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STATISTICS OF CYCLONIC DISTURBANCES IN THE NORTH INDIAN OCEAN

1. Tropical cyclonic disturbances are synoptic scale systems both weak and strong convective type *viz*., lows, depressions, cyclonic storms or cyclonic storms of higher intensity which generally develop over the north Indian Oceanic regions with a few developing over the interior land areas. Individual disturbances differ from one another in respect of point of formation, structure, intensity, movement, point of re-curvature and point of landfall with temporal variations on monthly, seasonal and annual time scales. Many studies were taken up in the past to understand their characteristics and also to predict their formation and movement. Bhalme (1972) studied cyclonic disturbances for trends and quasi-biennial oscillations and Murakami (1978) with the help of spectral analysis, studied monsoon lows, Mondal (1991) suggested slight

TABLE 1

Statistics of total cyclonic disturbances formed during the period 1891 - 1990 over the region 5° N-35° N / 50° E-100° E

Decade(s)	Winter		Pre-monsoon		Southwest Monsoon		Post-monsoon		Annual	
	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.
1901-1930	0.3	0.5	1.6	0.9	10.0	2.3	5.1	1.2	17.0	2.4
1931-1960	0.3	0.5	1.7	0.7	8.8	2.3	5.1	1.5	15.9	2.9
1961-1990	0.2	0.5	1.4	1.0	6.9	2.2	5.3	1.7	13.8	3.5
1891-1900	0.0	0.0	1.2	0.2	11.5	1.6	3.7	1.0	16.4	1.9
1901-1910	0.1	0.3	1.5	0.5	10.7	2.0	4.6	1.2	16.9	2.5
1911-1920	0.2	0.4	1.1	0.8	8.7	1.9	5.4	1.5	15.4	1.4
1921-1930	0.5	0.7	2.3	1.0	10.5	2.5	5.4	0.7	18.7	2.0
1931-1940	0.2	0.4	1.7	0.4	9.2	2.4	5.6	1.2	16.7	2.5
1941-1950	0.5	0.7	1.9	0.8	9.9	1.7	5.0	1.5	17.3	2.2
1951-1960	0.2	0.2	1.5	0.5	7.3	2.1	4.6	1.6	13.6	2.4
1961-1970	0.4	0.7	1.9	0.8	7.6	1.9	5.4	1.7	15.3	1.8
1971-1980	0.1	0.3	1.5	0.8	7.8	1.7	5.8	0.8	15.2	2.7
1981-1990	0.2	0.2	0.7	0.9	5.2	2.0	4.8	0.8	10.9	3.8

TABLE 2

Statistics of cyclonic storms or storms of higher intensity (percentage intensification in annual figures) formed during the period 1891 - 1990 over the region 5° N - 35° N / 50° E - 100° E

Decade(s)	Winter		Pre-monsoon		Southwest Monsoon		Post-monsoon		Annual	
	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.	Mean	Std.
1901-1930	0.1	0.3	1.2	0.8	2.1	1.3	2.6	1.0	5.9	1.8
1931-1960	0.1	0.3	0.9	0.8	1.8	1.3	2.3	1.1	5.1	1.9
1961-1990	0.0	0.1	1.1	0.9	1.2	1.0	3.1	1.4	5.4	1.9
1891-1900	0.0	0.0	1.0	0.5	3.0	1.4	1.9	1.1	5.8(35.4)	2.1
1901-1910	0.1	0.3	0.8	0.7	2.2	1.4	2.7	0.5	5.8(34.3)	1.7
1911-1920	0.1	0.3	0.9	0.5	1.9	0.9	2.3	1.2	5.2(33.8)	1.5
1921-1930	0.1	0.3	1.6	0.9	2.1	1.4	2.9	1.1	6.7(35.8)	2.0
1931-1940	0.1	0.3	1.1	1.0	2.1	1.2	2.7	1.0	6.1(36.5)	1.5
1941-1950	0.2	0.2	0.4	0.7	2.2	1.2	2.4	0.9	5.1(29.5)	2.1
1951-1960	0.0	0.0	1.0	0.5	1.2	1.1	1.9	1.1	4.1(30.2)	1.4
1961-1970	0.1	0.3	1.5	0.8	1.2	0.9	3.5	1.4	6.3(41.2)	0.9
1971-1980	0.0	0.0	1.2	0.9	1.8	1.0	3.2	1.4	6.2(40.8)	1.8
1981-1990	0.0	0.0	0.6	0.8	0.5	0.7	2.6	1.1	3.8(34.9)	1.8

