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FLUCTUATIONS OF CLIMATE OVER RAJASTHAN

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In the present paper, the nature of climatic shifts over Rajasthan during the past 60-90 years, fluctuations in aridity and trends in drought intensity are discussed primarily for estimating the frequency of drought over the area. As aridity results mainly due to lack of water in the soil for meeting the atmospheric demand of evapotranspiration, the fluctuations in the pattern of distribution of the southwest monsoon rainfall is studied. Significant periodicities somewhat paralleling the sunspot cycle observed in the rainfall distribution parameters, were further confirmed by the mean structure of the component patterns associated with the epochs of the sunspot cycle. Contrasting atmospheric circulation features associated with contrasting sunspot epochs are also discussed and the possible solar-weather relationships indicated.

INTRODUCTION

In the arid and semiarid regions, besides the rainfall being scanty and highly unreliable, the thermal climate also exhibits extreme variability with large diurnal and seasonal variations of temperature. Every year is more or less exceptional. Some years stand out as phenomenal, when rainfall was in excess, while in some others, the rainfall was scanty.

For crop planning purposes, one should be aware of the climatic environment as well as its vagaries. Climatic conditions, atleast of west Rajasthan, are very severe and unfavourable for crop production. Archaeological evidence of Harappan culture, historical evidence from Rigveda and recent C_{14}-dating of ground water corroborate to indicate that this part of the country enjoyed wetter climate about 4000 to 5000 years back, which was subsequently followed by a period of increasing drought. A number of investigators* have attempted to study the climate of Rajasthan and its neighbourhood from several angles with a view to understand how such arid conditions could have been initiated — whether due to 'climatic change' or due to human activity.

In view of the great importance the problem of climatic fluctuation on the understanding of the atmospheric circulation on the one hand and the problem of extended range forecasting of weather on the other, concerted studies on this subject have been undertaken at the Institute of Tropical Meteorology, Poona.

The results in respect of climatic shifts and fluctuations in the rainfall patterns over Rajasthan vis-a-vis some of the atmospheric circulation features are discussed here.

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*See Jagannathan (1968) for bibliographic details.

Normal Climate

The climate of Rajasthan and neighbourhood has been classified on the basis of climatic data of representative stations and using Thornthwaite's (1948) method utilising the moisture index Im derived indirectly from the mean annual values of 'water surplus' and 'water deficiency' and relating to the 'water need'. For estimating water deficiency and water surplus, it is assumed that a maximum of 10 cm of water can be retained in the soil as soil storage for utilisation during subsequent month. It may be mentioned, that even if the soil recharge is changed to 8 cm or 12 cm, the picture is not affected, particularly in the arid areas, where there is no excess of rainfall in any month; as a result there is only water deficiency, accumulating month after month and the entire rainfall received is used up in evapotranspiration.

Table I

Comparative moisture data of arid and semi-arid stations

Station	Water need (mms)	ppt (mms)	Net surplus (mms)	Net deficiency (mms)	Moisture Index	Climatic type
Barmer	1594.4	310.3	0.0	1284.1	—48.3	Arid
Bikaner	1475.0	304.7	0.0	1170.3	-47.6	Arid
Ganganagar	1420.2	296.3	0.0	1123.9	-47.5	Arid
Jodhpur	1540.0	380.1	0.0	1159.9	-45.2	Arid
Ajmer	1398.2	557.4	0.0	840.8	- 36.1	Semi Arid
Jaipur	1422.9	648.1	0.0	774.8	- 32.7	Semi Arid
Kotah	1557.6	841.5	117.6	833.7	- 24.5	Semi Arid
Agra	1463.2	765.4	0.0	697.8	-28.6	Semi Arid
Ahmedabad	1621.2	823.1	85.4	883.5	- 27.4	Semi Arid
Delhi	1437.2	714.2	0.0	723 0	- 30.2	Semi Arid
Dwarka	1535.6	418.9	0.0	1116.7	- 43.6	Arid
Indore	1330.5	1053.4	310.1	587.2	- 3.2	Dry Sub Humid
Veraval	1527.9	702.4	36.5	862.0	-31.5	Semi Arid

The normal water budget parameters are given in Table I. The annual value of water deficiency is highest in the extreme arid pocket of western Rajasthan and lowest in the southeastern sector. During winter, most of the stations have no water surplus except Ganganagar, which gets a surplus of 5.0 mm in January. The main surplus at the different stations occurs during the monsoon months. The surplus at Jaipur and Ajmer is less than 10 cm during the monsoon months, which serves to recharge the soil at the most and hence no run-off takes place while Kotah experiences an annual surplus of 11.8 cm which runs off.

All the stations considered are either arid or semi-arid, with the exception of Indore, which (I =—3.2) is classed as 'dry sub humid'. The isopleths of moisture indices follow more or less the rainfall pattern. There is a significant gradient of moisture indices on both sides of the Aravallis. Mount Abu on the Aravallis, according to this criterion, should be classed as 'humid' but being a high level station it has not been included. The line of separation between the arid and semi-arid passes through the Rann of Kutch, Pali and runs between Ganganagar and Ferozepur in Punjab.

