Trends and fluctuations of the cyclonic systems over North Indian Ocean

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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)

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

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 1866-1996 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-
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.
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.
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 cyclonic systems (C. S.) over north Indian ocean

<table>
<thead>
<tr>
<th>Season</th>
<th>Category</th>
<th>Periodicity in years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-monsoon</td>
<td>D</td>
<td>2.6</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>2.4</td>
</tr>
<tr>
<td></td>
<td>C. S.</td>
<td>2.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monsoon</td>
<td>D</td>
<td>2.4</td>
</tr>
<tr>
<td></td>
<td>C. S.</td>
<td>2.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post-monsoon</td>
<td>D</td>
<td>2.4</td>
</tr>
<tr>
<td></td>
<td>C. S.</td>
<td>2.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual</td>
<td>C. S.</td>
<td>2.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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 moving 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 peaks 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 CO₂ 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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References

Bengtsson, L., Botzet, M. and Esch, M., 1996, “Will green house gas induced warming over the next 50 years lead to higher frequency and greater intensity of hurricanes?”, Tellus, 48A, 57-73.


India Meteorological Department, 1979, “Tracks of Storms and Depressions in the Bay of Bengal and Arabian Sea 1877-1970”, India Meteorological Department, New Delhi, 186 p.


Mooley, D. A. and Mohile, C. M., 1983, “A study of the cyclonic storm incident on the different sections on the coast around Bay of Bengal”, *Mausam*, 34, 2, 139-152.