increase in tropical disturbances over north Indian Ocean region during westerly phase of Quasi Biennial Oscillation (QBO) which is statistically insignificant. Gray (1993) showed that tropical cyclonic frequency increased over north and south central Pacific and decreased over Atlantic.

Ever since the QBO in the lower stratospheric zonal winds was reported by Reed *et al.* (1961), many studies were conducted in search of quasi-biennial nature in meteorological parameters. In this present study, an attempt has been made to determine periodic or quasi-periodic nature in the total number of cyclonic

TABLE 3

Number of cyclonic disturbances (Season-wise) which formed over the region 5°N-35°N/50°E-100°E during the period 1891-1990

Total number of cyclonic disturbances	: 1564	Mean : 15.64	Standard deviation: 3.15	
Total number of cyclonic storms or storms of higher intensity	: 551	Mean : 5.51	Standard deviation: 1.92	
	Winter	Pre-monsoon	Southwest Monsoon	Post-monsoon
Total cyclonic disturbances	24	153	884	503
Cyclonic storms or storms of higher intensity	7	101	182	261
Percentage of the total cyclonic disturbances	1.5	9.8	56.5	32.2
Percentage of the cyclonic disturbances which reached cyclonic storm stage	29.2	66.0	20.6	51.9

TABLE 3(a)

Number of cyclonic disturbances (Season-wise) which formed over Bay of Bengal during the period 1891-1990

Total number of cyclonic disturbances	: 1212	Mean : 12.12		
Total number of cyclonic storms or storms of higher intensity	: 445	Mean : 4.45		
	Winter	Pre-monsoon	Southwest monsoon	Post-monsoon
Total cyclonic disturbances	23	116	662	411
Total cyclonic storms or storms of higher intensity	7	75	148	215
Percentage of the cyclonic disturbances	1.9	9.6	54.6	33.9
Percentage of the cyclonic disturbances which reached storm stage	30.4	64.7	22.4	52.3

disturbances and also in the systems with intensity of cyclonic storms or storms of higher intensity both in annual and in each of the four seasons.

2. Data on cyclogenesis in NIO (BOB & Arabian Sea) from 1891-1990 (100 years) has been collected from the two publications of India Meteorological Department entitled "Tracks of Cyclones and Depressions in Bay of Bengal and Arabian Sea", publications 1979, 1996. All figures mentioned, in Tables and text, have been worked out from these two publications.

3.1. *Statistics of cyclonic disturbances in each 30 years period* - (*i*) In annual total cyclonic disturbances and cyclonic storms or storms of higher intensity, it is seen that in each of the 30 years periods from 1901-90, the first period 1901-30 witnessed a mean cyclonic disturbances (cyclonic storms or storms of higher intensity) of 17.0 (5.9), for the period 1931-60 the figures are 15.9 (5.1) and for the next 30 years period 1961-90 the figures are 13.8 (5.4). The figures show a slight decrease in the formation of cyclonic disturbances and also cyclonic storms or storms of higher intensity during the 90 years period from 1901-90 (Tables 1 & 2). (*ii*) In seasonal total cyclonic disturbances and cyclonic storms or storms of higher intensity, it is also seen that on seasonal basis, there is slight decrease in total number of cyclonic disturbances and cyclonic storms or storms of higher intensity in winter, pre-monsoon, monsoon seasons from 1901-30 to 1961-90. However, there is slight increase in both total number of cyclonic disturbances and cyclonic storms or storms of higher intensity from 1901-30 to 1961-90 in the post monsoon season (Tables 1 & 2).

