Trend of shift in the area of cyclo-genesis over north Indian Ocean

CHARAN SINGH and B. R. LOE

India Meteorological Department, New Delhi – 110003, India

(Received 24 May 2005, Modified 5 June 2006)

e mail : csingh1964@yahoo.co.in

सार — इस–शोध पत्र में चक्रवात की उत्पत्ति के क्षेत्र के बनने और उसके दूसरे स्थान पर पहुँचने के संबंध में उत्तरी हिन्द महासागर (बंगाल की खाड़ी और अरब सागर) में चक्रवात की उत्पत्ति का अध्ययन किया गया है। इस अध्ययन की अवधि में विषेष माह और वर्ष के दौरान चक्रवातों के बनने की बारंबारता को प्रस्तुत किया गया है। इस अध्ययन से यह पता चला है कि चक्रवातों की उत्पत्ति जुलाई माह के दौरान अधिकतम संख्या में और उसके बाद अगस्त और सितम्बर माह में हुई। अरब सागर की अपेक्षा बंगाल की खाड़ी में चक्रवात की उत्पत्ति लगभग तीन गुना अधिक थी। चक्रवात की उत्पत्ति के लिए अनुकूल क्षेत्र बंगाल की खाड़ी में 15.0° उ. से 22.5° उ. अक्षांष और 86.0° पू. से 92.0° पू. देषांतर तथा अरब सागर में 7.0° उ. से 12.5° उ. अक्षांष और 60.0° पू. से 74.0° पू. देषांतर के मध्य पाए गए हैं। जबकि उत्तरी हिन्द महासागर में ये कहीं–कहीं पाए गए हैं और कभी–कभी ये उल्लेखनीय रूप से एक स्थान से दूसरे स्थान पर पहुँच गए हैं। इसमें वर्ष 1891–2000 के दषकों के कई चक्रवातों के मानक विचलन को परिकलित किया गया है। यह 1941–1950 के दौरान अधिकतम (1.96) और उसके बाद 1981–1990 में (1.92) पाया गया है।

ABSTRACT. Cyclo-genesis over north Indian Ocean (Bay of Bengal and the Arabian Sea) has been studied with reference to the formation and shift of cyclo-genesis area. The frequency of formation of cyclones during a particular month and year for the period of study has been presented. The study has shown that the maximum number of cyclo-genesis occurred during the month of July followed by August and September. Cyclo-genesis was about three times more in the Bay of Bengal as compared to that in the Arabian Sea. Areas favourable for cyclo-genesis were found between Lat. 15.0° N to 22.5° N and Long. 86.0° E to 92.0° E over the Bay of Bengal and Lat. 7.0° N to 12.5° N and 60.0° E to 74.0° E over the Arabian sea while meander over north Indian ocean, some times its shift significantly. Standard deviation of number of cyclones has been computed for the decades from 1891-2000. It was found that it was maximum (1.96) during 1941-1950 followed by 1981-1990 (1.92).

Key words – Area of cyclo-genesis, Shift, Standard deviation, Frequency, Average.

1. Introduction

Tropical cyclone climatology is essential for risk assessment, coastal planning etc. of a particular area and is, therefore, useful for safety from the loss of life and other damages to infrastructure. Objective techniques for track and intensity prediction also require climatological information's on cyclones. A good tropical cyclone climatology is the backbone for forecasting of tropical cyclones and disaster managements. An attempt has been made to bring out a comprehensive statistics of tropical cyclones that formed over north Indian Ocean during the period 1891-2004.

Frequency of formation of cyclonic disturbances and their intensification over north Indian Ocean have been studied by Srivastav *et al.* (2000). Singh (2000) has studied the frequency of monsoonal cyclonic disturbances over the north Indian Ocean. The region of cyclo-genesis in the north Indian Ocean oscillates with time. While it is closure to the equator during winter (January-February), it shifts to the central Bay of Bengal during pre-monsoon season (April-May) and then to north Bay of Bengal during the southwest monsoon season (June-September). During the post monsoon season (October-December) it shifts to southeast Bay of Bengal. These features are seen in the shift of the region of cyclo-genesis in the Arabian Sea also. Here cyclo-genesis is mainly confined over the east Arabian Sea.

The frequency of tropical cyclones in the north Indian Ocean is the least in comparison to elsewhere in the world. About 35%, 16% and 7% of the cyclonic disturbances intensified into a CS, SCS and VSCS or storm of a further higher intensity in the north Indian ocean. As reported by Mandal (1991) and Raghavan, (1973) about 45% of tropical cyclones in the past have intensified into SCS. Taking into consideration the storms crossing Indian coastline Jayanthi (1998) worked out the risk factor for the coastal segment of India.

