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Influence of solar activities on the cyclonic disturbances over Indian seas

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सार — 1891 से 1985 की अवधि के दौरान भारतीय समुद्रों (बंगाल की खाड़ी और अरब सागर तथा कुछ स्थली स्थानों पर निर्मित) के चक्रवातीय विक्षोभों की वार्षिक संख्या के वितरण की विशिष्टताएं (C) और सौर सक्रियता के साथ इसकी विविधता का वार्षिक माध्य सूर्य-धब्बों की संख्या के रूप में अध्ययन किया गया है। 11 वर्षों के सौर-चक्र में उतार-चढ़ाव सहित चक्रवातीय विक्षोभों में उतार-चढ़ाव, दोहरा सौर-चक्र और सूर्य-धब्बों की संख्या इन बातों को दर्शाती है : (*i*) 1940-50 के दशक के मध्य से S में वृद्धि के साथ-साथ C के औसत मूल्य में न्यूनता और (*ii*) S के वृहत्त मूल्य में C और S के मध्य ऋणात्मक सम्बन्ध। 85 के आसपास में S के क्रांतिक मान में भी वृद्धि पाई गई जिससे कि यह सम्बंध विशिष्ट बन गया है (1 % स्तर पर सार्थक सहसम्बंध गुणांक = —0.54,)।

ABSTRACT. The characteristics of the distribution of the annual number of cyclonic disturbances (C) over Indian seas (the Bay of Bengal and the Arabian Sea including a few formed over land) during the period 1891 to 1985 and its variation with solar activity, estimated in terms of annual mean sunspot number (S), has been studied. The variation of cyclonic disturbances with the variation of 11-year solar cycle, double solar cycle and the sunspot numbers indicate (*i*) a decrease in the average value of C with simultaneous increase in S from the middle of the decade, 1940-50, and (*ii*) a negative association between C and S for large value of the latter. A critical value of S in the neighbourhood of 85 has also been found exceeding to which this association becomes prominent (correlation coefficient = —0.54, significant at 1 % level).

1. Introduction

Tropical cyclones, depressions and storms, are the major weather systems causing frequent natural calamities and widespread destruction over the coastal regions of India every year. Statistical analyses of the frequency, periodicity, etc for the Bay of Bengal cyclones have been done by Rao *et al.* (1958), Mooley (1981), Subbaramayya and Rao (1984) and others.

Since the sun is the primary source of energy, many attempts have been made during the last few decades to understand the influence of solar activity on meteorological phenomena, *viz.*, southwest monsoon circulation (Jagannathan and Bhalme 1973), temperature (Mohankumar and Devanarayanan 1984), fluctuation of flood area (Bhalme and Mooley 1981) etc. The study by Ananthakrishnan and Parthasarathy (1984) on sunspots in relation to Indian rainfall using different statistical tests, faintly suggest that there may be a significant association of the annual rainfall with the 22-years' solar cycle. Chakraborty and Bandyopadhaya (1985, 1986, 1987) have shown that the association between rainfall and onset of Indian southwest monsoon with solar activity becomes significant, particularly when the sunspot number (S) exceeds the critical value of 140.

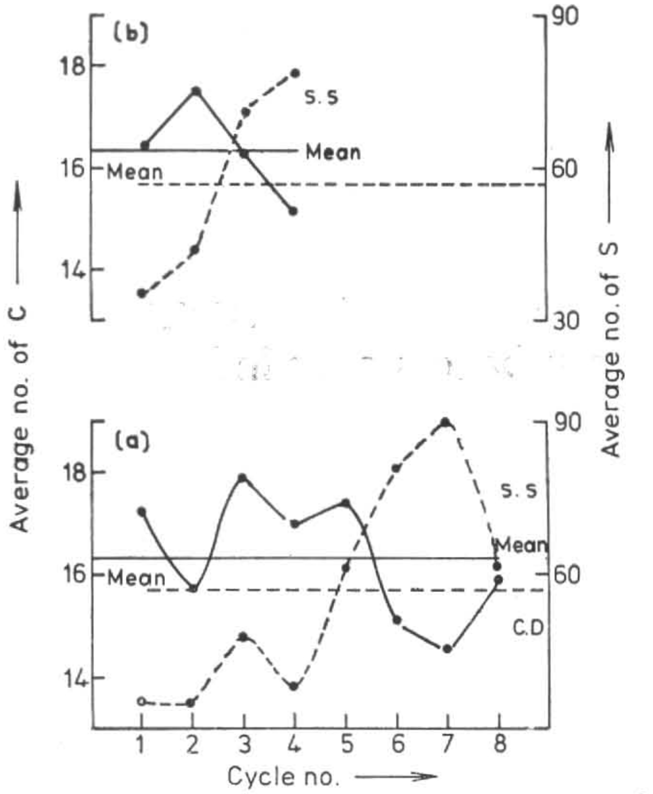
The role of solar activity on meteorological parameters is still a debatable topic (Pittock 1978, 1983; Bucha 1980, 1983). In the present paper an attempt has been made to study the influence of solar activity (estimated in terms of annual mean sunspot number) on the annual number of cyclonic disturbances over the Indian seas (*i.e.*, those formed over the Bay of Bengal, Arabian Sea and a few numbers over land).

