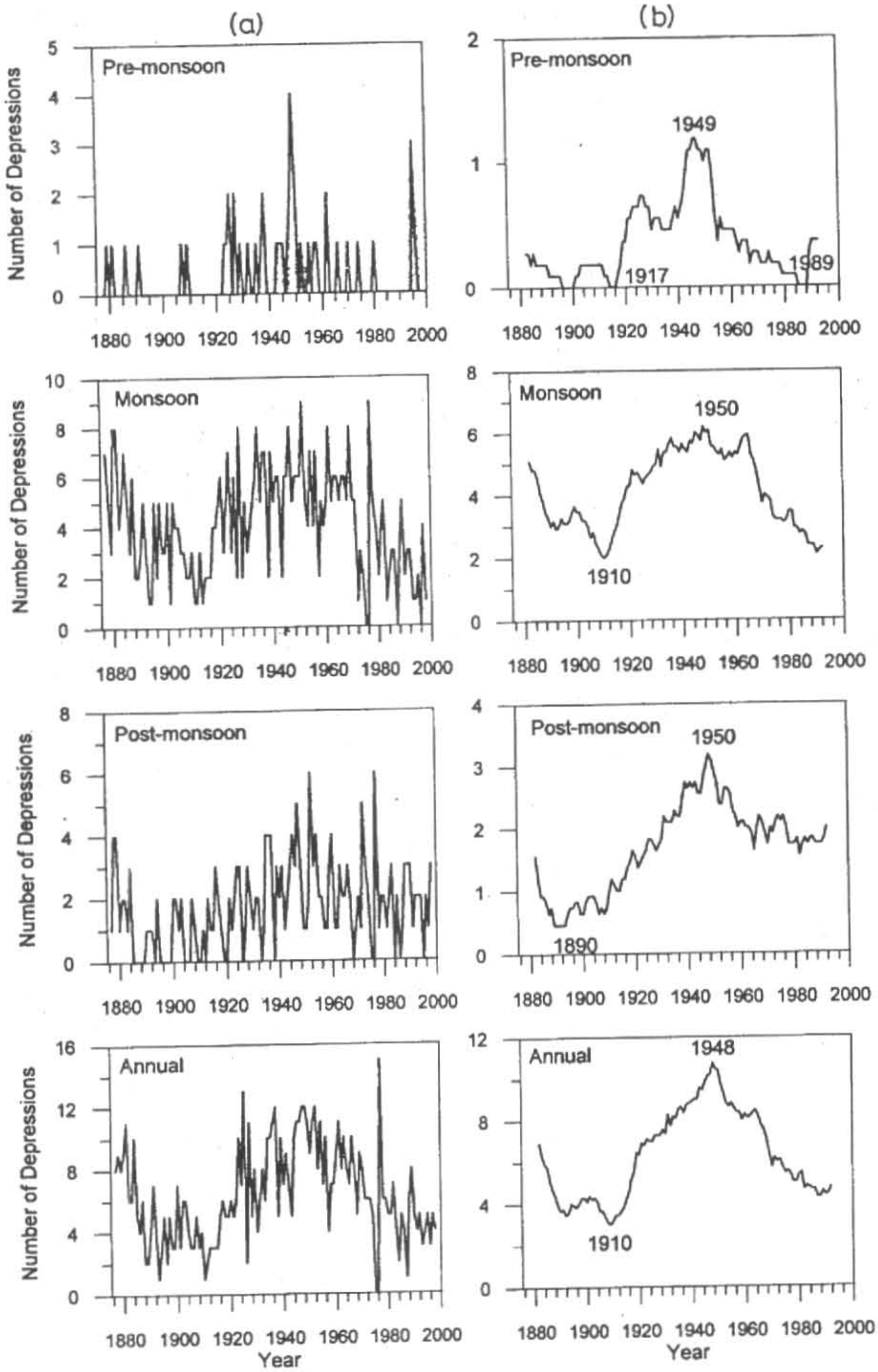
Few attempts have been made to study the fluctuations and trends of the cyclonic systems over North Indian Ocean. Mooley (1981) observed an increase in the mean annual frequency of the severe cyclonic storms over Bay of Bengal after 1964 and attributed this only to the improvements in storm detection. Mooley and Mohile (1983 and 1984) reported an increase in the frequency of the storms crossing the Indian coasts during 1965 and 1980. Of the studies related to other ocean basins, Gray (1990) found that the Atlantic Hurricane activity decreased during 1970-1987 by about 50% compared to the period 1947-1969. Gray (1995) reported decrease in the cyclone frequency over the Australian, Atlantic Oceans and south China Sea and an increase over the north and south central Pacific Ocean during El-Nino years. Studies for the Pacific Ocean indicated decrease in the number of hurricanes affecting the North American coast (Landsea and Gray, 1992 ; Goldenberg and Shapiro, 1996). Limited attempts have been made to study the periodicities of cyclone frequencies. Dominant periodicities at 2.1, 3.0 and 35-40 years for the cyclones over Bay of Bengal for the post-monsoon season were reported by Subbaramayya and Rama Mohana Rao (1984). Shapiro (1982) reported significant periodicities at 2.5 and 4.5 years for the Atlantic hurricanes. Elsner *et al.* (1999) examined the hurricane activity of the North Atlantic basin for the period 1886-1996 and observed dominant oscillations at 2.5 and 5-6 years periods and attributed them to Quasi-Biennial Oscillations (QBO) and ENSO and a near decadal frequency at 7-9 years.