2. Data and methodology

The frequencies of formation of tropical cyclones and depressions in the north Indian Ocean for the period
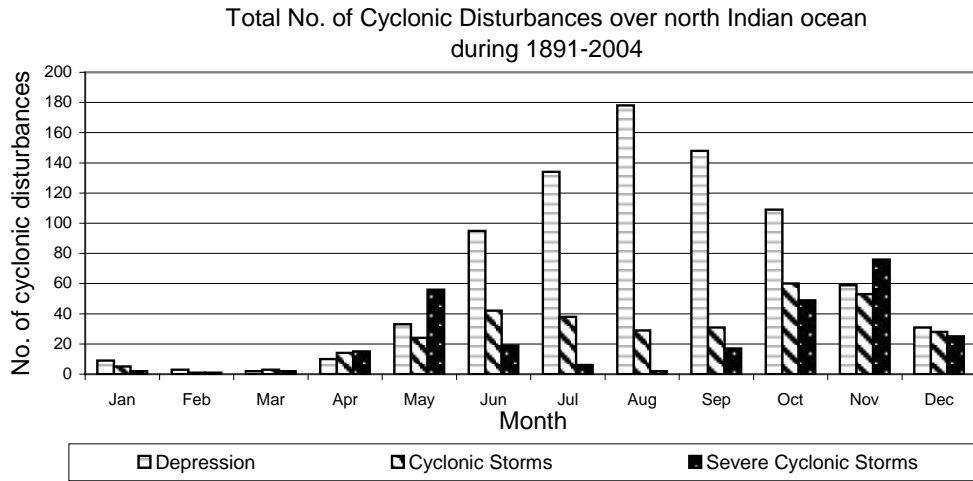
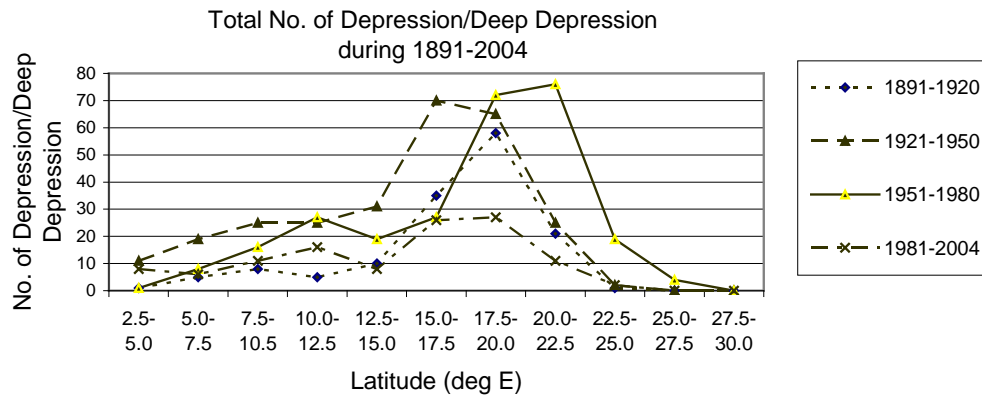**Total No. of Cyclonic Disturbances over north Indian ocean
during 1891-2004**

Fig. 1. Total No. of cyclonic disturbances over north Indian Ocean during 1891-2004

**Total No. of Depression/Deep Depression
during 1891-2004**

Fig. 2. Total No. of Depressions/Deep Depressions in 2.5° latitude belts during the period 1891-2004

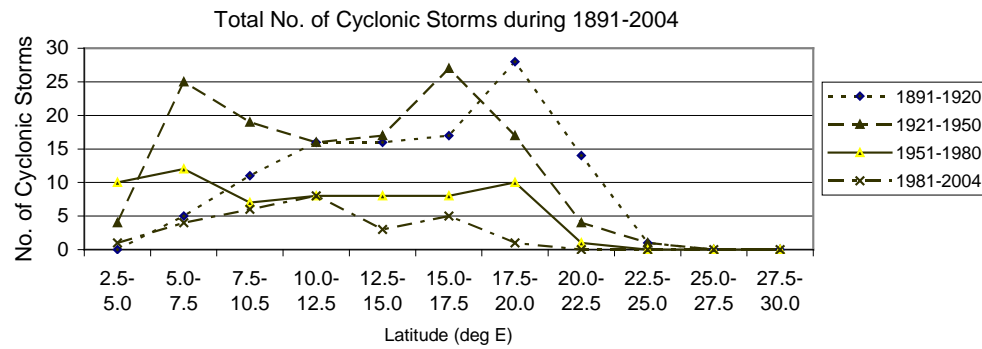**Total No. of Cyclonic Storms during 1891-2004**

Fig. 3. Total No. of Cyclonic Storms in 2.5° latitude belts during the period 1891-2004

Total No. of Cyclonic Storms and Storms of higher intensity
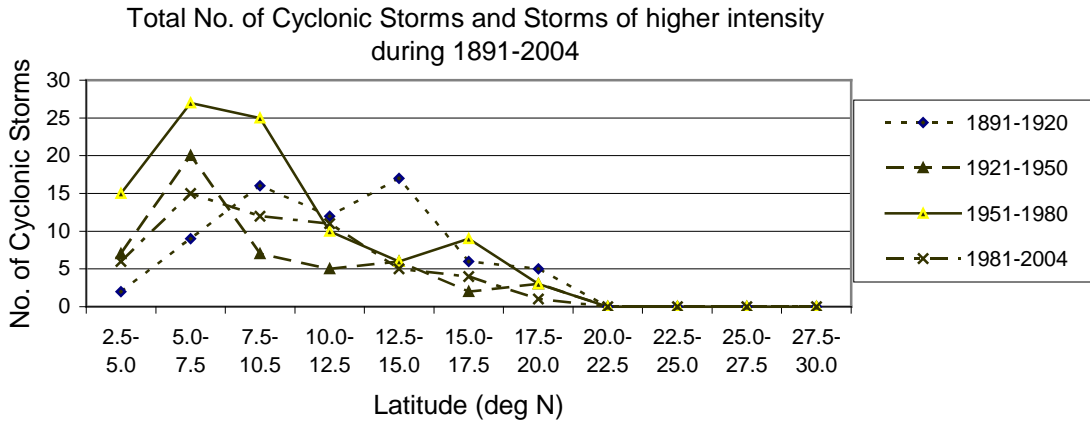during 1891-2004

