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Analysis of pre-monsoon thunderstorm frequency over Sriniketan, Alipore and Kalaikunda — The possible association with solar activity

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सार — श्री निकेतन (23°39'उ०, 87°42'पू०), अलीपुर (22°32'उ०, 88°20'पू०) तथा कलाईकुण्डा (22°20'उ०, 87°13'पू०) में 1957-89 के दौरान मानसून-पूर्व ऋतु में प्रेक्षित तड़ितझंझा आवृत्ति (टी.एस.एफ.) के सामान्य लक्षणों का अध्ययन किया गया है। यह देखा गया कि मानसून पूर्व टी.एस.एफ. 6 वर्ष 6 माह की विषम आवर्तिता का अनुसरण करता है। कुल मिलाकर कलाईकुण्डा (के.एल.के.) में प्रवृत्ति आरोही तथा श्रीनिकेतन (एस.के.टी.) में प्रवृत्ति अवरोही पाई गई है, जबकि अलीपुर (ए.एल.पी.) में प्रवृत्ति व्यावहारिक रूप से स्थिर रही है। इन तीनों केन्द्रों की अधिकतम टी.एस.एफ. लगभग वर्ष में दो बार की पाई गई है जो कि इन केन्द्रों की औसत टी.एस.एफ. है।

तड़ितझंझा (टी.एस.) की आवृत्ति पर सौर प्रभाव की जांच की गई और इसे रोचक पाया गया है, 1957 के दौरान, कलाईकुन्डा और श्रीनिकेतन में तड़ितझंझा आवृत्ति न्यूनतम रही, जबकि अलीपुर में यह न्यूनतम के निकट पाई गई, हालांकि वर्ष 1957 की पूरी अन्वेषणाधीन अवधि में सूर्य सबसे अधिक बार आच्छादित (एस.एस.) रहा। अब सामान्य रूप से यदि हम समान वर्ष के एस.एस. संख्या तथा तड़ितझंझा आवृत्ति को लें और सभी वर्षों के सहसंबंध गुणांक (सी.सी.) की गणना करें, अर्थात् बिना किसी अवरोध के एस.एस. लें तो सहसंबंध गुणांक बहुत कम रहेगा। परन्तु यदि अधिक एस.एस. संख्या वाले वर्षों के टी.एस.एफ. मान पर विचार किया जाए तो परिणाम बिल्कुल विपरीत रहता है। विशेषत: जब एस.एस. संख्या किसी क्रांतिक मान (≈140) से ज्यादा होती है तब तड़ितझंझा आवृत्ति तेजी से घटती है।

इसमें तड़ितझंझा पर सौर उप-चक्र, 11-वर्षीय चक्र और 22-वर्षीय चक्र के प्रभाव की चर्चा भी की गई है। यह देखा गया कि न्यूनतम-अधिकतम उप-प्रावस्थाओं के दौरान औसत तड़ितझंझा आवृत्ति अधिकतम न्यूनतम के सन्निकट उप-प्रावस्थाओं के मान की तुलना में अधिक है और यही स्थिति औसत एस.एस. के साथ विपरीत प्रावस्था में भी पाई गई है। 11 वर्षीय चक्र के दौरान भी अधिकांश मामलों में औसत टी.एस.एफ. और औसत एस.एस. के मध्य विपरीत प्रावस्था संबंध पाए गए हैं।

ABSTRACT. General characteristic features of thunderstorm frequency (TSF) observed during (1957-89) during pre-monsoon season at Sriniketan (23°39'N, 87°42'E), Alipore (22°32'N, 88°20'E) and Kalaikunda (22°20'N, 87°13'E) have been studied. It is seen that premonsoon TSF follows a rough periodicity of 6.6 years. For Kalaikunda (KLK) there is an overall upward trend and for Sriniketan (SKT) an overall downward trend; whereas, for Alipore (ALP) the trend pattern remains practically constant. The maximum TSF attained by all these three stations is nearly twice that of mean TSF of respective stations.

The solar influence on the frequency of thunderstorm (TS) has been investigated and found to be interesting. TSF over SKT and KLK attained minimum value while that over ALP was near minimum during 1957; which in turn, was the year of maximum sunspot (SS) number over the entire period of analysis. Now in general, if we take SS number and TSF of same year and calculate correlation coefficient (CC) considering all the years, *i.e.*, taking SS without any restriction, the CC comes out to be quite small. But the result is just the reverse when the TSF value of those years is considered when SS number is higher. In particular when SS number exceeds some critical value (≈140), TSF decreases sharply.

The effect of solar sub-cycle, 11-year cycle and 22-year cycle on TS has also been discussed. It is seen that during min-max sub-phases, mean TSF is comparatively higher than its value in neighbouring max-min sub-phases and also it is in opposite phase in relation with mean SS. During 11-year cycle also in most of the cases an opposite phase relationship exists between mean TSF and mean SS.

Key words — Pre-monsoon thunderstorm, Sunspot (SS) number, Critical value, Solar cycle.

1. Introduction

Thunderstorm (TS) is a major mesoscale weather phenomenon particularly during pre-monsoon seasons over NEE region of India. Statistical analysis of the frequency, periodicity, duration, diurnal variation, monthwise and seasonwise distribution etc. for TS have been done by Sohoni

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TABLE 1

Statistical features of thunderstorm frequency

S. No.	Parameter	SKT (23°39'N)	ALP (22°32'N)	KLK (22°20'N)
1.	Mean ($\overline{TSF}$)	16.7	20.6	27.7
2.	Standard deviation (σ_{TSF})	6.68	6.76	8.31
3.	Coeff. of variation (CV)	40.1	32.7	30.0
4.	Maximum TSF	32 (1963, 192%)	37 (1981, 179%)	47 (1981, 170%)
4.	Minimum TSF	1 (1957, 6%)	6 (1985, 29%)	11 (1957, 40%)
6.	Range of TSF	31 (186%)	31 (150%)	36 (130%)

N.B. Percentage figures are with respect to mean.

(1931), Raman and Raghavan (1961), Rao *et al.* (1971), Prasad and Pawar (1985), Sivaramkrishnan (1990) and Kumar (1992) among others.