3.2. *Statistics of cyclonic disturbances decade- wise*- (*i*) In annual cyclonic disturbances and cyclonic storms or storms of higher intensity, on decadal scale, the decade 1921-30 witnessed highest number of cyclonic disturbances 187 with a mean of 18.7 per year as well as highest number of cyclonic storms or storms of higher

TABLE 4

Number of occurrences of cyclonic disturbances (month-wise) over the region 5°N-35°N/50°E-100°E during the period 1891-1990

Month	Number of years cyclonic disturbances occurred with highest and year		Number of years cyclonic disturbances did not form	Number of occasions one or more occurred					
				1	2	3	4	5	6
January	19	2 (1923)	81	18	1	-	-	-	-
February	04	1	96	04	-	-	-	-	-
March	05	1	95	05	-	-	-	-	-
April	33	2 (1922, 1937,1942,1947)	67	29	4	-	-	-	-
May	71	4 (1947)	29	40	24	6	-	-	-
June	89	6 (1899), 5 (1917)	11	31	33	18	5	1	1
July	87	5 (1904,1927, 1929, 1943, 1944)	13	20	26	23	13	5	-
August	96	6 (1898)	04	19	30	25	15	6	1
September	96	5 (1891, 1905, 1926)	04	18	37	25	13	3	-
October	99	5 (1931, 1948, 1963)	01	20	43	23	10	3	-
November	90	5 (1960, 1977)	10	27	36	22	3	2	-
December	64	3 (1923,1931, 1964, 1972, 1973)	36	46	13	5	-	-	-

intensity 67 with a mean of 6.7 per year. The decade 1981-90 witnessed the lowest number 109 with a mean of 10.9 per year and 38 cyclonic storms or storms of higher intensity with a mean of 3.8 per year. In the decades 1961-70 and 1971-80 the intensification percentages are 41.2 & 40.8 respectively and are more than the average 35.2 (36.7 percent in Bay of Bengal) of the total number of cyclonic disturbances that formed over the area of study intensified into cyclonic storms or into more intense systems. Similarly, in the decades 1941-50 and 1951-60 the percentage intensification are 29.5, 30.2 respectively which are less than the average mentioned above (Tables 1 & 2). (*ii*) In case of seasonal cyclonic disturbances and cyclonic storms or severe intensity, season-wise study showed that highest number 2.3 (1.6) of cyclonic disturbances (cyclonic storms or storms of higher intensity) occurred in the decade 1921-30 & lowest number 0.7 (0.6) of cyclonic disturbances(cyclonic storms or storms of higher intensity) in the decade 1981-90 in pre-monsoon and highest number 11.5 (3.0) of cyclonic disturbances (cyclonic storms or storms of higher intensity) occurred in the decade 1891-1900 & lowest number 5.2 (0.5) of total cyclonic disturbances (cyclonic storms or more intense storms) in the decade 1981-90 in southwest monsoon season. In post monsoon highest number (5.8) of total cyclonic disturbances occurred in the decade 1971-80 & lowest number (3.7) in the decade 1891-1900 and highest number (3.5) of cyclonic storms or storms of higher intensity occurred in the decade 1961-70 & lowest number (1.9) in the decades 1891-1900 & 1951-60.

3.3. *Statistics of cyclonic disturbances on annual time scale* - **S**tudy for the period 1891-1990 (100 years) shown that the long period average is 15.64 with a standard deviation of 3.15 for total number of cyclonic disturbances. The long period average is 5.51 with a standard deviation of 1.92 for cyclonic storms or more intense systems. Of these 1564 total cyclonic disturbances over the region 5° N - 35° N / 50° E - 100° E, 77.49 percent (1212) alone formed over the Bay of Bengal (Tables 3 & 3a). In 100 years of data, 55 years recorded number of cyclonic disturbances above the long period average and 45 years recorded below the long period average. The highest number of cyclonic disturbances occurred in the year 1927 with the number being 23. The year 1984 is the least with only 7 cyclonic disturbances. For cyclonic storms or storms of higher intensity, the years 1893, 1926, 1930, 1976 are the highest with 10 and 1949, 1986 are lowest with only one.