In the present study "cyclonic disturbances" (hereinafter will be referred to as "disturbances") implies all the cyclonic circulations from depressions to severe cyclonic storms but not the ordinary low pressure areas. The 95 years' data (from 1891 to 1985) used in this analysis have been obtained from the "*Tracks of Storms and Depressions in the Bay of Bengal and the Arabian Sea*" and the "*Indian Daily Weather Reports*" published by the India Meteorological Department. The annual mean sunspot numbers have been obtained from the Indian Institute of Astrophysics, Bangalore.

TABLE 1

Values of S and C during 1891 to 1985

Year	S	C	Year	S	C	Year	S	C
1891	35.6	15	1924	16.7	18	1957	190.2	8
1892	73.0	15	1925	44.3	21	1958	184.8	12
1893	85.1	18	1926	63.9	17	1959	159.0	16
1894	78.0	17	1927	69.0	23	1960	112.3	15
1895	64.0	16	1928	77.8	17	1961	43.5	18
1896	41.8	16	1929	64.9	19	1962	30.7	13
1897	26.2	18	1930	35.7	17	1963	26.3	17
1898	26.7	16	1931	21.2	16	1964	10.6	16
1899	12.1	20	1932	11.1	16	1965	16.1	14
1900	9.5	13	1933	5.7	18	1966	47.4	18
1901	2.7	18	1934	8.7	17	1967	115.2	15
1902	5.0	18	1935	36.1	15	1968	118.3	13
1903	24.4	18	1936	79.7	18	1969	115.3	14
1904	42.0	18	1937	114.4	19	1970	142.6	15
1905	63.5	15	1938	109.6	11	1971	85.3	15
1906	53.8	16	1939	88.8	21	1972	83.3	18
1907	62.0	19	1940	67.8	16	1973	42.0	16
1908	48.5	21	1941	47.5	19	1974	35.9	12
1909	43.9	14	1942	30.6	15	1975	15.7	20
1910	18.6	12	1943	16.3	17	1976	14.1	14
1911	5.7	17	1944	9.6	20	1977	32.3	19
1912	3.6	14	1945	33.2	16	1978	103.5	15
1913	1.4	17	1946	92.6	20	1979	156.6	11
1914	9.6	14	1947	151.6	19	1980	139.8	14
1915	47.4	14	1948	136.3	18	1981	140.7	12
1916	57.1	15	1949	134.7	13	1982	108.1	19
1917	103.9	18	1950	83.9	16	1983	61.5	8
1918	80.6	15	1951	69.4	15	1984	41.0	7
1919	63.6	16	1952	31.5	17	1985	17.9	15
1920	37.6	14	1953	13.9	12			
1921	26.1	17	1954	4.4	14			
1922	14.2	20	1955	38.0	13			
1923	5.8	18	1956	141.7	14			



Figs. 1 (a & b). Variation of average number of CD. (C) and sunspot (S) during (a) 11 years' solar cycle and (b) double solar cycle

TABLE 2

Means of C and S according to sunspot cycles

Cycle No.	Period	Mean S	$Z_s = \frac{(S - \bar{S})}{\sigma_s}$	Mean C	$Z_c = \frac{(C - \bar{C})}{\sigma_c}$
1	1893-1904	34.8	—1.0	17.2	+0.8
2	1905-1916	34.6	—1.0	15.7	—0.5
3	1917-1927	47.8	—0.4	17.9	+1.3
4	1928-1936	37.9	—0.9	17.0	+0.6
5	1937-1946	61.0	+0.2	17.4	+0.9
6	1947-1956	80.5	+1.2	15.1	—1.0
7	1957-1969	90.0	+1.6	14.5	—1.5
8	1970-1978	61.6	+0.3	15.9	—0.3
	For all cycle				
Mean		56.0($\bar{S}$)		16.3($\bar{C}$)	
Std. deviation		21.1 (σ_s)		1.2 (σ_c)	
	Half cycle : 1979-1985				
		95.1		12.3	

2. General statistical features of annual number of cyclonic disturbances and that of sunspot number

One may note the following statistical features of the annual number of disturbances (C) and of sunspot number (S). For the yearly values of C and S for the entire period (1891 to 1985) of the study, refer to Table 1 . The sunspot number (S) is very highly variable (78%) while that of the number of disturbances (C) is moderate (18%).