Many successful investigations have been made during the last three decades to understand the influence of solar activity on meteorological phenomena, *viz.*, southwest monsoon circulation (Jagannathan and Bhalme 1973), fluctuation of flood area (Bhalme and Mooley 1981), temperature (Mohankumar and Davanarayanan 1984), agricultural productivity (Bishnoi 1986), nile flood (Mosallam and Tadros 1990), atmospheric electricity (Markson 1978 and Muir 1978) etc. Also, Chakraborty and Bondyopadhaya (1986, 1987, 1988, 1989) have shown that the association between different weather phenomenon, *viz.*, rainfall, onset of Indian southwest monsoon, variation of premonsoon temperature and cyclonic disturbances over Indian sea with solar activity becomes significant particularly when SS number exceeds some critical value. Mohankumar and Davanarayanan (1983, 1985) have established some phase relationship between stratopause temperature and mesospheric mean temperature with solar cycle. Ananthakrishnan and Parthasarathy (1984) showed some influence of SS cycle on annual rainfall.

The role of solar activity on meteorological parameters is still a debatable topic and some possess a critical view to this (Pittock 1978, 1983), while some others possess a very optimistic view (Bucha 1980, 1983 and Wilcox, 1973). This is why more and more studies on solar-terrestrial interaction are necessary. In the present paper, an attempt has been made to study the influence of solar activity (estimated in terms of annual mean SS number) on the pre-monsoon TSF.

It is also kown that the frequency of TS is maximum during pre-monsoon season (March to May) over the NE/E India. In the present paper, we consider the frequency of premonsoon TS over the three stations, Sriniketan (SKT) (23°39'N, 87°42'E), Alipore (ALP) (22°32'N, 88°20'E) and Kalaikunda (KLK) (22°20'N, 87°13'E) in the eastern India for the 33 years period, 1957 to 1989. Here number of TS days have been considered as frequency of TS. As SKT started its operation from July, 1960, the previous 4 years' data have been collected from its nearest station Suri (23°53'N, 87°32'E). The data used have been collected from Monthly Meteorological Report (MMR) published by India Meteorological Department (IMD). The annual mean SS number have been obtained from the Indian Institute of Astrophysics, Bangalore.

2. Results and discussion

2.1. *Some characteristic features of TSF over SKT, ALP and KLK*

2.1.1. *General statistical features of TSF*

Some general statistical features of TSF over SKT, ALP and KLK in pre-monsoon season (March-May) during 33 years (1957-89) of study have been presented in Table 1 and discussed briefly as follows :

(*i*) The maximum TSF attained in all three stations is nearly twice that of mean TSF of respective stations (vide Table 1).

(*ii*) The ranges for the three stations are not much different though the ranges calculated with respect to mean shows much variation.

(*iii*) During 33 years' analysis, there are 5 maxima and 5 minima of TSF curve for all the three stations (Fig. 1), which are ensured from Figs. 2 (a-c). Thus TSF curve follows nearly 6.6-year cycle.

(*iv*) It is interesting to note that minimum TSF for both SKT and KLK occurred in the year 1957. Even in ALP the TSF in that year was much below the mean TSF value.

(*v*) In case of ALP (22°32'N) the mean, standard deviation (σ), maximum and minimum of TSF, all have the values less than those of KLK (22°20'N), but higher than those of SKT (23°39'N). Whereas, maximum and range when expressed in terms of percentage with respect to mean, SKT (23°39'N) takes highest value, KLK (22°20'N) the lowest, with ALP (22°32'N) in between. Thus, it appears that there may be reasons like latitude-wise dependence of TSF. But there may be other dominating reasons present.

2.1.2. *Trend of TSF*

To understand the trend of TSF with time, let us find the three years' moving average (TYMA) values of TSF. This TYMA of any parameter A is defined as,

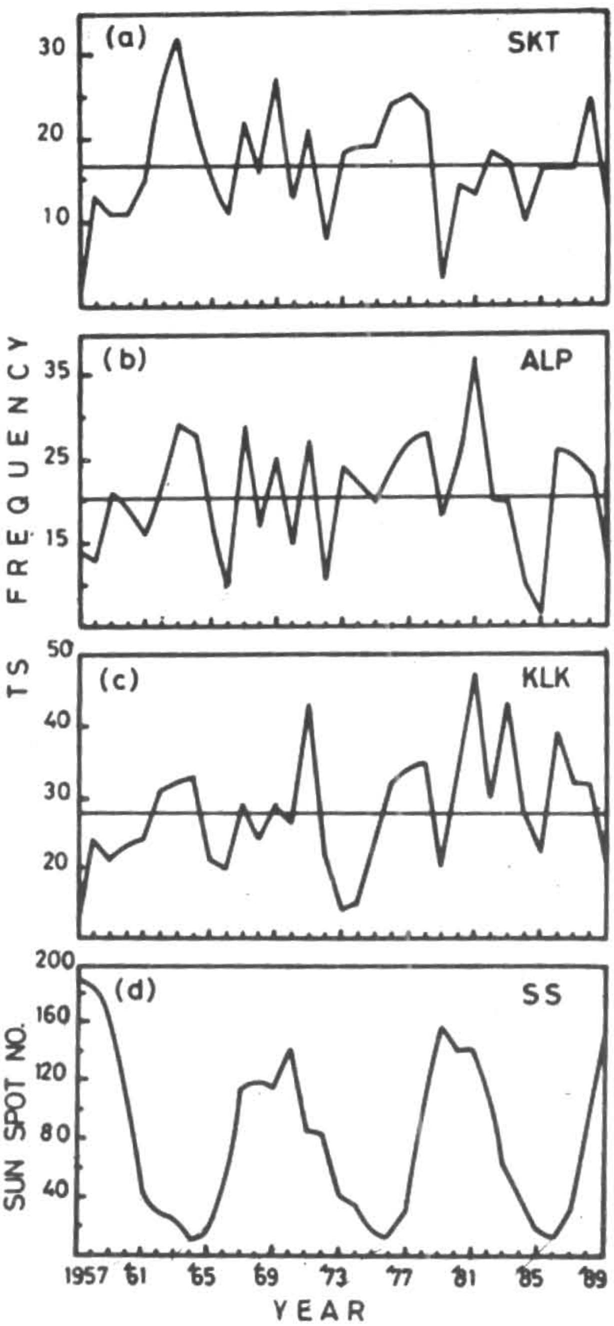
$$\tilde{A}_m = 1/3\ (A_{n-1} + A_n + A_{n+1}) \qquad (1)$$

where, n is the year for which the average value is required.