In this study an attempt has been made to analyse the cyclone frequency data available so far for the period 1877-1998 for the North Indian Ocean. The cyclonic systems have been classified into two categories as Depressions (wind speed in between 16-33 knots) and Cyclones (all systems with maximum winds > 33 knots). Systematic analysis has been made to identify long-term trends of the two categories separately for the three seasons *i.e.* Pre-monsoon, monsoon and Post-monsoon seasons along with annual totals. The epochs of increasing and decreasing trends during 1877-1998 have been identified. The dominant periodicities have been estimated through spectrum analysis using Maximum Entropy Method (MEM).

2. Data and method of analysis

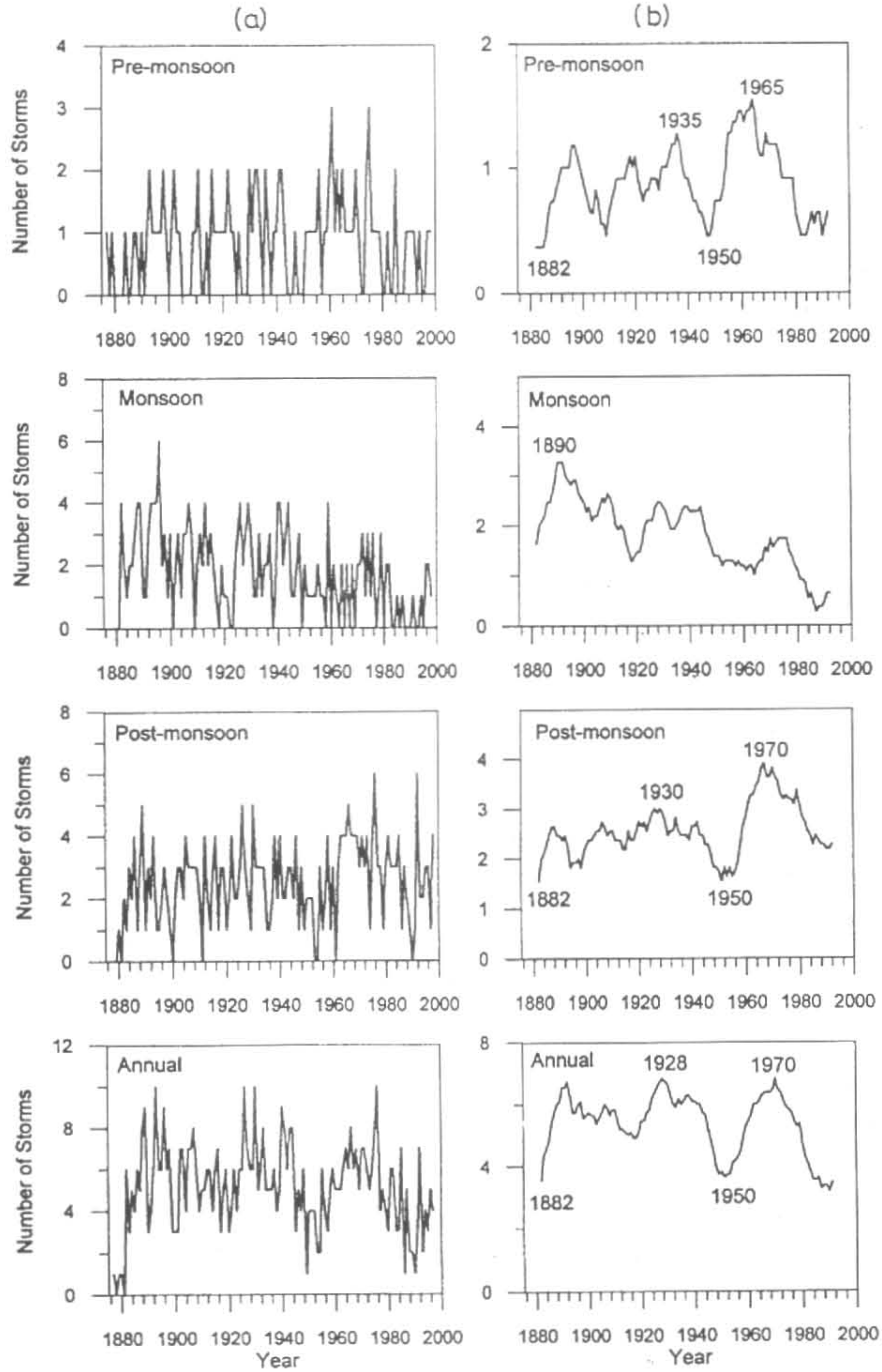
The data related to the number of cyclonic systems for the North Indian Ocean region has been collected for the period of 1877-1998 (122 Years). Data for the period 1877-1970 has been obtained from the published report of the India Meteorological Department (IMD, 1979). Data for 1971-1998 has been collected from the Indian Daily Weather Reports published by the IMD. The cyclonic systems have been classified into two categories (*i*) depressions with maximum wind speed between 16 to 33 knots and (*ii*) cyclones which include all storms with maximum wind speed greater than 33 knots. The occurrences of the number of depressions and cyclones have been categorised for every month during the period 1877-1998.