CLIMATIC SHIFTS

Considerable variations in the values of moisture indices occur in the different parts during good and bad rainfall years. The yearly series exhibit fluctuations of such a magnitude that the climate of certain areas is temporarily shifted by one or more stages into the dry or moist type. In the context of the arid zones, the magnitude and frequency of such shifts into the humid category is no doubt a welcome feature. Table II shows the percentage frequency under the different categories. It can be seen that the extreme arid western part of west Rajasthan, has remained consistently arid

TABLE II

Climatic Shifts over Rajasthan and neighbourhood

Station	Percentage frequency of years				Total No. of years	Duration
	Arid	Semi-arid	Dry Sub Humid	Humid		
Barmer	92.4	3.3	3.3	—	30	1932-1961
Bikaner	90.8	9.2		—	87	1879-1965
Ganganagar	73.1	26.9		—	26	1937-1962
Jodhpur	80.4	17.1	2.9	—	70	1897-1966
Ajmer	46.0	46.0	8.0	—	50	1901-1950
Jaipur	29.4	48.2	18.8	3.6	85	1881-1965
Kotah	19.1	45.6	33.8	1.5	68	1898-1965
Agra	15.5	57.8	26.7	—	90	1876-1965
Ahmedabad	20.4	46.9	30.6	2.1	49	1902.1950
Delhi	21.9	62.5	15.6	—	64	1901-1064
Dwaraka	67.8	28.8	3.4	—	59	1902-1960
Indore	2.3	34.1	57.9	5.9	88	1880-1967
Verabal	41.9	37.8	20.3	—	74	1893-1966

or semi-arid during the period under study except Barmer, which had once experienced dry sub-humid climate, i.e. in 1944 with $I_m = -11.5$. Jodhpur and Dwaraka, which are both normally arid, had experienced dry sub-humid conditions in two years during the 60 years. Ajmer, a semi-arid station had experienced the maximum number of shifts to the arid character, followed closely by Veraval. It is seen that roughly in 50% of the years the semi-arid stations retained their normal character. Kotah has shown the maximum number of shifts to the dry sub-humid direction. Kotah, Jaipur and Ahmedabad had experienced humid climate as given below.

TABLE III

Station	Year	Precipitation (cm)	P.E. (cm)	Water deficiency (cm)	Moisture index
Jaipur	1961	190.9	141.2	41.4	—46.3
	1963	162.3	146.3	77.1	—31.9
	1964	171.4	145.8	61.1	—34.3
Kotah	1917	159.6	145.6	46.9	—21.1
Ahmedabad	1927	199.7	160.8	89.7	—46.5

DROUGHT INDEXING

By drought we mean shortage of moisture to meet the demand. It is reasonable to state that a period during which 'the moisture need' exceeds 'moisture supply' by an unusal amount, could be considered as a period of abnormal moisture deficiency or 'drought'. By this postulate of abnormality, several situations relating to different climatic regimes can be compared and their relative intensity assigned. Palmer (1965) defined a drought as a "Period of prolonged and abnormal moisture deficiency" — a period of time generally of the order of months or years in duration, during which the actual moisture supply at a given place, rather consistently falls short of the climatically expected or the climatically appropriate moisture supply.

As regards agricultural drought, the shortage of moisture in the root zone, which can lead to wilting of the crops should be the criterion. This can be different for different crops and for the same crop at its different stages of development. As such no unique standard can exist. Further, the soil conditions as well as the cultural practices play important roles. Thus the problem of drought index is highly specialized involving the realms of soil physics, plant physiology and agricultural economics.

Since the amplitude of the departure of the aridity index from its mean value determines the severity of the drought situation, Subramanayam (1964) suggested $\frac{1}{2}\sigma$, σ and 2σ (where σ is the standard deviation) as the limits of aridity anomalies for designating 'large', 'severe' and 'disastrous', droughts. If the distribution of the aridity indices is of the 'Gaussian type', these limits will correspond to the probability limits of 30.9%, 15.9% and 2.3%, i.e. to 'return period' of 3.23, 6.29 and 43.48 years respectively. Using these criteria, the years have been designated as years with 'no drought' or years with specified intensity of drought.

TRENDS IN DROUGHT INTENSITY

The decade-wise frequency of occurrence of drought at the different stations are given in Table IV. The table is self explanatory. There is no systematic increase or

TABLE IV

Trend in drought character

Station	Period	D.C.	Frequency of drought with decades									Total	Percentage of effective drought (Years)
			1881-1890	1891-1900	1901-1910	1911-1920	1921-1930	1931-1940	1941-1950	1951-1960	1961-1970		
1	2	3	4	5	6	7	8	9	10	11	12	13	14
Barmer	1932-1960	M	X	X	X	X	X	1	3	2	X	6	
		L	X	X	X	X	X	3	1	1	X	5	
		S	X	X	X	X	X	2	—	2	X	4	
		D	X	X	X	X	X	—	—	—	X	0	0.31
Bikaner	1881-1965	M	1	2	2	—	6	—	1	3	—	14	
		L	3	3	2	3	1	2	2	2	—	18	
		S	1	1	2	2	—	2	2	—	2	12	
		D	—	—	—	—	—	—	—	—	—	0	0.35
Ganganagar	1937-1960	M	X	X	X	X	X	1	1	4	X	6	
		L	X	X	X	X	X	2	1	—	X	3	
		S	X	X	X	X	X	1	4	1	X	6	
		D	X	X	X	X	X	—	—	—	X	0	0.37
Jodhpur	1897-1966	M	X	—	3	2	—	3	1	2	2	13	
		L	X	1	1	2	2	2	3	—	1	12	
		S	X	1	3	3	2	—	—	1	—	10	
		D	X	—	—	—	—	—	—	—	—	0	0.31
Ajmer	1901-1950	M	X	X	5	1	—	—	1	X	X	7	
		L	X	X	2	3	2	1	3	X	X	11	
		S	X	X	1	2	2	2	—	X	X	7	
		D	X	X	—	—	—	—	—	X	X	0	0.36
Jaipur	1881-1965	M	5	2	—	—	2	3	3	—	—	15	
		L	—	2	3	2	4	1	1	3	—	16	
		S	—	2	2	2	—	2	1	1	—	10	
		D	—	—	1	1	—	—	—	—	—	2	0.33
Kotah	1898-1965	M	X	1	2	2	2	3	3	1	1	15	
		L	X	—	—	3	2	2	—	—	—	7	
		S	X	1	1	2	1	—	1	2	2	10	
		D	X	—	—	—	—	—	—	—	—	1	0.26