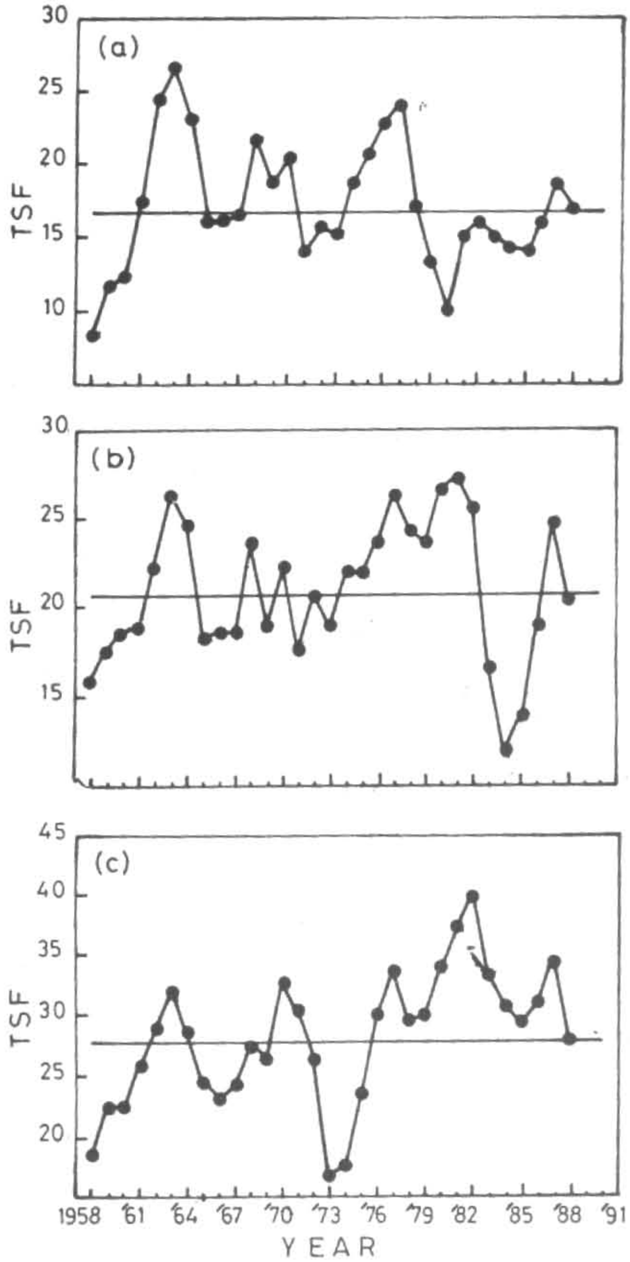
This TYMA value of TSF for SKT, ALP and KLK produces the Figs. 2 (a-c) respectively.

Now it is interesting to note from these figures that a common increasing trend persists from 1958 to 1963 for all three stations. Moreover, there is a decreasing trend between 1963-71 and 1977-80 for SKT, 1981-84 for ALP and 1983-88 for KLK. Whereas, the increasing trend is maintained between 1980-88 and 1971-77 for SKT, 1971-81 and 1984-87 for ALP and 1973-82 and 1982-88 for KLK.

Again for SKT there is nearly an overall downward trend, for ALP, no clearcut trend pattern



Figs. 1 (a-d). Annual Sun Spot (SS) number and yearly pre-monsoon thunderstorm frequency (TSF)



Figs. 2 (a-c). 3 years' moving average of TSF of (a) Sriniketan, (b) Alipore and (c) Kalaikunda

as a whole can be designated; whereas for KLK nearly an upward trend prevails.

For better understanding of the long term trend, three years' moving average (TYMA) of 3 years' moving average values of TSF have also been calculated and the formula used for any parameter A is given as :

$$A'_n = 1/3\ (\widetilde{A}_{n-1} + \widetilde{A}_n + \widetilde{A}_{n+1}) \qquad (2)$$

Same procedure has been followed as was done in case of TYMA and this also confirmed the same trend pattern, as observed in case of TYMA.

Fig. 2 (a) suggests that there is a reversal in direction of trend pattern for SKT with a gap during 1973-80. Again a much larger and distinct increasing trend prevails between 1973-81 for ALP [Fig. 2 (b)] and 1973-82 for KLK [Fig. 2 (c)], unlike other spells of respective stations. Thus the spell mentioned shows some disparity in the normal behaviour of TSF of different stations. There lies one common solar maximum year, *e.g.,* 1979 (Section 2.1.4). Let us discuss some characteristic features of TSF before and after 1979. We divide the entire period into two parts, 1957-78 and 1979-89.

2.1.3. *Characteristic features of TSF before and after 1979*

Some characteristic features of TSF for all three stations during the segmented period have been presented in Table 2.

(*i*) Among the three stations if we consider mean TSF during later half compared to that during first half, SKT which is in higher latitude position shows decrease in value, while ALP, whose latitude position is in middle shows marginal shift with KLK, the lower latitude station shows increase in value. However, as in section 2.1.1 (*v*) the latitude dependence may not be the only reason.

(*ii*) The dispersion value measured in terms of coefficient of mean deviation (CMD) remains same in magnitude with reverse in direction during each half for SKT and KLK; while that for ALP takes negligible value during each half in respect of SKT and KLK.

(*iii*) Coefficient of variation, which is a relative measure of fluctuation about mean, has decreased for SKT as well as for KLK, but increased remarkably for ALP during later period (1979-89) as reflected in Fig. 2 (b).

(*iv*) The trend of TSF for the stations before and after 1979 can be comprehended from Figs. 2 (a-c).