3.4. *Statistics of cyclonic disturbances on seasonal time scale* - (*i*) In winter, in 100 years, a total of 24 (7) cyclonic disturbances (cyclonic storms or storms of higher intensity) occurred in 21 (7) years. Of these years 1923, 1947, 1961 had highest number of 2 cyclonic disturbances. The individual monthly occurrences and probabilities of occurrence of cyclonic disturbances are presented because it is seen that Poisson's distribution fits well to monthly cyclonic disturbances (Tables 4 & 5). (*ii*) In pre-monsoon, in 100 years, a total of 153 (101) cyclonic disturbances (cyclonic storms or storms of higher intensity) occurred in 91 (73) years. Of these years 1925,

TABLE 5

Probability of occurrence of one or more cyclonic disturbances (CD) based on Poisson's distribution (month-wise)

No. of CD	Months											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	16.4	3.8	4.7	25.6	36.6	29.5	24.6	20.5	22.5	23.1	29.0	36.5
2	0.0	0.0	0.0	4.7	20.3	26.8	26.8	25.7	26.4	26.5	26.9	15.9
3	0.0	0.0	0.0	0.0	7.5	16.3	19.5	21.4	10.3	46.8	31.1	4.6
4	0.0	0.0	0.0	0.0	0.0	7.4	10.3	13.4	12.0	26.9	14.4	0.0
5	0.0	0.0	0.0	0.0	0.0	0.0	4.6	6.7	5.6	12.4	2.9	0.0

1927 and 1949 had highest number of 4 cyclonic disturbances and highest number of 3 cyclonic storms or storms of higher intensity in the years 1925, 1933, 1961 & 1974. The individual monthly occurrences and probabilities of occurrence of cyclonic disturbances are presented because it is seen that Poisson's distribution fits well to monthly cyclonic disturbances (Tables 4 & 5). (*iii*) In southwest monsoon**,** in 100 years, a total of 884 cyclonic disturbances in all the 100 years. The year 1899 witnessed highest number of 15 cyclonic disturbances and the years 1984, 1990 witnessed lowest number of 3 cyclonic disturbances. Of all the 100 years, a total of 182 cyclonic storms or storms of higher intensity occurred in 81 years. The year 1896 had highest number of 6 cyclonic storms or severe intensity. The individual monthly occurrences and probabilities of occurrence of cyclonic disturbances are presented because it is seen that Poisson's distribution fits well to monthly cyclonic disturbances (Tables 4 & 5). (*iv*) In post-monsoon, in all the 100 years, a total of 503 cyclonic disturbances occurred and in all the 100 years with highest number of 8 cyclonic disturbances in the years 1931, 1952, 1963, 1966, 1972, 1982. In only 97 years, of all 100 years, a total of 261 cyclonic storms or storms of higher intensity occurred. In 1900, 1953, 1961 no cyclonic storms or storms of higher intensity had occurred. The individual monthly occurrences and probabilities of occurrence of cyclonic disturbances are presented because it is seen Poisson's distribution fits well to monthly cyclonic disturbances (Tables 4 & 5).

4. *Low frequency mode in cyclogenesis* **-** To visualize the probable presence of quasi-biennial low latitude stratospheric characteristics and the low frequency modes of ENSO periods of 2 to 5 years in the time series of total cyclonic disturbances both on annual and seasonal time scales and also for cyclonic disturbances which reached the stage of cyclonic storms or more intensity, correlation analysis, Fourier analysis and spectral analysis were used. In total, two annual time series of 100 data points and 8 season-wise time series, 100 values each, were subjected to above methods of analysis. The study, in this paper, mainly confined to identification of periodicities of 2 years or more in the said time series. Well known mathematical relation was employed to estimate the lag-correlations in the time series. To identify periodicities, the following expression was used $f(t) = a_o + a_i \sin(2\pi it/P) + b_i \cos(2\pi it/P)$ and the significance of amplitudes estimated was tested against appropriate priori confidence level. Further, the individual 10 time series subjected to more rigorous spectral analysis, in order to decipher the hidden periodicities.

