MAUSAM, 51, 3 (July 2000), 235 - 244

551.553.21 : 551.515.4 : 551.547.3

Effect of altitude on the variation of pre-monsoon thunderstorm frequency during periods of higher sun spot number

INDRANI ROY

Regional Meteorological Centre, Alipore, Calcutta-700 027, India

and

R. BONDYOPADHAYA

Mathematics Department, Jadavpur University, Calcutta-700 032, India

(*Received 12 August 1998, Modified 21 June 1999*)

सार - 1955 से 1980 तक की अवधि में सूर्य के धब्बों (एस. एस.) पर आधारित मानसून ऋतु से पूर्व तड़ित झंझा की आवृति (टी. एस. एफ.) में आए परिवर्तन से संबंधित समूचे भारत में फैले हुए कुल 96 केन्द्रों से प्राप्त सूचना का अध्ययन किया गया है। अधिकाँश केन्द्रों से हमें माध्य एस. एस. के समीप सूर्य के धब्बों की विवेचनात्मक संख्या का पता चला है, जिनमें से 140 के संबंध में एस. एस. संख्या की वृद्धि के साथ-साथ माध्य टी. एस. एफ. की वृद्धि अथवा ह्रास की स्पष्ट प्रवृति देखी गयी है। यह भी देखा गया है कि यदि टी. एस. एफ. की संख्या विवेचनात्मक संख्या से अधिक है तो लगभग 280 मी. से अधिक ऊँचाई वाले सभी केन्द्रों पर एस.एस. की संख्या बढ़ने के साथ - साथ टी. एस. एफ. में वृद्धि हुई है।

ABSTRACT. The variation of pre-monsoon Thunder Storm Frequency (TSF) depending on the appearance of sun spot (S.S.) have been studied for the period 1955-80 for total 96 stations distributed all over India. For most of the stations we can identify a critical S.S. number in the neighbourhood of mean S.S. 140 above which a clear increasing or decreasing trend of mean TSF is observed with increase of S.S. number. It has also been seen that for almost all the stations having altitude greater than 280m, TSF increases with increase of S.S. number provided it is greater than the critical number.

Key words — Sun Spot number, Thunderstorm frequency, Altitude

1. Introduction

Regarding solar terrestrial interaction, many scientists possess optimistic attitude (Bucha 1980, 1983 and wilcox 1973) while some scientists show critical outlook (Pittock 1978, 1983). The efffect of solar activity on different meteorological phenomena *i.e.*, temperature (Mohankumar and Davanarayanan 1984), southwest monsoon circulation (Jagannathan and Bhalme 1973), fluctuation of flood area (Bhalme and Mooley 1981), atmospheric electricity [Markson (1978) and Muir (1978)] etc. have successfully been studied. Chakraborty and Bondyopadhaya (1986, 1987, 1988, 1989) have noted the existance of critical sun spot (S.S.) number in the neighbourhood of 140 to influence rainfall, onset of Indian southwest monsoon, pre-monsoon temperature and cyclonic disturbances over Indian seas. Kar and Bondyopadhaya (1996) have also showed the existance of critical S.S. number ~ 140 to influence pre-monsoon thunderstorm frequency of three individual stations *i.e.*, Sriniketan (altitude 59m), Alipore (altitude 6m) and Kalaikunda (altitude 61m).

In the present study an attempt has been initiated to study the effect of S.S. in higher ranges on pre-monsoon thunderstorm frequency taking into account a large network of stations comprising total 96 stations distributed all over India. Whether the altitude has any special effect over the variation of TSF above critical S.S. number has been studied. The data used have been collected from National Data Centre (NDC), Pune and the period considered is from 1955 to 1980.

2. Trend of variation of mean TSF with S.S. number

To study the effect of Sun Spot (S.S.) on thunderstorm frequency (TSF) in specific portion, we