TABLE 2

Characteristic features of TSF before and after 1979

Period	Mean			Standard deviation (SD)			Dispersion (%)					
							Coeff. of mean deviation (CMD)			Coeff. of variation (CV)		
	SKT	ALP	KLK	SKT	ALP	KLK	SKT	ALP	KLK	SKT	ALP	KLK
1957-78	17.8	20.8	25.8	7.1	5.9	7.43	+6.9	+0.9	−6.9	39.7	28.3	28.8
1979-89	14.4	20.3	31.5	5.1	8.2	8.63	−13.8	−1.8	+13.9	35.3	40.2	27.3

It is seen from these figures that for SKT the moving average values of TSF are mostly above mean line before 1979 and below mean line after 1979. This observation is also well verified from Table 2, where the mean TSF have decreased during later half and CMD reverses in direction taking positive value on first half to negative value on second half. Thus, there is a decreasing trend for SKT during later half compared to that during first half.

For ALP no clearcut trend pattern before and after 1979 can be designated from the figures as the points are equally distributed by numbers around the mean line. But Table 2 suggest that there is a decreasing trend (though marginally) on the later half for ALP and likewise dispersion (in CMD) value have changed in sign, *i.e.*, from positive on first half to negative on later half.

From Fig. 2 (c) it is seen that for KLK the moving average values of TSF are mostly below mean line before 1979 and above mean after 1979, thus showing an increasing trend after 1979. This is again in coincidence with the observation of mean and dispersion values (in CMD) of Table 2 for KLK, where the mean TSF value have increased and dispersion (in CMD) have reversed in sign with positive value on later half.

2.1.4. *Comparison between the variation of TSF and SS*

Let us now present some characteristic features of SS with reference to TSF.

(*i*) From Table-3 it is seen that SS is highly variable (CV≃68%): whereas TSF is moderate (Table 1).

TABLE 3

Statistical features of sunspot number

Mean ($\bar{S}$)	81.6
Standard deviation ($\bar{\sigma}_s$)	55.7
Coeff. of variation (CV)	68.3
Maximum	190.2 (1957, 233%)
Minimum	10.6 (1964, 13.0%)
Range	179.6 (220.1%)

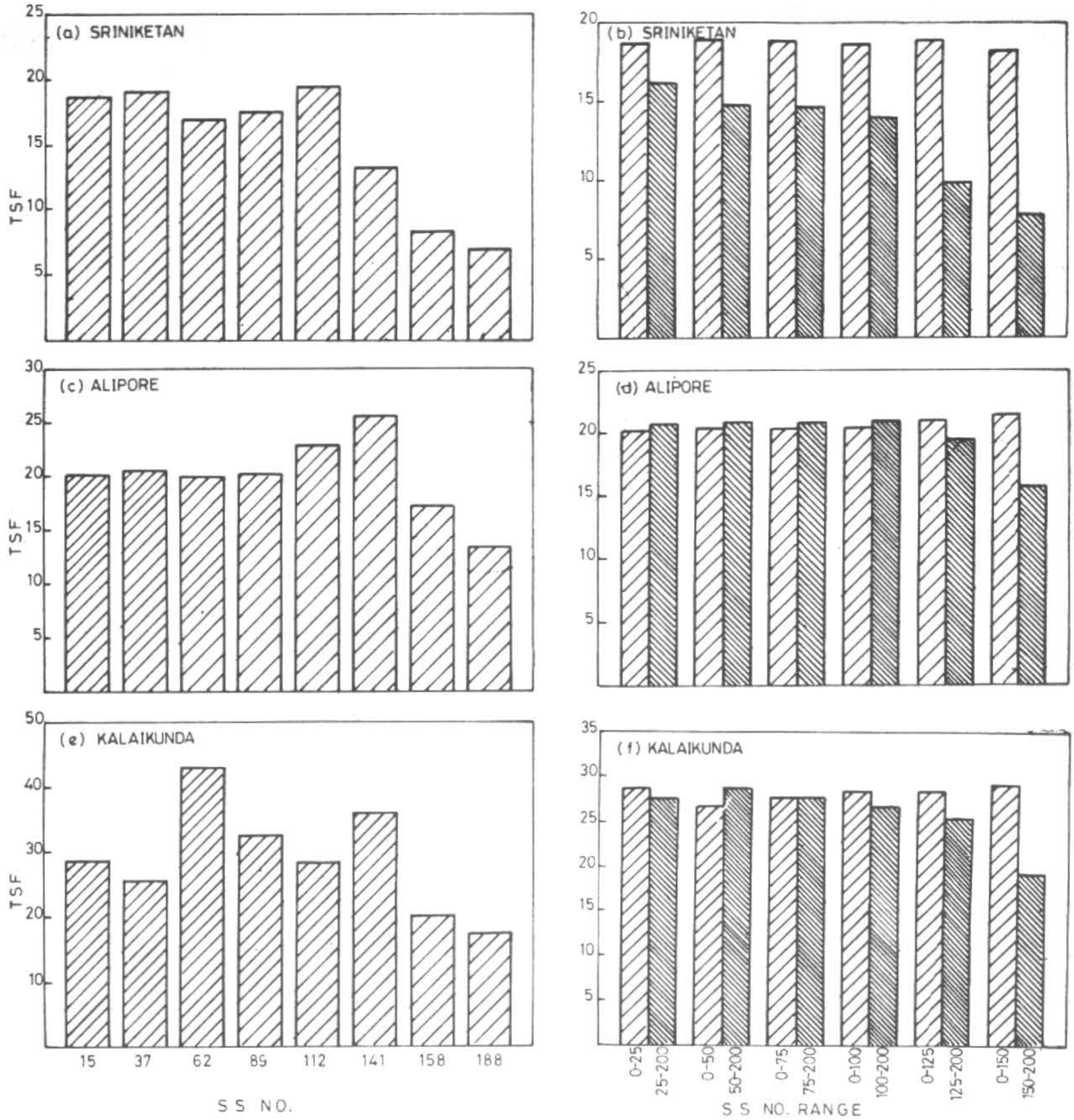
N.B. Percentage figures are with respect to mean.