Features	C	S
Mean	16.0	59.1
Standard deviation (σ)	2.9	46.0
Coefficient of variation (%)	18.1	77.8
Highest value	23 (1927)	190.2 (1957)
Percentage of mean (%)	143.75	321.83
Lowest value	7 (1984)	1.4 (1913)
Percentage of mean (%)	43.75	2.37
Range (highest-lowest)	16	188.8
Percentage of mean (%)	100	319.46

3. Variation of cyclonic disturbances with solar activity

It is well known that the sunspot series is periodic in nature with a period of approximately 11 years. In addition to this, the approximately 22 years' period of double solar cycle is also equally important when the polarity of the magnetic field on the sun becomes similar. The 95 years' period of our analysis falls into 8 solar cycles or 4 double solar cycles together with a half cycle (from 1979 to 1985). For each of the cycles the mean values of C and S are computed. We also calculate the deviations of these mean values of C and S from the corresponding means for the 11 years and double solar cycle in terms of their respective standard deviations. These are represented by Z_c and Z_s respectively (*vide* Tables 2 and 3). It may be mentioned here that the Z-value of any parameter x is given by $Z_x = (x - \bar{x}) / \sigma_x$ where $\bar{x}$ and σ_x respectively represent the mean and standard deviation of x.

3.1. *Variation with* 11 *years' solar cycle*

The means of C and S over each solar cycle, as in Table 2, are plotted in Fig. 1(a) against cycle numbers. This figure reveals that the variations in the means of C are in phase with the means of S between cycles 3 and 4. From the cycle number 6, which started in 1947, the variations are in the opposite direction. The means of S in cycles 6 and 7 are much greater than those in the other cycles, while the values of C are lower than the other cycles. Again, from cycle 7 to 8 with decrease of S, the C has increased. In cycle 7 when Z_s becomes maximum (=+1.6) corresponding

TABLE 3

Means of C and S over double (22 years) cycles

Cycle No.	Period	Mean S	Z_s	Mean C	Z_c
1	1893-1916	34.7	—1.0	16.4	+0.1
2	1917-1936	43.3	—0.6	17.5	+1.2
3	1937-1956	70.8	+0.7	16.3	0.0
4	1957-1978	78.4	+1.0	15.1	—1.2
For all double cycles :					
Mean		56.8 ($\bar{S}$)		16.3 ($\bar{C}$)	
Std. deviation		21.1($\sigma_{\bar{s}}$)		0.98($\sigma_{\bar{c}}$)	

to maximum mean value of S, Z_c also becomes maximum in opposite sense (=—1.5) corresponding to minimum mean value of C in Table 2. This suggests that the *negative association between means of C and S during solar cycles is marked for the higher mean values of S.*

Though the means of S and C are negatively associated, the correlation coefficient (CC) between the two, considering the values in Table 2, is —0.67, which is, however, not statistically significant even at 5% level.

3.2. *Variation with double solar cycle*

The mean values of C and S over two consecutive solar cycles in Table 3 are plotted in Fig. 1(b) against the respective cycles. The first two values of C and S vary in the same direction. But after cycle 2, as in section 3.1, when S becomes markedly greater, the values of C and S move in the opposite direction. Further, in cycle 4 when the deviation of S from the mean is maximum (Z_s=+1.0), the deviation of C from its mean has also been observed to be maximum (Z_c= —1.2) but in opposite sense. Thus, the variations of C and S during a double cycle are also similar as in the variation during the 11 years' cycles.

3.3. *Variation during the half cycle* 1979-1985

We find a half solar cycle (solar maximum to one year before the next solar minimum year) from 1979 to 1985. The means of S and C during this half cycle are respectively 95.1 and 12.3. Comparing the trend of variations of S and C, means prior to 1979 (from Table 2 and Table 3), one may note that mean S shows a marked rise and C a large decline during the period 1979-1985. This feature has been noticed in Figs. 1(a) and 1(b). This study, in respect of means, also indicates the similar negative association between C and S as in the variations during 11 years' cycle and double cycle.