(*Contd.*)

TABLE IV (*Contd.*)

1	2	3	4	5	6	7	8	9	10	11	12	13	14
Agra	1881-1965	M	2	1	3	3	1	2	2	1	—	15	
		L	2	3	1	1	2	1	—	—	—	10	
		S	—	—	1	—	—	2	1	1	—	5	
		D	—	1	1	2	—	—	—	—	—	5	0.24
Ahmedabad	1902-1950	M	X	X	4	2	3	5	—	X	X	14	
		L	X	X	1	—	—	2	1	X	X	4	
		S	X	X	—	1	1	—	1	X	X	3	
		D	X	X	1	2	—	—	—	X	X	3	0.20
Delhi	1901-1964	M	X	X	2	3	5	1	1	1	1	14	
		L	X	X	—	2	—	2	2	2	—	8	
		S	X	X	4	1	1	1	1	—	—	8	
		D	X	X	—	—	1	—	—	—	—	1	0.27
Dwarka	1902-1960	M	X	X	1	4	2	3	1	2	X	13	
		L	X	X	—	—	2	2	3	1	X	8	
		S	X	X	2	1	2	1	2	1	X	9	
		D	X	X	—	1	—	—	—	—	X	1	0.31
Indore	1881-1967	M	3	1	2	1	2	—	1	—	2	12	
		L	—	2	—	1	—	2	3	3	—	11	
		S	—	2	5	1	2	—	—	2	1	13	
		D	—	1	—	1	1	—	—	—	—	3	0.31
Veraval	1893-1966	M	X	3	2	—	1	5	1	1	1	14	
		L	X	1	—	2	3	—	—	1	—	7	
		S	X	1	2	2	5	1	2	—	—	13	
		D	X	—	1	—	—	—	—	—	—	1	0.28

D.C. — Drought Character. M — Moderate drought (aridity index between A and A+1/2 σ)
L — Large drought (aridity index between A + 1/2 σ and A + σ)
S — Severe drought (aridity index between A + σ and A + 2 σ)
D — Disastrous drought (aridity index greater than M + 2 σ)
— — No drought, X — No data, Effective drought — Aridity index > A + 1/2 σ
A — Mean aridity Index

decrease in the incidence of drought. It is seen that on the average about two moderate drought and 1-2 drought of large intensity had occurred in each of the decades. Droughts of severe intensity average between 1.3 to 2.5 over arid areas and 0.6 to 1.9 over the semi arid areas. During the period under study, the arid areas had not experienced any disastrous drought, while on the semi arid side 1-5 such droughts had been experienced; Agra had experienced the largest number; atleast once in every decade up to 1930. Bikaner shows the maximum liability for occurrence of effective drought (aridity index greater than M + $\frac{1}{2}\sigma$).

PATTERN OF RAINFALL

As aridity results mainly due to lack of rain, the pattern of distribution of rainfall is studied. The pattern of distribution of rainfall during the 25 pentads comprising of the period 31 May to 2 October corresponding to the 31st to 55th pentads of the

"IGY calendar" has been broken into five orthogonal component patterns such that the rainfall at time 't' can be represented as

$$R(t) = A_0F_0(t) + A_1F_1(t) + \ldots A_5F_5(t)$$

where $Fr(t)$ are the orthogonal component patterns such that $\int Fr(t)\, Fs(t)\, dt = O$, integration extending over the monsoon season. The coefficients are independent of A_r time within the season. Due to the property of orthogonality of the time functions, the influence of the several parameters is independent of each other and the coefficients of the functions indicate the extent of the influence of the different components independent of one another. Thus the coefficients can serve as independent, parameters of the rainfall distribution for comparison between the different stations and also between different years. These will be referred to as 'distribution parameters'. The year-to-year variation in the intensity of the component patterns as represented by the corresponding coefficients have been studied.

The distribution parameters in the different years have been obtained by correlating the individual monsoon rainfall series with the respective patterns $Fr(t)$

$$A_r = \int R(t)\, F_r(t)\, dt,\ r = 0, 1, 2, \ldots\ldots 5$$

Here we use Fisher's 'orthogonal polynomials' up to the 5th degree (see Fisher & Yates, 1963).

Table V shows the statistics of the distribution parameters. It is readily seen that the component patterns experience high variability. The standard errors of the means indicate the extent of the significance of the mean values of the parameters.

Before studying the year-to-year variations, it would be desirable to have an idea of the form of the component patterns.

A_0 Represents the mean 5-day rainfall at the station. As such the areal distribution of A_0 over the area will represent the mean rainfall distribution.

A_1 Measures the gradient of the linear trend in the rainfall with the advance of the season. A positive value indicates a general increase of rainfall with the advance of the season. Over Rajasthan, this term is positive but small. A significant increasing tendency is seen over the Aravallis.

A_2 The coefficient of the second degree term is negative, indicating the rainfall on account of this pattern, attains a maximum during the middle of the season. This feature increases eastward.

A_3 This component is negative over the area indicating that the rainfall associated with this pattern attains a maximum during the second half of the season and a minimum during the first half. This feature is significant over the Aravallis.