TABLE 1

Correlation coefficient of mean TSF and S.S. in different S.S. ranges

S. No.	Station	STN	Altitude (A) (m)	C.V.	Value of 'r'	C.C. of SET-I				SET-II	SET-III		
						0-90	0-120	0-150	0-180	0-210	90-210	120-210	150-210
(1)	(2)	(3)	(4)	(5)	(6)	(7)				(8)	(9)		
1.	Kodaikanal	KDK	2343	+25.7		-.30	-.16	-.02	+.26	-.13	-.10	-.12	+.46
2.	Mukteswar	MKS	2311	+4.4		-.04	0	-.01	+.07	-.16	-.15	+.12	+.91
3.	Shimla	SML	2202	+190.8		-.27	-.38	-.30	-.15	+.05	+.61	+.69	+.88
4.	Shillong	SHL	1598	+178.1		+.25	+.26	+.27	+.41	+.44	+.50	+.62	+.88
5.	Srinagar	SRN	1587	+46.8		+.36	+.46	+.52	+.56	+.39	-.05	+.14	+.65
6.	Mahabaleswar	MWR	1382	+59.5		-.20	-.11	-.07	+.24	+.21	+.47	+.38	-.89
7.	Cherrapunji	CPJ	1313	-29.5	.167	-.21	-.46	-.45	-.30	-.43	-.05	-.28	-.62
8.	Dharmasala	DRM	1211	+47.5	.143	-.05	+.05	+.05	-.03	+.11	+.14	+.20	+.35
9.	Chitradurga	CHT	960	+37.4	.125	-.40	-.34	-.16	-.06	-.20	-.01	-.29	+.19
10.	Bangalore	BNG	921	+258.5	.111	-.18	-.13	-.04	+.15	+.08	+.40	+.39	+.86
11.	Imphal	IMP	781	+312.3	.100	+.21	-.02	0	+.34	+.13	+.49	+.42	+.54
12.	Belgaum	BLG	747	-83.1	.200	+.18	+.22	+.05	+.22	-.12	-.37	-.03	+.47
13.	Dehradun	DDN	682	+133.1	.182	+.05	-.11	-.14	+.26	+.09	+.25	+.37	+.59
14.	Ranchi	RNC	652	-126.6	.273	-.05	-.01	+.08	+.24	-.13	-.26	-.44	-.03
15.	Gadag	GDG	650	+103.2	.250	-.10	+.25	+.18	+.14	+.14	-.13	+.36	+.71
16.	Pendra Road	PND	625	+81.7	.231	-.08	+.09	+.11	+.06	0	-.07	+.24	+.96
17.	Chikalthan	CTN	579	+297.4	.214	+.01	-.13	-.07	-.05	+.02	+.35	+.43	+.97
18.	Indore	IND	567	+297.7	.200	0	-.07	-.03	+.08	+.01	+.26	+.31	+.67
19.	Pune	PNE	559	+.53.5	.187	-.11	-.01	+.12	+.29	+.10	+.01	-.03	+.42
20.	Jagdalpur	JGD	553	+65.0	.182	+.26	+.02	+.01	+.13	-.10	+.01	+.29	+.96
21.	Hyderabad	HYD	545	+101.7	.174	+.36	+.08	+.16	+.16	+.03	+.17	+.04	+.81
22.	Bairagarh	BRG	523	+289.6	.167	+.11	-.12	-.17	+.15	+.14	+.61	+.70	+.63
23.	Ajmer	AJM	486	+199.2	.16	-.36	-.20	-.21	-.07	+.12	+.54	+.76	+.88
24.	Solapur	SLP	479	+299.5	.154	-.04	0	-.02	0	+.15	+.31	+.72	+.99
25.	Guna	GNA	478	+205.6	.136	-.10	-.33	-.28	+.17	+.01	+.55	+.43	+.14
26.	Peelamedu	PMD	399	-260.9	.182	-.21	-.12	-.08	+.50	-.24	-.39	-.58	-.89
27.	Jabalpur	JBP	393	+259.2	.174	+.06	-.11	-.12	0	+.06	+.53	+.62	+.77
28.	Jaipur	JPR	390	+28.9	.167	-.15	+.05	+.02	+.50	+.14	+.18	+.18	-.36
29.	Anantapur	ANT	350	+146.8	.160	+.02	+.11	+.23	+.38	+.25	+.20	+.07	+.62
30.	Satna	STN	317	+109.6	.154	-.17	-.28	-.16	-.06	-.19	+.14	-.28	+.56
31.	Nagpur	NGP	310	+276.1	.148	+.15	+.11	+.04	+.02	+.16	+.37	+.65	+.94
32.	Hoshangabad	HSB	302	+140.6	.143	-.40	-.20	-.16	-.01	+.04	+.32	+.44	+.47
33.	Raipur	RPR	298	+3.9	.138	+.29	+.27	+.10	-.09	-.06	-.24	+.33	+.99
34.	Churu	CRU	291	+28.1	.133	+.03	+.26	+.39	+.62	+.38	+.11	-.19	+.12
35.	Kurnool	KRN	281	+70.8	.129	-.11	+.05	+.11	+.12	+.14	-.02	+.21	+.63
36.	Ambala	AMB	278	-131.5	.161	-.28	-.11	+.01	+.22	-.07	-.29	-.45	-.64

TABLE 1 (*Contd.*)