The data has been analysed for the two different categories and for three different seasons *i.e.* pre-monsoon, monsoon and post-monsoon along with annual frequencies. The total frequencies in the months of April and May are taken for the pre-monsoon; of June, July, August and September for monsoon and October, November and December for Post-monsoon season. The trend during the period 1877-1998 has been fitted using linear regression technique. In order to study the long-



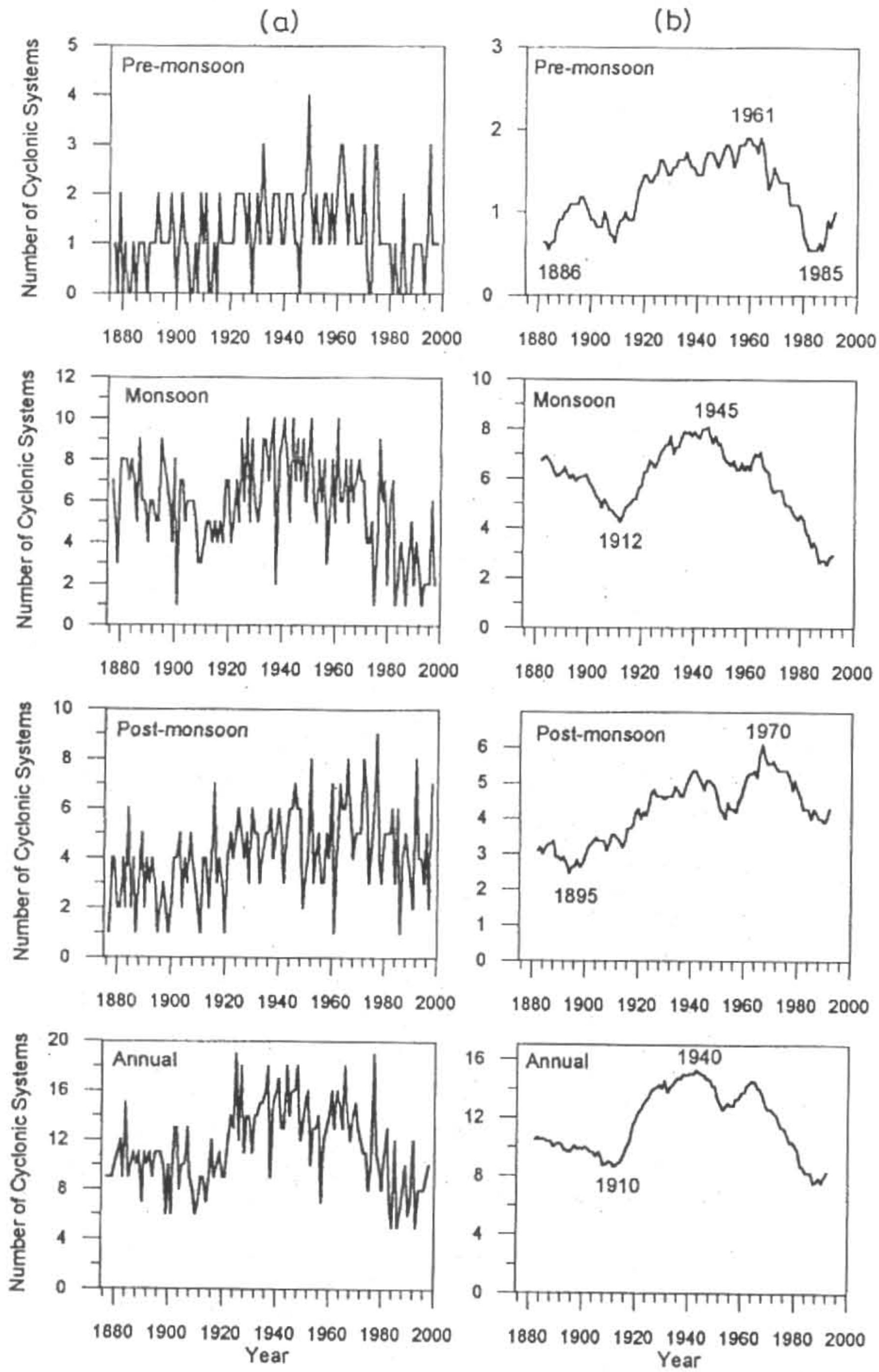
Figs. 1 (a&b). (a) Time Series and (b) 11-Year Moving Averages of Number of Depressions over North Indian Ocean