Fig. 4. Total No. of Severe Cyclonic Storms in 2.5° latitude belts during the period 1891-2004
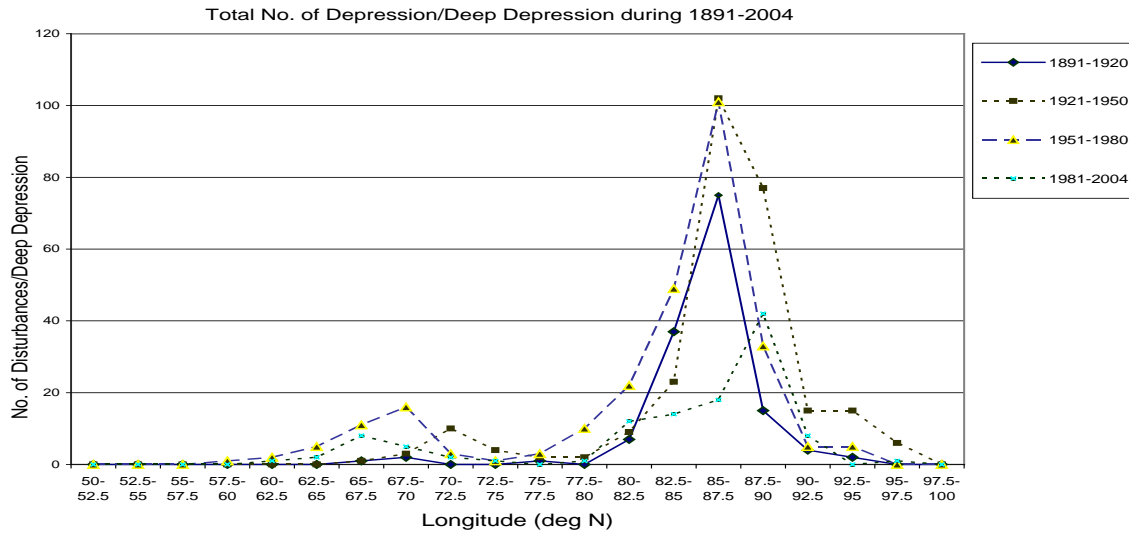

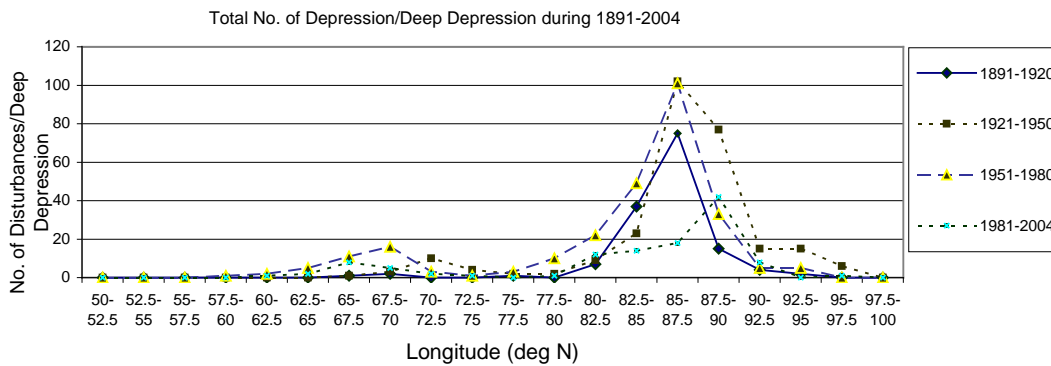**Fig. 5.** Total No. of Depressions/Deep Depressions in 2.5° longitudinal strips during the period 1891-2004

Fig. 6. Total No. of Cyclonic Storms in 2.5° longitudinal strips during the period 1891-2004
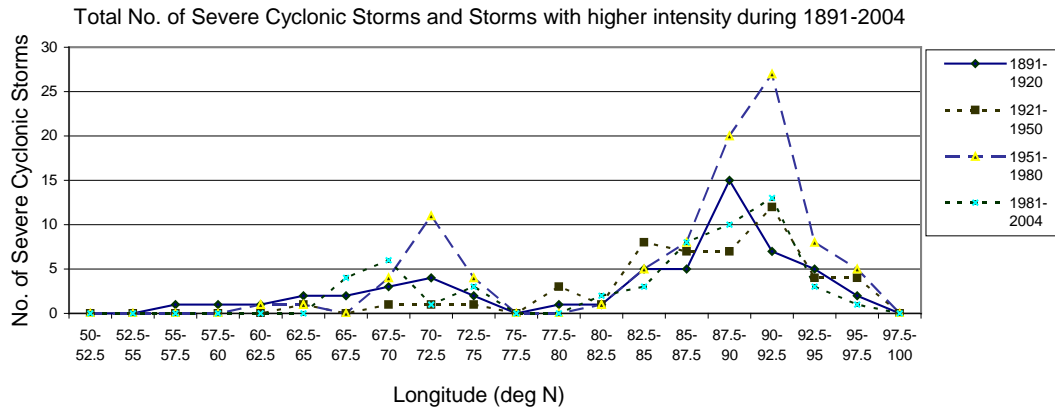
Total No. of Severe Cyclonic Storms and Storms with higher intensity during 1891-2004

Fig. 7. Total No. of Severe Cyclonic Storms in 2.5° longitudinal strips during the period 1891-2004