TABLE 4

Characteristic features of SS number before and after 1979

Period	Mean	Standard deviation (SD)	Dispersion (%)	
			Coeff. of mean deviation	Coeff. of variation (CV)
1957-78	78.4	56.23	−3.9	71.7
1979-89	88.0	54.04	7.8	61.4

(*ii*) The range when calculated in terms of % with respect to mean it takes much higher value for SS than that of TSF for all the three stations (Tables 3 & 1), implying much varied distribution of SS than TSF.



Figs. 3 (a-f). Variation of mean TSF for different SS range (a, c & e) and determination of critical values (b, d & f)

(*iii*) The maximum SS occurred on 1957 (Table 3) when there was minimum TSF in SKT and KLK [Section 24.1 (*iii*)].

(*iv*) The mean SS have increased during later half (Table 4) implying a increasing trend of SS during period 1979-89 in respect of period 1957-78.

(*v*) Coefficient of variation of SS and TSF of all stations except ALP have decreased during later half.

(*vi*) During period under consideration (33 years) there are 3 maxima and 3 minima of SS curve. Thus, on an average the SS curve follows 11.2-year cycle; whereas TSF curve follows 6.6-year cycle [section 2.1.1 (*iii*)], which is nearly half that of solar cycle.

(*vii*) During period of analysis there are 3 SS maximum years and these are 1957, 1970 and 1979. Now from Fig. 1, it is seen that during all solar maximum years, the TSF

TABLE 5

Average SS number and TSF in different SS intervals with corresponding year

SS class	Corresponding year	Average SS number	Average TSF		
			SKT	ALP	KLK
0-25	1964, 1965, 1975, 1976, 1985, 1986	14.6	18.7	20.2	28.5
> 25-50	1961, 1962, 1963, 1966, 1973, 1974, 1977, 1984, 1987	36.8	19.1	20.6	25.4
> 50-75	1983	61.5	17.0	20.0	43.0
> 75-100	1971, 1972, 1988	89.0	17.7	20.3	32.3
> 100-125	1960, 1967, 1968, 1969, 1978, 1982	112.1	19.5	23.0	28.3
> 125-150	1970, 1980, 1981	141.0	13.3	25.7	36.0
> 150-175	1959, 1979, 1989	157.9	8.3	17.3	20.3
> 175-200	1957, 1958	187.5	7.0	13.5	17.5

of all three stations are below mean line. Moreover, TSF attained minimum value during 1957 for SKT and KLK, and 1979 being another solar maximum year coincides with trough of TSF curve for all three stations.

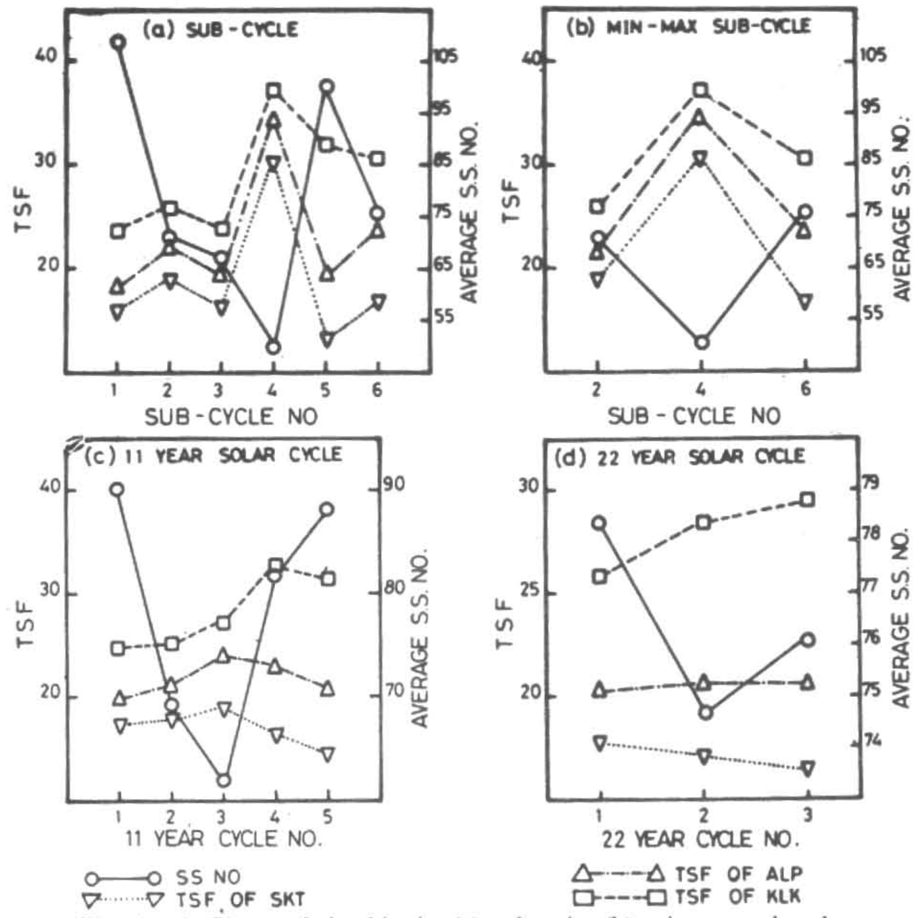
2.2. *Variation of TSF with large SS number and the existence of critical SS number*

Let us divide the entire SS range (0-200) into different SS classes with a convenient interval of 25. We plot mean values of TSF against mean values of SS in each SS intervals in Figs. 3 (a, c & e). From Table 5 and Figs. 3 (a, c & e), it is clear that, generally, if there is any influence of SS on TSF it is inverse in nature and only effective provided SS number is quite high even at the maximum end. In all the cases the inverse effect is prominent only when mean SS number > 140. But, before that, *i.e.*, 0 < SS number < 140, neither the variational nature is well defined nor it is very prominent in all the cases except the singular case, SS number ≃ 60 for KLK.