term trends in the frequencies of cyclonic systems, 11-year moving average analysis has been adopted. This analysis has been carried out to eliminate short-term fluctuations and for better delineation of the long-term trends. The epochs of the long - term fluctuations are identified from the lowest minimum and highest maximum points and the lengths of the trends are estimated.



Figs.2(a&b). (a) Time Series and (b) 11-Year moving averages of number of storms over North Indian Ocean

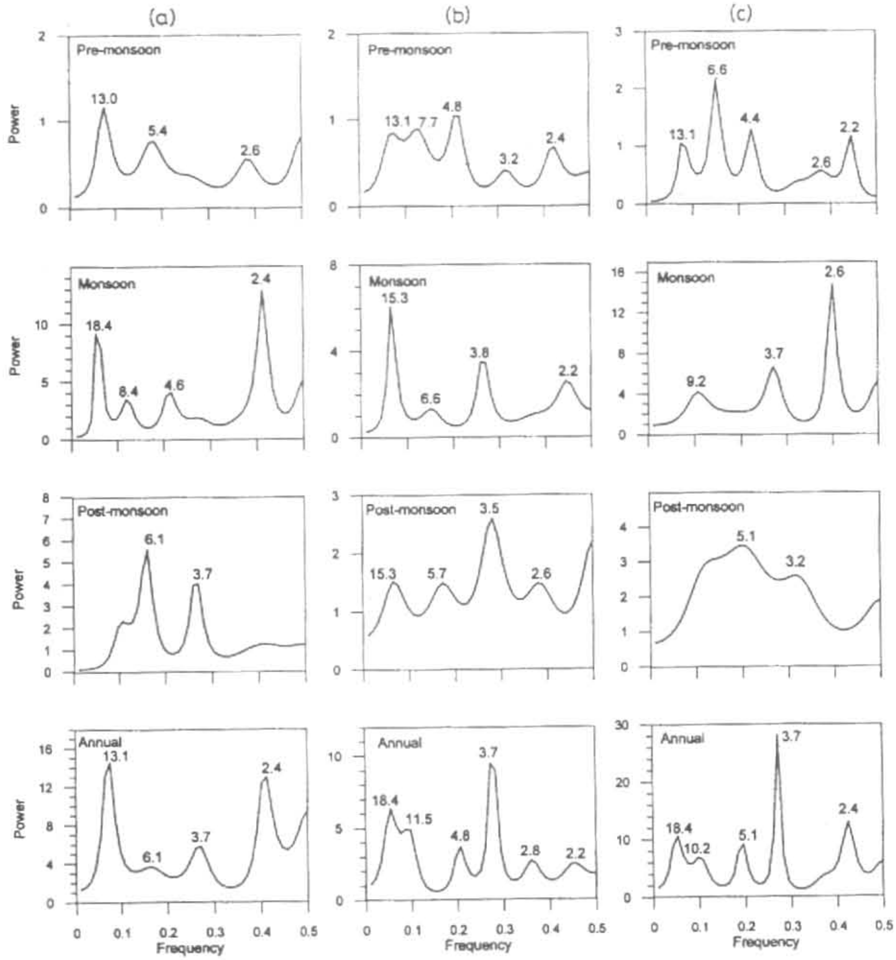
The time series of monthly cyclone frequencies for pre-monsoon, monsoon, post-monsoon and annual have been subjected to high-pass filter to eliminate periods greater than 21 years following the method of Mitchell *et al*. (1966). The filtered time series were then subjected to spectrum analysis using maximum entropy method (Barrodale and Erickson, 1980).