5.1. Angell and Korshover (1983) studied the seasonal and annual changes of global tropospheric temperatures. Angell (1990) studied the El-Nino association with the tropospheric temperature. Kane and Buriti (1997) analyzed temperature at five different levels in atmosphere and in seven different climatic zones and found that the temperature variations near equator resemble equatorial stratospheric winds in stratosphere and at the tropopause. They also reported that the temperature variations near equator at the surface and in troposphere are similar to equatorial eastern sea surface temperature which is an intrinsic part of the ENSO phenomenon. Emanuel (1988) proposed that difference of temperature between sea surface and tropical upper air tropospheric temperature plays an important role in development mechanisms of Hurricanes. Studies by others suggest the weakening of Hadley cell with the warming of upper troposphere or cooling of sea surface temperature. The Indian seas exhibit bi-modal characteristic in respect of sea surface temperature with one maxima occurring in the month of May and another in the month of November. Model studies based on Emanuel (1991) convective parameterization scheme indicated increase in intensity of model cyclone with the increase in sea surface temperature. Hence, it can be concluded that the warmer sea surface temperature and conditional instability of second kind (CISK) mechanisms may be

TABLE 6

Season-wise significant auto-correlations, Fourier amplitudes and periodicities in cyclonic disturbances and cyclonic storms or storms of higher intensity

Season	Total cyclonic disturbances			Total cyclonic storms or storms of higher intensity		
	Accs	Amp.	Periodicities	Accs	Amp.	Periodicities
Winter	37, 38	-	2.32, 1.88	28, 38	-	1.51, 1.44, 1.07
Pre monsoon	-	-	-	25, 35, 37, 38	-	1.33
Monsoon	1 to 7 & 14, 31	-	1.12, 1.04	1 to 3, 33 & 36	-	1.12, 1.04
Post monsoon	-	-	1.56	-	-	-

responsible for more cyclonic storms or storms of higher intensity in the month of May. The convective activity associated with sea surface temperature, in general, plays an important role in modification of Hadley cell and may as well change the type of interaction between equatorial wind oscillation and extra-tropical planetary waves. Rasmusson *et al.* (1990) identified through their studies the presence of two dominant modes of oscillation one with a time scale of 2 years and other with a time scale of 4 to 5 years. Singh *et al*. (2000) concluded that the tropical cyclone frequency in the North Indian Ocean has a prominent El-Nino - Southern Oscillation (ENSO) scale (2 - 5) years during five months of their study and the annual cyclone frequency also exhibits 2 - 5 years oscillations.

5.2. *Annual total cyclonic disturbances* - The time series for period 1891-1990 (100 years) has been utilized for the study in this paper. The first 50 auto-correlations have been estimated. It is seen that the first 5 lag-correlations are all significant at 5 percent level of significance. Since lag-one correlation is significant, it has been further compared with the second and third lag-correlations for persistence. It is concluded that Markov type of linear persistence exists. The first 5 positive and significant correlations suggest presence of low frequency modes of oscillations in the time series. Increase of lag-correlation is indicative of presence of 1 to 5 years oscillations. The application of Fourier technique, however, indicated insignificant intensities in harmonics. The further examination of the time series with the help of spectral analysis revealed a quasi-periodicity of 4.76 years in the time series significant only at 75 percent confidence level. It also suggests presence of quasi 1.47 year, 1.33 year, 1.14 year and 1.05 year oscillations significant at only 90 percent confidence level (Table 6).

5.3. *Annual total number of cyclonic storms or storms of higher intensity* - For this time series, estimated lag-correlations 1, 3, 4, 16, 19, 21, 32, 33, 34, 36, 37 are all significant at 5 percent level of significance. Again, presence of Markov type of persistence is indicated. The autocorrelogram suggests presence of 2 years and 33 years cycles in time series. However, estimation of intensities of various harmonics with application Fourier technique did not indicate any significant values at 95 percent confidence level. Spectral analysis of time series revealed 4.76, 1.33, 1.16 year quasi-periodic oscillations significant at 95 percent confidence level (Table 6).