(1)	(2)	(3)	(4)	(5)	(6)	(7)				(8)		(9)	
37.	Patiala	PTL	251	-43.9	.193	-.45	+.14	+.15	+.41	+.19	-26	-.03	-.29
38.	Jhansi	JHN	251	+185.7	.187	-.04	-.23	+.01	+.28	+.41	+.76	+.66	+.82
39.	Ludhiana	LDN	247	-140.9	.219	-.15	-.11	-.14	-.17	-.27	-.34	-.56	-.53
40.	Amritsar	AMR	234	-76.8	.250	-.45	-.10	-.29	+.27	-.18	-.04	+.28	-.04
41.	Jaisalmer	JSM	231	-128.4	.281	-.29	-.08	-.02	+.19	-.04	-.23	-.41	-.62
42.	Jharsuguda	JRG	230	+8.5	.500	-.01	+.15	+.03	-.01	-.03	-.13	+.33	+.88
43.	Bikaner	BKR	224	-141.4	.312	+.02	-.26	-.13	+.28	-.18	-.05	-.38	-.79
44.	Hissar	HSR	221	-143.7	.344	-.16	-.12	+.03	+.20	-.08	-.12	-.32	+.05
45.	Daltongang	DTG	221	+129.7	.333	+.39	+.38	+.42	+.43	+.51	+.31	+.40	+.91
46.	Jodhpur	JDP	217	+155.2	.323	0	-.35	-.27	+.24	-.04	+.44	+.14	-.30
47.	New Delhi	DLH	216	+175.8	.314	-.27	-.28	-.20	+.20	-.01	+.42	+.43	+.74
48.	Gwalior	GWL	207	-13.2	.343	-.31	-.22	-.34	+.10	-.21	+.10	+.37	-.34
49.	Barmer	BRM	194	+124.5	.333	-.26	-.31	-.37	+.17	+.06	+.57	+.62	-.01
50.	Sriganganagar	GGN	177	+93.4	.324	-.31	-.16	-.30	-.24	-.20	+.16	+.60	+.73
51.	Ramgundam	RMD	156	+170.5	.316	-.36	-.07	-.08	+.06	+.13	+.25	+.84	+.95
52.	Rajkot	RJK	138	+186.3	.308	+.02	+.13	+.05	+.23	+.22	+.25	+.57	+.42
53.	Lucknow	LKN	128	-220.3	.333	-.06	+.02	+.10	+.29	-.16	-.61	-.94	-.95
54.	Bahraich	BRC	124	-33.3	.359	+.13	-.12	+.01	+.15	-.17	-.09	-.43	-.19
55.	Gaya	GYA	118	-114.9	.385	-.09	-.12	-.10	-.08	-.34	-.56	-.65	-.06
56.	Dibrugarh	DBH	111	+242.2	.375	+.28	-.02	+.08	+.48	+.16	+.45	+.13	+.20
57.	N. Lakhimpur	NLP	102	-175.0	.400	+.30	+.39	+.33	+.56	+.09	-.60	-.50	-.32
58.	Mangalore Bajpe	MNG	102	-92.6	.425	+.12	+.18	+.8	+.41	+.11	-.21	-.03	+.13
59.	Allahabad	ALB	98	+288.2	.415	+.02	+.09	+.07	+.26	+.14	+.27	+.75	+.94
60.	Silchar	SLC	97	+158.4	.405	+.25	+.12	+.05	+.52	+.12	+.33	+.48	-.11
61.	Varanasi	VNS	90	-100.7	.428	+.10	+.05	-.05	+.53	+.10	-.01	-.14	-.68
62.	Tiruchirapalli	TRP	88	+227.1	.419	-.30	-.23	-.08	+.19	+.03	+.34	+.26	+.63
63.	Bhuj	BHJ	80	+222.8	.409	-.15	+.03	+.04	+.07	+.15	+.26	+.41	+.67
64.	Port Blair	PBL	79	-252.4	.432	-.24	-.08	+.05	+.48	-.12	-.32	-.67	-.28
65.	Gorakhpur	GRK	78	-111.8	.454	-.21	+.21	+.36	+.49	+.25	-.35	-.53	-.57
66.	Ratnagiri	RTN	67	-34.5	.477	+.22	-.05	-.19	-.24	-.29	-.33	+.18	+.84
67.	Patna	PTN	57	-183.4	.500	+.09	+.10	+.19	+.33	0	-.35	-.87	-.86
68.	Ahmedabad	AHM	55	-110.3	.523	-.02	+.14	-.06	+.39	+.06	-.07	+.20	-.46
69.	Guwahati	GHT	54	+28.5	.511	+.35	+.18	+.22	+.50	+.15	+.05	-.19	+.56
70.	Bhubaneswar	BWN	46	-111.9	.522	+.02	-.06	-.26	+.03	-.50	-.43	-.17	-.99
71.	Honavar	HNV	26	+118.9	.500	-.01	+.32	+.09	+.21	+.20	+.01	+.53	+.34
72.	Gannavaram	GNV	24	+46.8	.500	+.02	-.09	-.01	+.06	-.09	+.04	-.13	+.53
73.	Balasore	BLS	20	+61.0	.489	+.11	-.32	-.09	+.27	+.02	+.28	-.59	-.05
74.	Nellore	NLR	20	+30.8	.480	+.37	-.15	-.18	-.21	-.25	+.23	+.09	+.91
75.	Gopalpur	GPL	17	-4.9	.500	+.23	+.15	-.05	+.05	-.01	-.15	+.49	+.61
76.	Agartala	AGT	16	-37.7	.520	+.36	+.09	+.13	+.50	+.08	+.14	-.42	-.58

TABLE 1 (*Contd.*)

(1)	(2)	(3)	(4)	(5)	(6)	(7)				(8)		(9)	
77.	Minambakkam	MBM	16	0	.509	+.52	+.41	+.23	+.37	+.20	-.05	+.36	+.28
78.	Santacruz	SCZ	14	+76.2	.500	+.02	-.14	+.13	+.22	+.09	+.17	-.33	+.06
79.	Cuddalore	CDL	12	-127.0	.519	-.13	+.14	+.03	-.04	-.09	-.36	+.24	+.79
80.	Bombay	BMB	11	+109.0	.509	+.11	+.05	+.12	+.16	+.10	+.06	0	+.47
81.	Pambaa	PBN	11	-131.7	.528	-.06	-.14	+.02	-.09	-.19	-.19	-.41	-
82.	Nagapattinam	NPT	9	-28.7	.547	+.43	+.37	+.07	+.13	+.01	-.20	+.38	+.35
83.	Veraval	VVL	8	-64.4	.566	+.05	+.06	+.23	+.45	+.14	-.02	-.58	-.53
84.	Kakinada	KKN	8	-140.0	.585	+.15	-.07	-.11	+.15	-.18	-.27	-.40	-.72
85.	Porbandar	PBD	7	-105.1	.604	+.60	+.56	+.51	+.59	+.39	-.19	-.17	-.20
86.	Puri	PRI	6	-25.7	.623	-.25	+.02	+.06	+.31	+.14	-.13	-.09	-.68
87.	Kalingapatnam	KLN	6	-180.2	.641	+.08	+.33	+.22	+.24	+.09	-.49	-.02	+.14
88.	Dahanu	DHN	5	-84.4	.660	+.19	+.04	-.08	-.04	-.22	-.45	-.28	-.53
89.	Kozhikode	KZK	5	+61.0	.648	-.17	+.05	+.04	+.64	+.26	+.33	+.39	-.11
90.	Karwar	KWR	4	-138.6	.667	-.13	+.28	+.28	+.43	+.19	-.39	-.52	-.97
91.	Amini Divi	AMN	4	-134.7	.685	+.01	+.03	+.05	-.14	-.28	-.56	-.57	-
92.	Tuticorin	TTC	4	-39.1	.704	-.15	-.51	-.50	-.58	-.64	-.21	-.35	-
93.	Thiruvananthapuram	TRV	4	-25.9	.722	+.16	-.01	-.17	+.38	-.17	-.09	+.16	-.03
94.	Vishakhapatnam	VSK	3	+38.2	.709	+.36	+.24	+.27	+.28	+.14	-.05	+.05	+.76
95.	Machilipatnam	MPT	3	+103.7	.696	+.25	-.32	-.04	-.02	-.15	+.27	-.55	+.53
96.	Minicoy	MNC	2	+63.2	.714	-.01	-.25	-.20	+.09	-.09	+.11	-.08	+.40