Figs. 3 (a&b). (a) Time Series and (b) 11-Year Moving Averages of Number of Cyclonic Systems over North Indian Ocean

3. Results

The Mean and Standard Deviation (SD) of the cyclonic systems for the three seasons *i.e.* pre, monsoon and post-monsoon seasons along with the annual have been computed for Bay of Bengal and Arabian Sea separately (Table 1). The cyclonic systems in the Arabian Sea constitute a minor component contributing to only 10-20% compared to Bay of Bengal. Correspondingly the SD is higher than the mean indicating high variability



Figs. 4 (a-c). Power Spectra of Number of (a) Depressions, (b) Storms and (c) Cyclonic systems over North Indian Ocean. (The periodicities in years corresponding to the peaks are noted in the Figure)

over the Arabian Sea region. Due to this reason the means and SDs of only total cyclonic systems for Bay of Bengal and Arabian Sea and for the depressions, cyclones and total cyclonic systems for the North Indian Ocean were computed for the annual and three seasons and are presented in Table 1. Though the depressions and storms have nearly the same annual frequency, the depressions are more during the monsoon season while storm frequency is more during the post-monsoon season. The variability of the depressions is more during the pre and post-monsoon seasons while the variability of the storms is low and similar during the three seasons. This analysis indicates that cyclonic systems are more frequent over Bay of Bengal compared to the Arabian Sea and that the depression and storm frequencies are more during monsoon and post-monsoon seasons respectively with low variability.

3.1. *Trends*

An examination of the different time series show the presence of long-term trends, but the epochs of the trend changes cannot be identified due to short-term variations. So the time series were subjected to 11-year moving averages to eliminate short - term fluctuations which facilitate the identification of significant trends. The trends of depressions and storms over North Indian Ocean have been computed for the annual and three different seasons for different epochs of increasing and decreasing trends in the moving average series. The plot of time

TABLE 2

Periodicities of depressions (D), storms (S) and total syclonic systems (C. S.) over north Indian ocean

Season	Category	Periodicity in years										
	D	2.6			5.4						13.0	
Pre-monsoon	S	2.4	3.2	4.8			7.7				13.1	
	C. S.	2.2, 2.6		4.4		6.6					13.1	
	D	2.4		4.6				8.4				18.4
	S	2.2	3.8			6.6						15.3
Monsoon	C. S.	2.6	3.7						9.2			
	D		3.7			6.1						
	S	2.6	3.5		5.7							15.3
Post-monsoon	C. S.		3.2		5.1							
	D	2.4	3.7			6.1					13.1	
	S	2.2, 2.8	3.7	4.8						11.5		18.4
Annual	C. S.	2.4	3.7		5.1					10.2		18.4

series for the depressions and associated 11-year moving average series are presented in Fig.1. The depressions during the pre-monsoon season *i.e.* during April and May have a low mean value with 0.36 and with a negligible trend of 0.002 depressions/year. The moving averages show increasing trends and decreasing trends during 1917-1949 and 1949-1989 respectively. During the monsoon season the depressions have a mean of 4.11 and a very low decreasing trend of –0.006 depressions/year could be noted. The corresponding 11-year moving average series show clear and distinct trends with decreasing trend up to 1910 and increasing trend during 1910-1950 and again decreasing trend there after. The depressions during the post-monsoon season have a mean value of 1.70 and show an increasing trend of 0.010 depressions/year. The corresponding moving average series indicate decreasing trend up to 1890 and then an increasing trend up to 1950 followed by decreasing trend there after. The annual time series have a mean value of 6.29 and show a small increasing trend of 0.007 depressions/year. The associated moving average series show decreasing trend up to 1910 followed by increasing trend during 1910-1948 and then decreasing trend from 1948 onwards.