Naturally the question arises why the effect is only visible in case of maximum end of SS number? But before going to explain that let us go through the calculation made in Table 6 (a). Here again the entire SS range (0-200) is divided into 8 SS classes with a convenient interval of 25. Here we find, so long as entire range is concerned, the effect is although inverse but mostly insignificant. Obviously this implies either there is no influence or there is a unity of contradiction of two tendencies. Now already these tendencies are noticeable in Table 5 where, there are both tendencies for SS < 150. Furthermore, if we go through Tables 6 (a & b) and Figs. 3 (b, d & f), we can compare the two situations : one is what happens when SS number is taken from 0 to some value say x and the other is x−200. The contrast is extremely good for SKT and easily recognizable for ALP and KLK. The Figs. 3 (b, d & f) imply that if we take the SS range from 0 to any value between 25 & 200, the TSF value almost remains constant and CC although negative maintains non-significant level. But, as we move to find the dependence of TSF on the smaller and smaller range of SS towards maximum end like 25-200, 50-200, ..., 150-200 the inverse effect is more and more prominent, all are inverse in nature [Table 6 (b) and Figs. 3 (b, d & f)] and most of CC are significant.

Thus, we arrive at the conclusion that for large SS number (say > around 140) for all three stations SKT, ALP and KLK, the TSF decreases with the increase of SS. But for SS number 0-140 the influence is either sum of two tendencies [Figs. 3 (a, c & e)] or there is no influence. Naturally the second alternative seems to be more realistic as because, if there is very small or no SS number, the question of influence does not arise and any variation of TSF seems to be due to orography itself.

Thus, there exist SS number ≃ 140 beyond which the influence of SS on TS appears to be



Figs. 4 (a-d). Phase relationship in (a) sub-cycle, (b) min-max sub-cycle, (c) 11-year solar cycle and (d) 22-year solar cycle

TABLE 6 (a)

Correlation coefficient (CC) between SS and TSF for different ranges of SS number

Range	No. of obsn.	Mean TSF			Correlation coefficient (CC)		
		SKT	ALP	KLK	SKT	ALP	KLK
0-25	6	18.7	20.2	28.5	−.31	−.22	−.12
0-50	15	18.9	20.4	26.7	−.33	−.30	−.46
0-75	16	18.8	20.4	27.7	−.31	−.26	−.05
0-100	19	18.6	20.4	28.4	−.17	−.11	+.16
0-125	25	18.8	21.0	28.4	−.04	+.08	+.07
0-150	28	18.3	21.5	29.2	−.20	+.18	+.22
0-200	33	16.7	20.6	27.7	−.50	−.09	−.15

prominent. It is to note here that the result obtained by Chakraborty and Bondyopadhaya (1986, 1987, 1988) shows the existence of some critical value of SS in neighbourhood of 140 to influence rainfall over West Bengal, onset of Indian southwest monsoon and pre-monsoon temperature over eastern India.

Again it is seen that when average SS number increases from 140 to 158 the sharpness of decrease

TABLE 6 (b)

Range	No. of obsn.	Mean TSF			Correlation coefficient (CC)		
		SKT	ALP	KLK	SKT	ALP	KLK
25-200	27	16.2	20.7	27.5	−.52	−.14	−.16
50-200	18	14.8	20.8	28.6	−.58	−.27	−.58
75-200	17	14.6	20.9	27.7	−.61	−.32	−.50
100-200	14	14.0	21.0	26.7	−.74	−.50	−.51
125-200	8	9.9	19.5	25.5	−.54	−.61	−.71
150-200	5	7.8	15.8	19.2	−.20	−.56	−.42

of TSF is varied latitudewise (Table 5). The decrement is maximum for KLK followed by ALP and SKT respectively. The same latitudewise dependence is also maintained when we consider the declining effect of TSF from 125-200 to 150-200 range [Table 6 (b)].

Now same calculations for all three stations have also been done taking into account the SS of previous year in place of current year. But the result is not so encouraging as was obtained, taking current year SS data. This is because pre-monsoon TS, over NE/E India is mainly local scale phenomenon and may not dependable on previous year SS data.

2.3. *Variation of TSF with solar cycles*

Let us now investigate the effect of different SS cycle, if any, on TSF. The 33 years period of our analysis comprises of six complete sub-cycles, three complete 11-year cycles and one complete 22-year cycle. For elaborate study on the said effect, one may consider the overlapping cycles and thus obtain five 11-year cycles and three 22-year cycles. For each cycle, the mean and standard deviation of SS as well as TSF are computed vide Tables 7-9. Computations have also been made for the deviations of these mean values of TSF and SS from the corresponding means for each cycle, in terms of their respective standard deviations. These are represented by Z_{TSF} and Z_S respectively where,

$$Z_{TSF} = \left[\frac{TSF-\overline{TSF}}{\overline{\sigma}_{TSF}}\right], \quad Z_s = \left[\frac{S-\overline{S}}{\overline{\sigma}_s}\right] \qquad (2)$$

Here $\overline{TSF}$ and $\overline{S}$ are mean and $\overline{\sigma}_{TSF}$, $\overline{\sigma}_s$ standard deviation of TSF and SS respectively during the entire period (values given in Tables 1 and 3).

2.4. *Variation with solar sub-cycle*

(*i*) In respect of phase consideration (Fig. 4 (a) and Table 7) no clearcut consistency is observed with SS and TSF for all three stations during solar sub-cycles.

Though the minimum mean SS occurs when there is maximum mean TSF for all three stations (cycle-4). The standard deviation S.D. of SS and TSF are also minimum during the same sub-cycle for all three stations. In the said cycle-4, the departure is maximum negative for SS ($Z_s = -0.568$), whereas the departure is maximum positive for TSF of SKT ($Z_{TSF} = +2.03$), ALP ($Z_{TSF} = +1.73$) and KLK ($Z_{TSF} = +1.13$).

On the other hand maximum mean *S* corresponds to minimum mean TSF in case of ALP and KLK and very near to the minimum in case of SKT (sub-cycle 1). In this cycle Z_s takes maximum positive value ($Z_s = +0.451$) and Z_{TSF} takes maximum negative value in case of ALP ($Z_{TSF} = -0.22$) and KLK ($Z_{TSF} = -0.48$) and next to maximum negative value in case of SKT ($Z_{TSF} = -0.16$).