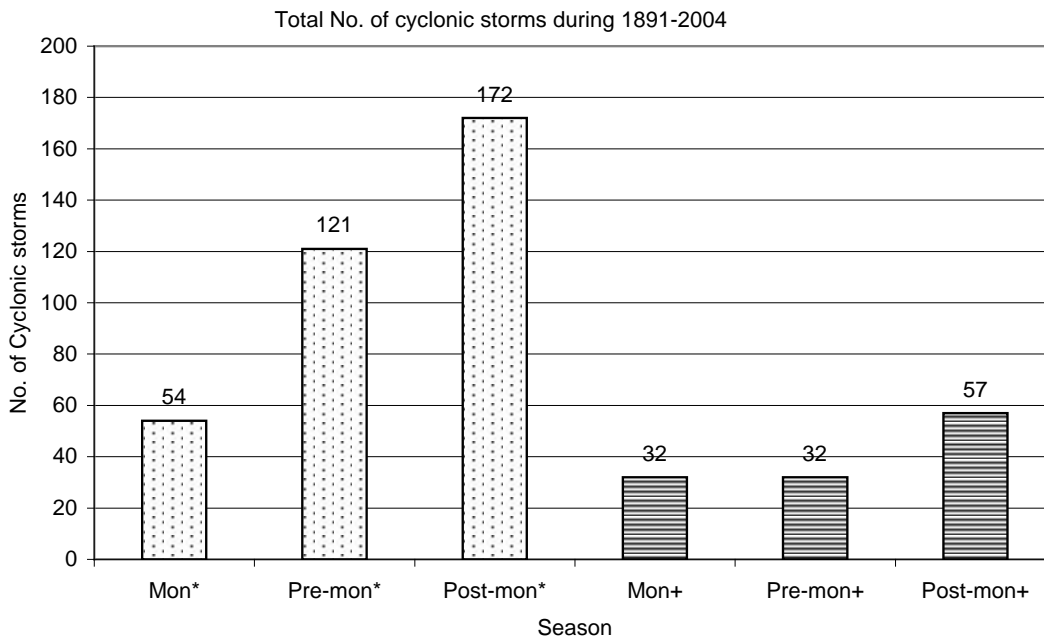Total No. of cyclonic storms during 1891-2004

Fig. 8. Total No. of Cyclonic Storms formed over north Indian Ocean, basin and season wise during the period 1891-2004

1891-1990 have been obtained from the Storm Atlas published by IMD (1979 & 1992) and WMO technical notes No.WMO/TD-No.430 on Tropical Cyclone. The data for the recent period 1991-2004 has been obtained from the Annual Reports published by RSMC - Tropical Cyclones New Delhi. Standard deviation of the number of cyclones per year has been compiled for every 10-year period beginning from the year 1891. Monthly and yearly distribution of cyclonic disturbances formed during 1891-2004, between Latitude 5.0° N to 30.0° N and Longitude 50.0° E to 100.0° E have been shown in Fig. 1. Taking the

intervals of 2.5° Latitude and Longitude, where the peak cyclo-genesis occurred are shown in Figs. 2-7 respectively, whereas the Table 1 represents season and year wise formation of cyclones over Bay of Bengal and Arabian Sea for the period 1891-2004. Basinwise and season wise cyclo-genesis for the same period has been shown in Fig. 8. Figs. 9(a-d), Figs. 10(a-d) and Figs. 11(a-d) indicate the total numbers of cyclo-genesis *i.e.*, D/DD, CS and SCS in the boxes of 2.5° × 2.5° between the area bounded by equator and 35.0° N and Longitude 50.0° E to 100.0° E.

TABLE 1

Cyclonic storms formed over North Indian Ocean during 1891-2004

Year	B*	B**	B***	A*	A**	A***	Total	Year	B*	B**	B***	A*	A**	A***	Total
1891	0	1	3	0	0	1	5	1948	0	2	1	0	1	2	6
1892	0	2	2	1	0	0	5	1949	0	0	1	0	0	0	1
1893	1	4	1	0	0	1	7	1950	0	2	1	0	0	0	3
1894	0	4	0	0	0	1	5	1951	1	0	1	0	1	1	4
1895	0	2	0	0	1	0	3	1952	1	1	1	0	0	0	3
1896	0	5	0	1	0	1	7	1953	1	0	0	0	0	0	1
1897	0	1	1	0	1	0	3	1954	1	0	1	0	0	0	2
1898	0	3	2	1	0	0	6	1955	2	1	3	0	0	0	6
1899	0	1	1	0	0	0	2	1956	1	2	1	0	0	0	4
1900	0	2	0	0	0	0	2	1957	1	0	1	0	0	1	3
1901	0	1	1	1	0	0	3	1958	1	0	2	0	0	2	5
1902	0	2	0	1	1	1	5	1959	1	0	1	0	1	1	6
1903	0	2	1	1	2	0	6	1960	0	1	1	0	1	1	4
1904	1	1	1	0	0	0	3	1961	1	0	0	1	1	0	3
1905	0	2	1	0	0	1	4	1962	1	1	2	0	0	0	4
1906	1	2	2	0	0	1	6	1963	0	0	1	0	1	2	4
1907	1	1	2	0	2	1	6	1964	0	0	3	2	0	1	6
1908	0	3	1	0	0	1	5	1965	0	0	2	0	0	1	3
1909	0	0	2	0	0	0	2	1966	0	1	4	1	0	1	7
1910	0	1	1	0	0	0	2	1967	0	1	1	0	0	0	2
1911	0	2	0	1	0	0	3	1968	1	0	4	0	0	0	5
1912	0	2	1	0	0	2	5	1969	1	1	3	0	0	0	5
1913	0	4	1	0	0	0	5	1970	1	0	1	1	1	0	4
1914	1	1	0	0	0	0	2	1971	2	0	1	0	0	1	4
1915	0	3	3	0	0	0	6	1972	3	1	2	0	0	1	7
1916	0	2	2	1	0	1	6	1973	1	0	2	1	0	0	4
1917	1	0	0	0	1	1	3	1974	2	0	0	1	2	0	5
1918	1	0	3	0	0	0	4	1975	0	0	2	0	1	1	4
1919	0	2	1	1	0	1	4	1976	1	1	2	1	1	1	7
1920	0	0	0	0	1	1	2	1977	0	0	3	1	0	2	6
1921	1	1	2	0	0	0	4	1978	1	0	2	0	0	2	5
1922	0	0	1	1	0	0	2	1979	1	1	1	1	0	0	4
1923	1	0	1	0	0	1	3	1980	0	0	3	0	0	0	3
1924	2	1	2	0	0	0	5	1981	2	0	3	0	0	1	6
1925	2	1	1	1	0	0	5	1982	0	1	2	0	0	1	4
1926	0	2	0	0	2	0	4	1983	0	0	1	0	0	0	1
1927	1	2	2	1	0	1	7	1984	0	0	3	0	0	0	3
1928	1	3	3	0	0	0	7	1985	1	1	4	0	0	0	6
1929	1	2	1	0	1	0	5	1986	0	0	0	0	0	0	0
1930	1	1	3	0	1	1	7	1987	0	1	2	0	0	0	3
1931	0	1	3	0	0	0	4	1988	0	0	2	0	0	0	2
1932	1	1	2	1	0	1	6	1889	1	1	1	0	0	0	3
1933	0	3	3	1	0	0	7	1890	0	1	0	0	0	0	1
1934	1	1	1	0	0	1	4	1991	0	0	1	0	0	0	1
1935	0	1	2	0	1	0	4	1992	0	0	2	1	0	1	4
1936	1	2	1	0	1	0	5	1993	0	0	1	0	0	1	2
1937	0	2	0	0	0	0	2	1994	0	0	1	1	0	1	3
1938	0	0	2	0	0	1	3	1995	0	0	1	0	0	1	2
1939	1	1	2	0	0	0	4	1996	0	0	2	1	0	1	4
1940	1	4	1	0	0	1	7	1997	0	0	1	0	0	0	1
1941	0	2	2	1	0	0	5	1998	0	0	2	1	0	2	5
1942	0	1	2	0	0	0	3	1999	0	1	2	0	1	0	4
1943	1	3	3	0	0	0	7	2000	0	1	3	0	0	0	4
1944	1	3	1	0	1	0	6	2001	0	0	1	0	1	1	3
1945	0	1	2	0	0	0	3	2002	0	0	3	0	1	0	4
1946	0	0	3	0	1	1	5	2003	0	1	1	0	0	1	3
1947	0	1	0	1	0	0	2	2004	0	1	0	0	1	2	4
									54	121	172	32	32	57	468