This analysis indicates that the depressions had a decreasing trend during the earlier part up to about 1910 and then an increasing trend from 1910 onwards till around 1950 followed by a continuous decreasing trend from 1950. This is interesting as very long-term trends are indicated with near centennial variations.

The time series and associated 11-year moving averages for the storms during the three seasons and annual are presented in Fig. 2. The storms during the pre-monsoon season have mean of 0.84 and show a small increasing trend of 0.002 storms/year. The associated mov- ing averages show increasing trends between 1882-1935 and 1950-1965 and decreasing trends during 1935-1950 and from 1965 onwards. The storms during monsoon season have a mean of 1.72 and show a decreasing trend of 0.012 storms/year. The associated moving averages show increasing trend up to 1890 followed by long decreasing trend from 1890 continuing till now. The storms during the post-monsoon season have a mean of 2.47 and show a small increasing trend of 0.009 storms/year. The corresponding moving averages show increasing trends during 1882-1930 and 1950-1970 and decreasing trends during 1930-1950 and from 1970 onwards. The annual mean of the storms has a value of 5.15 and show negligible negative trend with the value of 0.002 storms/year. The corresponding moving averages show two increasing trends during the period of 1882-1928 and 1950-1970 and two decreasing trends during 1928-1950 and from 1970 onwards.

The above analysis indicate that the storms have increasing trends during 1880-1930 and 1950-1970, while decreasing trends could be observed during 1930-1950 and from 1970 onwards. In contrast, the storms have shorter duration of 20-30 years for increasing and decreasing trends compared to those of depressions.

Similar analysis for North Indian Ocean cyclonic systems (all systems with strength of depression and more) has been performed and the results are presented in Fig. 3. The time series has a mean value of 1.20 and show small increasing trend of 0.003 cyclones/year. During the pre-monsoon season the number of cyclonic systems is less compared to the other two seasons. The 11-year moving averages show increasing trend up to 1961 followed by a decreasing trend up to 1985 and indication of increasing trend after 1985 could be noted. For the monsoon season the cyclonic systems have a mean of 5.84 and show decreasing trend of 0.018 cyclones/year. The associated 11-year moving averages show a decreasing trend up to 1912 followed by increasing trend till 1945. Subsequent to this, a decreasing trend is present till 1990.

During post-monsoon season the total cyclonic systems have a mean of 4.17 and show an increasing trend of 0.019 cyclones/year. The corresponding moving average series show an increasing trend from 1895-1970 followed by a decreasing trend after 1970. The time series for annual has a mean value of 11.43 and shows a small increasing trend of 0.005 cyclones/year. The moving average series for the annual total show increasing trend from 1910 till 1940 and decreasing trend there after. In summary it may be concluded that there is an increasing trend from 1900 to the middle of the century followed by a decreasing trend.

3.2. *Periodicities*

The time series have been passed through a high-pass filter to filter out the periods greater than 21 years. The filtered time series were then subjected to spectrum analysis using Maximum Entropy Method (MEM) to identify the important periodicities. Separate analyses have been performed for the annual and the pre-monsoon, monsoon and post-monsoon seasons and for two categories *i.e.* depressions, storms and all cyclonic systems. The peaks have been noted in the order showing their relative intensity such that the first noted periodicity has the maximum power spectral density [Figs. 4 (a-c)].

The depressions during the pre-monsoon season show peaks at 13.0, 5.4 and 2.6 years. During the monsoon season strong peaks at 2.4 and 18.4 years have been noted along with peaks at 4.6 and 8.4 years. During the post monsoon season only two peaks were noted corresponding to 6.1 and 3.7 years. For the annual totals three prominent pea s at 13.1, 2.4 and 3.7 years are present along with a weak signal at 6.1 years.