(*ii*) Now when we concentrate on min-max phases 2, 4, 6 only (Table 7), a definite opposite phase relationship is observed [Fig. 4 (b)] for each station under consideration, which is not so clear during max-min phases.

Again TSF is comparatively high, in almost all the cases of minimum to maximum phases in comparison to neighbouring maximum to minimum phases of SS sub-cycle of all three stations. If we consider the mean values of TSF during all max-min phases and compare the same with those during min-max phases, then the above observation is confirmed for all three stations as follows :

	SKT	ALP	KLK
Max-min phase	14.97	19.47	26.57
Min-max phase	21.93	25.02	31.29

It may be noted that the pre-monsoon TS activity over NE/E India is a result of convective phenomenon for which higher value of temperature is one of the most important factor. Thus higher TSF may be expected during solar min-max phases when the correlation between temperature and SS number is positive (Chakraborty and Bondyopadhaya 1988).

(*iii*) From Fig. 4 (a) it is seen that in each sub-cycle mean TSF takes highest value for KLK (22°20′N), followed by ALP (22°32′N) and SKT (23°39′N) respectively.

2.5. *Variation with 11-year solar cycle*

From Table 8 and Fig. 4 (c) it is seen that,

(*i*) SS and TSF are opposite in phase in almost all the cases of three stations under consideration during 11-year solar cycle. But on the contrary no general consistency of TSF of three stations is observed when we concentrate on maximum mean S (Cycle 3) and minimum mean S (Cycle 1) 11-year cycle.

Cycle 3 corresponds to minimum mean S, minimum σ_s and maximum departure below mean ($Z_s = -0.358$). Whereas on the same cycle of TSF, there is maximum mean TSF value, with maximum departure above mean for SKT as well as for ALP but not for KLK. In this cycle SD of ALP is minimum and that of SKT is very close to minimum.

Cycle 1 corresponds to maximum mean S, with maximum standard deviation and maximum departure above mean ($Z_s = +0.151$), whereas it corresponds to minimum mean TSF for ALP and KLK with minimum SD for KLK and very near to minimum for ALP and maximum departure below mean for both ALP and KLK.

(*ii*) During each 11-year cycle as well, KLK takes highest mean TSF value and SKT the lowest value, with ALP in between.

2.6. *Variation with 22-year solar cycle*

From Table 9 and Fig. 4 (d) it is seen that,

(*i*) There is no general consistency in phase relationship is observed between SS and TSF of three stations.

It could be noted that minimum mean *S* (Cycle 2), minimum SD (σ_s), with maximum departure below mean line (Z_s) corresponds to moderate mean TSF, moderate SD of TSF, with minimum departure above mean (Z_{TSF}) for all three stations.

Further maximum mean *S* (Cycle 1), with maximum SD (σ_s) and minimum negative departure Z_s, corresponds to maximum mean TSF, maximum σ_{TSF}, maximum positive departure Z_{TSF} (= +0.17) above mean line for SKT; whereas minimum mean, minimum SD for TSF of ALP and KLK.

(*ii*) During each 22-year cycle as well as sub-cycle and 11-year cycle, mean TSF of KLK is highest, SKT the lowest with ALP in between.

3. Conclusions

The present study reveals the following general conclusions :

(*i*) There is rough periodicity of 6.6 years for TSF of all three stations.

(*ii*) Normally during solar maximum years low TSF occurs.

(*iii*) There exists an overall upward trend of TSF for KLK, a downward trend for SKT, but no clearcut trend for ALP during entire period of analysis.

(*iv*) Inverse association between TSF and SS is observed only for high SS values. This, inturn, implies the existence of a critical value of SS beyond which TSF decreases rapidly. This critical value is roughly 140 for all the three stations.

(*v*) Analysis during solar sub-phases also indicate an inverse association between mean TSF and mean SS during minimum to maximum phase. Furthermore, minimum to maximum sub-phases have been found to contain some favour on higher TS compared to the neighbouring maximum to minimum sub-phases.

(*vi*) In almost all the 11-year solar cycles an opposite phase relationship is found to

TABLE 7

Variation of mean TSF with half solar cycle

Phase	Cycle no.	Period	SS number			TSF								
			Mean (S)	SD (σ_s)	Z_S	Mean (TSF)			SD (σ_{TSF})			Z_{TSF}		
						SKT	ALP	KLK	SKT	ALP	KLK	SKT	ALP	KLK
Max-Min	1	1957-63	106.7	67.7	+.451	15.6	19.1	23.7	9.6	5.1	6.5	−.16	−.22	−.48
Min-Max	2	1964-69	70.5	47.2	−.199	18.8	21.0	26.0	5.3	6.9	4.7	+.32	+.05	−.20
Max-Min	3	1970-75	67.5	41.9	−.253	16.3	19.8	24.0	4.5	5.4	9.6	−.05	−.12	−.45
Min-Max	4	1976-78	50.0	38.6	−.568	30.3	32.3	37.1	0.8	1.7	1.2	2.03	1.73	1.13
Max-Min	5	1979-85	95.1	50.8	+.242	13.0	19.4	32.0	4.8	9.3	9.5	−.55	−.18	+.52
Min-Max	6	1986-89	75.6	57.2	−.108	16.8	21.8	30.8	4.7	5.2	6.8	+.01	+.17	+.37

TABLE 8

Variation of mean TSF with 11-year solar cycle

Phase	Cycle no.	Period	SS number			TSF								
			Mean (S)	SD (σ_s)	Z_S	Mean (TSF)			SD (σ_{TSF})			Z_{TSF}		
						SKT	ALP	KLK	SKT	ALP	KLK	SKT	ALP	KLK
Max-Max	1	1957-69	90.0	61.8	+.151	17.1	20.0	24.8	8.1	6.1	5.8	+.06	−.09	−.35
Min-Min	2	1964-75	69.0	44.7	−.226	17.6	20.4	25.0	5.1	6.2	7.6	+.14	−.03	−.33
Max-Max	3	1970-78	61.6	41.7	−.358	18.9	22.0	27.2	5.2	5.5	9.1	+.33	+.20	−.06
Min-Min	4	1976-85	81.6	51.8	−.001	16.3	21.5	32.5	6.5	8.5	8.0	−.06	+.13	+.58
Max-Max	5	1979-89	88.0	54.0	+.115	14.4	20.3	31.5	5.1	8.2	8.6	−.35	−.05	+.46