have divided the entire S.S. ranges starting from S.S. number 0 to S.S. number 210 into 7 classes with equal width of 30. The width 30 is convenient to choose because it is the minimum width with which, each S.S. class can contain atleast one observation. Thus 7 S.S. classes so formed are 0-30, 30-60, 60-90, 90-120, 120-150, 150-180 and 180-210 respectively. Now we first identify the seven sets of years when those S.S. class occur. Then we calculate the mean of S.S.number occurring in those seven sets of years. The means come out to be 17, 39, 84, 113, 141, 158 and 188 respectively. Similarly means of TSF occurring in those identified years have been calculated for 96 stations under consideration. Now to find the trend of variation of these seven (7) mean TSF (A_n) depending on S.S. number three data moving average method could be used conveniently using the formula.

$$\widetilde{A}_m = 1/3\ (A_{n-1}+A_n+A_{n+1}),\ m = 1,2,3,4,5$$

Where, $\widetilde{A}_m$ is the calculated mean TSF value. Also a set of 5 mean S.S. values have been calculated likewise and these are 47, 79, 113, 137 and 162. Now with these three data moving average of mean TSF values and with 5 mean S.S. values as obtained above, we draw the curves of TSF *vs* S.S. for all 96 stations under consideration (Fig.1). Here mean TSF have been plotted along *Y*-axis and mean S.S. along *X*-axis. In the figure, the abbreviated names of stations (Table 1) under column heading STN (stations) and the altitude (*A*) [in meter (m)] of the stations have also been shown.

Since Kar and Bondyopadhaya (1996) have shown the existance of some S.S. number in the neighbourhood of mean S.S. 140 to influence the variation of mean TSF in case of three individual stations. Hence in this section we mainly concentrate on the nature of variation of mean TSF in highest S.S. ranges *i.e.*, between mean S.S. 137 and 162. Now it is seen from Fig.1 that maximum and minimum values of mean TSF *i.e.*, ranges of the graphs are different for different stations. To generalise such variation of mean TSF in higher S.S. ranges, we have calculated coefficient of variance (C.V.) of mean