In the case of pre-monsoon storms, peaks were observed at 4.8, 7.7, 13.1, 2.4 and 3.2 years. The monsoon storms show peaks at 15.3, 3.8 and 2.2 followed by a weak peak at 6.6 years. The post monsoon storms have peaks at 3.5, 15.3, 5.7 and 2.6 years. The annual totals have a strong peak at 3.7 years followed by 18.4, 11.5, 4.8, 2.8 and 2.2 years.

Considering the total cyclonic systems during the pre-monsoon season, peaks were noted at 6.6, 4.4, 2.2, 13.1 and 2.6 years. During the monsoon season, peaks at 2.6, 3.7 and 9.2 years could be noted. During the post-monsoon season, only two peaks at 5.1 and 3.2 years are observed. For the annual cyclonic systems, peaks at 3.7, 2.4, 18.4 and 5.1 years along with a weak signal at 10.2 years are noted.

The periodicities noted for the categories of depressions and storms and the total for the three different seasons and the annual are presented in Table 2.

From the above observations three significant periodicities have been found at 2.2-2.8 years, 3.5-6.5 years and 10-15 years which could be attributed to the quasi-biennial oscillation, ENSO phenomenon and decadal variations.

4. Summary and conclusions

The data for all the cyclonic systems which are classified as depressions and cyclones for the period 1877-1998 has been analysed to study the long-term trends and periodicities for the annual totals and for the pre-monsoon, monsoon and post-monsoon seasons. The frequent occurrence of depressions during monsoon season and cyclones during the pre and post-monsoon seasons has been the consideration for classification into two categories as depressions and cyclones. The time series have been subjected to 11-year moving averages to eliminate short-term fluctuations and to facilitate delineation of increasing and decreasing trends. The following conclusions could be drawn from the above analysis:

(a) The depressions (maximum wind speed between 16-33 knots) corresponding to the annual as well as the pre-monsoon, monsoon and post-monsoon seasons show three consistent trends which are a decreasing trend up to 1910 followed by an increasing trend up to 1950s and then a decreasing trend from 1950s till the present time. This indicates a long decreasing trend from 1950s continuing till now.

(b) The trends of the cyclones (all systems with maximum wind > 33 knots) show an increasing trend till 1930s followed by a decreasing trend up to 1950 and then an increasing trend up to

1970 and a decreasing trend there after. This observation indicates that there was an increasing trend after middle of this century for about 20 years and decreasing trend there after.

(c) Considering all the cyclonic systems two significant trends have been observed *i.e.* an increasing trend till the middle of this century followed by a decreasing trend.

The above results indicate that the decreasing trend after the middle of this century is consistent both in the depressions as well as the total cyclonic systems. However the storms also show decreasing trend after 1970s which was preceded by an increasing trend of 20 years. This clearly indicates a decreasing tendency in all cyclonic systems after 1970s which may be coinciding with the observation of global warming and climate change during the last three decades. This result may support the model result of Bengtsson *et al.*(1996), that doubling of CO_2 reduces the number of cyclonic storms. However, it may not be concluded that this decrease is due to global warming because of the observation of decreasing trends before 1950s and the trend for the total period 1877-1998 is negligible. Further studies should be conducted to establish any possible links of the global warming to the decrease of cyclone frequency.

The analysis of the identification of dominant periodicities yielded interesting results. The periodicities at 2.2-2.8; 3.5-6.5 and 10-15 years have been consistently observed in both depressions and cyclones in all the three seasons. Peaks at periodicities above 15 years have been ignored because of the cut-off frequency of the high-pass filter used in this analysis to eliminate periods higher than 21 years. The periodicity of 2.2-2.8 years can easily be attributed to the observed quasi-biennial oscillation as reported in previous studies (Shapiro, 1982, Subbaramayya and Rama Mohana Rao, 1984, Elsner *et al.*, 1999). The fluctuations with 3.5-6.5 years may be consequences of ENSO (Trenberth, 1976 and Elsner *et al.*, 1999). and the signal at 10-15 years may be due to decadal oscillation (Elsner *et al.*, 1999).

The above results indicate that the observed QBO and ENSO phenomenon have a clear reflection in the cyclone frequencies over North Indian Ocean. It might be interesting to explore the periodicities of the sea surface temperatures and upper tropospheric parameters like wind and temperatures to further understand their association. The mean decadal oscillation may be an indication of its association with 11-year Sunspot activity (Elsner *et al.* 1999).

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