A_4 This component indicates oscillatory features in the rainfall with peaks and troughs alternating in about 6 weeks. It is practically insignificant over the area as far as the mean picture is concerned.

A_5 This component indicates oscillation in the rainfall with peaks and troughs alternating in about 4 weeks. It is also practically insignificant in the mean.

TABLE V

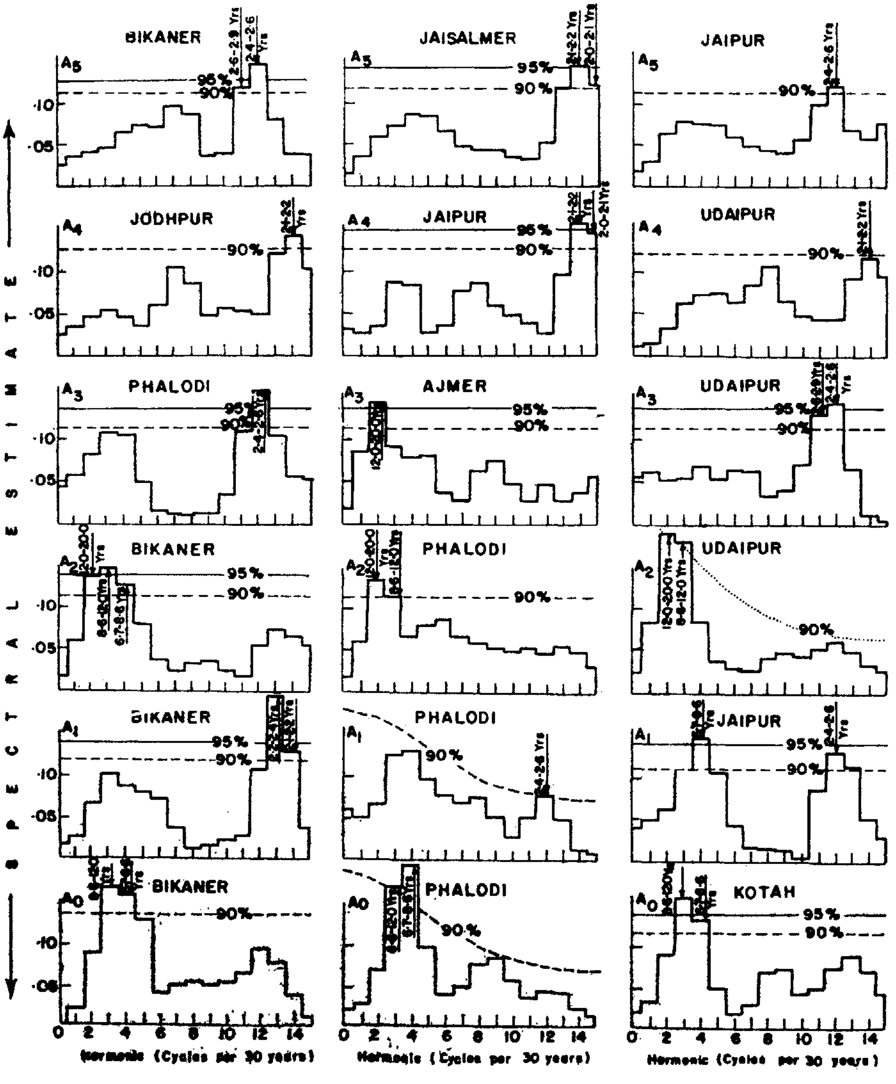
Statistics of rainfall distribution parameters

Station	A_0				$10\ A_1$				10^2A_2				10^3A_3				10^3A_4				10^3A_5			
	M	S.D	C.V	S.E	M	S.D	C.V	S.E	M	S.D	C.V	S.E	M	S.D	C.V	S.E	M	S.D	C.V	S.E	M	S.D	C.V	S.E
Ajmer	.71	.32	44	.04	.04	.31	627	.04	–.70	.48	69	.06	–.17	.96	539	.13	.07	.33	461	.04	–.05	.43	850	.06
Barmer	.30	.26	65	.02	.07	.12	296	.02	–.49	.47	95	.06	–.35	.85	239	.11	.07	.23	335	.03	.06	.34	553	.04
Bikaner	.40	.22	55	.03	.03	.18	521	,02	–.43	.41	94	.05	–.11	.64	547	.09	.07	.24	325	.03	–.03	.32	928	.04
Jaipur	.82	.34	42	.04	.10	.34	315	.04	–.88	.59	66	.08	–.14	.96	664	.13	.14	.32	229	.04	–.03	.431	416	.06
Jaisalmer	.24	.16	69	.02	.04	.12	277	.01	–.29	.26	91	.03	–.20	.57	282	.08	.04	.15	334	.02	.02	.22	807	.03
Jodhpur	.50	.29	58	.04	.09	.27	297	.02	–.51	.52	101	.07	–.23	.76	326	.10	.06	.26	409	.03	.05	.47	863	.06
Kotah	1.11	.44	39	.06	.14	.37	257	.05	–1.16	.71	61	.09	–.071	.211	721	.17	.12	.41	322	.05	–.11	.61	515	.08
Phalodi	.32	.19	59	.02	.03	.19	593	.02	–32	.31	95	.04	–.23	.60	251	.08	.03	.23	718	.03	.03	.33	920	.04
Udaipur	.90	.35	38	.04	.07	.33	475	.05	–76	.60	78	.08	–.061	.001	526	.14	.31	.333	245	.04	–.05	.56	995	0.7

M — Mean
S.D — Standard Deviation
C.V — Coefficient of Variation (%)
S.E — Standard Error.