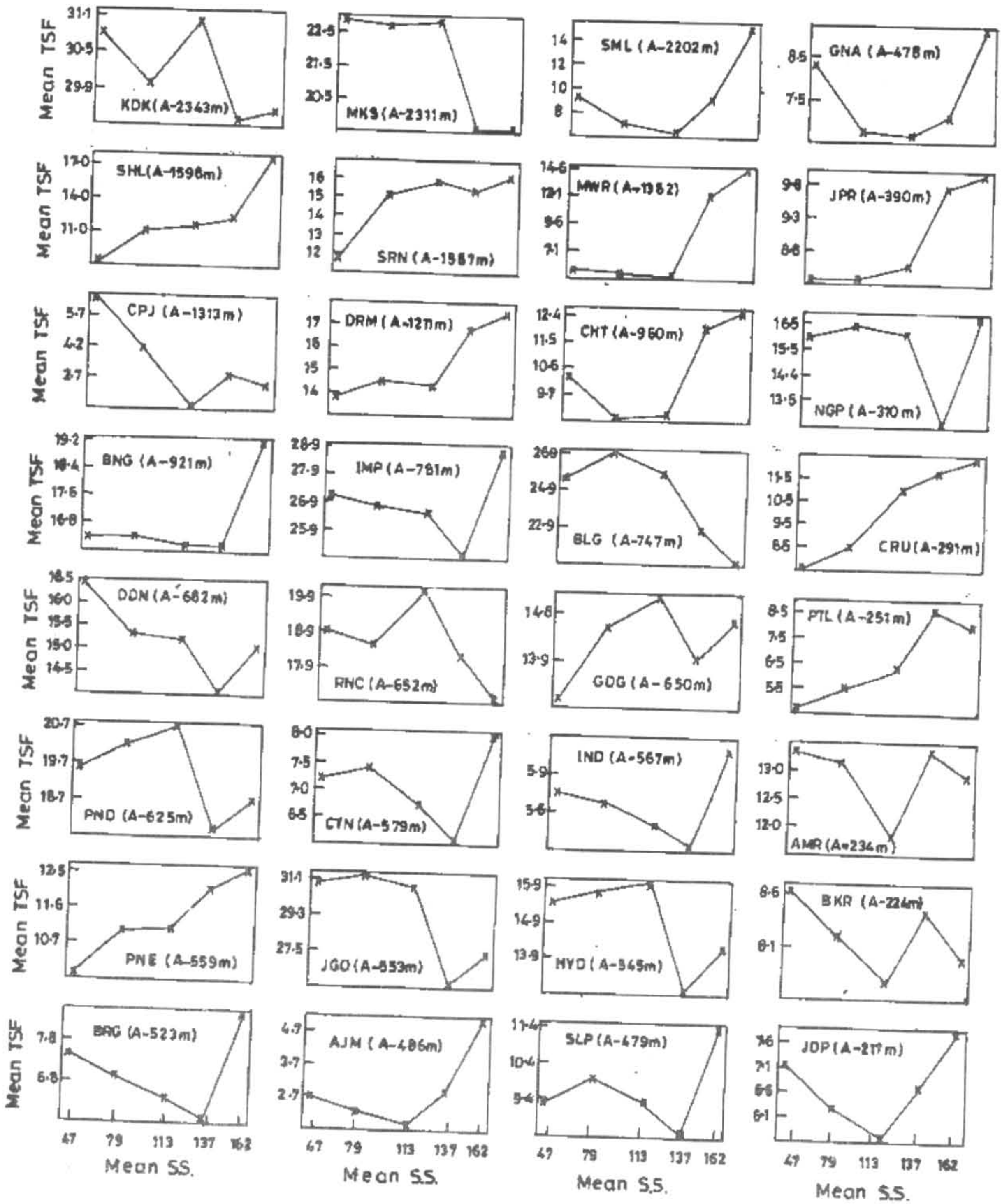

Fig.1. Trend of TSF in different S.S. classes

TSF for last two S.S. ranges for each station using the formula,

$$C.V. = (m_2 - m_1) \times 100 / S.D.$$

Where, m_2 is the mean TSF of last S.S. range with mean S.S. 162, m_1 is the mean TSF of the preceding lower S.S. range with mean S.S. 137 and S.D. is the standard deviation of all 5 mean TSF values *i.e.*, starting

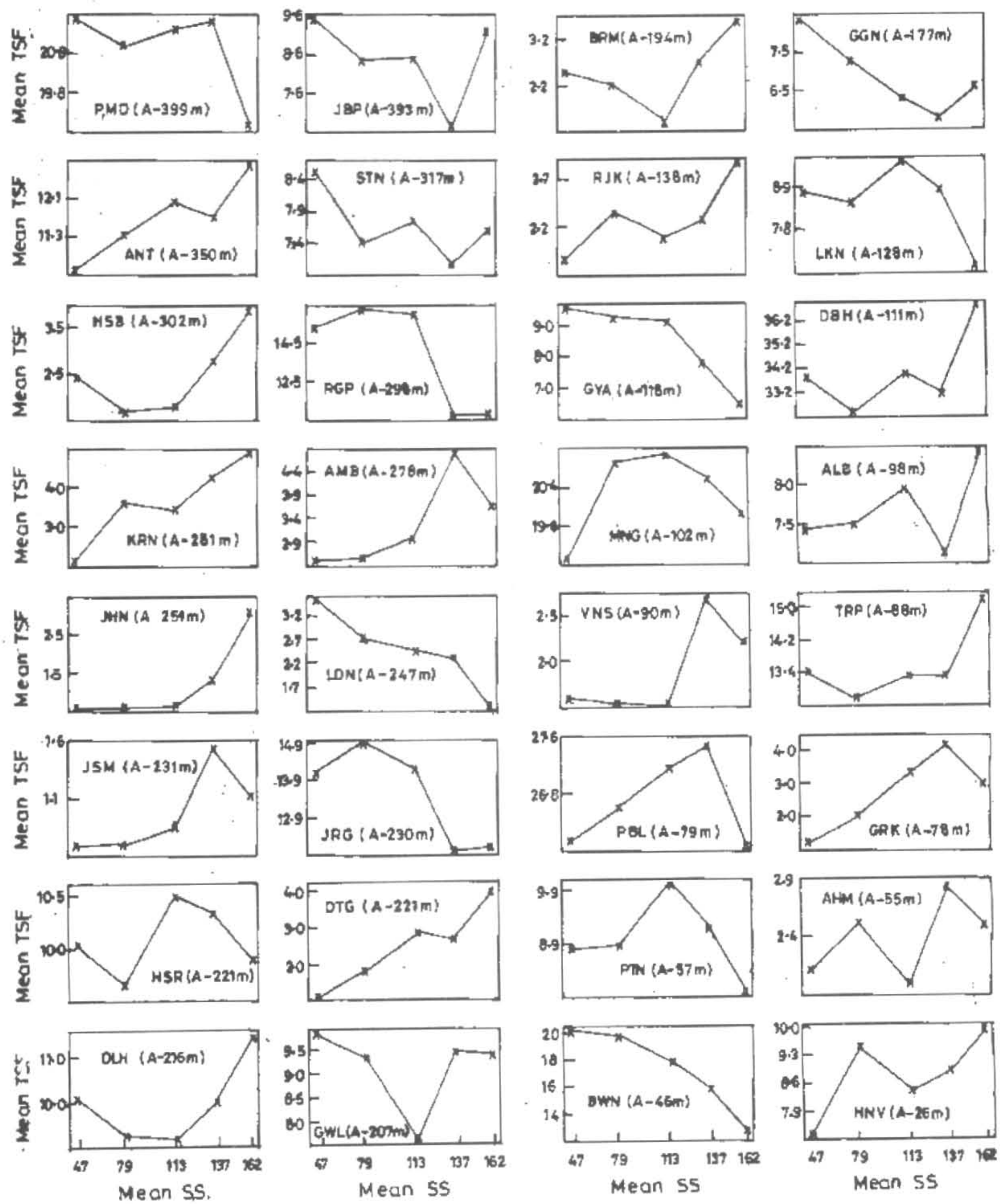

Fig.1 (*Contd.*). Trend of TSF in different S.S. classes

from $\widetilde{A}_1$ upto $\widetilde{A}_5$. The values of C.V. thus calculated for all stations have been shown in Table 1. Now +ve and –ve value of C.V. obviously imply increase and decrease in value of mean TSF between mean S.S. 137 and 162 and may be defined as increasing or decreasing trend of mean TSF for S.S. number > 137.