Legends :   B* - Bay of Bengal Pre-Monsoon,   B** - Bay of Bengal Monsoon,   B*** - Bay of Bengal Post-Monsoon,
A* - Arabian Sea Pre-Monsoon,   A** - Arabian Sea Monsoon,   A*** - Arabian Sea Post-Monsoon
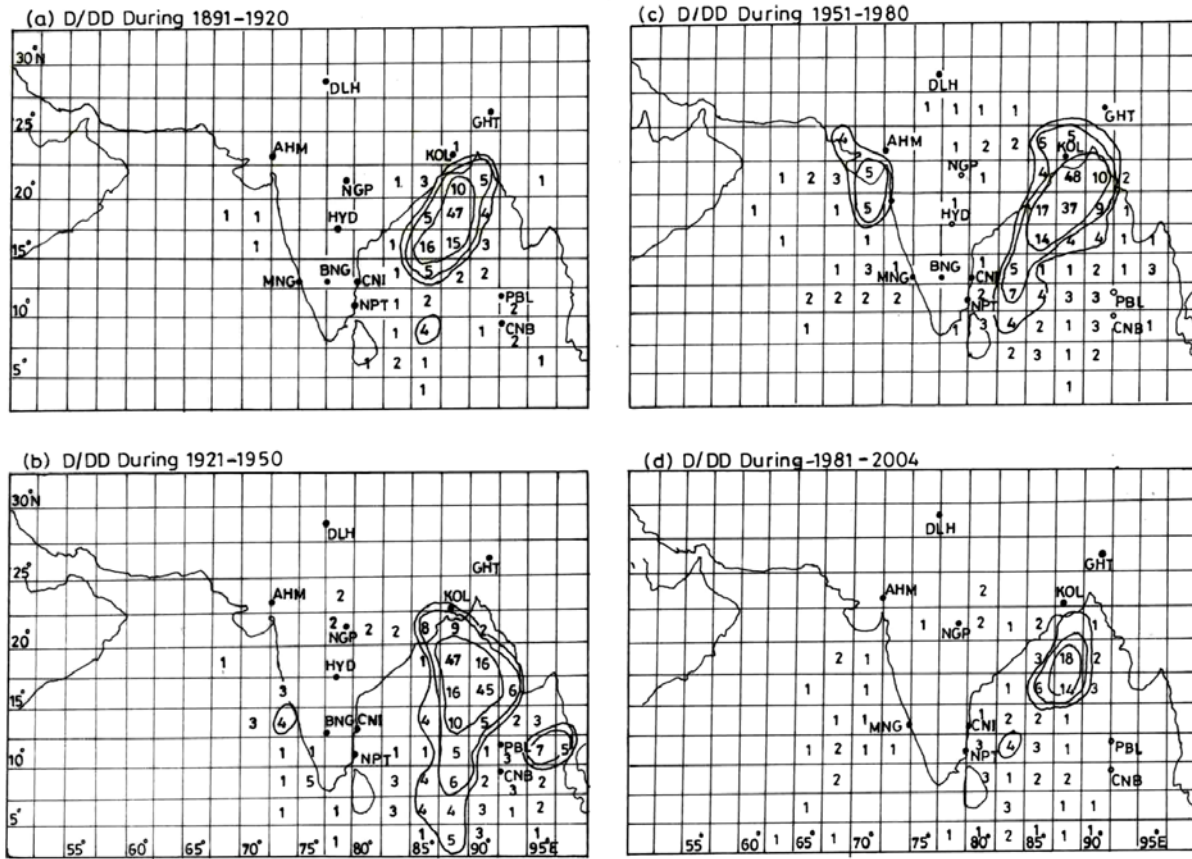
Figs. 9(a-d). Total No. of Depressions/Deep Depression in 2.5° Lat. × 2.5° Long. boxes. The area of significant cyclo-genesis has been encircled

The total number of cyclones formed over north Indian Ocean from 1891-2004 for all seasons are 468, out of which 347 formed over Bay of Bengal and 121 over Arabian Sea. The total 229 (48.93 %) of the cyclone formed in post monsoon season whereas 153 (32.69 %) in monsoon season and rest 86 (18.38 %) in pre-monsoon season.