FLUCTUATIONS IN RAINFALL PATTERNS

The trend in the year-to-year fluctuations in the intensity of the component patterns was studied by polynomial analysis of the time-series. Of the 9 stations examined, A_1 for Udaipur and A_2 for Bikaner showed significant 5th degree trends indicating oscillation in the value with a period of about 20 years. A_4 for Phalodi showed a third degree oscillation i.e. with a period of about 35 years. A_5 for Udaipur showed a fourth degree trend. Thus the representative parameters at some of the stations reveal oscillatory tendency during the period. To determine if these fluctuations are due to systematic oscillation or due to any aperiodic variations, the



POWER SPECTRA OF RAINFALL DISTRIBUTION PARAMETERS

FIG. 1

time series were subjected to power-spectrum analysis. Autocorrelations up to 15-lags were used. As an example, Fig. 1 shows some of the spectra in respect of distribution parameters. The spectral peaks observed were tested by Tukey's (1950) test. In cases when the series indicated Markov-linear persistence, the appropriate red-noise spectrum was used for the test. In the absence of any persistence the white noise spectrum was used. Before accepting the peak, the possible higher frequency oscillation which might throw alised power at the observed frequency was also investigated and suitable allowance made. The period ranges which came out as significant are only considered. Out of the several periodicities exhibited in the individual spectra, the cycles corresponding to the solar cycle and its higher harmonics appear over wide areas of the region. Since these cycles have been observed in several atmospheric phenomena, even though the cause-effect relationship are still obscure, they can justifiably be considered as probable. The quasi-biennial oscillation (QBO), which is observed predominantly, is one of the group of cycles in the atmosphere that are somewhat connected with the sunspot cycle and has gained considerable currency in recent years. The other cycles which have not been anticipated on *apriori* considerations, when tested with more stringent criteria appropriate to the highest observed powers out of the several powers calculated, fell out as insignificant. The following are some of the salient features :—

A_0 Significant QBO is observed in Barmer and Jaipur, while Bikaner, Jodhpur, Kotah, Phalodi and Udaipur exhibit oscillations nearing the sunspot cycle.

A_1 All the stations except Ajmer, Kotah and Udaipur exhibit QBO with period of about 2 to 2.5 years.

A_2 Sunspot cycle is observed over Barmer, Phalodi, Bikaner and Udaipur, while Jaipur revealed QBO.

A_3 Ajmer showed sunspot cycle and practically all the rest of the stations revealed QBO.

A_4 Jaipur and Jodhpur showed QBO.

A_5 Jaisalmer, Bikaner on the west and Jaipur and Kotah on the east showed QBO.

VARIATIONS ASSOCIATED WITH SUNSPOT

The above analysis clearly shows that the several characteristic parameters representing the pattern of distribution of monsoon rainfall experienced oscillation corresponding to the solar cycle. It is known that the sunspot series also exhibit a feeble QBO. We shall presently examine the contrasting patterns associated with the different phases of the sunspot cycle.

The composite patterns corresponding to the epochs of sunspot maximum, sunspot minimum, sunspot increasing and sunspot decreasing have been obtained by pooling together the different years of like sunspot character. Only the central years in which the specified feature is observed, have been utilized. The mean values of the parameters at the different epochs are given in Table VI.

TABLE VI

Rainfall distribution parameters corresponding to sunspot epochs

Station	Sunspot epochs	Mean Distribution Parameters					
		A_0	A_1	A_2	A_3	A_4	A_5
1	2	3	4	5	6	7	8
Ajmer	Min.	+ .712	-.010	-.0092	+.0005	+.00028	-.00016
	Inc.	+ .684	+.009	-.0069	-.0004	-.00003	+.00033
	Max.	+ .497	-.002	-.0035	-.0003	-.00007	+.00005
	Dec.	+ .589	+.009	—.0085	-.0002	+.00014	-.00003
	Normal	+ .719	+.304	+.0048	-.00017	+.00007	-.00005
Barmer	Min.	+ .299	-.007	-.0045	+.0002	+.00010	-.00002
	Inc.	+ .332	+.012	-.0031	—.0003	—.00009	+.00005
	Max.	+ .246	+.009	—.0026	-.0006	+.00001	+.00015
	Dec.	+ .616	+.017	-.0071	-.0009	+.00012	+.00012
	Normal	+ .401	+.007	+.0049	-.0003	+.00007	+.00006
Bikaner	Min.	+ .347	—.003	-.0055	-.0001	+.00020	+.00008
	Inc.	+ .359	+.008	-.0039	-.0003	+.00008	+.00018
	Max.	+ .230	+.011	-.0023	-.0005	—.00006	+.00012
	Dec.	+ .467	+.007	—.0059	+.0000	+.00005	-.00013
	Normal	+ .401	+.003	—.0043	-.0001	+.00007	-.00003
Jaipur	Min.	+ .909	+.006	-.0113	+.0002	+.00022	+.00002
	Inc.	+ .909	+.027	-.0113	-.0011	+.00012	+.00027
	Max.	+ .493	+.005	-.0048	-.0002	+.00012	+.00002
	Dec.	+ .723	-.001	-.0097	-.0003	+.00021	+.00019
	Normal	+ .829	+.010	—.0088	—.0009	+.00014	-.00003
Jaisalmer	Min.	+ .249	+.002	-.0043	-.0001	+.00915	+.00007
	Inc.	+ .160	+.002	-.0018	-.0000	+.00001	+.00005
	Max.	+ .159	+.008	-.0013	-.0004	—.00008	+.00010
	Dec.	+ .238	—.002	—.0019	—.0002	+.00003	—.00005
	Normal	+ .241	+.004	—.0029	—.0002	+.00004	+.00002
Jodhpur	Min.	+ .517	—.003	—.0082	+.0002	+.00023	—.00025
	Inc.	+ .373	+.009	—.0023	—.0002	+.00009	+.00015
	Max.	+ .370	+.000	—.0040	—.0002	+.00002	+.00011
	Dec.	+ .475	+.013	—.0017	—.0007	+.00013	+.00021
	Normal	+ .503	+.009	—.0052	—.0002	+.00006	+.00005
Kotah	Min.	+1.091	+.011	—.0143	+.0002	+.00039	—.00020
	Inc.	+1.202	+.026	—.0125	—.0006	—.00006	—.00021
	Max.	—1.082	—.009	—.0094	—.0000	—.00013	—.00029
	Dec.	— .889	—.009	—.0098	—.0002	—.00019	—.00003
	Normal	—1.128	—.014	—.0116	—.0001	—.00012	—.00011