4. Declining tendency of the number of disturbances from the decade 1940-1950

We now proceed to study the trend in S and C for the whole period of our study. Three years' moving averages of S and C are shown in Fig. 2. Considering the deviations above and below the mean lines for S and C,

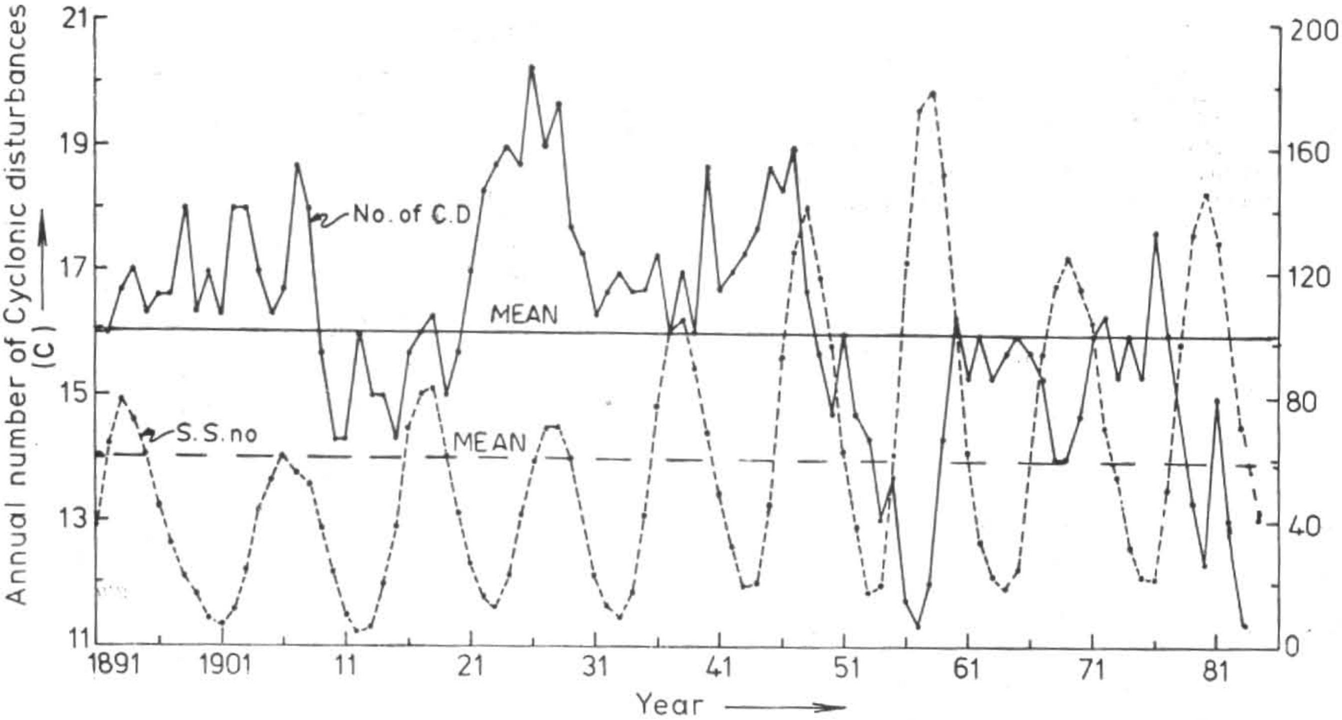


Fig. 2. Three years' moving average values of annual number of cyclonic disturbances and sunspot number

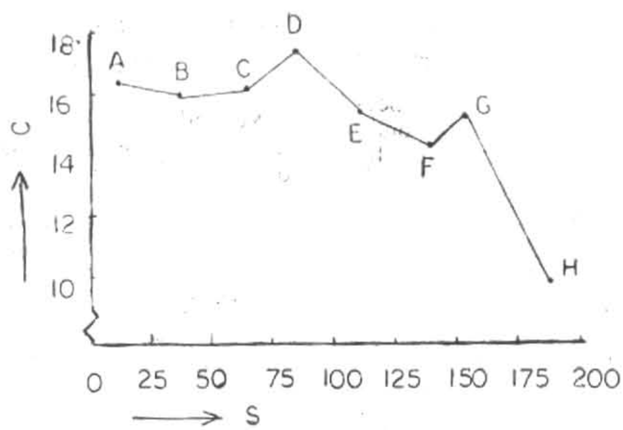


Fig. 3. Variation of mean values of C for different sunspot (S) intervals

TABLE 4

Period	C			S		
	Mean	Std. deviation	Coeff. of variation	Mean	Std. deviation	Coeff. of variation
1891-1946	16.9	2.4	14.2%	43.2	30.7	71.1%
1947-1985	14.6	3.0	20.5%	81.9	55.9	68.3%

one may observe from Fig. 2 that from the decade of forty the deviations of the moving average values of S are mostly above the mean line, while the same for C from the middle of the decade of forty are mostly below the corresponding mean line.