It is found from Table 1 that our of total 96 stations, +ve and –ve C.V. are 58% and 42% respectively. Thus we can say if we consider S.S. number > 137 then the increase of TSF with increase of S.S. number is more promiment. Now among +ve C.V. (total 56 by number),

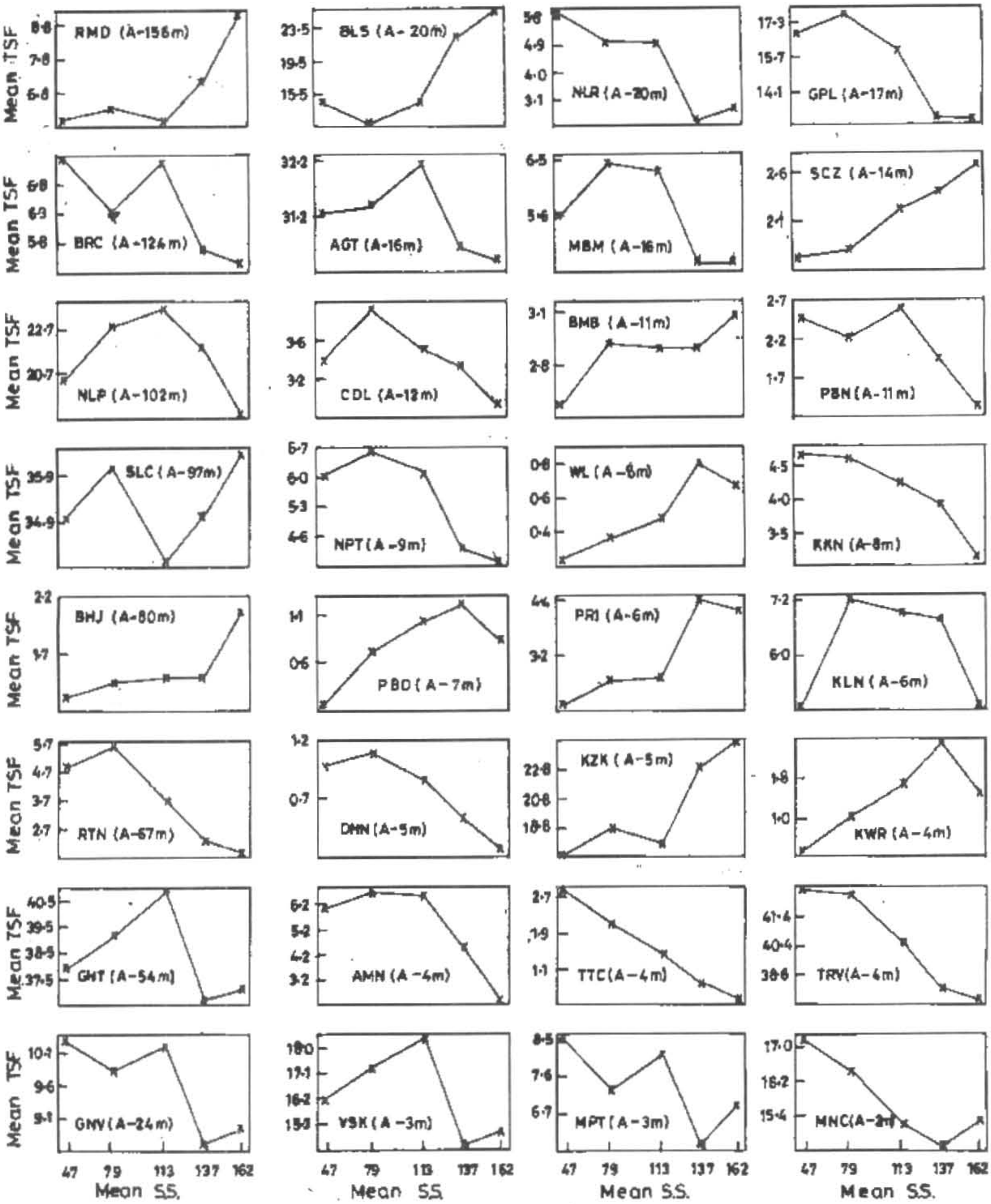

Fig.1 (*Contd.*). Trend of TSF in different S.S. classes

cases those exceed 30% value of C.V. are 88% (49 out of 56) and cases of even higher magnitude of C.V., exceeding 100% are 59% (33 out of 56). Whereas for –ve C.V. (total 40 by number), cases exceeding 30% value of C.V. are 82% (33 out of 40) and cases where C.V. are quite high; even exceeding 100% are 57% (23 out of 40).

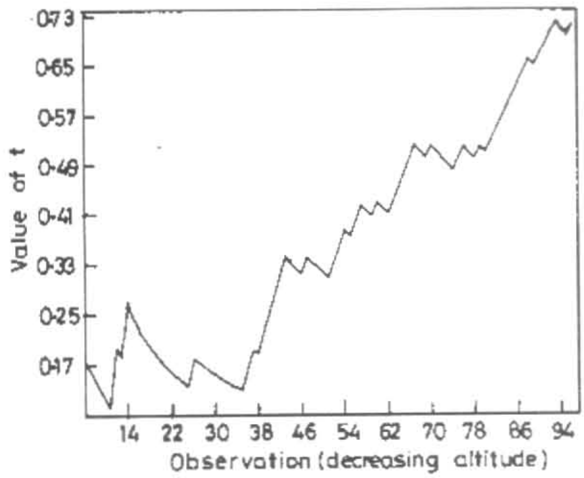

Fig.2. Determination of critical altitude

These imply that the variation of TSF in maximum S.S. ranges are noteworthy for majority of cases irrespective of the mathematical sign of C.V.; however +ve C.V. with high magnitude are more than the –ve one.