TABLE VI (Contd.)

1	2	3	4	5	6	7	8
Phalodi	Min.	— .397	—.005	—.0064	—.0001	—.00017	—.00000
	Inc.	— .247	—.007	—.0032	—.0004	—.00001	—.00018
	Max.	— .173	—.002	—.0024	—.0001	—.00003	—.00001
	Dec.	— .311	—.005	—.0027	—.0005	—.00003	—.00000
	Normal	— .327	—.003	—.0032	—.0002	—.00003	—.00003
Udaipur	Min.	—1.019	—.002	—.0146	—.0001	—.00033	—.00004
	Inc.	— .875	—.009	—.0066	—.0004	—.00005	—.00002
	Max.	— .642	—.001	—.0037	—.0003	—.00013	—.00016
	Dec.	—1.059	—.001	—.0134	—.0004	—.00035	—.00019
	Normal	— .900	+.007	—.0076	—.0006	—.00001	—.00005

Min. — Sunspot minimum
Inc. — Sunspot increasing
Max. — Sunspot maximum
Dec. — Sunspot decreasing
Normal — Average value of the parameter based on values for the period 1901-1950

The contrasting variations in the component patterns of the rainfall distribution associated with the four epochs along with the integrated patterns in respect of three selected stations are shown in Fig. 2.

The salient features of the variations associated with sunspot are mentioned below :

A_0—The mean rainfall during sunspot minimum is larger than that during sunspot maximum at all stations.

A_1—The mean anomalies are positive over West Rajasthan and insignificant over the rest of the area, indicating that rainfall due to this component over west Rajasthan increases with the advance of the season during periods of sunspot maximum over that during sunspot minimum.

A_2—The anomalies are positive at all the stations indicating that the maximum in this pattern, which occurs during the middle of the season is enhanced during the sunspot minimum.

A_3—The anomalies are all negative indicating the maximum in this pattern which occurs during the later half of the season is enhanced during sunspot maximum.

A_4—The anomalies are all negative indicating that the maximum in the rainfall associated with this pattern occur more prominently during sunspot minimum.

A_5—The variations in the anomalies are not significant.