To study the trends further, the whole period has been split into two—from 1891 to 1946 and from 1947 to 1985. The second spell has been chosen from 1947 as this was the year of solar maximum. The differences between the means of C and S during the periods 1891-1946 and 1947-1985, as obtained from Table 4, are statistically significant. It is interesting that *while the mean S increases, the mean C decreases very significantly* [This is in consistent with the observations made in the previous sections].

5. General variation with sunspot number and the critical value

It has been remarked earlier that the negative association between variations in C and S is prominent for the higher values of S. The correlation coefficient (CC) between C and S of the same year for all the 95 years of data is only —0.24, significant at 2% level. Though the magnitude of this CC is not high, the main result continues to be the negative association between C and S. The CC between C and S for the periods 1891-1946 (+0.9) and 1947-1985 (—0.17) are, however, not significant. Since these values are not significant, the negative association between C and S for the second spell when S was comparatively very high would have to be noted and examined further. This is consistent with the results in the previous sections. Ananthakrishnan and Parthasarathy (1984) have obtained the same order of negative CC between S and annual Indian rainfall. But when the period of their analysis was split into two (each of 54 years) significant changes in the values of CC were noted as in the present study. The significance of the change in the sign of CC would thus need careful consideration before drawing inferences.

It may be mentioned here that for knowing the level of significance of the CC using Student's t-test, the series in C is required to be tested for normality. However, as a rough test it is seen that the range in the series of C (=16) is approximately six times the standard deviation (=2.9) and the mean value of C (=16) lies approximately in the middle of the highest and the lowest value. Thus, the series in C may be considered to be approximately normal (Chambers 1955). The level of significance has been estimated on the basis of double-tailed t-test.

TABLE 5

Mean value of C for different ranges of S

S interval	No. of years	Mean S	Mean C
0-25	26	11.3	16.4
25-50	26	37.4	16.0
50-75	13	64.1	16.2
75-100	10	83.5	17.5
100-125	9	111.2	15.4
125-150	6	139.3	14.3
150-175	3	155.7	15.3
175-200	2	187.5	10.0

Now to have an idea of the minimum value of S, which may be designated as the critical value, exceeding of which the feature of negative association between C and S becomes prominent, we now plot the mean values of C against the mean values of S for different S intervals in Fig. 3. Instead of plotting the individual annual values of C and S we choose the intervals for S of width 25 and compute the means C of those years when S lay in the respective S intervals (Table 5). Though for the critical value our aim is to find a range in S of minimum width, the attempt to plot the mean values of C and S for different S intervals of lower widths 10 or 20 showed absence of values for the S intervals, 120 to 130 and 160 to 180. The S-width of 25 has, thus, been chosen to obtain a continuity in the variations of mean values of C and S. It may be observed from Fig. 3 that approximately from the point D the values of C decrease gradually with increase of S. This shows that the negative association between C and S is prominent when S exceeds a critical value in the neighbourhood of the point D, *i.e.*, at $S \approx 85$. However, this association is markedly seen when S exceeds 155.

It will be interesting to calculate the CC between S and C for those years when S attained values of 80-85 and higher. For all those years when S was greater than 80 (in 27 occasions), the CC worked out to be —0.54. This is significant at 1% level. It may be added here that the existence of similar critical value of S for influencing rainfall and onset of Indian southwest monsoon has been noted in our other studies (Chakraborty and Bandyopadhaya 1985, 1986, 1987).

6. Conclusion and remarks

The main results of our study are the following :

(*i*) In general, a negative association between cyclonic disturbances and sunspot number has been noted. When S exceeds 80 this negative association is marked.

(*ii*) Decrease in average value of cyclonic disturbances simultaneously with increase in sunspot number from the middle of the decade 1940-50, particularly from the solar cycle started in 1947.

The present paper merely throws some light on the sun-weather relationship, the establishment of which will require much extensive and detailed works in future.

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