Season wise cyclonic storms formed over Bay of Bengal 54 (11.54%) in pre-monsoon season, 121 (25.85%) in monsoon season and 172 (36.75%) in post-monsoon season. Over Arabian Sea 32 (6.84%), in pre-monsoon season, 32 (6.84%) in monsoon season and 57 (12.18%) in post-monsoon season. Fig. 12 shows the total numbers of D/DD, CS and SCS vertically in the same grid area and Figs. 13(a-c) shows the significant shifts of area of cyclo-genesis in each category of the storms.

3. Monthly and yearly variation of cyclo-genesis areas

The monthwise average of cyclonic storms during 1891-2004 is January – 0.04, February – 0.02,

March – 0.04, April – 0.14, May – 0.40, June – 0.46, July – 0.34, August – 0.27, September – 0.42, October – 0.75, November –0.88 and December – 0.32 respectively.

No cyclone formed over north Indian Ocean in 1986 followed only one cyclone in each year *i.e.*, 1949, 1953, 1983, 1990, 1991 and 1997, while in 11 years *i.e.*, 1893, 1896, 1927, 1928, 1930, 1933, 1940, 1943, 1966, 1972 and 1976 the maximum frequency was 7. It appears that the frequency of cyclonic storm has slightly decreased during 1981-1990 (Table 1). There is, however, no apparent trend or periodicity in the long-term data for the development of cyclonic storms. Jayaraman (1964) examined the combined series of storms and depressions for the period 1901-1955 for trend and suitability of Poisons distribution. Thiruvengadathan (1976) made a detailed study on the climatological behavior of the storms and distribution in the Arabian Sea during the period 1891-1974 dividing the period into six equal parts of duration 14 years each. The annual average of tropical cyclones in the north Indian Ocean is about 4.17 (3.11 in Bay of Bengal and 1.06 in Arabian Sea) [Mooley, (1981)].
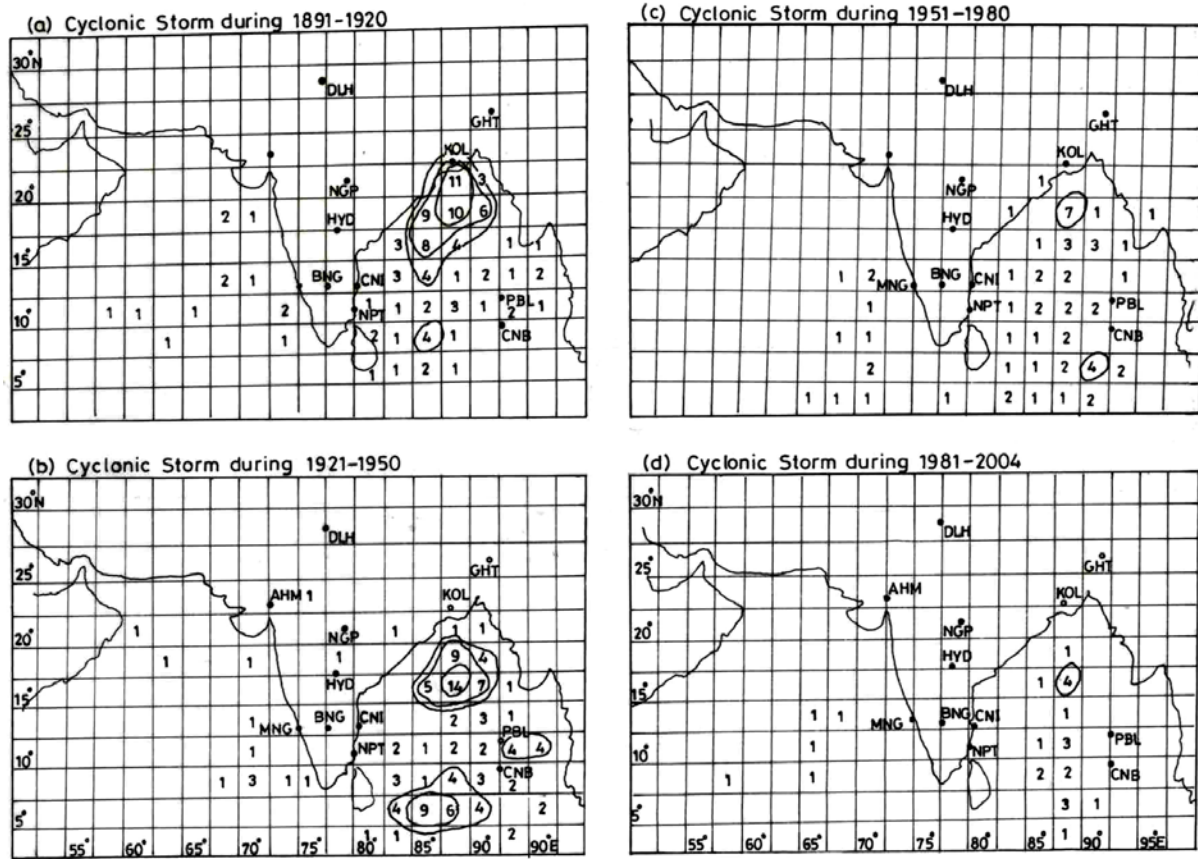
Figs. 10(a-d). Total No. of Cyclonic Storms in 2.5° Lat. × 2.5° Long. boxes. The area of significant cyclo-genesis has been encircled
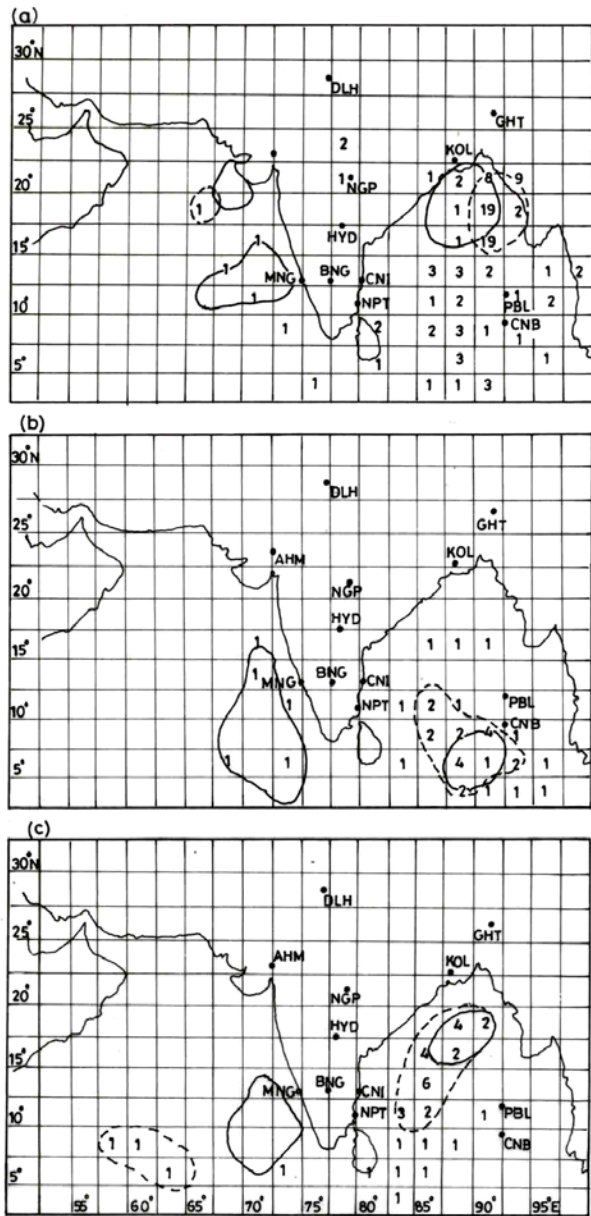
The basinwise and season wise figures are also shown in Fig. 8.