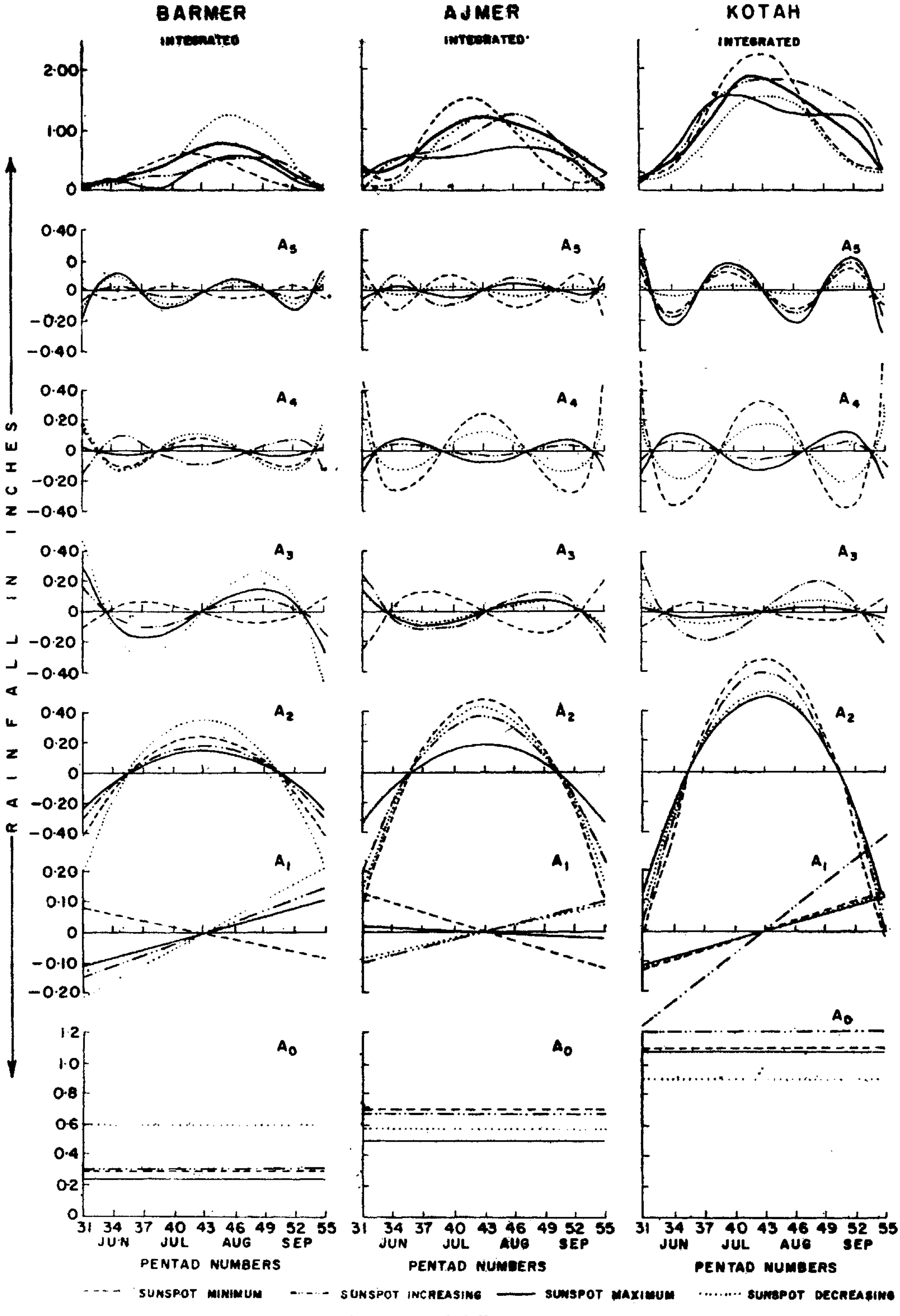


FIG. 2 Rainfall patterns

ANOMALOUS CIRCULATION FEATURES ASSOCIATED WITH SUNSPOTS

The foregoing analysis clearly brings out that the rainfall distribution during the monsoon season takes different patterns during the different sunspot epochs. However, as the intensities of the variations differ over the different parts, it appears that the influence of sunspots as evidenced by the differential rainfall patterns should have arisen due to changes introduced in the atmospheric circulation features.

(i) The composite surface pressure field associated with sunspot maximum and sunspot minimum epochs, Fig. 3, show that during sunspot maximum, the core of the negative pressure departure lies near the foot of the Himalaya — a condition usually associated with 'break monsoon' condition, while during sunspot minimum epochs, this core is situated further south over Orissa — Madhya Pradesh — east Rajasthan as during the active monsoon conditions.