3. Existence of some critical altitude to influence TSF in higher ranges of S.S.

Here we are interested mainly to study whether there is any effect of specific altitude to influence the variation of TSF in higher S.S. ranges. For this purpose graphs of TSF *vs* S.S. for all 96 stations in Fig.1, have been arranged row-wise in a descending order of altitude. From these graphs an interesting aspect can be observed namely 88.5% (31 out of 35) stations having altitude higher than 280m show increasing trend of TSF with +ve value of C.V., provided, of course, S.S. number of concerned years are above mean S.S. number *viz.* ~ 137. But for stations having altitude less than 280 m, the observation is not so consistent. Here out of 61 cases only 36 cases *i.e.*, 59% show decreasing trend of mean TSF (*i.e.*, with –ve value of C.V.) for mean S.S. > 137 (Table 2). Thus we can say that the increasing effect is prominent mainly when $A > 280$m. This 280m altitude may be termed as somewhat critical altitude. Here we can note that stations having $A > 280$m have S.No.1-35; whereas stations having $A < 280$m have S.No.36-96 (Table 1).

Let us now discuss why we have choosen the altitude 280m as some kind of critical altitude? To do so we have introduced a new parameter 't' and upto each particular S.No. of observation this is a ratio as defined by,

$$t = \frac{\text{Total number of } - \text{ve C.V. (only in highest S.S. range)}}{\text{Total number of } + \text{ve C.V. (only in highest S.S. range)}}$$

Here the value of 't' starts from S.No.7 where at the first time it can assume –ve value of C.V. [here 't' = 1/6 = .167]. The values of 't' thus calculated for each S.No. have been shown in Table 1. Taking these 't' values a graph has been plotted with 't' along Y-axis and S.No. of observations along X-axis (Fig.2). We must note that the value of 't' at some S.No. carries the influence of all the stations having S.No. less than that.

From Fig.2 and Table 1 it is seen that a decreasing trend exists between S.No.12 upto 35; at S.No.35 't' possess minimum value and thereafter 't' more or less increases with S.No. (although 't' has slightly lower value for S.No.9-11; but the total number of observations in those cases are very few). Thus for practical purposes S.No.35 behaves like a turning point for reversal of trend of 't' (here it is from decreasing trend to increasing one). Now as per definition of 't', increasing 't' implies decreasing TSF and since after S.No.35, the altitude decreases, therefore it can be concluded that TSF decreases with decreasing altitude and that starts from S.No.35. Conversely it can be said that TSF increases with increasing altitude provided S.No. < 35 *i.e.*, altitude >280m. But we should remember two aspects in this context. Firstly the increase or decrease of 't' at certain S.No. (*i.e.* at certain altitude) means only that upto that height the majority of stations have exhibited increase or decrease of C.V. Secondly all these observations are restricted to highest range of S.S. No. Hence for practical purpose approximately the altitude for S.No. 35 *i.e.*, 280m may be designated as a kind of critical altitude above and below which the reverse influence of S.S. on TSF is likely in 'majority' of cases provided, of course, at that time S.S. number is also quite high; within maximum range (137-162). It may be mentioned here that the inverse effect on mean TSF due to mean S.S. > 140 in cases of stations Sriniketan (A = 59m), Alipore (6m) and Kalaikunda (61m) have already been observed (Kar and Bondyopadhaya, 1996). This is consistent with our present observation as well.

4. Correlation coefficient study

For better understanding of observations covering different S.S. ranges, correlation coefficients (C.C.) between mean TSF and mean S.S. have been calculated for different S.S. ranges (Table 1). Here we have considered three sets of S.S. ranges. In SET-I, we have considered S.S. ranges all of which have fixed lower limit of 0 and the upper limits are so chosen that there would be an interval of 30 from preceding upper limit. Thus the upper limits considered here are 90, 120, 150 and 180. In SET-II we have considered only one range of S.S. *i.e.*, starting from 0 upto 210. In SET-III we have considered those S.S. ranges which end with S.S. number 210 but

TABLE 2

Determination of critical altitude

Altitude (m)	Number of Obs.	C.V.		C.C. of Set III	Level of significance of C.C.	
		+ve	-ve		90% level	99% level
> 280	35	31	4	31 +ve	19	12
				4 -ve	3	2
< 280	61	25	36	27 +ve	14	5
				34 -ve	10	3
Total	96	56	40	58 +ve	46	22
				38 -ve		

starts from some lower limits. The lower limits of these sets maintain as interval of 30 between the successive ranges. Evidently in SET-III the mode of choice of S.S. ranges are such that the influence of higher S.S. number could be better understood. Calculated C.C. are placed in Table 1, but stations are arranged in a descending order of altitude.

It is seen from Table 1 that for SET-II, all the C.C. values are small and insignificant irrespective of the altitudes of stations. This implies that there is hardly any effect of occurrence of S.S. on TSF for any station when we take into consideration the effect of all S.S. values without any discrimination. In case of SET-I as well, almost all the C.C. are very small in magnitude and insignificant; implying thereby lower number of S.S. could not influence TSF. But in case of SET-III, we find that C.C. for the range 150-210 assume quite high value for most of the stations irrespective of altitudes and 48% (*i.e.*, 46 out of 96 cases) among them are significant upto 90% level and 23% (*i.e.*, 22 out of 96 cases) are significant even upto 99% level (shown in last row of Table 2). Thus comparing the C.C. between S.S. numbers of SET-I, II and III one can conclude that the effect of S.S. on TSF is important only in the higher S.S. ranges for most of the stations irrespective of altitudes.