5.4. *Results on seasonal time scale* - (*i*) In winter, of the total, 1.53 percent of cyclonic disturbances formed during this season which is equal to 24 and 29.17 (7) intensified into storms or more intense systems. In total cyclonic disturbances, only the 37th, 38th lag-correlations are significant at 95 percent confidence level. Fourier analysis did not suggest any significant amplitude. However, spectrum analysis suggested periodicities of 2.33 years and 1.88 years which are significant at 95 percent confidence level. In case of cyclonic storms or severe intensity, only 28th, 38th lag-correlations are significant. Fourier analysis did not suggest any significant amplitude. Spectrum analysis suggested 1.51 year, 1.44 year, 1.09 year, 1.07 year, 1.03 year periodicities significant at 98 percent confidence level. No significant periodicities above 2 years are noticed in the spectrum (Table 6). (*ii*) In pre-monsoon, of the total, 9.78 percent of cyclonic disturbances formed during this season which is equal to 153 and 66.01 percent (101) intensified into storms or more intense systems. In total number of cyclonic disturbances, no significant lag-correlations in the first 50 auto-correlations, no significant amplitudes and no significant periodicities are noticed. In cyclonic storms or higher intensity, 25^{th}, 35^{th}, 37^{th}, 38^{th} lag-correlations are significant at 95 percent confidence level. Fourier analysis did not suggest any significant amplitude. However, spectrum analysis suggested a periodicity of 1.33 years significant at 99 percent confidence level (Table 6). (*iii*) In southwest monsoon the 100 years data suggest that highest number 884 which is 56.53 percent of

the total number of cyclonic disturbances are formed during this season and 20.59 percent (182) intensified into storms or severe intense systems. Even though in this season, highest number of cyclonic storms or more intense systems appear, the intensification of systems is more likely in pre-monsoon and post-monsoon seasons in order. In total cyclonic disturbances, 1st to 7th and 14th & 31st lag correlations are significant at 95 percent confidence level. The first seven lag-correlations are all positive and Markov type of persistence is indicated. Fourier analysis has not suggested any significant amplitude. However, periodicities of 1.12 year, 1.04 year are suggested by spectrum analysis both significant at 99 percent confidence level. In the case of cyclonic storms or higher intensity, again, 1st to 3rd & 33rd lag-correlations are significant. The first three lag-correlations are positive and indicated Markov type persistence. Spectrum analysis suggest 1.12 year, 1.04 year periodicities significant at 99 percent confidence level (Table 6) (*iv*) In post-monsoon, of the total, 32.2 percent of cyclonic disturbances formed during this season which is equal to 503 and 51.9 percent (261) intensified into storms or more intense systems. In total number of cyclonic disturbances, no significant lag-correlations, no significant amplitudes are noticed. Spectrum analysis suggested a 1.56 year periodicity significant at 95 percent confidence level. In case of cyclonic storms or higher intensity, only 36th lag-correlation is significant at 95 percent confidence level. No significant amplitudes and no significant periodicities are noticed (Table 6).

6. The application of statistical methods of analysis to the various time series could predict only the predominance of quasi low frequency modes of oscillations in annual total cyclonic disturbances and annual total cyclonic storms or storms of higher intensity. The prominent spectral peaks in annual total number of cyclonic disturbances and also in the total number of cyclonic storms or storms of severe intensity show presence of 4 to 5 year and 1 to 2 year quasi periodic oscillations. In case of seasonal analysis, the spectral peaks are indicative of presence of 2.33 year quasi-periodic oscillations in winter significant at 95 percent confidence level and no significant periodicities were observed which are greater than or equal to 2 years in the remaining three seasons, *viz*., pre-monsoon, monsoon and post-monsoon.

7. The author sincerely express his thanks to Deputy Director General of Meteorology, Regional Meteorological Centre, Kolkata for providing necessary facilities for carrying out this research work. He also thank the referee for his valuable suggestions

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(*10 August 2001, Modified 20 April 2004*)