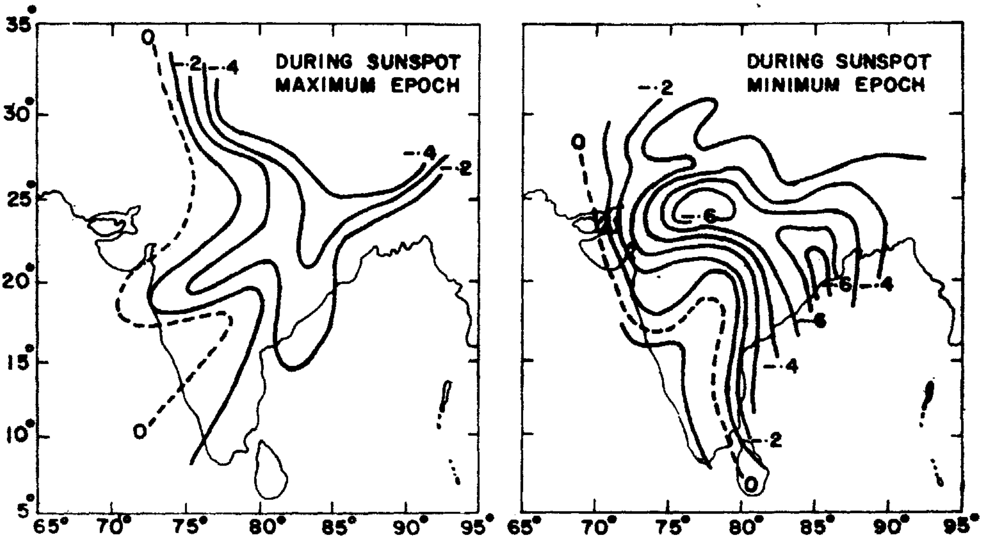


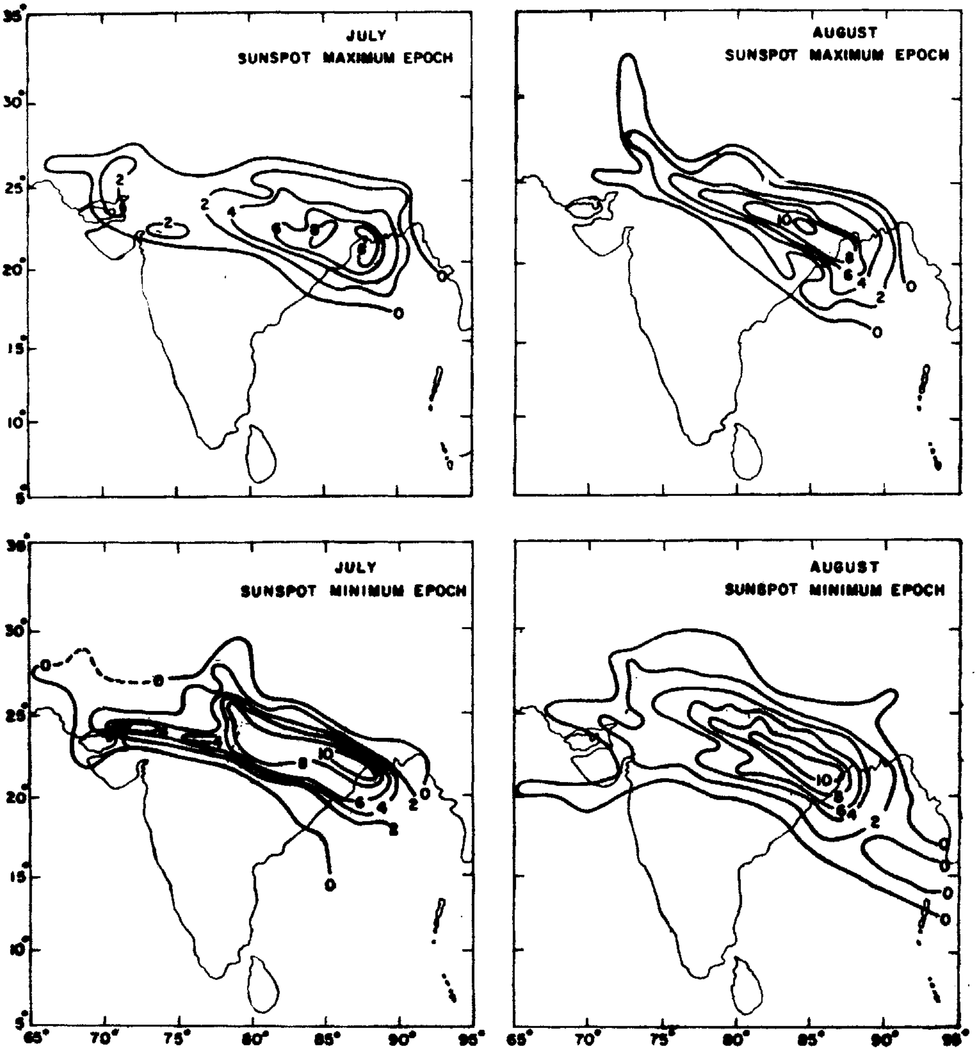
FIG. 3. Surface pressure departures (mp)

(ii) The following table (extracted from Ramamurthy's data, 1969) show the relative frequency of 'breaks in the monsoon' during July and August of the different years. It can be seen that the total number of days of 'break in the monsoon' are significantly larger during sunspot maximum than during sunspot minimum.

TABLE VIII

Year	Days of breaks Sunspot min.	Year	Days of breaks Sunspot max.
1901	4	1906	28
1912	11	1918	23
1923	0	1928	12
1933	7	1938	0
1943	0	1948	3
Total	22		66

(iii) It is well known that the fluctuations in the intensity of the rainfall during the monsoon season are to a large extent associated with the series of storms and depressions and their movement. The number of storms and depressions, which crossed each degree square during the two epochs in respect of the normally strong monsoon months July and August are shown in Fig. 4. It is seen that the frequency of storms and depressions is more during the minimum epoch than during the maximum epoch. Further, the length of the tracks as well as the duration of the systems are longer during minimum epochs than during maximum epochs.



FREQUENCY OF STORMS AND DEPRESSIONS (1901-1950)

FIG. 4

CONCLUDING REMARKS

Largely west Rajasthan is arid, while east Rajasthan can be classed as semi-arid. However, the year-to-year moisture indices exhibit large fluctuations in climate at practically all stations, shifting them by one or more stages to the worse or better side. As a normal feature, west Rajasthan can be expected to have 3-4 years of 'effective drought' in a decade and in east Rajasthan 2-3 years.

The rainfall in addition to being very scanty is highly variable. However, the year-to-year fluctuations in the characteristic parameters, here identified, representing the pattern of monsoon rainfall are not entirely random as a significant part of their fluctuations are time controlled. Power-spectra of the time series of the parameters reveal oscillations with periods near about the sunspot cycle or some higher harmonics thereof; the quasi-biennial oscillation (QBO) is present significantly in some of the parameters. It will be relevant to mention here that in two previous investigations Jagannathan and Raghavendra (1964, 1956) concluded that

(i) the duration of wet spells over Rajasthan were related to sunspotedness,

(ii) there was no significant variation in the frequency distribution of daily intensities of rainfall between epochs of sunspot maximum and sunspot minimum, however the maximum daily intensities in the different years exhibited significant negative correlation with sunspot numbers, (CC= —.33) suggesting inverse relationship between highest daily rainfall in the year and the sunspot number, i.e. years with low sunspot number were associated with highest daily intensity in the year.

(iii) there was a long-period trend in the daily intensities by which the smaller daily intensities showed an increase during the forty years ending 1960. This increase should be at the expense of the larger daily intensities as the total monsoon rainfall over the area did not show any increasing or decreasing trend.

(iv) the decrease in the larger daily intensities was also corroborated by the diversion of the tracks of storms and depressions of the monsoon season.

The geographical pattern of response to the sunspot cycle as well as the anomalous behaviour of some of the circulation features, suggest that the real cause-effect in the solar weather relationships may be traceable to the changes introduced in the atmospheric circulation.

Since solar radiation plays a central role in the operation of the general circulation, it is natural to seek radiative explanations for long period changes in the circulation features. The variability could arise in solar radiation and/or terrestrial radiation. Variations in the incident solar energy could arise also due to variations in absorbing constituents of the atmosphere and the differences in the conducting and reflecting properties of the earth's surface. The fluctuations in the radiative equilibrium temperatures associated with the fluctuations in the several atmospheric constituents are being studied intensively at the Institute* with a view to examine the development of some of the observed circulation features and the possible causes of climatic fluctuations.

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* By R. R. Kelkar with the guidance of the Senior Author,

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