Figs. 9 (a-d) shows the maximum cyclo-genesis during the specific period of 30 years. In case of depression/ deep depression it was maximum during 1921-1950 in Bay of Bengal, in Arabian Sea it was during 1951-1980. In case of cyclonic storm it was confined over northwest Bay of Bengal and there were 2 maxima areas during 1921-1950 [Figs. 10 (a-d)], one over northwest and other one was over southwest Bay of Bengal. Similar result was obtained in the study of Mooley and Mohile, (1983). The occurrence of cyclo-genesis in the area bounded by 2.5° Lat. × 2.5° Long. box are also studied by Bhaskar Rao *et al.* (2001). Considering the case of SCS the area of maximum cyclo-genesis was over south Bay of Bengal [Figs. 11 (a-d)] and it was maximum during 1950-1980. Fig. 12 shows the total number of cyclonic

disturbances in each 2.5° Lat. × 2.5° Long. box. Shift of cyclo-genesis area is seen in each category of the systems in some decades. Some time the shift is noticeable, but in most of the decades it is not.

4.   **Result and discussion**

The study has shown that the maximum disturbances occurred in month of August (209) followed by September (196) and July (178). During the pre-monsoon, systems attain the intensity upto the cyclonic storm. They reach occasionally upto the intensity of VSCS or more. Maximum frequencies for attaining the intensity of the CS or more were noticed in the month of November followed by October and May respectively, where as 76 (40.4%) SCS or more and 53 (28.2%) CS and remaining 59 (31.4 %) D, in the month of November. It was 49 (22.3 %), 60 (27.5 %) and 109 (50 %) in the month of October. In May

Figs. 11(a-d). Total No. of Severe Cyclonic Storms in 2.5° Lat. × 2.5° Long. boxes. The area of significant cyclo-genesis has been encircled

Fig. 12. Total No. of Cyclonic Disturbances during 1891-2004. The area of significant cyclo-genesis has been encircled for each category of cyclonic storms

Figs. 13(a-c). In case of (a) D/DD, (b) CS and (c) SCS, circles with dashes show the shift of cyclo-genesis area and circles with continuous line show significant cyclo-genesis area for 110 years

it was 56 (49.5 %), 24 (21.2 %) and 33 (29.2 %) respectively.

Cyclo-genesis was on peak during 1951-1980 followed by 1921-1950 (Figs. 5-7). The latitude of peak cyclo-genesis was between 15.0° N to 22.5° N, in Bay of Bengal and 7.5° N to 12.5° N over Arabian Sea. The peak frequency of CS occurred during 1951-1980 in the latitude belt 5.0° N to 7.5° N over Arabian Sea. During 1981-2004, the area of cyclo-genesis shifted to latitude belt

15.0° N to 20.0° N for CS in the Bay of Bengal. In the case of SCS, it was in the latitude belt 5.0° N to 15.0° N over the north Indian Ocean.