In fact, when we require to study the effect of S.S. on TSF we must keep in mind the following. When S.S. appears small in number they may not possess the potential to influence the occurrence of thunderstorm; whereas when high number of S.S. appears they are likely to have enough energy and capable to influence different weather phenomena including thunderstorm. Now when overall effect of S.S. on TSF is considered, the effect of higher ranges are nullified by opposite tendencies and thus yielding insignificant results. The mean S.S. value ~ 140 from which the variation of mean TSF is quite prominent (as discussed from Fig.1) for most of the stations may be termed as critical S.S. number with respect to TSF. The existence of similar critical S.S. number to effect TSF of three individual stations *i.e.*, Sriniketan, Alipore and Kalaikunda has already been studied by Kar and Bondyopadhaya (1996). In fact, the existance of such critical S.S. number in the neighbourhood of mean S.S. 140 to influence different meteorological phenomena has been discussed long ago by Chakraborty and Bondyopadhaya (1986, 1987, 1988, 1989).

Now SET-III comprises two types of stations; one having altitude > 280m and the rest with $A < 280$m. From Table 2 it is seen that in case of $A > 280$m, C.C. of 63% cases (*i.e.*, 22 cases out of 35) are significant upto 90% level, but in case of $A < 280$m only 39% cases (*i.e.*, 24 cases out of total 61 cases) show significant result upto 90% level; which is much lower than that of the former percentage. In case of stations with $A > 280$m, surprisingly 88% (*i.e.*, 31 out of 35) cases show +ve C.C. (Table 2). Out of these 31 cases, 19 cases are significant upto 90% level; including 12 cases to be significant even upto 99% level. For stations having $A < 280$m, 27 out of 61 cases show +ve C.C. and 14 cases out of these are significant upto 90% level. Now in case of –ve C.C. of $A < 280$m, total 10 cases are significant upto 90% level and 3 of them are significant even upto 99% level, as shown in Table 2.

In fact, when we study the overall effect of S.S. on TSF without any discrimination of altitude as specified in last column of Table 2, the only observation that can be made is that the number of stations with +ve C.V. and +ve C.C. of SET-III are comparatively high than that with –ve C.V. and –ve C.C. But when attention is focused on altitude, after segmenting total observations above and below 280m altitude (Table 2), it is seen that in case of stations with A >280m, the C.V. and C.C. of SET-III are +ve for almost all the stations and 63% C.C. of SET-III of Table 2 are significant upto 90% level including 40 % (14 out of 35) to be significant even upto 99% level; whereas in case of A < 280m the C.V. and C.C. are –ve for majority of cases and only 39% C.C. of SET-III are significant upto 90% level and only 13% (8 out of 61) to be significant upto 99% level and these percentages are much lower than respective percentages for A > 280m. Thus apart from C.V. study, C.C. study also supports to identify 280m altitude to be a critical value of altitude with respect to variation of TSF with S.S., above and below which the variation of TSF in higher ranges of S.S. reverses the direction for most of the stations; though the variation is quite prominent mainly above 280m altitude.

Hence it seems, before going to study the possible influence of higher ranges S.S. on TSF phenomena, it is better to classify the stations located below and above the altitude A = 280m. It may also be mentioned here that during high S.S. years, which can be predicted quite beforehand from the knowledge of different solar cycles, prediction of TSF can be done keeping in mind that – apart from effect of altitude as discussed above, there must be some other parameters *i.e.*, orography of the places *etc.* which are yet to be taken into account and whose role is yet to be studied for the purpose of accurate long range prediction of TSF.

5. Conclusions

(*i*) Existence of critical S.S. number to influence TSF have been noted in the neighbourhood of mean S.S. number 140, above which the influence of S.S. on TSF becomes quite prominent for most of the stations.

(*ii*) Altitude 280m may be identified as critical value of altitude in respect of variation of TSF with S.S. number in higher ranges. Above this altitude TSF increases with S.S. number in higher ranges for almost all the stations.

Acknowledgement

Authors wish to express sincere gratitude to Dr. M.K. Guha, Deputy Director General of Meteorology, RMC Calcutta for providing facilities during the work. They are also thankful to Shri S. Sen, Met.-II, RMC Calcutta for necessary cooperation for the study.

References

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**, 1041-1048.

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**, 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**, 19-45.

Chakraborty, P.K. and Bondyopadhaya, R., 1986, 'Solar effect on rainfall in West Bengal", *Mausam*, **37**, 2, 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.*, **53A**, 2, 303-307.

Chakraborty, P.K. and Bondyopadhaya, R., 1988, "Variation of pre-monsoon temperature over eastern India and the solar activity", *Proc. Indian Nat. Sci. Acad.*, **54A**, 1, 106-113.

Chakraborty, P.K. and Bondyopadhaya, R., 1989, "Influence of solar activities on the cyclonic disturbances over Indian seas", *Mausam*, **40**, 3, 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, 691-700.

Kar, I. and Bondyopadhaya, R., 1996, "Analysis of pre-monsoon thunderstorm frequency over Sriniketan, Alipore and Kalaikunda – The possible association with solar activity", *Mausam*, **47**, 4, 383-394.

Markson, Ralph, 1978, "Atmospheric electricity and the sun weather problem", Solar Terrestrial influences on weather and climate, Publication, 215-231.

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

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

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

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

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