TABLE 9

Variation of mean TSF with 22-year solar cycle

Phase	Cycle no.	Period	SS number			TSF								
			Mean (S)	SD (σ_s)	Z_S	Mean (TSF)			SD (σ_{TSF})			Z_{TSF}		
						SKT	ALP	KLK	SKT	ALP	KLK	SKT	ALP	KLK
Max-Max	1	1957-78	78.4	56.2	−.057	17.8	20.8	25.8	7.1	5.9	7.4	+.17	+.03	−.23
Min-Min	2	1964-85	74.7	48.4	−.124	17.0	20.9	28.4	5.8	7.3	8.6	+.05	+.04	+.09
Max-Max	3	1970-89	76.1	50.6	−.098	16.4	21.1	29.6	5.6	7.1	9.1	−.04	+.06	+.23

prevail between mean TSF of all stations and mean SS.

(*vii*) Among the three stations, latitudewise variation of mean TSF is observed. KLK (22°20′N) possess highest mean TSF, followed by ALP (22°32′N) and SKT (23°39′N) respectively. The same tendency is also being maintained during each solar sub-cycle, 11-year as well as

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22-year cycle. Again the drop of TSF above critical value is varied latitudewise. For KLK the drop is maximum followed by ALP and SKT respectively. However, before we draw the conclusion about the latitudinal dependence we must check whether the orographical explanation is sufficient to explain this variation or not.

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References

Ananthakrishnan, R. and Parthasarathy, B., 1984, "Indian Rainfall in relation to the Sunspot Cycle : 1871-1978", *J. Clim.*, **4**, pp. 149-169.

Bhalme, H. N. and Mooley, D. A., 1981, "Cycle fluctuations in the flood area and relationship with double (Hale) Sunspot cycle", *J. Appl. Met.*, **20**, pp. 1041-1048.

Bishnoi, O. P., 1986, "Solar radiation & productivity in India-I : Potential productivity", *Mausam*, **37**, 4, pp. 501-506.

Bucha, V., 1980, "Mechanism of the relations between the charges of the geomagnetic field, solar corpuscular radiation, atmospheric circulation and climate", *J. Geomag. Geoelect.*, **32**, pp. 217-264.

Bucha, V., 1983, "Direct relations between solar activity and atmospheric circulation : Its effect on changes of weather and climate", *Studia Geoph. Etgeod*, **27**, pp. 19-45.

Chakraborty, P. K. and Bondyopadhaya, R., 1986, "Solar effect on rainfall in West Bengal", *Mausam*, **37**, 2, pp. 251-258.

Chakraborty, P. K. and Bondyopadhaya, R., 1987, "Variation of the onset of Indian southwest monsoon over Kerala with solar activity", Proc. Indian Nat. Sci. Acad., 53, A, No. 2, pp. 303-307.

Chakraborty, P. K. and Bondyopadhaya, R., 1988, "Variation of premonsoon temperature over eastern Indian and the solar activity", Proc. Indian Nat. Sci. Acad., 54, A, No. 1, pp. 106-113.

Chakraborty, P. K. and Bondyopadhaya, R., 1989, "Influence of solar activities on the cyclonic disturbances over Indian seas", *Mausam*, **40**, 3, pp. 287-292.

Jagannathan, P. and Bhalme, H. N., 1973, "Changes in the pattern of distribution of southwest monsoon rainfall over India associated with sunspots", *Mon. Weath. Rev.*, **101**, 9, pp. 691-700.

Kumar, Awadhesh, 1992, "A climatological study of thunderstorm at Lucknow airport", *Mausam*, **43**, 4, pp. 441-444.

Markson Ralph, 1978, "Atmospheric electricity and the sun-weather problem", Solar Terrestrial Influences on Weather and Climate, pp. 215-231.

Mohankumar, K. and Devanarayanan, S., 1984, "Stratospheric and mesospheric temperatures and solar activity", *Mausam*, **35**, 1, pp. 97-98.

Mohankumar and Devanarayanan, 1983, Proc. Indian Acad. Sci. 92, pp. 31-36.

Mohankumar, 1985, Planet Space. Sci., 33, pp. 795-805.

Mosallam Shaltaut and Tadros M.T.Y., 1990, "Correlation analysis between the Sunspots and the Nile flood", *Mausam*, **41**, 4, pp. 565-568.

Muir, 1978, "The role of atmospheric electricity in sun-weather relationship", Solar-terrestrial influences on weather and climate, pp. 259-263.

Pittock, A. B., 1978, "A critical look at the long-term sun-weather relationship", *Rev. Geophys., and Space Phys.*, **16**, pp. 400-420.

Pittock, A. B., 1983, "Solar variability, weather and climate : An update", *Quart. J. R. Met. Soc.*, **109**, pp. 23-55.

Prasad, S. K. and Pawar, B. C., 1985, "Climatological studies of TS to the west & east of the western ghats in the state of Maharashtra & Goa : Part-I", p. 107.

Raman and Raghavan, 1961, "Diurnal variation of thunderstorms in India during different seasons", *Indian J. Met. Geophys.*, **12**, 1, p. 115.

Rao, K. N., Dainet, C. E. J. and Pejabi, K. G., 1971, India Met. Dep. Pre-Publ. Sci. Rep. No. 154.

Sivaramkrishnan, T. R., 1990, "An analytical study of thunderstorm over Sriharikota", *Mausam*, **41**, 1, pp. 489-491

Sohoni, V. V., 1931, "Thunderstorms of Calcutta, 1990-1926", Scientific Notes, Vol. I, No. 5, pp. 26-36.

Wilcox, J. M., 1973, Science 180 (1973), "Solor magnetic structure in relation to circulation of the earth's atmosphere", pp. 185-186.