Occurrence of D/DD, CS SCS and VSCS (earlier nomenclature as SCS with core of Hurricane winds) in 2.5° longitude strips is shown in Figs. 5-7. The zone of maximum cyclo-genesis is 85.0° E to 95.0° E and 65.0° E to 75.0° E in case of D/DD, in case of CS it is located between 67.5° E to 75.0° E and   85.0° E to 92.5° E. In case of SCS it is located between 67.5° E to 75.0° E and 87.5° E to 95.0° E longitudes.

The area of cyclo-genesis of D/DD, CS and SCS for the period 1891-2004 as a whole is shown in Fig. 12. Trend of shift of cyclo-genesis was studied for every decade. In case of D/DD shift was noticed in the decade 1911-1920 towards south, in 1951-1980 it was slightly southwestwards and it was significant in the decade 1941-1950 towards east-southeastwards Fig. 13(a). In remaining decades it was almost over the normal area. Over Arabian sea it was almost over its normal area except in the decades 1951-1960 when it shifted towards north Fig. 13(a).

In case of CS, the shift was noticed towards southwards, southwestwards and southeastwards. During 1941-1950 the area of cyclo-genesis occurred between Lat. 5.0° N to 8.0° N and Long. 85.0° E to 92.0° E. The maximum shift in 1901-1910 was towards southwestwards Fig. 13(b). No significant shift in the area of cyclo-genesis was noticed over Arabian Sea. In case of SCS significant shift was noticed in the decade 1961-1970 towards south-westwards over Bay of Bengal Fig. 13(c). There is no significant shift in the area of cyclo-genesis area over Arabian Sea.

5.   Conclusion

(*i*)   The Standard Deviation (SD) was maximum (1.96) during the period 1941-1950 and minimum during 1971-1980 (1.31). Thus if the cyclo-genesis occurs over south Bay of Bengal, there is maximum possibility of the system attaining the intensity of VSCS.

(*ii*) In case of Depression/Deep Depression area of significant cyclo-genesis is between the Lat. 16.0° N to 22.0° N & Long. 86.0° E to 92.0° E over the Bay of Bengal and 19.0° N to 22.0° N & 67.5° E to 71.0° E and Lat. 11.0° N to 15.0° N & Long. 66.0° E to 74.0° E over Arabian Sea. In case of cyclonic storms the area lies over Bay of Bengal between Lat. 15.5° N to 19.5° N & Long. 85.5° E to 92.0° E and over Arabian sea it was between Lat. 6.0° N to 14.0° N & Long. 68.0° E to 75.0° E. In case of severe cyclonic storms the area lies between Lat. 4.0° N to 9.0° N & Long. 86.0° E to 92.5° E over Bay of Bengal

and Lat. 3.0° N to 15.5° N and Long. 68.0° E to 74.0° E. over Arabian Sea.

(*iii*) Trend of shift of cyclo-genesis in case of D/DD was significant over Bay of Bengal. Over Arabian Sea it was almost over its normal area except during the decade 1951-1960 when it shifted towards north. In case of CS the maximum shift was seen in the decade 1901-1910 towards northwestwards. In the case of severe cyclonic storm shift in the area of cyclo-genesis was significant in the decade 1961-1970 towards southwestwards over Bay of Bengal.

(*iv*) The average occurrence of cyclone per year over north Indian Ocean is 4.14 and basin wise 3.07 in Bay of Bengal and 1.07 in Arabian Sea.

References

Bhaskar Rao, D. V., Naidu, C. V., Rao and Srinivasa, B. R., 2001, "Trends and fluctuations of the cyclonic systems over north Indian Ocean", *Mausam*, **52**, 1, 37-46.

India Meteorological Department (IMD), 1979, "Tracks of cyclones and depressions in the Bay of Bengal and Arabian Sea 1877-1970".

India Meteorological Department (IMD), 1992, "Tracks of cyclones and depressions in the Bay of Bengal and Arabian sea 1971-1990".

Jayanthi, N., 1998, "Cyclone hazard coastal vulnerability and disaster risk assessment along the Indian coasts", *Vayu Mandal*, July-December, 115-119.

Jayaraman, S., 1964, "On the distribution of storms and depressions in the Arabian Sea", *Indian J. Met. & Geophys.*, **15**, 2, 287-288.

Mooley, D. A., 1981, "Increase in annual frequency of the severe cyclonic storms of the Bay of Bengal after 1964-possible causes", *Mausam*, **32**, 1, 35-40.

Mooley, D. A. and Mohile, C. M., 1983, "Cyclonic storms incident on the different sections on the coast around Bay of Bengal", *Mausam*, **34**, 2, 139-152.

Mooley, D. A. and Mohile, C. M., 1983, "Cyclonic storms of the Arabian sea, 1877-1980", *Mausam*, **35**, 2, 127-134.

Mandal, G. S., 1991, "World Meteorological Organization", Technical Document, WMO/TD-No. 430 (Report No. TCP-28).

Raghavan, V. K., 1973, "A statistical analysis of the number of cyclonic storms and depression in the Bay of Bengal during 1890-1969", *Indian. J. Met. & Geophys.*, **24**, 125-130.

Singh, O. P., 2000, "Long term trends in the frequency of monsoonal cyclonic disturbances over the north Indian ocean", *Mausam*, **52**, 4, 655-658.

Srivastav, A. K., Sinha Ray, K. C. and De, U. S., 2000, "Trends in the frequency of cyclonic disturbances and their intensification over Indian seas", *Mausam*, **51**, 2 , 113-118.

Thiruvengadathan, A., 1976, "Climatological behaviour of storms and depressions in the Arabian sea", *Indian J. Met. Hydrol. & Geophy*s., **27**, 2, 205-206.